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5-21000-OPS-GT

EG&G

ROCKY FLATS

ENVIRONMENTAL MANAGEMENT DEPARTMENT

VOLUME III: GEOTECHNICAL

MARCH 1992

1/851

DOCUMENT CLASSIFICATION REVIEW WAIVER PER CLASSIFICATION OFFICE

ADMIN RECORD

SW-A-004696

INFORMATION ONLY

THIS IS ONE VOLUME OF A SIX VOLUME SET WHICH INCLUDES:

VOLUME I: FIELD OPERATIONS (FO)
VOLUME II: GROUNDWATER (GW)
VOLUME III: GEOTECHNICAL (GT)
VOLUME IV: SURFACE WATER (SW)
VOLUME V: ECOLOGY (EE)
VOLUME VI: AIR (AP)

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GT.01	Logging Alluvial and Bedrock Material	2	05/12/92
94-DMR-001007	LIMITED SCOPE - Section GT.01 Text and Form GT.1A Modification	2	06/01/94
GT.02	Drilling and Sampling Using Hollow Stem Auger Techniques	2	05/12/92
93-DMR-000955	Form GT.2A Modification	2	01/10/94
93-DMR-000960	QC Sample Collection Modification	2	01/10/94
94-DMR-000382	Approval Process and Sampling Collection Modification	2	03/28/94
94-DMR-000405	Sample Liner Taping Changes	2	03/28/94
94-DMR-000995	LIMITED SCOPE - Section GT.02 Text Modification	2	06/01/94
GT.03	Isolating Bedrock from Alluvium with Grouted Surface Casing	2	05/12/92
93-DMR-000956	Form GT.3A Modification	2	01/10/94
94-DMR-000418	Advanced Notification to the State of Colorado	2	04/22/94
GT.04	Rotary Drilling and Rock Coring	2	05/12/92
93-DMR-000957	FORM GT.4A Modification	2	01/10/94
94-DMR-000419	Advanced Notification to the State of Colorado	2	04/22/94
94-DMR-000935	Procedure Modification to Allow Sonic Drilling Technique Usage	2	06/01/94
GT.05	Plugging and Abandonment of Boreholes	2	05/12/92
93-DMR-000961	Form GT.5A Modification	2	01/10/94

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GT.06	Monitoring Wells and Piezometer Installation	2	05/12/92
94-DMR-000801	CO Regulatory Statute Reference Citations and Text Modification	2	06/01/94
94-DMR-000994	LIMITED SCOPE - Section 6 Text Modification	2	06/01/94
GT.07	Logging & Sampling of Test Pits and Trenches	2	05/12/92
94-DMR-000276	Section GT.07 and form Modifications	2	02/28/94
GT.08	4-E42-ER-OPS-GT.08 - Surface Soil Sampling	3	01/25/94
94-DMR-000133	Sampling Modifications	3	02/04/94
94-DMR-000229	Editorial Correction GT.08	3	03/14/94
94-DMR-000857	LIMITED SCOPE - Expansion of Scope of 94-DMR-000133	3	07/19/94
GT.09	Soil Gas Sampling and Field Analysis	2	05/12/92
94-DMR-000431	Calibration Occurrence Clarification	2	04/11/94
94-DMR-001521	Clarification of Soil Gas Procedures	2	09/02/94
GT.10	Borehole Clearing	2	05/12/92
GT.11	Plugging and Abandonment of Wells	2	05/12/92
93-DMR-000962	Form GT.11A Modification	2	01/10/94
94-DMR-000561	Section 11 Modification	2	05/06/94
GT.15	Geophysical Borehole Logging	2	05/12/92
GT.17	Land Surveying	2	05/12/92
94-DMR-000560	Text Modification	2	05/06/94
GT.18	Surface Geophysical Surveys	2	05/12/92
GT.19	Field Gas Chromatographs	2	05/12/92

Procedure No.	Title	Rev. No.	Effective Date
GT.20	Procedures for Soil Interstitial Water Sampling and Sampler Installation	2	05/12/92
94-DMR-000297	Section GT.20 and form Modifications	2	02/28/94
GT.21	Cone Penetrometer Testing	1	05/12/92
GT.24	Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)	0	05/12/92

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LOGGING ALLUVIAL AND BEDROCK MATERIAL

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.1, Rev. 2
	Page:	1 of 34
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
LOGGING ALLUVIAL AND BEDROCK MATERIAL

Approved By: [signature] 5/12/92
(Name of Approver) (Date)

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By [signature]
Date March 9, 1992

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2.0 PURPOSE AND SCOPE

Over the period of the last few years, it has become apparent that a standardized procedure is needed for logging alluvial and bedrock material. This need has arisen because each subcontractor has slightly different procedures and criteria for logging borehole material. Beginning in 1991, all subcontractors will use the procedures that are covered in this SOP.

By applying these techniques and procedures, it will be possible to standardize the logging of alluvial and bedrock materials. In addition, the number of errors and the amount of relogging will be reduced. This will allow lithologic descriptions to be compared from year to year and will enable the environmental management staff on the Rocky Flats Plant (RFP) site to make interpretations based on reliable data.

On the RFP site, "alluvial material" includes alluvium, colluvium, fill, and agronomic soils. Samples of alluvium, colluvium, fill, and agronomic soils are to be classified and described using the Unified Soil Classification System (U.S.C.S.) and enhanced by Item 10.1 in ASTM D2488, "Description and Identification of Soils (Visual-Manual Procedure)." Bedrock material, regardless of the degree of weathering, is to be classified and described by using many of the procedures and techniques described in Compton's "Manual of Field Geology" (1962), which has been incorporated with additional material in this SOP.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

The EG&G project manager has the overall responsibility for implementing this SOP. The subcontractor's project manager will be responsible for assigning project staff to implement this SOP and for ensuring that the procedures are followed by all subcontractor personnel.

All personnel performing these procedures are required to have the appropriate health and safety training as specified in the site-specific Health & Safety Plan. In addition, all personnel are

required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures.

Only qualified personnel will be allowed to perform these procedures. Required qualifications vary depending on the activity to be performed. In general, qualifications are based on education, previous experience, on-the-job training, and supervision by qualified personnel. Personnel who log alluvial boreholes must study the RFP Alluvial Reference Set that contains examples of all 15 sample classifications within the U.S.C.S. System. Personnel who log bedrock boreholes must be qualified geologists or geologic engineers, who have received special permission to log bedrock holes. All of the loggers must study the Core Reference Set that contains 15 representative samples of the stratigraphic section in the RFP area. In addition, they must study the Alluvial Reference Set. These reference sets are used as training guides to help ensure consistency among logging geologists. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project Quality Assurance (QA) files.

All project staff are responsible for reporting deviations from this SOP to the individual's project manager. The subcontractor's project manager will report deviations and nonconformances to the EG&G project manager.

When field conditions require deviations from the SOP, a Document Change Notice (DCN) will be authorized by an EG&G EMD logging supervisor. An EG&G EM Department Administrative Procedure outlines the DCN approval process.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

ASTM. Method for Particle - Size Analysis of Soils; Soil and Rock Dimensions, Stone and Geo-Synthetics. Vol. 04.08. Sec. D422. 1989.

ASTM. Practice for Description and Identification of Soils for Engineering Purposes (Visual-Manual Procedures); Soil and Rock Dimensions, Stone and Geo-Synthetics. Vol. 04.08. Sec. D2488. 1989.

Blatt, H., Middleton, G., Murray, R. Origin of Sedimentary Rocks. Prentice-Hall. 1972.

Compton, Robert R. Manual of Field Geology. John Wiley & Sons, Inc. 1962.

Harlan, R.L., Kolm, K.E., Gutentag, E. D. Water-Well Design and Construction. Development in Geotechnical Engineering, #60. Elsevier. 1989.

Krumbein, W.C., Pettijohn, F.J. Manual of Sedimentary Petrography. Appleton-Century-Crofts. 1966.

Unified Soil Classification System. Appendix A: Characteristics of Soil Groups Pertaining to Embankments and Foundations, Appendix B: Characteristics of Soil Groups Pertaining to Roads and Airfields. (U.S.) Army Engineer Waterways Experiment Station. Vicksburg, MS. 1960.

5.0 CLASSIFICATION/DESCRIPTION

5.1 UNIFIED SOIL CLASSIFICATION SYSTEM (U.S.C.S)

The U.S.C.S. classification system will be used at RFP. The U.S.C.S., as used in this SOP, has been modified from the Army Corps of Engineers' Technical Memorandum No. 3-357, "The Unified Soil Classification System" (1960). Physical characteristics, which are normally determined through

laboratory analyses, are not included in this SOP because they are neither practical to do in the field nor appropriate to geologic logging. A reprint of the U.S.C.S. is enclosed in Appendix GT.1A.

5.1.1 Basis of Classification

The U.S.C.S. historically has been used to classify "soils" based on their textural properties, liquid limit, and organic content. In the past, the term "soil" has been used by engineers as a catchall term that includes all unconsolidated material. Because engineers are concerned with how the soil behaves as a construction material, this all-inclusive approach has served them quite well.

However, in this SOP, the U.S.C.S. will be applied only to alluvium, colluvium, fill, and agronomic soils. This has been done to separate unconsolidated cover material from bedrock that has well-defined sedimentologic and depositional patterns, regardless of the degree to which the bedrock has been weathered. In the RFP area, it is more important to determine the possible paths of groundwater movement based on lithologic variability and geologic processes than it is to determine the engineering properties of weathered bedrock based on its physical behavior.

5.1.2 Texture

5.1.2.1 Grain Size Scale

The U.S.C.S. grain size scale is divided into four main categories: (1) cobbles, (2) gravel, (3) sand, and (4) fines. The gravel, sand, and fines are subdivided into coarse and fine gravel; coarse, medium, and fine sand; and silt and clay.

Table GT.1-1 is a summary of the U.S.C.S. grain size scale as well as the Wentworth, Atterberg, and U.S. Department of Agriculture grain size scales (Krumbein and Pettijohn 1966; and Compton 1962). In this SOP, the U.S.C.S grain size scale is used when logging alluvium, colluvium, fill, and agronomic soils; whereas the Wentworth scale is used for logging bedrock.

Neither the U.S.C.S. nor the U.S. Department of Agriculture grain size scales have a common base. However, both the Wentworth and the Atterberg grain size scales are geometric series with a base of 2 and 10, respectively.

It should be noted that the divisions between gravel and sand, as well as those between sand and silt, vary from scale to scale. This makes it somewhat difficult to compare the U.S.C.S. grain size analyses with analyses based on other scales. Most geotechnical laboratories show only the U.S.C.S. grain size ranges on the graph paper. Figure GT.1-1 is a modified graph that shows both the U.S.C.S. and Wentworth grain size ranges. ASTM D422, "Particle-Size Analysis of Soils," should be used to perform the grain size analyses but should be modified to include a 230 sieve when bedrock is being analyzed.

Sieves and grain size charts should be used regularly when grain size determinations are made. It is important to mention that a small degree of error is inherent between grain size determinations made in the field and those derived in the laboratory. Field analyses are based on volumetric (visual) measurements, whereas the laboratory analyses are based on weight measurements. However, the procedures employed in this SOP significantly reduce the margin of error.

The logger is responsible for subdividing the core into intervals of similar lithologies. From each interval, a small representative sample will be collected, dried, desegregated, and sieved, using the appropriate sieve nest. The volume of material in each size class will be measured using graduated cylinders and beakers and recorded. The logger must record the percentages of gravel, sand, silt, and clay. Percentages of silt and clay can be estimated with the aid of a binocular microscope. The percentage of abundance diagrams in Figure GT.1-5 and the soil reference set will be used when appropriate. All percentages should normalize to 100% and be recorded in the grain size column of the logging form.

TABLE GT.1-1

Grain Size Scales (millimeter[mm])

U.S.C.S.	Wentworth	Atterberg	U.S. Dept. Ag.	Component
>76.2	256-64	200-20	>80	Cobbles
–	64-32*	–	–	V.C. Gravel
76.2-19	32-16*	–	–	C. Gravel
–	16-8*	20-2*	80-2	M. Gravel
19-4.76	8-4*	–	–	F. Gravel
–	4-2	–	–	Granule
–	2-1	–	2-1	V.C. Sand
4.76-2	1-0.5	2-0.2	1-0.5	C. Sand
2-.42	0.5-0.25	–	0.5-0.25	M. Sand
.42-.074	0.25-0.125	0.2-0.02	0.25-0.1	F. Sand
–	0.125-0.0625	–	0.1-0.05	V.F. Sand
<.074	0.0625-0.0039	0.02-0.002	0.05-0.002	Silt
–	<0.0039	<0.002	<.002	Clay
Variable	Base 2	Base 10	Variable	
*Pebbles				

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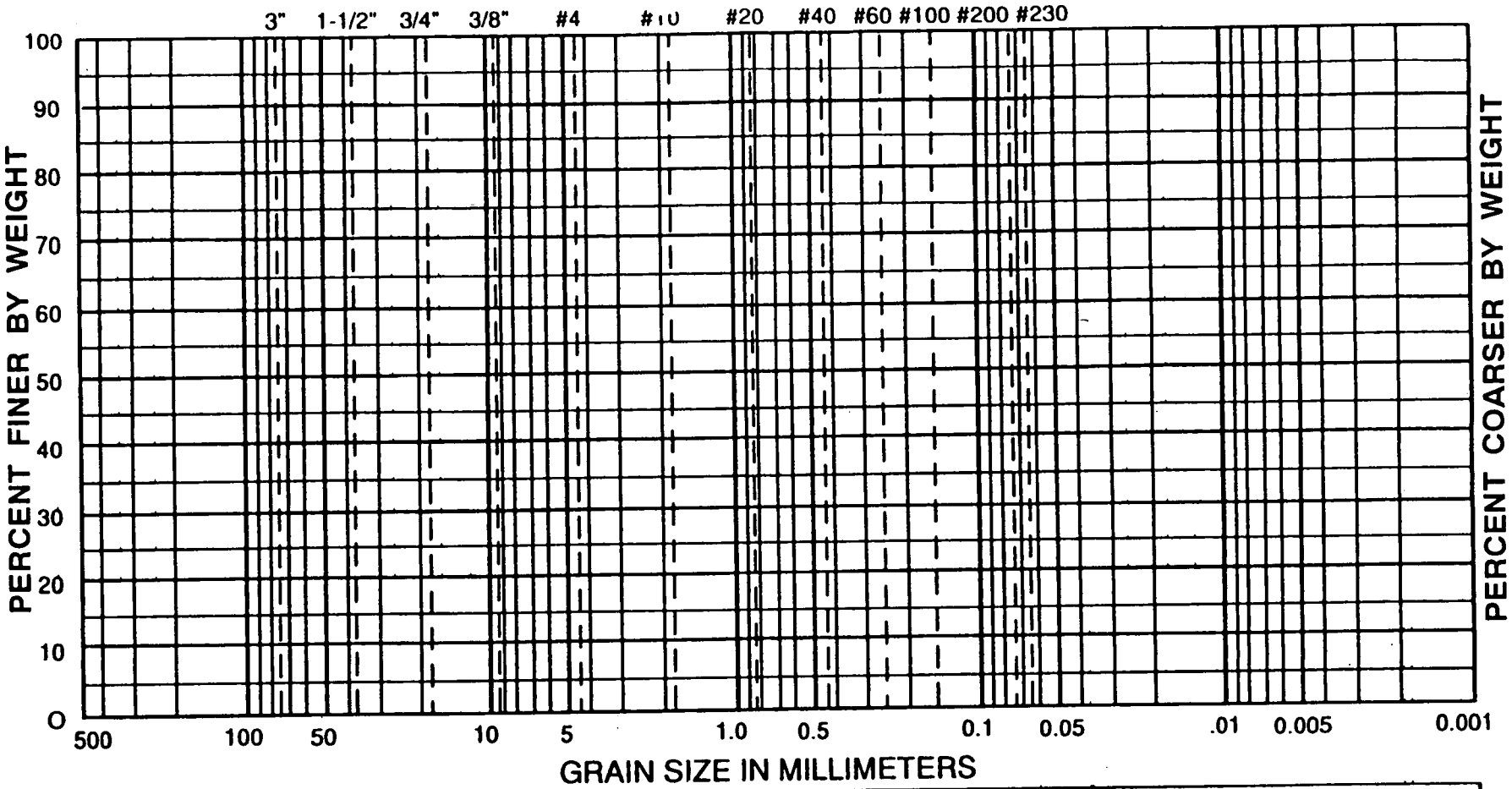


U.S. STANDARD SIEVE SIZE
FIGURE GT.1-1

USCS	COBBLES	GRAVEL		SAND			SILT OR CLAY	
		COARSE	FINE	COARSE	MEDIUM	FINE		

WENTWORTH	COBBLES TO BOULDERS	PEBBLE GRAVEL				SAND			SILT	CLAY
		COARSE	MED	FINE	GRAN	COARSE	MED	FINE		

WELLNAME: _____ SAMPLE NO.: _____ DATE: _____ PROJECT NO.: _____

AREA	DEPTH	CLASSIFICATION

5.1.2.2 Graded Material

The concept of graded material is used to describe the number of grain size ranges that are present within the central portion (approximately 80 percent) of the grain size distribution for samples with less than 5 percent fines (silt and clay). If 80 percent of the sample contains predominantly one or two grain size ranges (such as medium and fine sand), it is poorly graded and has a symbol (P). If 80 percent of the sample contains three or more grain size ranges (such as fine gravel, coarse sand, medium sand, and fine sand), it is well graded and has a symbol (W).

Field values may be checked after the grain size analyses have been calculated and plotted. The uniformity coefficient is a useful value that may help determine whether a gravel or a sand is well graded. The formula for the uniformity coefficient is:

$$U_c = D_{60}/D_{10}$$

where the D values are read directly from the grain size plots and represent the amount of material that is finer by weight. Well-graded gravels have a value greater than 4, and well-graded sands have a value greater than 6.

5.1.3 **Field Estimates of Plasticity**

The plasticity characteristics of fine-grained alluvium or the fine fraction of a coarse alluvium should be determined per the procedures covered in the U.S.C.S. (Appendix GT.1A). The following paragraph and paragraph excerpts are taken from the U.S.C.S in Appendix GT.1A:

"Particles larger than about the No. 40 sieve size are removed (by hand), and a specimen of soil about the size of a 1/2-inch cube is molded to the consistency of putty. If the soil is too dry, water must be added, and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. The sample is rolled by hand on a smooth surface or between

the palms into a thread about 1/8 inches in diameter. The thread is then folded and rerolled repeatedly. During this manipulation, the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. The higher the position of the soil above the 'A' line on the plasticity chart. . . the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the soil is remolded after rolling."

5.1.3.1 Low Plasticity

Alluvial samples with a low plasticity "form a weak thread and . . . cannot be lumped together into a coherent mass below the plastic limit."

5.1.3.2 Medium Plasticity

Alluvial samples with a medium plasticity "form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily."

5.1.3.3 High Plasticity

Alluvial samples with a high plasticity form a stiff thread "as their water content approaches the plastic limit and the tougher are the lumps as the soil is remolded after rolling."

5.1.4 U.S.C.S. Sample Classification

The sample classifications of the U.S.C.S. are illustrated in Figure GT.1-2. In order to classify alluvium, colluvium, fill, and agronomic soils, it is necessary first to estimate the percent of all the grain size ranges in the sample and determine the plasticity of the fines if they comprise more than

50 percent of the sample. With this information, enter Figure GT.1-2 from the left and progress to the right matching the textural, plasticity, and organic characteristics of the sample.

The progression through Figure GT.1-2 is an "if/then" sequence of decisions that ultimately leads to the proper sample classification. For borderline gravel and sand soil classifications whose fines content ranges from 5 to 12 percent, a split classification should be assigned based on the two dominant soil types with the main type given first. A split classification is also justified for gravel and sand soil types having equivalent percentages of coarse fraction material passing the no. 4 sieve. Log descriptions should identify the appropriate U.S.C.S. symbol(s) and associated lithologic (graphic) log; however, the sample description should reflect the most frequent grain size in a manner consistent with the classification for bedrock units (see Section 5.2.5). Two examples follow:

- Example 1: Seventy-five percent of the material is greater than the No. 200 sieve; 53 percent greater than the No. 4 sieve (gravel); 22 percent is sand; and 25 percent is fines (10 percent silt and 15 percent clay). The proper classification for this sample is a sandy gravel with some clay and silt (GC).

- Example 2: Eighty-five percent of the material is smaller than the No. 200 sieve; 5 percent is gravel; 10 percent is sand; 30 percent is silt; and 55 percent is clay that has a low to medium plasticity. The proper classification for this sample is a silty clay with some sand and a trace of gravel (CL).

Note: Both examples use the range of abundance terms defined in Section 5.2.3.1.

Generally, sample descriptions should be made in the following order:

- Main textural classification with modifiers

FIGURE GT.1-2 SOIL TYPES

Major Divisions			Letter	Symbol	Description
Coarse Grained Soils More than 50% of material is larger than no. 200 sieve size	Gravel and Gravely Soils More than 50% of coarse fraction retained on no. 4 sieve	Clean Gravels (< 5% fines)	GW		Well graded gravels or gravel-sand mixtures, little or no fines. Uc > 4 (lab only)
			GP		Poorly graded gravels or gravel-sand mixtures, little or no fines.
		Gravels with Fines (> 12% fines)	GM		Silty gravels, gravel-sand-silt mixtures.
			GC		Clayey gravels, gravel-sand-clay mixtures.
	Sand and Sandy Soils More than 50% of coarse fraction passed no. 4 sieve	Clean Sand (< 5% fines)	SW		Well-graded sands or gravelly sands, little or no fines. Uc > 6 (lab only)
			SP		Poorly-graded sands or gravelly sands, little or no fines.
		Sands with Fines (> 12% fines)	SM		Silty sands, sand-silt mixtures.
			SC		Clayey sands, sand-clay mixtures.
Fine Grained Soils More than 50% of material is smaller than no. 200 sieve size	Silts and Clays	Low Plasticity	ML		Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity
			CL		Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
			OL		Organic silts and organic silty clays of low plasticity
		High Plasticity	MH		Inorganic silts, micaceous or diatomaceous fine sand or silty soils
			CH		Inorganic clays of high plasticity, fat clays
			OH		Organic clays of medium to high plasticity, organic silts
Highly Organic Soils			PT		Peat, humus, swamp soils with high organic contents

Note: Dual Symbols are used to indicate borderline soil classifications whose fines range from 5 to 12%.

Unified Soil Classification System

Modified from "Water-Well Design and Construction; Development in Geotechnical Engineering, 60", by R.L. Harlan, K.E. Koln and E.D. Gutentag; Elsevier, 1989.

- Color*
- Grain size
- Grading
- Angularity (ASTM D2488)
- Plasticity
- Composition
- Bedding
- Moisture content
- Top of bedrock, if present

* See Section 5.2.4 for guidelines on describing color. For alluvial gravels, the color reported will be that of the matrix.

5.1.5 Problems With the U.S.C.S.

The following are problems that are intrinsic to the U.S.C.S. An obvious problem with the U.S.C.S. is that a change of one or two percent in coarse or fine material on either side of the 50 percent boundary may cause the sample classification to vary considerably. For example, a clayey gravel (GC) or a clayey sand (SC) could easily change to a gravelly clay or a sandy clay with low plasticity (CL) or a sandy clay with high plasticity (CH). Clearly a classification system that is this sensitive is subject to errors, especially in the field.

Another problem is that it is all but impossible to determine a liquid limit in the field. For the purposes of this SOP, the liquid limit has been replaced by field estimate of plasticity (see Subsection 5.1.3). All loggers will refer to the RFP Alluvial Reference Set as an aide in making plasticity determinations.

The U.S.C.S. also lacks the textural property of angularity that helps to determine the maturity of a sediment.

Finally, the U.S.C.S. is a purely descriptive classification that has been designed for construction purposes and concentrates heavily on the physical properties of clay. Because of this, the U.S.C.S. has 15 sample classifications and is very cumbersome.

5.2 BEDROCK DESCRIPTIONS

All bedrock material should be classified and described by using many of the procedures and techniques described in Compton (1962), which has been incorporated with additional material in this SOP.

5.2.1 Basis of Classification

Compton classifies sedimentary rocks on the basis of their texture, fabric, and composition. Rock descriptions such as conglomerate, sandstone, siltstone, and shale (claystone and mudstone) are textural classifications based solely on grain size. When other properties like sorting, roundness, bed thickness and contacts, cross-stratification, color, composition, cement, porosity, and fossil content are included, it is possible to make interpretations of where, how, and under what conditions the sediments were deposited.

5.2.2 Textural Parameters

5.2.2.1 Grain Size Scale

The Wentworth grain size scale is divided into six main categories: (1) cobbles, (2) pebbles, (3) granules, (4) sand, (5) silt, and (6) clay. The pebble and sand categories are subdivided into very coarse, coarse, medium, and fine pebbles; and very coarse, coarse, medium, fine, and very fine sand (see Table GT.1-1). The scale is a geometric series with a base of 2.

Unlike the U.S.C.S. in which the sand/silt boundary occurs at 0.074 mm, the sand/silt boundary occurs at 0.0625 mm in the Wentworth scale. Since geotechnical laboratories generally plot grain size analyses on graph paper that is compatible with the U.S.C.S., it is important to ensure that they also include the range of Wentworth grain size intervals on the graph paper (Figure GT.1-1). The grain size distribution of bedrock materials are made using the sieving techniques as described in Section 5.1.2.1.

5.2.2.2 Degree of Sorting

Sorting is a measure of the extent to which a sediment has been winnowed or reworked during transport. It also is a good indicator of the maturity of a sediment, the energy of the transporting agent, and the environment of deposition.

In order to determine the degree of sorting, Compton (1962) states, "an estimate is made of the range of grain sizes that include the bulk (here 80 percent) of the detrital materials." It is then necessary to count the number of size ranges that are contained in the 80 percent sample (see Table GT.1-1). The number of size ranges is then compared with Figure GT.1-3 to determine the degree of sorting that describes the sample best.

5.2.2.3 Degree of Rounding

Rounding is a measure of the amount of abrasion a grain has undergone. However, it is not generally used to describe sediments that are much finer than sand, because grains finer than sand tend to have elastic collisions that do not affect the shape of the grain. Two properties that must be considered when estimating the degree of rounding are (1) the composition and (2) the original shape of the grain. Rounding can be an indication of sediment maturity, sediment transport history and sometimes provenance. The shapes shown in Figure GT.1-4 should be used to estimate the degree of rounding of individual grains.

TERMS FOR DEGREE OF SORTING

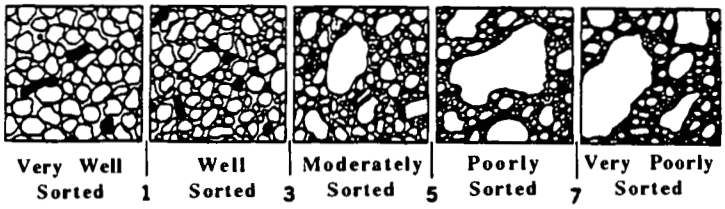


FIGURE GT.1-3

Terms for degrees of sorting. The numbers indicate the number of size-classes included by the great bulk (80 percent) of the material. The drawings represent sandstones as seen with a hand lens. Silt and clay-size materials are shown diagramatically by the fine stipple. Taken from Compton, 1962.

TERMS FOR DEGREE OF ROUNDING

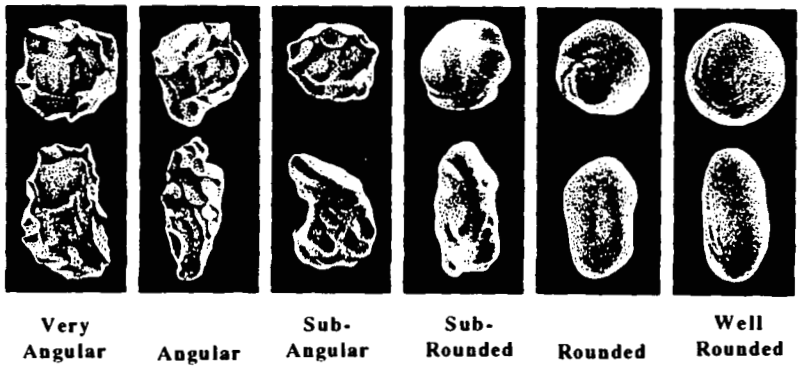


FIGURE GT.1-4

Terms for degree of rounding grains as seen with a hand lens. After Powers, M. C., 1953, "Journal of Sedimentary Petrology", v. 23, p. 118. Courtesy of the Society of Economic Paleontologists and Mineralogists. Taken from Compton, 1962.

5.2.2.4 Porosity

Porosity is not always an easy property to estimate in the field because the bedrock can be drastically altered during drilling and coring as well as by weathering. Generally, samples exhibit more porosity than the rock actually contains.

Porosity will be estimated at 20X using a binocular microscope and expressed as a percentage of the total rock volume. The abundance charts shown in Figure GT.1-5 will be used. The porosity seen at 20X power is an estimate of the effective aquifer porosity.

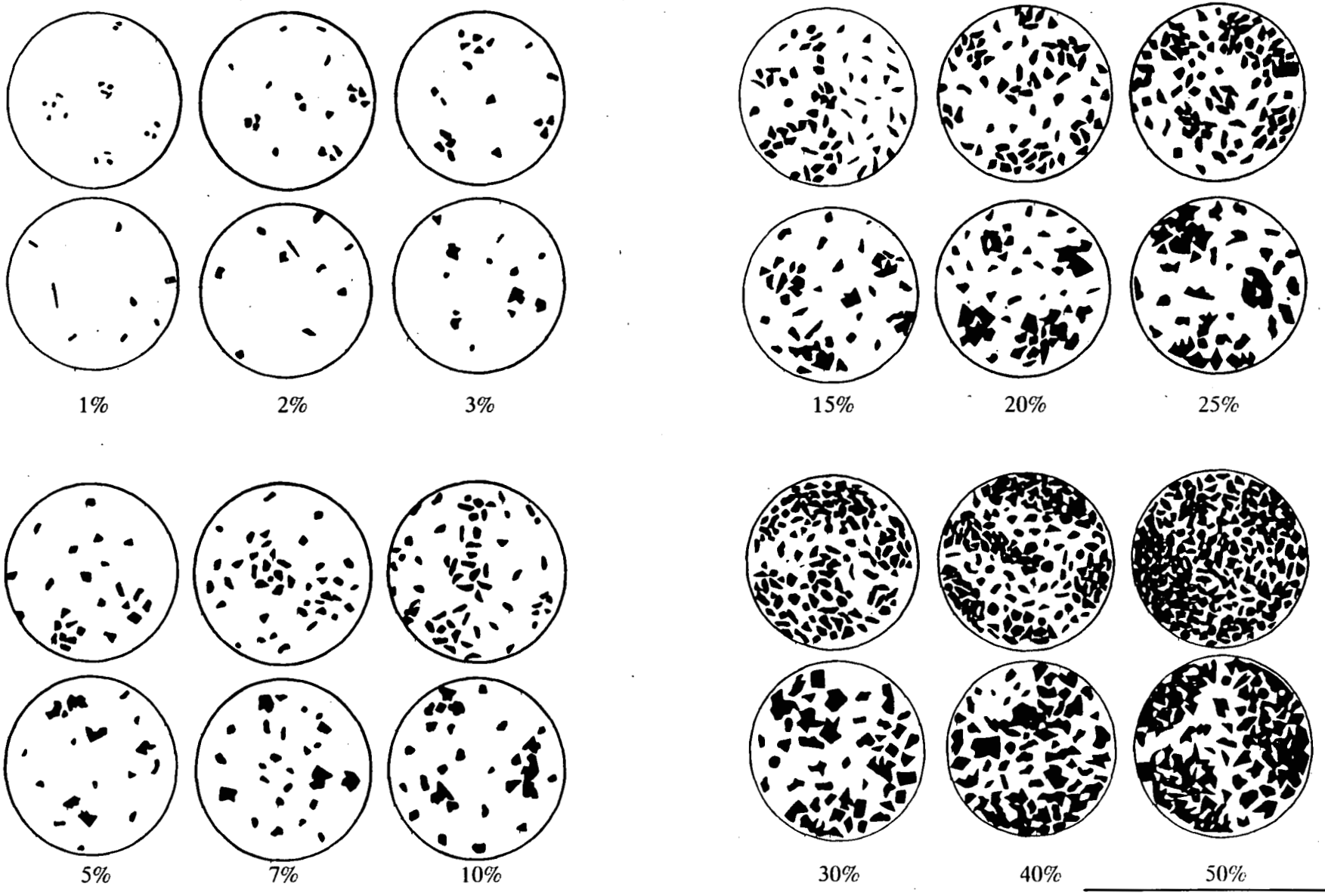
5.2.3 Estimate of Abundance

Figure GT.1-5 is composed of several drawings that represent the field of view commonly seen through a microscope or hand lens. Each circle contains a number of black areas. Below each circle is the actual percentage of black area that the circle contains. All loggers should review Figure GT.1-5 until they are adept at estimating the percentages that are contained in the circles.

5.2.3.1 Division of Abundance

Quite often it is necessary to determine the relative abundance of a variable. In these cases, the use of the terms trace, some, and abundant has a utility. The ranges for each are given in Table GT.1-2.

CHARTS FOR ESTIMATING PERCENTAGE COMPOSITION OF ROCKS AND SEDIMENT



Prepared by R. D. Terry and G. V. Chilingar for "Journal of Sedimentary Petrology" (v. 25, pp. 229-234, 1955); reprinted as 'Data Sheet 6' of "Geotimes" available from the American Geological Institute, 2101 Constitution Ave., N.W., Washington, D. C. Reprinted here by permission of the authors and the Society of Economic Paleontologists and Mineralologists. Taken from Compton, 1962.

FIGURE GT.1-5

(4011-930-0119-930)(Figure GT.1-5)(03/01/92)

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TABLE GT.1-2
RANGE OF ABUNDANCE

Division	Range of Percent
Trace	>0 to 5
Some	6 to 25
Abundant	26 to 100

These terms generally follow a "with" statement; such as, Sandstone; light olive gray (5Y6/1), very fine to fine grained, with a trace of carbonaceous material.

5.2.4 Color

Color can convey a great deal of information. It helps to identify the components of the sediment or rock as well as the cement. In addition, color is indicative of the current chemical environment from which the sample was taken. For example, at RFP, highly weathered (oxidized) sandstones are commonly brownish-orange while unweathered sandstones are light olive grey.

To ensure that the color descriptions are accurate and standardized, each sample should be described while it is wet by using the Geological Society of America "Rock-Color Chart" (1984). If the sample has dried, it should be moistened with clean water from a squirt bottle. Care should also be taken to remove sunglasses when a color determination is being made.

5.2.5 Rock Classification

Clastic rocks are primarily classified on the basis of their most frequent grain size. The majority of rocks at RFP are claystone, siltstones, and sandstones; however, hybrids of these end members are quite common. The second and sometimes third most frequent constituents act as modifiers and precede the major rock name in the description; such as, silty sandstone or clayey siltstone. If, however, a rock is composed of 80 percent or more of one constituent, then it should be described solely as that rock type. The secondary textural modifiers should then be described in the description following a "with" statement. Figure GT.1-6 shows all the rock classifications and their lithologic symbols that should be used while logging bedrock samples.

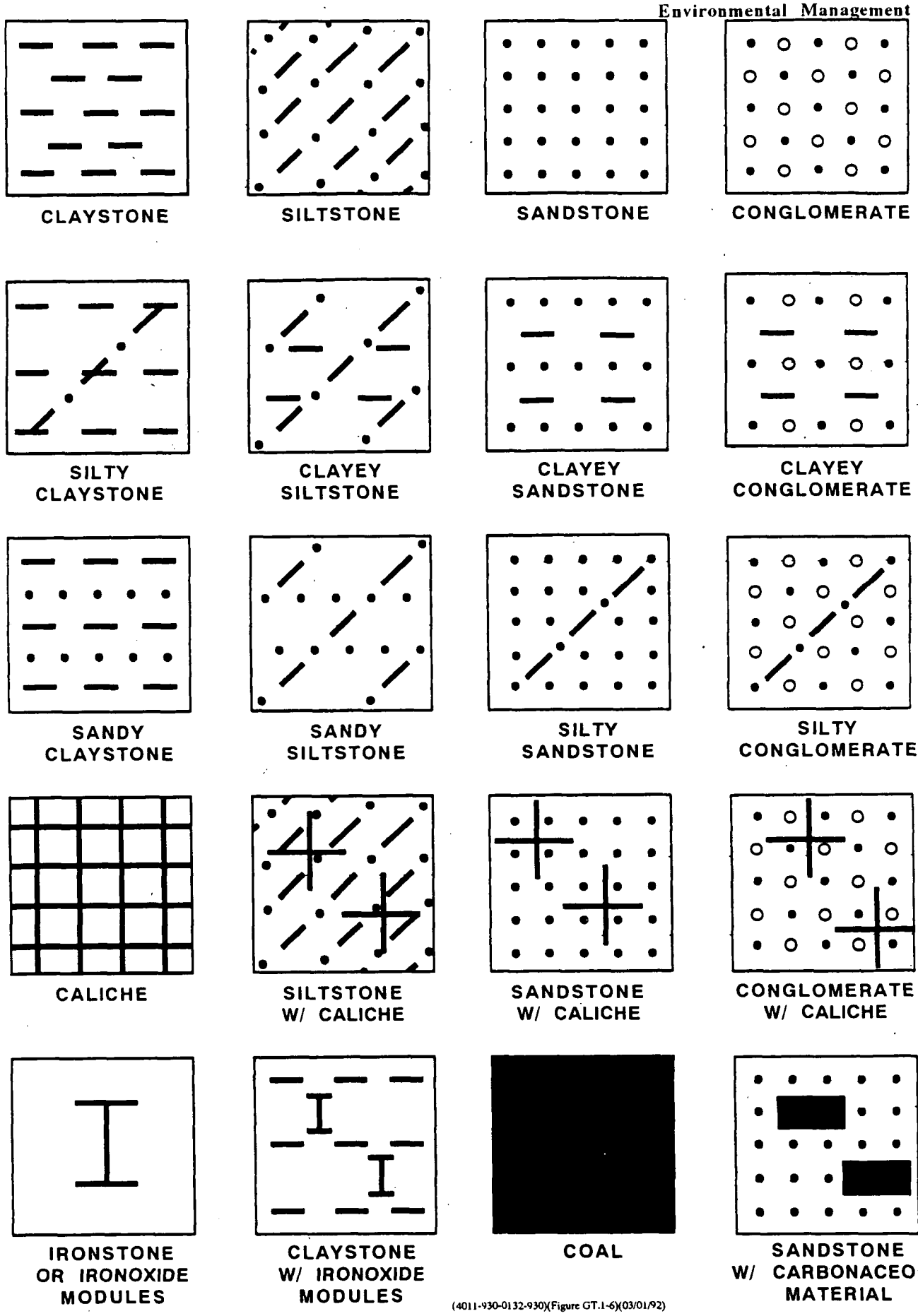
5.2.6 Cement

The nature of the cementing medium should be described whenever possible. Typical cementing agents are clay (argillaceous cement), silica, and calcium carbonate (caliche).

5.2.7 Friability

The tendency of a rock to crumble is related to how well it is cemented and the extent to which it has been weathered. Table GT.1-3 shows the degree of friability.

FIGURE GT.1-6 LITHOLOGIC SYMBOLS FOR COMMON CLASTIC ROCKS



(4011-930-0132-930)(Figure GT.1-6)(03/01/92)

TABLE GT.1-3

DEGREE OF FRIABILITY

Term	Definition
Highly Friable	Crumbles readily into individual grains upon minor disturbance
Moderately Friable	Will crumble into individual grains with extensive rubbing
Slightly Friable	Can be broken into individual grains by scraping it with a pocket knife
Non-Friable	Cannot be broken into individual grains by any of the methods described above

5.2.8 Composition

It is not the objective of this SOP to classify sedimentary rocks on the basis of their mineral content by using tertiary diagrams with quartz/chert, feldspar, and lithic fragments at each pole. Since Compton wrote the "Manual of Field Geology" in 1962, several classifications have been published. Two of the most widely used classifications are those published by Earl McBride in 1963 and Robert Folk in 1974. Blatt, et al., (1972) presents an excellent evaluation of these and other classifications. For the purpose of this SOP, the geologist is concerned with describing only accessory minerals, fossils, and other components that distinguish one rock from another. The descriptive term(s) should follow a "with" statement; such as, silty sandstone; light olive grey (5Y6/1), very fine grained, with some pink feldspar rock fragments.

5.2.9 Bedding and Internal Structure

In sedimentary rocks, bedding is related to differences in texture, composition, and color, and reflects changes in the environment of deposition and/or the source material. Depending on the depositional processes that are involved, bedding boundaries may or may not represent a specific moment in time.

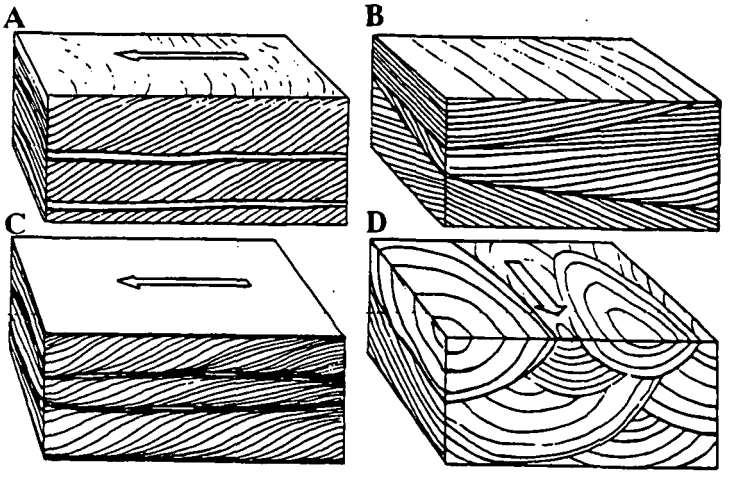
Compton classifies bedding as repeated sequences of beds, shapes of individual beds, and cross-bedding (cross-stratification). Repeated bedding is produced by cyclic changes in the sedimentary processes. Individual bed shapes are classified as tabular, lenticular, linear, wedge-shaped, or irregular. Cross-stratification is classified on the basis of its external and internal characteristics. External forms of cross-stratification are tabular, wedge shaped, and trough shaped. Internal descriptive terms that are commonly used are graded, massive, laminated, and tangential (Figure GT.1-7). Other internal features to be described include ripple marks, flow structures, burrows and tubes, load casts, and desiccation cracks (mud cracks).

5.2.10 Fractures and Slickensides

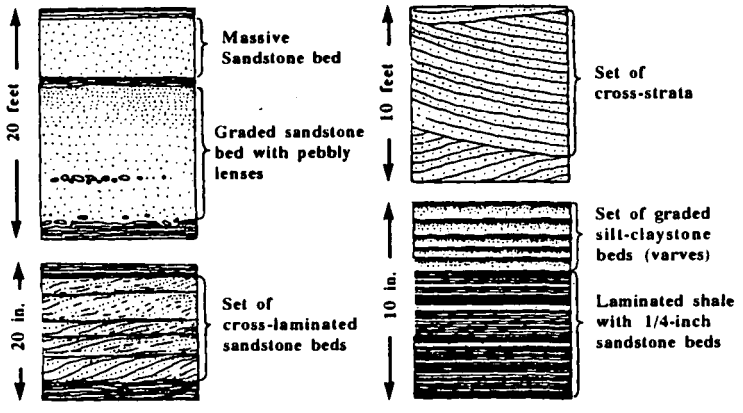
Fractures should be described whenever they are present. Fractures occur naturally in bedrock and should not be confused with breaks induced by coring and handling. The characteristics that should be noted about the fracture are:

- Whether the fracture is opened or healed
- The composition of the material filling the fracture, if any
- The angle of the fracture from the horizontal
- The apparent displacement of bedding across the fracture
- Whether slickensides are present and the angle of any striations from the horizontal

BEDDING AND INTERNAL STRUCTURES



Cross-bedded rocks. (A) Tabular sets with diagonal patterns. (B) Wedge sets, showing considerable erosion between each set. (C) Tabular to lenticular sets with tangential patterns; typically, these are laminated marine beds. (D) Symmetrical trough sets with distinctly linear axes; typically, these are large-scale fluvial features. The arrows indicate current directions. Taken from Compton, 1962.



Various beds and sets of beds. Taken from Compton, 1962.

FIGURE GT.1-7

5.2.11 Moisture Content

The core will be described as dry, moist, or saturated, and the depth to the top of the saturated interval will be recorded. If a static water level can be measured, it will be noted. The moisture content and static water level (if present) will be recorded in the field on the back of the core logging form. The core logger will include this information in the core description.

5.2.12 Lithologic Description

Generally, lithologic descriptions should be made in the following order:

- Top of bedrock, if present
- Main rock type with modifiers
- Color
- Grain size
- Degree of sorting
- Degree of rounding
- Porosity
- Cement
- Friability
- Composition
- Bedding and internal structure
- Fractures and slickensides
- Moisture content

6.0 LOGGING

This section describes the field procedures used while logging.

It is the responsibility of the logging personnel to ensure that all of the materials and equipment needed for logging are at the site.

6.1 LOGGING EQUIPMENT

The following is a list of equipment that is necessary to properly log the alluvial and bedrock material.

- Core Reference Set
- Alluvial Reference Set
- Rock-Color Chart
- Logging forms
- Hand lens
- Nos. 4, 10, 40, 200, and 230 sieves (8-inch) with lid and base
- Six-foot metal tape measure in tenths of a foot
- Core boxes (2 feet long, 5 columns each 2-1/2 inches wide) (such as, Boise Cascade No. 17-505 top and bottom)
- Wood blocks (2-1/2 inches x 3/4 inches) for marking depths and sample locations
- Jars for cuttings
- Wentworth and/or Amstrat grain size charts
- Knife
- Acid (10 percent HCl) in squirt bottle
- Water in squirt bottle
- Black waterproof (permanent) markers and pens
- Protective clothing and equipment (see Health & Safety Plan)

- Flashlight
- Hammer
- Clipboard
- Table
- Duct tape
- Paper towels
- Plastic wrap
- Protractor
- Camera (35 mm) with film (Kodak color patch)
- Flat-bladed screwdriver
- Awl
- Binocular microscope
- Mortar and pestal
- Hot plate
- Spot plate
- 500 ml beakers
- 10 ml and 50 ml graduated cylinders
- Watch glass

6.2 CORES AND CUTTINGS

6.2.1 Scanning the Core

After an interval of core has been cut and the sampler has been opened, the core will be scanned for hazardous and radioactive contamination. The field use of monitors for the detection of volatile organics and radionuclides is discussed in SOPs FO.8, Handling of Drilling Fluids and Cuttings; FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs); and FO.16, Field Radiological Measurements. Once the core has been scanned, it will be handled in accordance with

the Health and Safety Plan. See Section 6.3, Core Boxes for a discussion on isolating core sections that are suspected of containing radioactive and/or hazardous substances.

6.2.2 Percent Recovery

The core should be consolidated in the sampler, measured to the nearest tenth of a foot, and if competent, etched with two parallel lines using an awl and a flat-bladed screwdriver. The awl line will be etched on the left side of the core, for the entire length of the core. The screwdriver line will be etched on the right side of the core, for the entire length of the core. These etched lines denote the "up" position. All competent core will be etched with enough pressure so the lines are readily visible, but not with enough pressure so the core's features are obliterated or altered. Once etched, the core will be slid out onto the plastic wrap that has been placed in the core box. The interval drilled and the interval recovered will be recorded on the logging form. Figure GT.1-8 is an example of a completed logging form. Wood blocks with footage values marked on them in black waterproof ink will be placed at each end of each core run. Intervals of no recovery should be recorded on wooden blocks and placed at appropriate locations in the core box. If only cuttings were collected, a representative sample will be collected every 2 feet, unless drilling rates and/or depth constraints make this impractical in which case 5-foot samples will be collected. The EG&G project manager will determine the collection interval. The samples will be placed in labeled jars in the core box.

If the cores or drill cuttings are logged at a separate location removed from the drill site, the following information will be recorded on Form GT.1B (located on the back of Form GT.1B): generalized lithologic descriptions, moisture content, depth to water table, and all geochemical and geotechnical sample numbers with corresponding sampling depths. Cores and logging forms will be delivered to the remote location within one day of filling each core box. The first four columns of the log will either be filled out in the field, or the information to properly fill out the columns will be provided on Form GT.1B.

6.2.3 Logging

The core or cuttings will be logged according to all of the procedures previously covered in this SOP.

6.2.4 Photographing the Core

Any and all photographing procedures must conform to plant security controls. Each box of core should be photographed with a 35 mm camera before it has been logged and sampled. If the core is photographed at RFP, the camera will have to be cleared and left on site until the project is completed. In addition, all of the film must be processed by RFP. An identification tag and a Kodak color patch should appear in each photograph. The identification tag should contain:

- The well name
- Footage values of the core in the box
- The box number and the total number of boxes for that borehole, such as Box 1 of 7
- Date core was taken
- Project number

6.2.5 Sampling

Samples that are taken for grain size analyses and permeameter tests should be removed only after the core has been logged and photographed. At the time a sample is taken, a wood block with the following information must be placed in the core box at the point the sample was removed:

ROCKY FLATS PLANT BOREHOLE LOG

Borehole Number: Well or BH Number
Location - North: 749718.7 East: 2086747.7
Date: 11/17/91
Geologist: JBP/Stratigrapher Initials
Drilling Equip.: CME 75
Surface Elevation: 5962 ft
Area: East Trenches
Total Depth: 22.0 ft
Company: Subcontractor Project No.: OU #
Sample Type: Continuous Core

EG&G LOGGING SUPERVISOR
APPROVAL _____ DATE _____

TOP/BOTTOM OF CORE IN BOX	TOP/BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL (FIELD MEASUREMENT)	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	SOIL/ LITHOLOGIC LOG	SAMPLE DESCRIPTION
10.0	10.0	10.0						10		SM-SW 10.0'-12.7'
	Run 6	2.0'				Gravel 37% Sand 52% Silt 7% Clay 4%	SM	11		Gravelly Sand Dark yellowish brown (10YR 4/2) to moderate yellowish brown (10YR 5/4) Sand: coarse grained; subangular Gravel: avg. size = 0.5 inches max. size = 1.0 inch subangular to angular Well graded; sand predom.
	12.0							12		Quartz; gravel predom.
Box 2 of 8 10.0'-16.5'	Run 7	1.9'	Sample Number .8					13		Qua e and feldspar. alcite; dry
	14.0		<					14		14.0'-16.5'
			C Sample Number			Sand 40% Silt 4%				Sandy Clay with trace of silt Dusky yellowish brown (10YR 2/2) to dark yellowish brown (10YR 4/2) Sand: fine grained; subangular Low plasticity; dry
16.5	Run 8	4.3'						16		Top of Bedrock at 16.5'
						>95% Clay		17		Claystone 16.5'-20.5' Dusky yellowish brown (10YR 4/2) Some carbonaceous material; moderately friable; moist
Box 3 of 8 16.5'-22.0'			Sample Number .8					18		
	19.0		<					19		
			C Sample Number					20		

EXAMPLE

NOTES: General: USCS is modified for this log as follows:
Materials amounts are estimated by % volume instead of % weight.
(1) Badly broken core, accurate footage measurements not possible.
(2) Core breaks cannot be matched, accurate footage measurements not possible.

FIGURE GT.1-8

- Sample number
- Depth
- Purpose
- Date
- Company

This information will be marked on the wood block with a black waterproof (permanent) marker.

6.3 CORE BOXES

The core boxes will be similar to the boxes described in Subsection 6.1 above. Each core box and lid will be marked with the following information:

- Well name
- Depth interval
- Date
- Project name
- Well site geologist's initials
- Logger's initials (after logging is completed)
- Box number and the total number of boxes
- Appropriate hazardous waste labels

After samples have been scanned as discussed in Subsection 6.2.1, the core will be containerized. Radiation and volatile organic analysis (VOA) readings will be written on the tops of the core boxes. Sections of the core suspected of containing radioactive and/or hazardous substances will be removed, segregated by their potential contaminant characterization, and placed in core boxes designated for potentially contaminated core. The remaining core will then be placed in separate core boxes. Wood blocks will be placed within the core boxes to indicate the position where

potentially contaminated core sections were removed. Blocks will be marked with the interval of the core section removed and where the section can be located.

The core boxes will be closed and secured in a manner such that core will not be disturbed or mislocated during transportation. Core boxes suspected of containing low-level radioactive substances will be labeled with a "White I" radioactive label. Core boxes suspected of containing volatile organic or mixed substances will be labeled with a Department of Transportation "Other Regulated Material Class E" (ORM-E) label (see SOP FO.10, Receiving, Labeling, and Handling Environmental Materials Containers). If the suspected contamination is mixed substances, the core box will also be marked with the words "SUS RAD" for suspected radioactive contamination.

Core boxes suspected of containing radioactive and/or hazardous substances will be stored in a facility designated for potentially contaminated core. All other core boxes will be stored at the main core storage facility at RFP.

7.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting all information required by the SOP on the Borehole Log Form (Form GT.1A). Drilling activities will also be documented on the hollow-stem auger or rotary and core drilling Field Activities Report Forms (see SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques, and SOP GT.4, Rotary Drilling and Rock Coring).

The logger will primarily be responsible for each aspect and each procedure.

ROCKY FLATS PLANT BOREHOLE LOG

PAGE ___ OF ___

Borehole Number: _____ Surface Elevation: _____

Location - North: _____ East: _____ Area: _____

Date: _____ Total Depth: _____

Geologist: _____ Company: _____ Project No.: _____

Drilling Equip.: _____ Sample Type: _____

EG&G LOGGING SUPERVISOR

APPROVAL _____ DATE _____

TOP/BOTTOM OF CORE IN BOX	TOP/BOTTOM OF INTERVAL	FEET OF CORE IN INTERVAL (FIELD MEASUREMENT)	SAMPLE NUMBER	FRACTURE ANGLE	BEDDING ANGLE	GRAIN SIZE DISTRIBUTION	USCS SYMBOL	DEPTH IN FEET	SOIL/ LITHOLOGIC LOG	SAMPLE DESCRIPTION

NOTES: General: USCS is modified for this log as follows:
Materials amounts are estimated by % volume instead of % weight.
(1) Badly broken core, accurate footage measurements not possible.
(2) Core breaks cannot be matched, accurate footage measurements not possible.

PRELIMINARY WELL-SITE FIELD LOG

PAGE ___ OF ___

Date: _____ Borehole Number: _____

Rig Geologist: _____ Company: _____

FEET

NOTES:

APPENDIX GT.1A

UNIFIED SOIL CLASSIFICATION SYSTEM

CHARACTERISTICS OF SOIL GROUPS

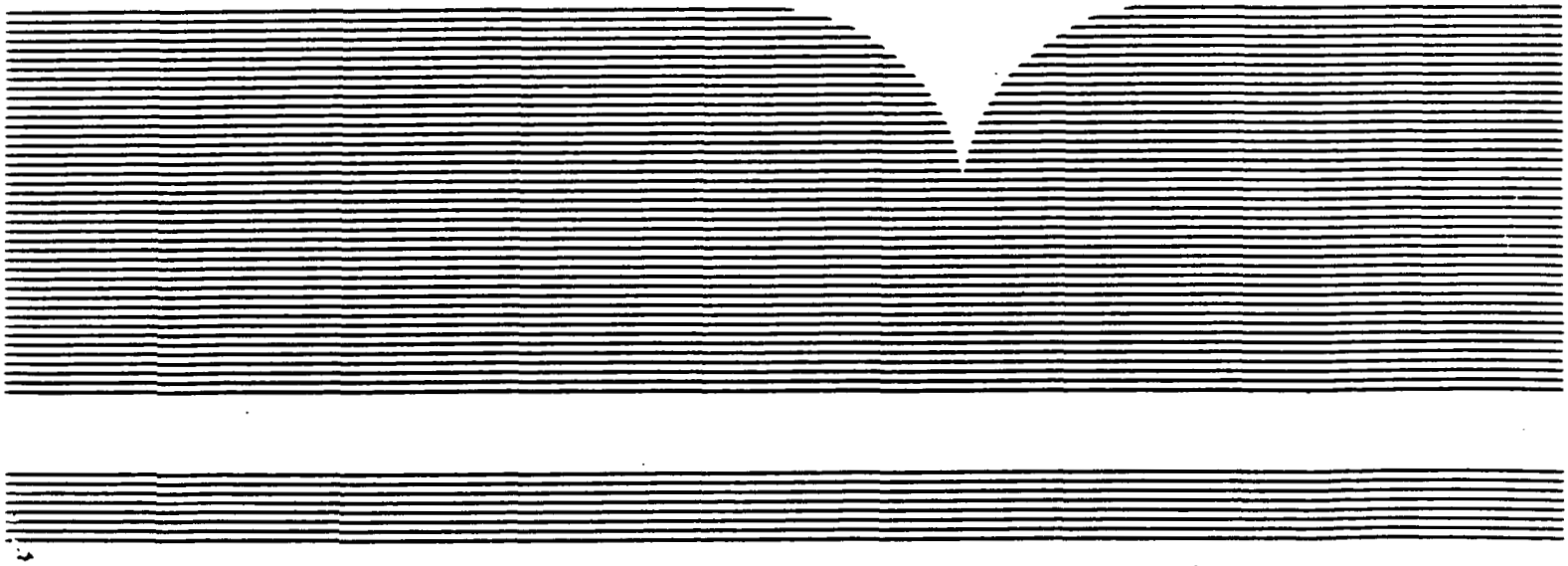
PERTAINING TO EMBANKMENTS AND FOUNDATIONS

AD/A026 473

THE UNIFIED SOIL CLASSIFICATION SYSTEM - APPENDIX A: CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS - APPENDIX B: CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

(U.S.) Army Engineer Waterways Experiment Station
Vicksburg, MS

Apr 60



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AD/A026 473

TECHNICAL MEMORANDUM NO. 3-357

THE UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

APPENDIX B
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

April 1960
(Reprinted May 1967)

Sponsored by

Office, Chief of Engineers
U. S. Army

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

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TECHNICAL MEMORANDUM NO. 3-357

APPENDIX A
CHARACTERISTICS OF SOIL GROUPS PERTAINING TO EMBANKMENTS AND FOUNDATIONS

March 1953

Sponsored by

Office, Chief of Engineers
U. S. Army

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U. S. Army Engineer Waterways Experiment Station
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Vicksburg, Mississippi

A-i

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NOTICE

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Preface

The purpose of this manual is to describe and explain the use of the "Unified Soil Classification System" in order that identification of soil types will be on a common basis throughout the agencies using this system.

The program of military airfield construction undertaken by the Department of the Army in 1941 revealed at an early stage that existing soil classifications were not entirely applicable to the work involved. In 1942 the Corps of Engineers tentatively adopted the "Airfield Classification" of soils which had been developed by Dr. Arthur Casagrande of the Harvard University Graduate School of Engineering. As a result of experience gained since that time, the original classification has been expanded and revised in cooperation with the Bureau of Reclamation so that it applies not only to airfields but also to embankments, foundations, and other engineering features.

Acknowledgment is made to Dr. Arthur Casagrande, Professor of Soil Mechanics and Foundation Engineering, Harvard University, for permission to incorporate in this manual considerable information from the paper "Classification and Identification of Soils" published in Transactions, American Society of Civil Engineers, volume 113, 1948. This manual was prepared under the direction of the Office, Chief of Engineers, by the Soils Division, Waterways Experiment Station.

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UNIFIED SOIL CLASSIFICATION SYSTEM

Introduction

Need for a classification system

1. The adoption of the principles of soil mechanics by the engineering profession has inspired numerous attempts to devise a simple classification system that will tell the engineer the properties of a given soil. As a consequence, many classifications have come into existence based on certain properties of soils such as texture, plasticity, strength, and other characteristics. A few classification systems have gained fairly wide acceptance, but it is seldom that any particular system has provided the complete information on a soil that the engineer needs. Nearly every engineer who practices soil mechanics will add judgment and personal experience as modifiers to whatever soil classification system he uses, so that it may be said that there are as many classification systems as there are engineers using them. Obviously, within a given agency, where designs and plans are reviewed by persons entirely removed from a project, a common basis of soil classification is necessary so that when an engineer classifies a soil as a certain type, this classification will convey to another engineer not familiar with the region the proper characteristics and behavior of the material. Further than this, the classification should reflect those behavior characteristics of the soil that are pertinent to the project under consideration.

Basis of the unified soil classification system

2. The unified soil classification system is based on the

identification of soils according to their textural and plasticity qualities and on their grouping with respect to behavior. Soils seldom exist in nature separately as sand, gravel, or any other single component, but are usually found as mixtures with varying proportions of particles of different sizes; each component part contributes its characteristics to the soil mixture. The unified soil classification system is based on those characteristics of the soil that indicate how it will behave as an engineering construction material. The following properties have been found most useful for this purpose and form the basis of soil identification. They can be determined by simple tests and with experience can be estimated with some accuracy.

a. Percentages of gravel, sand, and fines (fraction passing No. 200 sieve).

b. Shape of the grain-size-distribution curve.

c. Plasticity and compressibility characteristics.

In the unified soil classification system the soil is given a descriptive name and a letter symbol indicating its principal characteristics.

Purpose and scope of manual

3. It is the purpose of this manual to describe the various soil groups in detail and to discuss the methods of identification in order that a uniform classification procedure may be followed by all who use the system. Placement of the soils into their respective groups is accomplished by visual examination and laboratory tests as a means of basic identification. This procedure is described in the main text of this manual. The classification of the soils in these groups according to their engineering behavior for various types of construction, such as

embankments, foundations, roads, and airfields, is treated separately in appendices hereto which will be issued as the need arises. It is recognized that the unified classification system in its present form may not prove entirely adequate in all cases. However, it is intended that the classification of soils in accordance with this system have some degree of elasticity, and that the system not be followed blindly nor regarded as completely rigid.

Definitions of soil components

4. Before soils can be classified properly in any system, including the one presented in this manual, it is necessary to establish a basic terminology for the various soil components and to define the terms used. In the unified soil classification the names "cobbles," "gravel," "sand," and "fines (silt or clay)" are used to designate the size ranges of soil particles. The gravel and sand ranges are further subdivided into the groups presented below. The limiting boundaries between the various size ranges have been arbitrarily set at certain U. S. Standard sieve sizes in accordance with the following tabulation:

Component	Size Range
Cobbles	Above 3 in.
Gravel	3 in. to No. 4 (4.76 mm)
Coarse gravel	3 in. to 3/4 in.
Fine gravel	3/4 in. to No. 4 (4.76 mm)
Sand	No. 4 (4.76 mm) to No. 200 (0.074 mm)
Coarse sand	No. 4 (4.76 mm) to No. 10 (2.0 mm)
Medium sand	No. 10 (2.0 mm) to No. 40 (0.42 mm)
Fine sand	No. 40 (0.42 mm) to No. 200 (0.074 mm)
Fines (silt or clay)	Below No. 200 (0.074 mm)

These ranges are shown graphically on the grain-size sheet, plate 1. In

the finest soil component (below No. 200 sieve) the terms "silt" and "clay" are used respectively to distinguish materials exhibiting lower plasticity from those with higher plasticity. The minus No. 200 sieve material is "silt" if the liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2), and is "clay" if the liquid limit and plasticity index plot above the "A" line on the chart (all Atterberg limits tests based on minus No. 40 sieve fraction of a soil). The foregoing definition holds for inorganic silts and clays and for organic silts, but is not valid for organic clays since these latter soils plot below the "A" line. The names of the basic soil components can be used as nouns or adjectives in the name of a soil, as explained later.

The Classification System

5. A short discussion of the unified soil classification sheet, table 1, is presented in order that the succeeding detailed description may be more easily understood. This sheet is designed to apply generally to the identification of soils regardless of the intended engineering uses. The first three columns of the classification sheet show the major divisions of the classification and the group symbols that distinguish the individual soil types. Names of typical and representative soil types found in each group are shown in column 4. The field procedures for identifying soils by general characteristics and from pertinent tests and visual observations are shown in column 5. The desired descriptive information for a complete identification of a soil is presented in column 6. In column 7 are presented the laboratory

classification criteria by which the various soil groups are identified and distinguished. Table 2 shows an auxiliary schematic method of classifying soils from the results of laboratory tests. The application and use of this chart are discussed in greater detail under a subsequent heading in this manual.

Soil groups and group symbols

6. Major divisions. Soils are primarily divided into coarse-grained soils, fine-grained soils, and highly organic soils. On a textural basis, coarse-grained soils are those that have 50 per cent or less of the constituent material passing the No. 200 sieve, and fine-grained soils are those that have more than 50 per cent passing the No. 200 sieve. Highly organic soils are in general readily identified by visual examination. The coarse-grained soils are subdivided into gravel and gravelly soils (symbol G), and sands and sandy soils (symbol S). Fine-grained soils are subdivided on the basis of the liquid limit; symbol L is used for soils with liquid limits of 50 and less, and symbol H for soils with liquid limits in excess of 50 (see plate 2). Peat and other highly organic soils are designated by the symbol Pt and are not subdivided.

7. Subdivisions, coarse-grained soils. In general practice there is no clear-cut boundary between gravelly soils and sandy soils, and as far as behavior is concerned the exact point of division is relatively unimportant. For purposes of identification, coarse-grained soils are classed as gravels (G) if the greater percentage of the coarse fraction (retained on No. 200 sieve) is larger than the No. 4 sieve and as sands (S) if the greater portion of the coarse fraction is finer than the No. 4

sieve. Borderline cases may be classified as belonging to both groups. The gravel (G) and sand (S) groups are each divided into four secondary groups as follows:

a. Well-graded material with little or no fines. Symbol W. Groups GW and SW.

b. Poorly-graded material with little or no fines. Symbol P. Groups GP and SP.

c. Coarse material with nonplastic fines or fines with low plasticity. Symbol M. Groups GM and SM.

d. Coarse material with plastic fines. Symbol C. Groups GC and SC.

8. Subdivisions, fine-grained soils. The fine-grained soils are subdivided into groups based on whether they have a relatively low (L) or high (H) liquid limit. These two groups are further subdivided as follows:

a. Inorganic silts and very fine sandy soils; silty or clayey fine sands; micaceous and diatomaceous soils; elastic silts. Symbol M. Groups ML and MH.

b. Inorganic clays. Symbol C. Groups CL and CH.

c. Organic silts and clays. Symbol O. Croups OL and CH.

Discussion of Coarse-grained Soils

GW and SW groups

9. These groups comprise well-graded gravelly and sandy soils having little or no nonplastic fines (less than 5 per cent passing the No. 200 sieve). The presence of the fines must not noticeably change the strength characteristics of the coarse-grained fraction and must not interfere with its free-draining characteristics. If the material contains less than 5 per cent fines that exhibit plasticity, this

information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." In areas subject to frost action, the material should not contain more than about 3 per cent of soil grains smaller than 0.02 mm in size. Typical examples of GW and SW soils are shown on plate 3.

GP and SP groups

10. Poorly-graded gravels and sands containing little or no nonplastic fines (less than 5 per cent passing the No. 200 sieve) are classed in the GP and SP groups. The materials may be classed as uniform gravels, uniform sands, or nonuniform mixtures of very coarse material and very fine sand, with intermediate sizes lacking (sometimes called skip-graded, gap-graded, or step-graded). The latter group often results from borrow excavation in which gravel and sand layers are mixed. If the fine fraction exhibits plasticity, this information should be evaluated and the soil classified as discussed subsequently under "Laboratory Identification." Typical examples of various types of GP and SP soils are shown on plate 4.

GM and SM groups

11. In general, the GM and SM groups comprise gravels or sands with fines (more than 12* per cent passing the No. 200 sieve) having low or no plasticity. The plasticity index and liquid limit (based on minus No. 40 sieve fraction) of soils in the group should plot below the "A" line on

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* In the preceding two paragraphs soils of the GW, GP, SW, and SP groups were defined as having less than 5 per cent passing the No. 200 sieve. Soils which have between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33 under that heading.

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the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included. Some of the sands and gravels in this group will have a binder composed of natural cementing agents, so proportioned that the mixture shows negligible swelling or shrinkage. Thus the dry strength of such materials is provided by a small amount of soil binder or by cementation of calcareous material or iron oxide. The fine fraction of other materials in the GM and SM groups may be composed of silts or rock flour types having little or no plasticity and the mixture will exhibit no dry strength. Typical examples of types of GM and SM soils are shown on plate 5.

GC and SC groups

12. In general, the GC and SC groups comprise gravelly or sandy soils with fines (more than 12 per cent passing the No. 200 sieve) which have either low or high plasticity. The plasticity index and liquid limit of soils (fraction passing the No. 40 sieve) in the group should plot above the "A" line on the plasticity chart. The gradation of the materials is not considered significant and both well- and poorly-graded materials are included. The plasticity of the binder fraction has more influence on the behavior of the soils than does variation in gradation. The fine fraction is generally composed of clays. Typical examples of GC and SC soils are shown on plate 6.

Discussion of Fine-grained Soils

ML and MH groups

13. In these groups the symbol M has been used to designate

predominantly silty materials and micaceous or diatomaceous soils. The symbols L and H represent low and high liquid limits, respectively, and an arbitrary dividing line between the two is set at a liquid limit of 50. The soils in the ML and MH groups are sandy silts, clayey silts, or inorganic silts with relatively low plasticity. Also included are loess-type soils and rock flours. Micaceous and diatomaceous soils generally fall within the MH group but may extend into the ML group when their liquid limit is less than 50. The same is true for certain types of kaolin clays and some illite clays having relatively low plasticity. Typical examples of soils in the ML and MH groups are shown on plate 7.

CL and CH groups

14. In these groups the symbol C stands for clay, with L and H denoting low or high liquid limit. The soils are primarily inorganic clays. Low plasticity clays are classified as CL and are usually lean clays, sandy clays, or silty clays. The medium and high plasticity clays are classified as CH. These include the fat clays, gumbo clays, certain volcanic clays, and bentonite. The glacial clays of the northern United States cover a wide band in the CL and CH groups. Typical examples of soils in these groups are shown on plate 8.

OL and OH groups

15. The soils in the OL and OH groups are characterized by the presence of organic matter, hence the symbol O. Organic silts and clays are classified in these groups. The materials have a plasticity range that corresponds with the ML and MH groups. Typical examples of OL and OH soils are presented on plate 9.

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Discussion of Highly Organic Soils

Pt group

16. The highly organic soils usually are very compressible and have undesirable construction characteristics. They are not subdivided and are classified into one group with the symbol Pt. Peat, humus, and swamp soils with a highly organic texture are typical soils of the group. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

Identification of Soil Groups

17. The unified soil classification is so arranged that most soils may be classified into at least the three primary groups (coarse grained, fine grained, and highly organic) by means of visual examination and simple field tests. Classification into the subdivisions can also be made by visual examination with some degree of success. More positive identification may be made by means of laboratory tests on the materials. However, in many instances a tentative classification determined in the field is of great benefit and may be all the identification that is necessary, depending on the purposes for which the soils in question are to be used. Methods of general identification of soils are discussed in the following paragraphs, and a laboratory testing procedure is presented. It is emphasized that the two methods of identification are never entirely separated. Certain characteristics can only be estimated by visual examination, and in borderline cases it may be necessary to verify the classification by laboratory tests. Conversely, the field

methods are entirely practical for preliminary laboratory identification and may be used to advantage in grouping soils in such a manner that only a minimum number of laboratory tests need be run.

General Identification

18. The easiest way of learning field identification of soils is under the guidance of experienced personnel. Without such assistance, field identification may be learned by systematically comparing the numerical test results for typical soils in each group with the "feel" of the material while field identification procedures are being performed.

Coarse-grained soils

19. Texture and composition. In field identification of coarse-grained materials a dry sample is spread on a flat surface and examined to determine gradation, grain size and shape, and mineral composition. Considerable experience is required to differentiate, on the basis of a visual examination, between well-graded and poorly-graded soils. The durability of the grains of a coarse-grained soil may require a careful examination, depending on the use to which the soil is to be put. Pebbles and sand grains consisting of sound rock are easily identified. Weathered material is recognized from its discolorations and the relative ease with which the grains can be crushed. Gravels consisting of weathered granitic rocks, quartzite, etc., are not necessarily objectionable for construction purposes. On the other hand, coarse-grained soils containing fragments of shaley rock may be unsuitable because alternate wetting and drying may result in their partial or complete disintegration. This property can be identified by a slaking test.

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The particles are first thoroughly oven- or sun-dried, then submerged in water for at least 24 hours, and finally their strength is tested and compared with the original strength. Some types of shales will completely disintegrate when subjected to such a slaking test.

20. Examination of fine fraction. Reference to the identification sheet (table 1) shows that classification criteria of the various coarse-grained soil groups are based on the amount of material passing the No. 200 sieve and the plasticity characteristics of the binder fraction (passing the No. 40 sieve). Various methods may be used to estimate the percentage of material passing the No. 200 sieve; the choice of method will depend on the skill of the technician, the equipment at hand, and the time available. One method, decantation, consists of mixing the soil with water in a suitable container and pouring off the turbid mixture of water and fine soil; successive decantations will remove practically all of the fines and leave only the sand and gravel sizes in the container. A visual comparison of the residue with the original material will give some idea of the amount of fines present. Another useful method is to put a mixture of soil and water in a test tube, shake it thoroughly, and allow the mixture to settle. The coarse particles will fall to the bottom and successively finer particles will be deposited with increasing time; the sand sizes will fall out of suspension in 20 to 30 seconds. If the assumption is made that the soil weight is proportional to its volume, this method may be used to estimate the amount of fines present. A rough estimate of the amount of fines may be made by spreading the sample out on a level surface and making a visual estimate of the percentage of fine particles present. The presence of fine sand can

usually be detected by rubbing a sample between the fingers; silt or clay particles feel smooth and stain the fingers, whereas the sand feels gritty and does not leave a stain. The "teeth test" is sometimes used for this purpose, and consists of biting a portion of the sample between the teeth. Sand feels gritty whereas silt and clay do not; clay tends to stick to the teeth while silt does not. If there appears to be more than about 12 per cent of the material passing the No. 200 sieve, the sample should be separated as well as possible by hand, or by decantation and evaporation, removing all of the gravel and coarse sand, and the characteristics of the fine fraction determined. The binder is mixed with water and its dry strength and plasticity characteristics are examined. Criteria for dry strength are shown in column 5 of the classification sheet, table 1; evaluation of soils according to dry strength and plasticity criteria is discussed in succeeding paragraphs in connection with fine-grained soils. Identification of active cementing agents other than clay usually is not possible by visual and manual examination, since such agents may require a curing period of days or even weeks. In the absence of such experience the soils should be classified tentatively into their apparent groups, neglecting any possible development of strength because of cementation.

Fine-grained soils

21. The principal procedures for field identification of fine-grained soils are the test for dilatancy (reaction to shaking), the examination of plasticity characteristics, and the determination of dry strength. In addition, observations of color and odor are of value, particularly for organic soils. Descriptions of the field identification

procedures are presented in the following paragraphs. The dilatancy, plasticity, and dry strength tests are performed on the fraction of the soil finer than the No. 40 sieve. Separation of particles coarser than the No. 40 sieve is done most expediently in the field by hand. However, separation by hand probably will be most effective for particles coarser than the No. 10 sieve. Some effort should be made to remove the No. 10 to No. 40 fraction but it is believed that any particles in this size range remaining after hand separation would have little effect on the field identification procedures.

22. Dilatancy. The soil is prepared for test by removing particles larger than about the No. 40 sieve size (by hand) and adding enough water, if necessary, to make the soil soft but not sticky. The pat of moist soil should have a volume of about 1/2 cubic inch. The pat of soil is alternately shaken horizontally in the open palm of one hand, which is struck vigorously against the other hand several times, and then squeezed between the fingers. A fine-grained soil that is nonplastic or exhibits very low plasticity will become livery and show free water on the surface while being shaken. Squeezing will cause the water to disappear from the surface and the sample to stiffen and finally crumble under increasing finger pressure, like a brittle material. If the water content is just right, shaking the broken pieces will cause them to liquefy again and flow together. A distinction may be made between rapid, slow, or no reaction to the shaking test, depending on the speed with which the pat changes its consistency and the water on the surface appears or disappears. Rapid reaction to the shaking test is typical for nonplastic, uniform fine sand, silty sand (SP, SM), and inorganic silts (ML)

particularly of the rock-flour type, also for diatomaceous earth (MH). The reaction becomes somewhat more sluggish with decreasing uniformity of gradation (and increase in plasticity up to a certain degree). Even a slight content of colloidal clay will impart to the soil some plasticity and slow up materially the reaction to the shaking test. Soils which react in this manner are somewhat plastic inorganic and organic silts (ML, OL), very lean clays (CL), and some kaolin-type clays (ML, MH). Extremely slow or no reaction to the shaking test is characteristic of all typical clays (CL, CH) as well as of highly plastic organic clays (OH).

23. Plasticity characteristics. Examination of the plasticity characteristics of fine-grained soils or of the fine fraction of coarse-grained soils is made with a small moist sample of the material. Particles larger than about the No. 40 sieve size are removed (by hand) and a specimen of soil about the size of a 1/2-in. cube is molded to the consistency of putty. If the soil is too dry, water must be added and if it is sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. The sample is rolled by hand on a smooth surface or between the palms into a thread about 1/8 in. in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached. After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles. The higher the position of a soil above the "A" line on the plasticity chart, plate 2 (CL, CH), the stiffer are the threads as their water content approaches the plastic limit and the tougher are the lumps as the

soil is remolded after rolling. Soils slightly above the "A" line (CL, CH) form a medium tough thread (easy to roll) as the plastic limit is approached but when the threads are formed into a lump and kneaded below the plastic limit, the soil crumbles readily. Soils below the "A" line (ML, MH, OL, OH) form a weak thread and, with the exception of the OH soils, cannot be lumped together into a coherent mass below the plastic limit. Plastic soils containing organic material or much mica (well below the "A" line) form threads that are very soft and spongy near the plastic limit. The binder fraction of coarse-grained soils may be examined in the same manner as fine-grained soils. In general, the binder fraction of coarse-grained soils with silty fines (GM, SM) will exhibit plasticity characteristics similar to the ML soils, and that of coarse-grained soils with clayey fines (GC, SC) will be similar to the CL soils.

24. Dry strength. The resistance of a piece of dried soil to crushing by finger pressure is an indication of the character of the colloidal fraction of a soil. To initiate the test, particles larger than the No. 40 sieve size are removed from the soil (by hand) and a specimen is molded to the consistency of putty, adding water if necessary. The moist pat of soil is allowed to dry (in oven, sun, or air) and is then crumbled between the fingers. Soils with slight dry strength crumble readily with very little finger pressure. All nonplastic ML and MH soils have almost no dry strength. Organic silts and lean organic clays of low plasticity (OL), as well as very fine sandy soils (SM), have slight dry strength. Soils of medium dry strength require considerable finger pressure to powder the sample. Most clays of the CL group and some OH soils exhibit medium dry strength. This is also true of the fine

fraction of gravelly and sandy soils having a clay binder (GC and SC). Soils with high dry strength can be broken but cannot be powdered by finger pressure. High dry strength is indicative of most CH clays, as well as some organic clays of the OH group having very high liquid limits and located near the A-line. In some instances high dry strength in the undisturbed state may be furnished by a cementing material such as calcium carbonate or iron oxide.

25. Color. In field soil surveys color is often helpful in distinguishing between various soil strata, and to an engineer with sufficient preliminary experience with the local soils, color may also be useful for identifying individual soils. The color of the moist soil should be used in identification as soil color may change markedly on drying. To the experienced eye certain dark or drab shades of gray or brown, including almost black colors, are indicative of fine-grained soils containing organic colloidal matter (OL, OH). In contrast, brighter colors, including medium and light gray, olive green, brown, red, yellow, and white, are generally associated with inorganic soils. Use of the Munsell soil color charts and plates, prepared for the U. S. Department of Agriculture by the Munsell Color Company, Baltimore, Maryland, is suggested in the event more precise soil color descriptions are desired or to facilitate uniform naming of soil colors.

26. Odor. Organic soils of the OL and OH groups usually have a distinctive odor which, with experience, can be used as an aid in the identification of such materials. This odor is especially apparent from fresh samples. It gradually diminishes on exposure to air, but can be revived by heating a wet sample.

Highly organic soils

27. The field identification of highly organic soils (group Pt) is relatively easy inasmuch as these soils are characterized by undecayed or partially carbonized particles of leaves, sticks, grass, and other vegetable matter which impart to the soil a typical fibrous texture. The color ranges generally from various shades of dull brown to black. A distinct organic odor is also characteristic of the soil. The water content is usually very high. Another aid in identification of these soils may be the location of the soil with respect to topography: low-lying, swampy areas usually contain highly organic soils.

Laboratory Identification

28. The identification of soils in the laboratory is accomplished by determining the gradation and plasticity characteristics of the materials. The gradation is determined by sieve analysis and a grain-size curve is usually plotted as per cent finer (or passing) by weight against a logarithmic scale of grain size in millimeters. Plate 1 is a typical grain-size chart. Plasticity characteristics are evaluated by means of the liquid and plastic limits tests on the soil fraction finer than the No. 40 sieve. A suggested laboratory method of identification is presented schematically in the chart shown as table 2 and is discussed in the succeeding paragraphs. It should be recognized that although a definite procedure for identification is outlined on the chart, the laboratory technician engaged in classification may be able to use "short cuts" in his work after he becomes thoroughly familiar with the criteria for each soil group.

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Identification of major soil groups

29. Reference to the identification procedure chart, table 2, shows that the first step in the laboratory identification of a soil is to determine whether it is coarse grained, fine grained, or highly organic. This may be done by visual examination in most cases, using the procedures outlined for field identification. In some borderline cases, as with very fine sands or coarse silts, it may be necessary to screen a representative dry sample over a No. 200 sieve and determine the percentage passing. Fifty per cent or less passing the No. 200 sieve identifies the soil as coarse grained, and more than 50 per cent identifies the soil as fine grained. The percentage limit of 50 has been selected arbitrarily for convenience in identification as it is obvious that a numerical difference of 1 or 2 in this percentage will make no significant change in the behavior of the soil. After the major group in which the soil belongs is established, the identification procedure is continued in accordance with the proper headings in the chart.

Identification of subgroups,
coarse-grained soils

30. Gravels (G) or sands (S). A complete sieve analysis is run on coarse-grained soils and the gradation curve is plotted on a grain-size chart. For some soils containing a substantial amount of fines, it may be desirable to supplement the sieve analysis with a hydrometer analysis in order to define the gradation curve below the No. 200 sieve size. Preliminary identification is made by determining the percentage of material in the gravel (above No. 4 sieve) and sand (No. 4 to No. 200 sieve) sizes. If there is a greater percentage of gravel than sand the material is

classed as gravel (G); if there is a greater percentage of sand than gravel the material is classed as sand (S). Once again the distinction between these groups is purely arbitrary for convenience in following the system. The next identification step is to determine the amount of material passing the No. 200 sieve. Since the subgroups are the same for gravels and sands, they will be discussed jointly in the following paragraphs.

31. GW, SW, GP, and SP groups. These groups comprise nonplastic soils having less than 5 per cent passing the No. 200 sieve and in which the fine fraction does not interfere with the soils' free-draining properties. If the above criteria are met, an examination is made of the shape of the grain-size curve. Materials that are well graded are classified as GW or SW; poorly-graded materials are classified as GP or SP. The grain-size distributions of well-graded materials generally plot as smooth and regular concave curves with no sizes lacking or no excess of material in any size range (plate 3); the uniformity coefficient (60 per cent grain diameter divided by the 10 per cent grain diameter) of well-graded gravels is greater than 4, and of well-graded sands is greater than 6. In addition, the gradation curves should meet the following qualification in order to be classed as well graded.

$$\frac{(D_{30})^2}{D_{60} \times D_{10}} \text{ between 1 and 3}$$

where D_{30} = grain diameter at 30 per cent passing

D_{60} = grain diameter at 60 per cent passing

D_{10} = grain diameter at 10 per cent passing

The foregoing expression, termed a coefficient of curvature, insures

that the grading curve will have a concave curvature within relatively narrow limits for a given D_{60} and D_{10} combination. All gradations not meeting the foregoing criteria are classed as poorly graded. Thus, poorly-graded soils (GP, SP) are those having nearly straight line gradations (plate 4, fig. 1, curve 3), convex gradations, nearly vertical (uniform) gradations (plate 4, fig. 1, curve 1), and gradation curves with "humps" typical of skip-graded materials (plate 4, fig. 1, curve 2).

32. GM, SM, GC and SC groups. The soils in these groups are composed of those materials having more than a 12* per cent fraction passing the No. 200 sieve; they may or may not exhibit plasticity. For identification, the liquid and plastic limits tests are required on the fraction finer than the No. 40 sieve. The tests should be run on representative samples of moist material, and not on air- or oven-dried soils. This precaution is desirable as drying affects the limits values to some extent as will be explained further in the discussion of fine-grained soils. Materials in which the liquid limit and plasticity index plot below the "A" line on the plasticity chart (plate 2) are classed as GM or SM (plate 5). Gravels and sands in which the liquid limit and plasticity index plot above the "A" line on the plasticity chart are classed as GC or SC (plate 6). It is considered that in the identification of materials in these groups the plasticity characteristics overshadow the gradation characteristics; therefore, no distinction is made between well- and poorly-graded materials.

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* In the preceding paragraph soils of the GW, GP, SW, and SP groups were defined as having less than a 5 per cent fraction passing the No. 200 sieve. Soils having between 5 and 12 per cent passing the No. 200 sieve are classed as "borderline" and are discussed in paragraph 33.

33. Borderline soils. Coarse-grained soils containing between 5 and 12% material passing the No. 200 sieve are classed as borderline and carry a dual symbol, e.g., GW-GM. Similarly, coarse-grained soils having less than 5% passing the No. 200 sieve, but which are not free draining, or wherein the fine fraction exhibits plasticity, are also classed as borderline and are given a dual symbol. Additional discussion of borderline classification is presented in paragraphs 38-41.

Identification of subgroups, fine-grained soils

34. Use of plasticity chart. Once the identity of a fine-grained soil has been established, further identification is accomplished principally by the liquid and plastic limits tests in conjunction with the plasticity chart (plate 2). The plasticity chart was developed by Dr. Casagrande as the result of considerable experience with the behavior of soils in many different regions. It is a plot of liquid limit versus plasticity index on which is imposed a diagonal line called the "A" line and a vertical line at a liquid limit of 50. The "A" line is defined by the equation PI = 0.73 (LL-20). The "A" line above a liquid limit of about 29 represents an important empirical boundary between typical inorganic clays (CL and CH), which are generally located above the line, and plastic soils containing organic colloids (OL and OH) or inorganic silty soils (ML and MH). The vertical line at liquid limit of 50 separates silts and clays of low liquid limit (L) from those of high liquid limit (H). In the low part of the chart below a liquid limit of about 29 and in the range of PI from 4 to 7 there is considerable overlapping of the properties of the clayey and silty soil types. Hence, the separation between

CL and OL or ML soil types in this region is accomplished by a cross-hatched zone on the plasticity chart between 4 and 7 PI and above the "A" line. CL soils in this region are those having a PI above 7 while OL or ML soils are those having a PI below 4. Soils plotting within the cross-hatched zone should be classed as borderline as discussed later. The various soil groups are shown in their respective positions on the plasticity chart. Experience has shown that compressibility is approximately proportional to liquid limit and that soils having the same liquid limit possess approximately equal compressibility, assuming that other factors are essentially the same. On comparing the physical characteristics of soils having the same liquid limit, one finds that with increasing plasticity index, the cohesive characteristics increase and the permeability decreases. From plots of the results of limits tests on a number of samples from the same fine-grained deposit, it is found that for most soils these points lie on a straight line or in a narrow band approximately parallel to the "A" line. With this background information in mind, the identification of the various groups of fine-grained soils is discussed in the following paragraphs.

35. ML, CL, and OL groups. A soil having a liquid limit of less than 50 falls into the low liquid limit (L) group. A plot of the liquid limit and plasticity index on the plasticity chart will show whether it falls above or below the "A" line and cross-hatched zone. Soils plotting above the "A" line and cross-hatched zone are classed as CL and are usually typical inorganic clays (plate 8, fig. 1). Soils plotting below the "A" line or cross-hatched zone are inorganic silts or very fine sandy silts, ML (plate 7, fig. 1), or organic silts or organic silt-clays of low

plasticity, OL (plate 9, fig. 1). Since two groups fall below the "A" line or cross-hatched zone, further identification is necessary. The distinguishing factor between the ML and OL groups is the absence or presence of organic matter. This is usually identified by color and odor as explained in the preceding paragraphs under field identification. However, in doubtful cases a comparison may be made between the liquid and plastic limits of a moist sample and one that has been oven-dried. An organic soil will show a radical drop in plasticity after oven-drying or air-drying. An inorganic soil will generally show a change in the limits values of only 1 or 2% which may be either an increase or a decrease. For the foregoing reasons the classification should be based on the plot of limits values determined before drying. Soils containing organic matter generally have lower specific gravities and may have decidedly higher water contents than inorganic soils; therefore, these properties may be of assistance in identifying organic soils. In special cases, the determination of organic content may be made by chemical methods, but the procedures just described are usually sufficient.

36. MH, CH, and OH groups. Soils with a liquid limit greater than 50 are classed in group H. To identify such soils, the liquid limit and plasticity index values are plotted on the plasticity chart. If the points fall above the "A" line, the soil classifies as CH; if it falls below the "A" line, a determination is made as to whether or not organic material is present, as described in the preceding paragraph. Inorganic materials are classed as MH and organic materials are classed as OH.

Identification of highly organic soils

37. Little more can be said as to the laboratory identification of

highly organic soils (Pt) than has been stated previously under field identification. These soils are usually identified readily on the basis of color, texture, and odor. Moisture determinations usually show a natural water content of several hundred per cent, which is far in excess of that found for most soils. Specific gravities of the solids in these soils may be quite low. Some peaty soils can be remolded and tested for liquid and plastic limits. Such materials usually have a liquid limit of several hundred per cent and fall well below the "A" line on the plasticity chart.

Borderline classifications

38. It is inevitable in the use of the classification system that soils will be encountered that fall close to the boundaries established between the various groups. In addition, boundary zones for the amount of material passing the No. 200 sieve and for the lower part of the plasticity chart have been incorporated as a part of the system, as discussed subsequently. The accepted rule in classifying borderline soils is to use a double symbol; for example, GW-GM. It is possible, in rare instances, for a soil to fall into more than one borderline zone and, if appropriate symbols were used for each possible classification, the result would be a multiple designation consisting of three or more symbols. This approach is unnecessarily complicated and it is considered best to use only a double symbol in these cases, selecting the two that are believed most representative of the probable behavior of the soil. In cases of doubt the symbols representing the poorer of the possible groupings should be used.

39. Coarse-grained soils. It will be recalled that in previous

discussions (paragraph 31) the coarse-grained soils were classified in the GW, GP, SW, and SP groups if they contained less than 5% of material passing the No. 200 sieve. Similarly, soils were classified in the GM, GC, SM, and SC groups if they had more than 12% passing the No. 200 sieve (paragraph 32). The range between 5 and 12% passing the No. 200 seive is designated as borderline, and soils falling within it are assigned a double symbol depending on both the gradation characteristics of the coarse fraction and the plasticity characteristics of the minus No. 40 sieve fraction. For example, a well-graded sandy soil with 8% passing the No. 200 sieve and with LL = 28 and PI = 9 would be designated as SW-SC. Another type of borderline classification occurs for those soils containing appreciable amounts of fines, groups GM, GC, SM, and SC, and whose Atterberg limits values plot in the lower portion of the plasticity chart. The method of classifying these soils is the same as for fine-grained soils plotting in the same region, as presented in the following paragraph.

40. Fine-grained soils. Mention has been made of a zone on the plasticity chart (plate 2) below a liquid limit of about 29 and ranging between plasticity index values of 4 and 7. Several soil types exhibiting low plasticity plot in this general region on the plasticity chart and no definite boundary between silty and clayey soils exists. Thus, if a fine-grained soil, groups CL and ML, or the minus No. 40 sieve fraction of a coarse-grained soil, groups GM, GC, SM, and SC, plots within the cross-hatched zone on the plasticity chart, a double symbol (ML-CL, etc.) is used.

41. "Silty" and "clayey." It will be noted on the classification sheet, table 1, that the adjectives "silty" and "clayey" may be used as part of the descriptive name for silt or clay soils. Since the

definitions of these terms are now somewhat different from those used by many soils engineers, it is considered advisable to discuss their connotation as used in this system. In the unified soil classification the terms "silt" and "clay" are used to describe those soils with Atterberg limits plotting respectively below and above the "A" line and cross-hatched zone on the plasticity chart. As a logical extension of this concept, the terms "silty" and "clayey" may be used as adjectives in the soil names when the limits values plot close to the "A" line. For example, a clay soil with LL = 40 and PI = 16 may be called a silty clay. In general, the adjective "silty" is not applied to clay soils having a liquid limit in excess of about 60.

Expansion of Classification

42. It may be necessary, in some cases, to expand the unified classification system by subdivision of existing groups in order to classify soils for a particular use. The indiscriminate use of subdivisions is discouraged and careful study should be given any soil group before such a step is adopted. In all cases subdivisions should be designated preferably by a suffix to an existing group symbol. The suffix should be selected carefully so that there will be no confusion with existing letters that already have meanings in the classification system. In each case where an existing group is subdivided, the basis and criteria for the subdivision should be explained in order that anyone unfamiliar with it may understand the subdivision properly.

Descriptive Soil Classification

43. At many stages in the soils investigation of a project -- from the preliminary boring log to the final report -- the engineer finds it convenient to give the soils he is working with a "name" rather than an "impersonal" classification symbol such as GC. This results primarily from the fact that he is accustomed to talking in terms of gravels, sands, silts, and clays, and finds it only logical to use these same names in presenting the data. The soil names have been associated with certain grain sizes in the textural classification as shown on the grain-size chart, plate 1. Such a division is generally feasible for the coarse-grained soils; however, the use of such terms as silt and clay may be entirely misleading on a textural basis. For this reason the terms "silt" and "clay" have been defined on a plasticity basis as discussed previously. Within a given region of the country, use of a name classification based on texture is often feasible since the general behavior of similar soils is consistent over the area. However, in another area the same classification may be entirely inadequate. The descriptive classification, if used intelligently, has a rightful place in soil mechanics, but its use should be carefully evaluated by all concerned.

Description from classification sheet

44. Column 4 of the classification sheet, table 1, lists typical names given the soil types usually found within the various classification groups. By following either the field or laboratory investigation procedure and determining the proper classification group in which the soil

belongs, it is usually an easy matter to select an appropriate name from the classification sheet. Some soils may be readily identified and properly named by only visual inspection. A word of caution is considered appropriate on the use of the classification system for certain soils such as marls, caliches, coral, shale, etc., where the grain size can vary widely depending on the amount of mechanical breakdown of soil particles. For these soils the group symbol and textural name have little significance and the locally used name may be important.

Other descriptive terms

45. Records of field explorations in the form of boring logs can be of great benefit to the engineer if they include adequate information. In addition to the group symbol and the name of the soil, the general characteristics of the soils as to plasticity, strength, moisture, etc., provide information essential to a proper analysis of a particular problem. Locally accepted soil names should also be used to clarify the data to local bidders, and to protect the Government against later legal claims. For coarse-grained soils, the size of particles, mineralogical composition, shape of grains, and character of the binder are relevant features. For fine-grained soils, strength, moisture, and plasticity characteristics are important. When describing undisturbed soils such characteristics as stratification, structure, consistency in the undisturbed and remolded states, cementation, drainage, etc., are pertinent to the descriptive classification. Pertinent items to be used in describing soils are shown in column 6 of table 1. In order to achieve uniformity in estimating consistency of soils, it is recommended that the Terzaghi classification based on unconfined compressive strength be

used as a tentative standard. This classification is given below:

Unconfined Compressive Strength Tons/Sq Ft	Consistency
< 0.25	Very soft
0.25-0.50	Soft
0.50-1.00	Medium
1.00-2.00	Stiff
2.00-4.00	Very stiff
> 4.00	Hard

Several examples of descriptive classifications are shown below:

a. Uniform, fine, clean sand with rounded grains (SP).

b. Well-graded gravelly silty sand; angular chert gravel, 1/2-in. maximum size; silty binder with low plasticity, well-compacted and moist (SM).

c. Light brown, fine, sandy silt; very low plasticity; saturated and soft in the undisturbed state (ML).

d. Dark gray, fat clay; stiff in the undisturbed state; soft and sticky when remolded (CH).

(Ta

Major Divisions			Group Symbols	Typical Names	Field Identificati (Excluding particles la and basing fractions on
1	2		3	4	5
Coarse-grained Soils More than half of material is larger than No. 200 sieve size.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes a amounts of all intermedia
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a some intermediate sizes m
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines w (for identification proce
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identifi see CL below).
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size an of all intermediate parti
			SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a with some intermediate si
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines w (for identification proce
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identifi see CL below).
Fine-grained Soils More than half of material is smaller than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.					Identification on Fraction Smaller than Dry Strength (Crushing characteristics) / Dilatancy (Reaction to shaking)
	Silts and Clays Liquid limit is less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight / Quick to s
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high / None to ve slow
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium / Slow
	Silts and Clays Liquid limit is greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium / Slow to no
			CH	Inorganic clays of high plasticity, fat clays.	High to very high / None
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high / None to ve slow
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by colo and frequently by fibrou

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of grou

FIELD IDENTIFICA

These procedures are to be performed on the minus N screening is not intended, simply

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing cha

After removing particles consistency of putty, by oven, sun, or air-d between the fingers. the colloidal fraction increasing plasticity.

High dry strength is cha ganic silt possesses o have about the same st when powdering the dri has the smooth feel of

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Table 1

UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)	Information Required for Describing Soils	Laboratory Classification Criteria
5	6	7

...e range in grain sizes and substantial amounts of all intermediate particle sizes.	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 Not meeting all gradation requirements for GW
...ominantly one size or a range of sizes with some intermediate sizes missing.		
...plastic fines or fines with low plasticity (for identification procedures see ML below).	Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.	Atterberg limits below "A" line or PI less than 4 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
...astic fines (for identification procedures see CL below).		Atterberg limits above "A" line with PI greater than 7
...e range in grain size and substantial amounts of all intermediate particle sizes.	Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3 Not meeting all gradation requirements for SW
...ominantly one size or a range of sizes with some intermediate sizes missing.		
...plastic fines or fines with low plasticity (for identification procedures see ML below).		Atterberg limits below "A" line or PI less than 4 — Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
...astic fines (for identification procedures see CL below).		Atterberg limits above "A" line with PI greater than 7

Determining percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows:

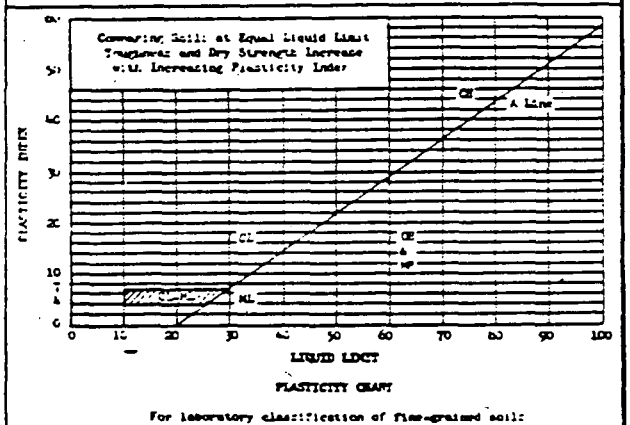
Less than 5%: GW, GP, SW, SP.
More than 12%: GM, GC, SM, SC.
5% to 12%: Borderline cases requiring use of dual symbols.

Use grain-size curve in identifying the fractions as given under field identification.

Identification Procedures on Fraction Smaller than No. 40 Sieve Size

Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)	
...e to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.
...ium to high	None to very slow	Medium	
...ht to ...ium	Slow	Slight	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.
...ht to ...ium	Slow to none	Slight to medium	
...to very ...h	None	High	
...um to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).

...ily identified by color, odor, spongy feel ...frequently by fibrous texture.



PLASTICITY CHART

For laboratory classification of fine-grained soils.

...combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

FIELD IDENTIFICATION PROCEDURE FOR FINE-GRAINED SOILS OR FRACTIONS

...formed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, ...not intended, simply remove by hand the coarse particles that interfere with the tests.

Strength (crushing characteristics)

...ter removing particles larger than No. 40 sieve size, mold a pat of soil to the ...nsistency of putty, adding water if necessary. Allow the pat to dry completely ...by oven, sun, or air-drying, and then test its strength by breaking and crumbling ...between the fingers. This strength is a measure of the character and quantity of ...the colloidal fraction contained in the soil. The dry strength increases with ...increasing plasticity.

...dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts ...have about the same slight dry strength, but can be distinguished by the feel ...when crushing the dried specimen. Fine sand feels gritty whereas a typical silt ...has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line. Highly organic clays have a very weak and spongy feel at the plastic limit.

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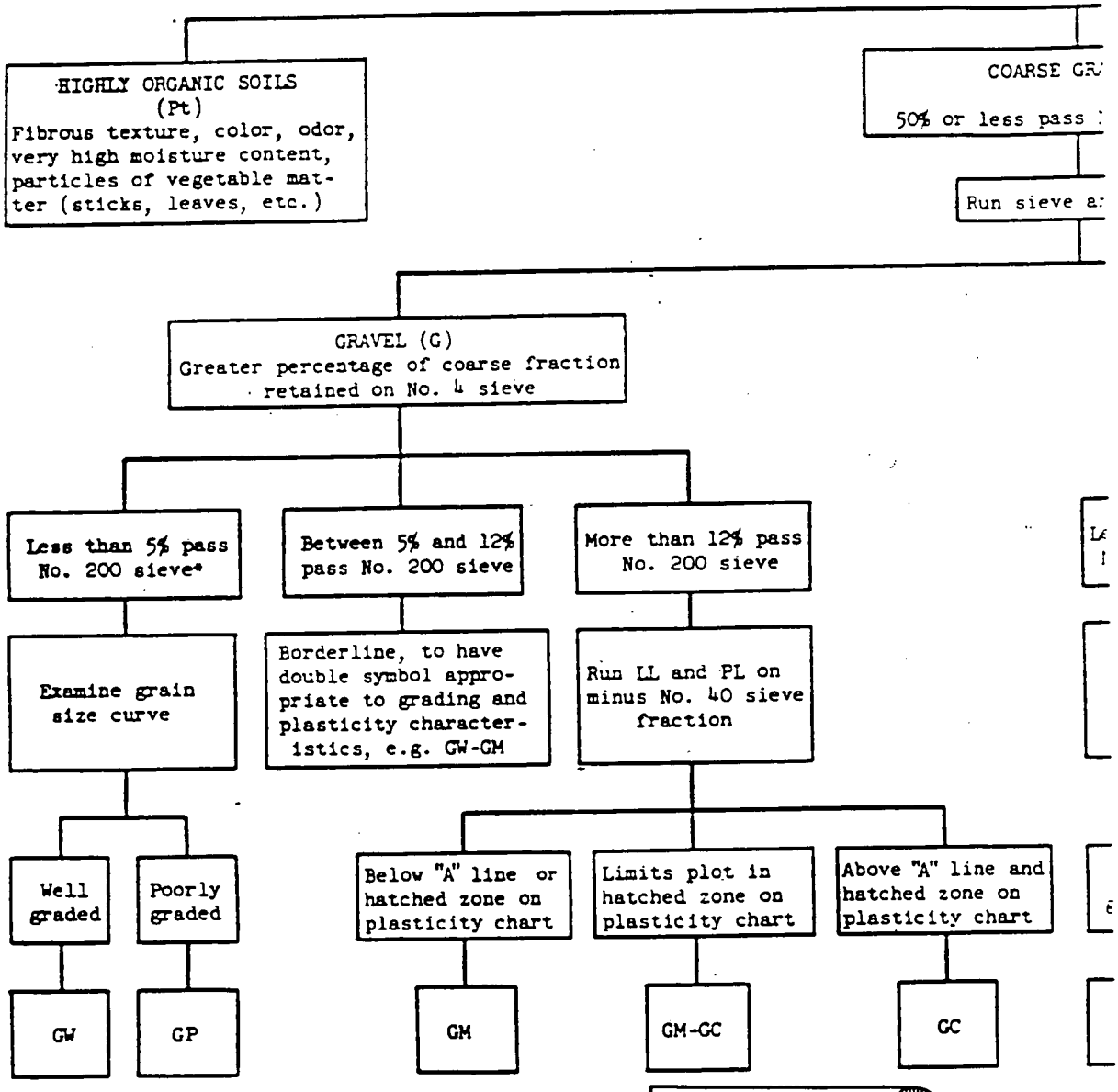

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Note: Sieve sizes are U. S. Standard.

* If fines interfere with free draining properties use double symbol such as GW-GM, etc.

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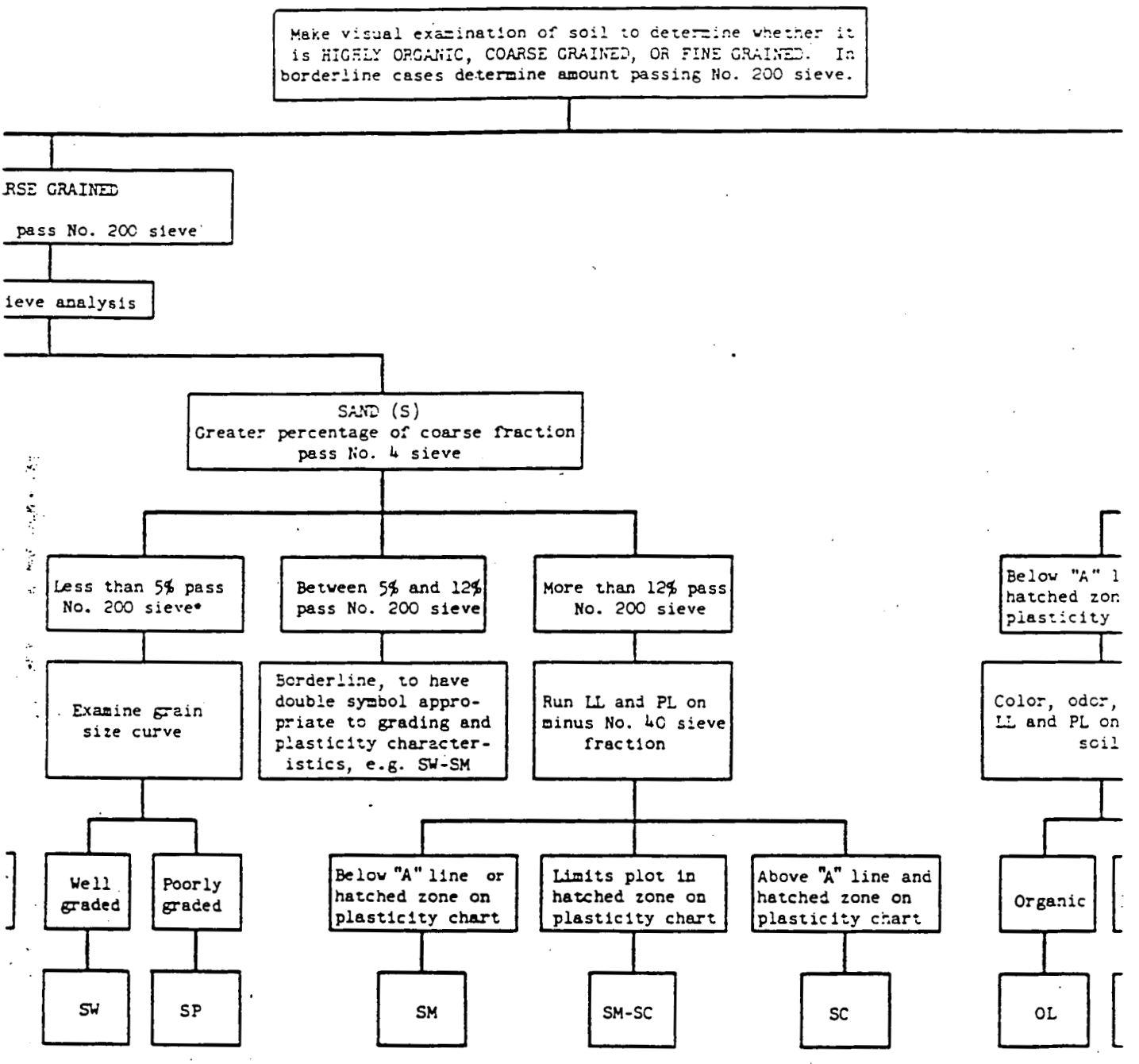
Table 2

AUXILIARY LABORATORY IDENTIFICATION PROCEDURE



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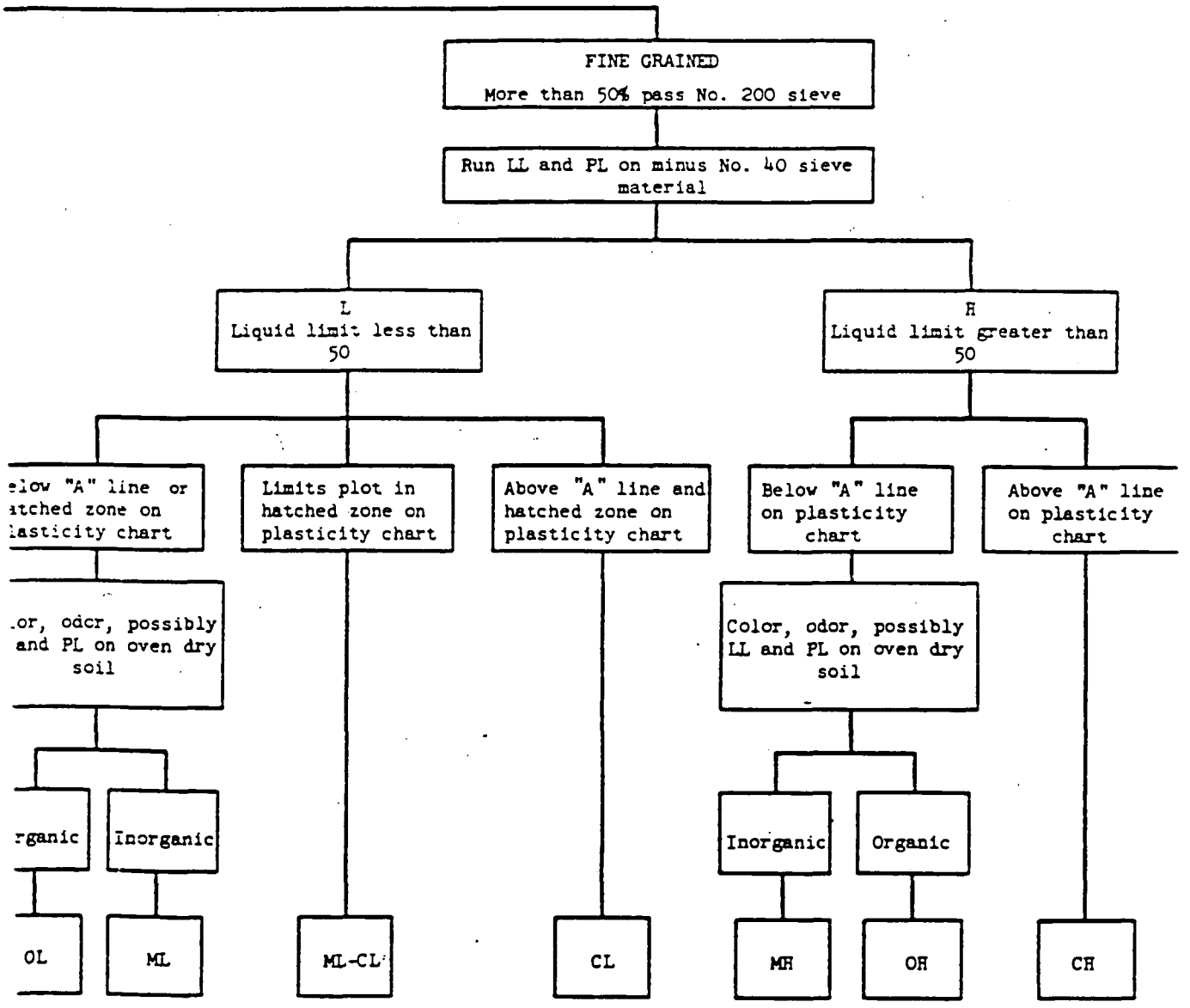

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UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX A

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO

EMBANKMENTS AND FOUNDATIONS

Introduction

1. The major properties of a soil proposed for use in an embankment or foundation that are of concern to the design or construction engineer are its strength, permeability, and consolidation and compaction characteristics. Other features may be investigated for a specific problem, but in general some or all of the properties mentioned above are of primary importance in an earth embankment or foundation project of any magnitude. It is common practice to evaluate the properties of the soils in question by means of laboratory or field tests and to use the results of such tests as a basis for design and construction. The factors that influence strength, consolidation, and other characteristics are numerous and some of them are not completely understood; consequently, it is impractical to evaluate these features by means of a general soils classification. However, the soil groups in a given classification do have reasonably similar behavior characteristics, and while such information is not sufficient for design purposes, it will give the engineer an indication of the behavior of a soil when used as a component in construction. This is especially true in the preliminary examination for a project when neither time nor money for a detailed soils testing program is available.

2. It should be borne in mind by engineers using the classification

that only generalized characteristics of the soil groups are included therein, and they should be used primarily as a guide and not as the complete answer to a problem. For example, it is possible to design and construct an earth embankment of almost any type of soil and upon practically any foundation; this is in accordance with the worth-while principle of utilizing the materials available for construction. However, when a choice of materials is possible, certain of the available soils may be better suited to the job than others. It is on this basis that the behavior characteristics of soils are presented in the following paragraphs and on the classification sheet. The use to which a structure is to be put is often the principal deciding factor in the selection of soil types as well as the type of protective measures that will be utilized. Since each structure is a special problem within itself, it is impossible to cover all possible considerations in the brief description of pertinent soil characteristics contained in this appendix.

Features Shown on Soils Classification Sheet

3. General characteristics of the soil groups pertinent to embankments and foundations are presented in table A1. Columns 1 through 5 of the table show major soil divisions, group symbols, and hatching and color symbols; names of soil types are given in column 6. The basic features are the same as those presented in the soils classification manual. Columns 7 through 12 show the following: column 7, suitability of the materials for use in embankments (strength and permeability characteristics); column 8, the minimum or range of permeability values to be expected for the soil groups; columns 9 and 10, general compaction

characteristics; column 11, the suitability of the soils for foundations (strength and consolidation); and column 12, the requirements for seepage control, especially when the soils are encountered in the foundation for earth embankments (permeability). Brief discussions of these features are presented in the following paragraphs.

Suitability of soils for embankments

4. Three major factors that influence the suitability of soils for use in embankments are permeability, strength, and ease of compaction. The gravelly and sandy soils with little or no fines, groups GW, GP, SW, and SP, are stable, pervious, and attain good compaction with crawler-type tractors and rubber-tired rollers. The poorly-graded materials may not be quite as desirable as those which are well graded, but all of the materials are suitable for use in the pervious sections of earth embankments. Poorly-graded sands (SP) may be more difficult to utilize and, in general, should have flatter embankment slopes than the SW soils. The gravels and sands with fines, groups GM, GC, SM, and SC, have variable characteristics depending on the nature of the fine fraction and the gradation of the entire sample. These materials are often sufficiently impervious and stable to be used for impervious sections of embankments. The soils in these groups should be carefully examined to insure that they are properly zoned with relation to other materials in an embankment. Of the fine-grained soils, the CL group is best adapted for embankment construction; the soils are impervious, fairly stable, and give fair to good compaction with a sheepsfoot roller or rubber-tired roller. The MH soils, while not desirable for rolled-fill construction, may be utilized in the core of hydraulic-fill structures. Soils of

the ML group may or may not have good compaction characteristics, and in general must be closely controlled in the field to secure the desired strength. CH soils have fair stability when used on flat slopes but have detrimental shrinkage characteristics which may necessitate blanketing them or incorporating them in thin interior cores of embankments. Soils containing organic matter, groups OL, OH, and Pt, are not commonly used for embankment construction because of the detrimental effects of the organic matter present. Such materials may often be utilized to advantage in blankets and stability berms where strength is not of importance.

Permeability and seepage control

5. Since the permeability (column 8) and requirements for seepage control (column 12) are essentially functions of the same property of a soil, they will be discussed jointly. The subject of seepage in relation to embankments and foundations may be roughly divided into three categories: (1) seepage through embankments; (2) seepage through foundations; and (3) control of uplift pressures. These are discussed in relation to the soil groups in the following paragraphs.

6. Seepage through embankments. In the control of seepage through embankments, it is the relative permeability of adjacent materials rather than the actual permeability of such soils that governs their use in a given location. An earth embankment is not watertight and the allowable quantity of seepage through it is largely governed by the use to which the structure is put; for example, in a flood-control project considerable seepage may be allowed and the structure will still fulfill the storage requirements, whereas for an irrigation project much less seepage is

allowable because pool levels must be maintained. The more impervious soils (GM, GC, SM, SC, CL, MH, and CH) may be used in core sections or in homogeneous embankments to retard the flow of water. Where it is important that seepage not emerge on the downstream slope or the possibility of drawdown exists on upstream slopes, more pervious materials are usually placed on the outer slopes. The coarse-grained, free-draining soils (GW, GP, SW, SP) are best suited for this purpose. Where a variety of materials is available they are usually graded from least pervious to more pervious from the center of the embankment outward. Care should be used in the arrangement of materials in the embankment to prevent piping within the section. The foregoing statements do not preclude the use of other arrangements of materials in embankments. Dams have been constructed successfully entirely of sand (SW, SP, SM) or of silt (ML) with the section made large enough to reduce seepage to an allowable value without the use of an impervious core. Coarse-grained soils are often used in drains and toe sections to collect seepage water in downstream sections of embankments. The soils used will depend largely upon the material that they drain; in general, free-draining sands (SW, SP) or gravels (GW, GP) are preferred, but a silty sand (SM) may effectively drain a clay (CL, CH) and be entirely satisfactory.

7. Seepage through foundations. As in the case of embankments, the use of the structure involved often determines the amount of seepage control necessary in foundations. Cases could be cited where the flow of water through a pervious foundation would not constitute an excessive water loss and no seepage control measures would be necessary if adequate provisions were made against piping in critical areas. If seepage control

is desired, then the more pervious soils are the soils in which necessary measures must be taken. Free-draining gravels (GW, GP) are capable of carrying considerable quantities of water, and some means of positive control such as a cutoff trench may be necessary. Clean sands (SW, SP) may be controlled by a cutoff or by an upstream impervious blanket. While a drainage trench at the downstream toe or a line of relief wells will not reduce the amount of seepage, either will serve to control seepage and route the flow into collector systems where it can be led away harmlessly. Slightly less pervious material, such as silty gravels (GM), silty sands (SM), or silts (ML), may require a minor amount of seepage control such as that afforded by a toe trench, or if they are sufficiently impervious no control may be necessary. The relatively impervious soils (GC, SC, CL, OL, MH, CH, and OH) usually pass such a small volume of water that seepage control measures are not necessary.

8. Control of uplift pressures. The problem of control of uplift pressures is directly associated with pervious foundation soils. Uplift pressures may be reduced by lengthening the path of seepage (by a cutoff or upstream blanket) or by measures for pressure relief in the form of wells, drainage trenches, drainage blankets, or pervious downstream shells. Free-draining gravels (GW, GP) may be treated by any of the aforementioned procedures; however, to obtain the desired pressure relief, the use of a positive cutoff may be preferred, as blanket, well, or trench installations would probably have to be too extensive for economical accomplishment of the desired results. Free-draining sands (SW, SP) are generally less permeable than the gravels and, consequently, the volume of water that must be controlled for pressure relief is usually less.

Therefore a positive cutoff may not be required and an upstream blanket, wells, or a toe trench may be entirely effective. In some cases a combination of blanket and trench or wells may be desirable. Silty soils -- silty gravels (GM), silty sands (SM), and silts (ML) -- usually do not require extensive treatment; a toe drainage trench or well system may be sufficient to reduce uplift pressures. The more impervious silty materials may not be permeable enough to permit dangerous uplift pressures to develop and in such cases no treatment is indicated. In general, the more impervious soils (GC, SC, CL, OL, MH, CH, and OH) require no treatment for control of uplift pressures. However, they do assume importance when they occur as a relatively thin top stratum over more pervious materials. In such cases uplift pressures in the lower layers acting on the base of the impervious top stratum can cause heaving and formation of boils; treatment of the lower layer by some of the methods mentioned above is usually indicated in these cases. It is emphasized that control of uplift pressures should not be applied indiscriminately just because certain types of soils are encountered. Rather, the use of control measures should be based upon a careful evaluation of conditions that do or can exist, and an economical solution reached that will accomplish the desired results.

Compaction characteristics

9. In column 9 of the table are shown the general compaction characteristics of the various soil groups. The evaluations given and the equipment listed are based on average field conditions where proper moisture control and thickness of lift are attained and a reasonable number of passes of the compaction equipment is required to secure the

desired density. For lift construction of embankments, the sheepsfoot roller and rubber-tired roller are commonly used pieces of equipment. Some advantages may be claimed for the sheepsfoot roller in that it leaves a rough surface that affords better bond between lifts, and it kneads the soil thus affording better moisture distribution. Rubber-tired equipment referred to in the table is considered to be heavily loaded compactors or earth-moving equipment with a minimum wheel load of 15,000 lb. If ordinary wobble-wheel rollers are used for compaction, the thickness of compacted lift is usually reduced to about 2 in. Granular soils with little or no fines generally show good compaction characteristics, with the well-graded materials, GW and SW, usually furnishing better results than the poorly-graded soils, GP and SP. The sandy soils in most cases are best compacted by crawler-type tractors; on the gravelly materials rubber-tired equipment and sometimes steel-wheel rollers are also effective. Coarse-grained soils with fines of low plasticity, groups GM and SM, show good compaction characteristics with either sheepsfoot rollers or rubber-tired equipment; however, the range of moisture contents for effective compaction may be very narrow, and close moisture control is desirable. This is also generally true of the silty soils in the ML group. Soils of the ML group may be compacted with rubber-tired equipment or with sheepsfoot rollers. Gravels and sands with plastic fines, groups GC and SC, show fair compaction characteristics, although this quality may vary somewhat with the character and amount of fines; rubber-tired or sheepsfoot rollers may be used. Sheepsfoot rollers are generally used for compacting fine-grained soils. The compaction characteristics of such materials are variable -- lean clays and sandy clays

(CL) being the best, fat clays and lean organic clays or silts (OL and CH) fair to poor, and organic or micaceous soils (MH and OH) usually poor. For most construction projects of any magnitude it is highly desirable to investigate the compaction characteristics of the soil by means of a field test section. In column 10 of table A1 are shown ranges of unit dry weight of the soil groups for the standard AASHO (Proctor) compactive effort. It is emphasized that these values are for guidance only and design or construction control should be based on laboratory test results.

Suitability of soils for foundations

10. Suitability of soils for foundations of embankments or structures is primarily dependent on the strength and consolidation characteristics of the subsoils. Here again the type of structure and its use will largely govern the adaptability of a soil as a satisfactory foundation. For embankments, large settlements may be allowed and compensated for by overbuilding; whereas the allowable settlement of structures such as control towers, etc., may be small in order to prevent overstressing the concrete or steel of which they are built, or because of the necessity for adhering to established grades. Therefore a soil may be entirely satisfactory for one type of construction but may require special treatment for other types. Strength and settlement characteristics of soils are dependent upon a number of variables, such as structure, in-place density, moisture content, cycles of loading in their geologic history, etc., which are not readily evaluated by a classification system such as used here. For these reasons only very general statements can be made as to the suitability of the various soil types as foundations; this is especially true for fine-grained soils. In general, the gravels and

gravelly soils (GW, GP, GM, GC) have good bearing capacity and undergo little consolidation under load. Well-graded sands (SW) usually have a good bearing value. Poorly-graded sands and silty sands (SP, SM) may exhibit variable bearing capacity depending on their density; this is true to some extent for all the coarse-grained soils but is especially critical for uniformly graded soils of the SP and SM groups. Such soils when saturated may become "quick" and present an additional construction problem. Soils of the ML group may be subject to liquefaction and may have poor bearing capacity, particularly where heavy structure loads are involved. Of the fine-grained soils, the CL group is probably the best from a foundation standpoint, but in some cases the soils may be soft and wet and exhibit poor bearing capacity and fairly large settlements under load. Soils of the MH groups and normally-consolidated CH soils may show poor bearing capacity and large settlements. Organic soils, OL and OH, have poor bearing capacity and usually exhibit large settlement under load. For most of the fine-grained soils discussed above, the type of structure foundation selected is governed by such factors as the bearing capacity of the soil and the magnitude of the load. It is possible that simple spread footings might be adequate to carry the load without excessive settlement in many cases. If the soils are poor and structure loads are relatively heavy, then alternate methods are indicated. Pile foundations may be necessary in some cases and in special instances, particularly in the case of some CH and OH soils, it may be desirable and economically feasible to remove such soils from the foundation. Highly organic soils, Pt, generally are very poor foundation materials. These may be capable of carrying very light loads but in general are unsuited

for most construction purposes. If highly organic soils occur in the foundation, they may be removed if limited in extent, they may be displaced by dumping firmer soils on top, or piling may be driven through them to a stronger layer; proper treatment will depend upon the structure involved.

Graphical Presentation of Soils Data

11. It is customary to present the results of soils explorations on drawings or plans as schematic representations of the borings or test pits with the soils encountered shown by various symbols. Commonly used hatching symbols are small irregular round symbols for gravel, dots for sand, vertical lines for silts, and diagonal lines for clays. Combinations of these symbols represent various combinations of materials found in the explorations. This system has been adapted to the various soil groups in the unified soil classification system and the appropriate symbols are shown in column 4 of table A1. As an alternative to the hatching symbols, they may be omitted and the appropriate group letter symbol (CL, etc.) written in the boring log. In addition to the symbols on logs of borings, the effective size, D_{10} (grain size in mm corresponding to 10 per cent finer by weight), of coarse-grained soils and the natural water content of fine-grained soils should be shown by the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain special instances the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of table A1.

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Table A1

CHARACTERISTICS PERTINENT TO EMBANKMENTS AND FOUNDATIONS

Major Divisions (1)	(2)	Letter (3)	Symbol Hatching (4)	Symbol Color (5)	Name (6)	Value for Embankments (7)	Permeability Cm Per Sec (8)	Compaction Characteristics (9)	Std AASHO Max Unit Dry Weight Lb Per Cu Ft (10)	Value for Foundations (11)	Requirements for Seepage Control (12)
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Very stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	125-135	Good bearing value	Positive cutoff
		GP			Poorly-graded gravels or gravel-sand mixtures, little or no fines	Reasonably stable, pervious shells of dikes and dams	$k > 10^{-2}$	Good, tractor, rubber-tired, steel-wheeled roller	115-125	Good bearing value	Positive cutoff
		GM		Yellow	Silty gravels, gravel-sand-silt mixtures	Reasonably stable, not particularly suited to shells, but may be used for impervious cores or blankets	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	120-135	Good bearing value	Toe trench to some
		GC			Clayey gravels, gravel-sand-clay mixtures	Fairly stable, may be used for impervious core	$k = 10^{-6}$ to 10^{-8}	Fair, rubber-tired, sheepsfoot roller	115-130	Good bearing value	None
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Very stable, pervious sections, slope protection required	$k > 10^{-3}$	Good, tractor	110-130	Good bearing value	Upstream blanket and toe drainage or wells
		SP			Poorly-graded sands or gravelly sands, little or no fines	Reasonably stable, may be used in dike section with flat slopes	$k > 10^{-3}$	Good, tractor	100-120	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SM		Yellow	Silty sands, sand-silt mixtures	Fairly stable, not particularly suited to shells, but may be used for impervious cores or dikes	$k = 10^{-3}$ to 10^{-6}	Good, with close control, rubber-tired, sheepsfoot roller	110-125	Good to poor bearing value depending on density	Upstream blanket and toe drainage or wells
		SC			Clayey sands, sand-silt mixtures	Fairly stable, use for impervious core for flood control structures	$k = 10^{-6}$ to 10^{-8}	Fair, sheepsfoot roller, rubber tired	105-125	Good to poor bearing value	None
FINE GRAINED SOILS	SILTS AND CLAYS LL < 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor stability, may be used for embankments with proper control	$k = 10^{-3}$ to 10^{-6}	Good to poor, close control essential, rubber-tired roller, sheepsfoot roller	95-120	Very poor, susceptible to liquefaction	Toe trench to none
		CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Stable, impervious cores and blankets	$k = 10^{-6}$ to 10^{-8}	Fair to good, sheepsfoot roller, rubber tired	95-120	Good to poor bearing	None
		OL			Organic silts and organic silt-clays of low plasticity	Not suitable for embankments	$k = 10^{-4}$ to 10^{-6}	Fair to poor, sheepsfoot roller	80-100	Fair to poor bearing, may have excessive settlements	None
	SILTS AND CLAYS LL > 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor stability, core of hydraulic fill dam, not desirable in rolled fill construction	$k = 10^{-4}$ to 10^{-6}	Poor to very poor, sheepsfoot roller	70-95	Poor bearing	None
		CH			Inorganic clays of high plasticity, fat clays	Fair stability with flat slopes, thin cores, blankets and dike sections	$k = 10^{-6}$ to 10^{-8}	Fair to poor, sheepsfoot roller	75-105	Fair to poor bearing	None
		OH			Organic clays of medium to high plasticity, organic silts	Not suitable for embankments	$k = 10^{-6}$ to 10^{-8}	Poor to very poor, sheepsfoot roller	65-100	Very poor bearing	None
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not used for construction		Compaction not practical		Remove from foundations	

Notes: 1. Values in columns 7 and 11 are for guidance only. Design should be based on test results.
2. In column 9, the equipment listed will usually produce the desired densities with a reasonable number of passes when moisture conditions and thickness of lift are properly controlled.
3. Column 10, unit dry weights are for compacted soil at optimum moisture content for Standard AASHO (Standard Proctor) compactive effort.

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APPENDIX GT.1B
UNIFIED SOIL CLASSIFICATION SYSTEM
CHARACTERISTICS OF SOIL GROUPS
PERTAINING TO ROADS AND AIRFIELDS

UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX B

CHARACTERISTICS OF SOIL GROUPS PERTAINING TO ROADS AND AIRFIELDS

Introduction

1. The properties desired in soils for foundations under roads and airfields and for base courses under flexible pavements are: adequate strength, good compaction characteristics, adequate drainage, resistance to frost action in areas where frost is a factor, and acceptable compression and expansion characteristics. Certain of these properties, if inadequate in the soils available, may be supplied by proper construction methods. For instance, materials having good drainage characteristics are desirable, but if such materials are not available locally, adequate drainage may be obtained by installing a properly designed water collecting system. Strength requirements for base course materials, to be used immediately under the pavement of a flexible pavement structure, are high and only good quality materials are acceptable. However, low strengths in subgrade materials may be compensated for in many cases by increasing the thickness of overlying concrete pavement or of base materials in flexible pavement construction. From the foregoing brief discussion, it may be seen that the proper design of roads and airfield pavements requires the evaluation of soil properties in more detail than is possible by use of the general soils classification system. However, the grouping of soils in the classification system is such that a general indication of their behavior in road and airfield construction may be obtained.

Features Shown on Soils Classification Sheet

2. General characteristics of the soil groups pertinent to roads and airfields are presented in table B1. Columns 1 through 5 show major

soil divisions, group symbols, hatching and color symbols; column 6 gives names of soil types; column 7 evaluates the performance (strength) of the soil groups when used as subgrade materials that will not be subject to frost action; column 8 and column 9 make a similar evaluation for the soils when used as subbase and base materials; potential frost action is shown in column 10; compressibility and expansion characteristics are shown in column 11; column 12 presents drainage characteristics; column 13 shows types of compaction equipment that perform satisfactorily on the various soil groups; column 14 shows ranges of unit dry weight for compacted soils; column 15 gives ranges of typical California Bearing Ratio (CBR) values; and column 16 gives ranges of modulus of subgrade reaction (k). The various features presented are discussed in the following paragraphs.

Subdivision of
coarse-grained soil groups

3. It will be noted in column 3, letter symbols, that the basic soil groups, GM and SM, have each been subdivided into two groups designated by the suffixes d and u which have been chosen to represent desirable and less desirable (undesirable) base materials, respectively. This subdivision applies to roads and airfields only and is based on field observation and laboratory tests on the behavior of the soils in these groups. Basis for the subdivision is the liquid limit and plasticity index of the fraction of the soil passing the No. 40 sieve. The suffix d is used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u is used otherwise. Typical symbols for soils in these groups are GMd and SMu, etc.

Values of soils as subgrade,
subbase, or base materials

4. The descriptions in columns 7, 8, and 9 give a general indication of the suitability of the soil groups for use as subgrades, subbase, or base materials, provided they are not subject to frost action. In areas where frost heaving is a problem, the value of materials as subgrades or subbases will be reduced, depending on the potential frost action of the material, as shown in column 10. Proper design procedures

should be used in situations where this is a problem. The coarse-grained soils in general are the best subgrade, subbase, and base materials. The GW group has excellent qualities as a subgrade and subbase, and is good as base material. It is noted that the adjective "excellent" is not used for any of the soils for base courses; it is considered that the adjective "excellent" should be used in reference to a high quality processed crushed stone. Poorly-graded gravels and some silty gravels, groups GP and GMd, are usually only slightly less desirable as subgrade or subbase materials, and under favorable conditions may be used as base materials for certain conditions; however, poor gradation and other factors sometimes reduce the value of such soils to such extent that they offer only moderate strength and therefore their value as a base material is less. The GMu, GC, and SW groups are reasonably good subgrade materials, but are generally poor to not suitable as bases. The SP and SMd soils usually are considered fair to good subgrade and subbase materials but in general are poor to not suitable for base materials. The SMu and SC soils are fair to poor subgrade and subbase materials, and are not suitable for base materials. The fine-grained soils range from fair to very poor subgrade materials as follows: silts and lean clays (ML and CL), fair to poor; organic silts, lean organic clays, and micaceous or diatomaceous soils (OL and MH), poor; fat clays and fat organic clays (CH and OH), poor to very poor. These qualities are compensated for in flexible pavement design by increasing the thickness of overlying base material, and in rigid pavement design by increasing the pavement thickness or by the addition of a base course layer. None of the fine-grained soils are suitable as subbase or base materials. The fibrous organic soils (group Pt) are very poor subgrade materials and should be removed wherever possible; otherwise, special construction measures should be adopted. They are not suitable as subbase and base materials. The California Bearing Ratio (CBR) values shown in column 15 give a relative indication of the strength of the various soil groups as used in flexible pavement design. Similarly, values of subgrade modulus (k) in column 16 are relative indications of strengths from plate-bearing tests as used in rigid pavement design. As these tests are used for the design of pavements, actual

test values should be used for this purpose instead of the approximate values shown in the tabulation.

5. For wearing surfaces on unsurfaced roads sand-clay-gravel mixtures (GC) are generally considered the most satisfactory. However, they should not contain too large a percentage of fines and the plasticity index should be in the range of 5 to about 15.

Potential frost action

6. The relative effects of frost action on the various soil groups are shown in column 10. Regardless of the frost susceptibility of the various soil groups two conditions must be present simultaneously before frost action will be a major consideration. These are a source of water during the freezing period and a sufficient period for the freezing temperature to penetrate the ground. Water necessary for the formation of ice lenses may become available from a high ground-water table, capillary supply, water held within the soil voids, or through infiltration. The degree of ice formation that will occur in any given case is markedly influenced by environmental factors such as topographic position, stratification of the parent soil, transitions into cut sections, lateral flow of water from side cuts, localized pockets of perched ground water, and drainage conditions. In general, the silts and fine silty sands are the worst offenders as far as frost is concerned. Coarse-grained materials with little or no fines are affected only slightly if at all. Clays (CL and CH) are subject to frost action, but the loss of strength of such materials may not be as great as for silty soils. Inorganic soils containing less than three per cent of grains finer than 0.02 mm in diameter by weight are generally nonfrost-susceptible. Where frost-susceptible soils are encountered in subgrades and frost is a definite problem, two acceptable methods of design of pavements are available. Either a sufficient depth of acceptable granular material is placed over the soils to prevent freezing in the subgrade and thereby prevent the detrimental effects of frost action, or a reduced depth of granular material is used, thereby allowing freezing in the subgrade, and design is based on the reduced strength of the subgrade during the frost-melting period. In many cases appropriate drainage measures to prevent the accumulation of

water in the soil pores will help to diminish ice segregation in the subgrade and subbase.

Compressibility and expansion

7. These characteristics of soils may be of two types insofar as their applicability to road and runway design is concerned. The first is the relatively long-term compression or consolidation under the dead weight of the structure, and the second is the short-term compression and rebound under moving wheel loads. The long-term consolidation of soils becomes a factor in design primarily when heavy fills are made on compressible soils. If adequate provision is made for this type of settlement during construction it will have little influence on the load-carrying capacity of the pavement. However, when elastic soils subject to compression and rebound under wheel load are encountered, adequate protection must be provided, as even small movements of this type soil may be detrimental to the base and wearing course of pavements. It is fortunate that the free-draining, coarse-grained soils (GW, GP, SW, and SP), which in general make the best subgrade and subbase materials, exhibit almost no tendency toward high compressibility or expansion. In general, the compressibility of soils increases with increasing liquid limit. The foregoing is not completely true, as compressibility is also influenced by soil structure, grain shape, previous loading history, and other factors that are not evaluated in the classification system. Undesirable compressibility or expansion characteristics may be reduced by distribution of load through a greater thickness of overlying material. This, in general, is adequately handled by the CBR method of design for flexible pavements; however, rigid pavements may require the addition of an acceptable base course under the pavement.

Drainage characteristics

8. The drainage characteristics of soils are a direct reflection of their permeability. The evaluation of drainage characteristics for use in roads and runways is shown in column 12. The presence of moisture in base, subbase, and subgrade materials, except for free-draining, coarse-grained soils, may cause the development of pore water pressures and loss of strength. The moisture may come from infiltration of rain water or by

capillary rise from an underlying water table. While free-draining materials permit rapid draining of water, they permit rapid ingress of water also, and if such materials are adjacent to less pervious materials and have free access to water they may serve as reservoirs to saturate the less pervious materials. It is obvious, therefore, that in most instances adequate drainage systems should be provided. The gravelly and sandy soils with little or no fines (groups GW, GP, SW, and SP) have excellent drainage characteristics. The GMd and SMd groups have fair to poor drainage characteristics, whereas the GMu, GC, SMu, and SC groups may be practically impervious. Soils of the ML, MH, and Pt groups have fair to poor drainage characteristics. All of the other groups have poor drainage characteristics or are practically impervious.

Compaction equipment

9. The compaction of soils for roads and runways, especially for the latter, requires that a high degree of density be attained at the time of construction in order that detrimental consolidation will not take place under traffic. In addition, the detrimental effects of water are lessened in cases where saturation or near saturation takes place. Processed materials, such as crushed rock, are often used as base course and such materials require special treatment in compaction. Types of compaction equipment that will usually produce the desired densities are shown in column 13. It may be noted that several types of equipment are listed for some of the soil groups; this is because variations in soil type within a given group may require the use of different equipment. In some cases more than one type of equipment may be necessary to produce the desired densities. Steel-wheeled rollers are recommended for angular materials with limited amounts of fines, crawler-type tractors or rubber-tired rollers for gravels and sands, and sheepsfoot rollers for coarse-grained or fine-grained soils having some cohesive qualities. Rubber-tired rollers are also recommended for final compaction operations for most soils except those of high liquid limit (group H). Suggested minimum weights of the various types of equipment are shown in note 2 of the table. In column 14 are shown ranges of unit dry weight for soils compacted according to test method 100 (CE 55 compaction effort),

MIL-STD-621A. These values are included primarily for guidance; design or control of construction should be based on test results.

Graphical Presentation of Soils Data

10. It is customary to present the results of soils explorations on drawings as schematic representations of the borings or test pits or on soil profiles with the various soils encountered shown by appropriate symbols. As one approach, the group letter symbol (CL, etc.) may be written in the appropriate section of the log. As an alternative, hatching symbols shown in column 4 of table B1 may be used. In addition, the natural water content of fine-grained soils should be shown along the side of the log. Other descriptive abbreviations may be used as deemed appropriate. In certain special instances the use of color to delineate soil types on maps and drawings is desirable. A suggested color scheme to show the major soil groups is described in column 5 of table B1.

Designation: D 422 – 63 (Reapproved 1972)ε1

Standard Method for Particle-Size Analysis of Soils[1]

This standard is issued under the fixed designation D 422; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

ε1 NOTE—Section 2 was added editorially and subsequent sections renumbered in July 1984.

1. Scope

1.1 This method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 μm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Notes 1 and 2).

NOTE 1—Separation may be made on the No. 4 (4.75-mm), No. 40 (425-μm), or No. 200 (75-μm) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

NOTE 2—Two types of dispersion devices are provided: (*1*) a high-speed mechanical stirrer, and (*2*) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-μm size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 μm.

2. Referenced Documents

2.1 *ASTM Standards:*

D 421 Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[2]

E 11 Specification for Wire-Cloth Sieves for Testing Purposes[3]

E 100 Specification for ASTM Hydrometers[4]

3. Apparatus

3.1 *Balances*—A balance sensitive to 0.01 g for weighing the material passing a No. 10 (2.00-mm) sieve, and a balance sensitive to 0.1 % of the mass of the sample to be weighed for weighing the material retained on a No. 10 sieve.

3.2 *Stirring Apparatus*—Either apparatus A or B may be used.

3.2.1 Apparatus A shall consist of a mechanically operated stirring device in which a suitably mounted electric motor turns a vertical shaft at a speed of not less than 10 000 rpm without load. The shaft shall be equipped with a replaceable stirring paddle made of metal, plastic, or hard rubber, as shown in Fig. 1. The shaft shall be of such length that the stirring paddle will operate not less than ¾ in. (19.0 mm) nor more than 1½ in. (38.1 mm) above the bottom of the dispersion cup. A special dispersion cup conforming to either of the designs shown in Fig. 2 shall be provided to hold the sample while it is being dispersed.

3.2.2 Apparatus B shall consist of an air-jet dispersion cup[5] (Note 3) conforming to the general details shown in Fig. 3 (Notes 4 and 5).

NOTE 3—The amount of air required by an air-jet dispersion cup is of the order of 2 ft^3/min; some small air compressors are not capable of supplying sufficient air to operate a cup.

NOTE 4—Another air-type dispersion device, known as a dispersion tube, developed by Chu and Davidson at Iowa State College, has been shown to give results equivalent to those secured by the air-jet dispersion cups. When it is used, soaking of the sample can be done in the sedimentation cylinder, thus eliminating the need for transferring the slurry. When the air-dispersion tube is used, it shall be so indicated in the report.

NOTE 5—Water may condense in air lines when not in use. This water must be removed, either by using a water trap on the air line, or by blowing the water out of the line before using any of the air for dispersion purposes.

3.3 *Hydrometer*—An ASTM hydrometer, graduated to read in either specific gravity of the suspension or grams per litre of suspension, and conforming to the requirements for hydrometers 151H or 152H in Specifications E 100. Dimensions of both hydrometers are the same, the scale being the only item of difference.

3.4 *Sedimentation Cylinder*—A glass cylinder essentially 18 in. (457 mm) in height and 2½ in. (63.5 mm) in diameter, and marked for a volume of 1000 mL. The inside diameter shall be such that the 1000-mL mark is 36 ± 2 cm from the bottom on the inside.

3.5 *Thermometer*—A thermometer accurate to 1°F (0.5°C).

3.6 *Sieves*—A series of sieves, of square-mesh woven-wire cloth, conforming to the requirements of Specification E 11. A full set of sieves includes the following (Note 6):

[1] This method is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.03 on Texture, Plasticity, and Density Characteristics of Soils.

Current edition approved Nov. 21, 1963. Originally published 1935. Replaces D 422 – 62.

[2] *Annual Book of ASTM Standards*, Vol 04.08.

[3] *Annual Book of ASTM Standards*, Vol 14.02.

[4] *Annual Book of ASTM Standards*, Vol 14.01.

[5] Detailed working drawings for this cup are available at a nominal cost from the American Society for Testing and Materials, 1916 Race St., Philadelphia, PA 19103. Order Adjunct No. 12-404220-00.

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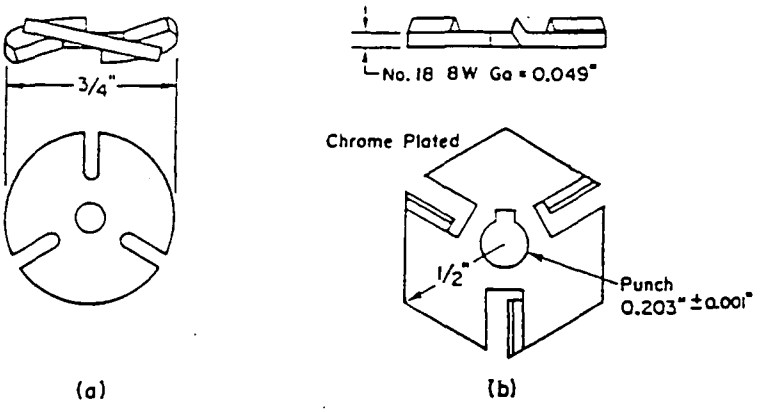


Metric Equivalents					
in.	0.001	0.049	0.203	½	¾
mm	0.03	1.24	5.16	12.7	19.0

FIG. 1 Detail of Stirring Paddles

3-in. (75-mm)	No. 10 (2.00-mm)
2-in. (50-mm)	No. 20 (850-μm)
1½-in. (37.5-mm)	No. 40 (425-μm)
1-in. (25.0-mm)	No. 60 (250-μm)
¾-in. (19.0-mm)	No. 140 (106-μm)
⅜-in. (9.5-mm)	No. 200 (75-μm)
No. 4 (4.75-mm)	

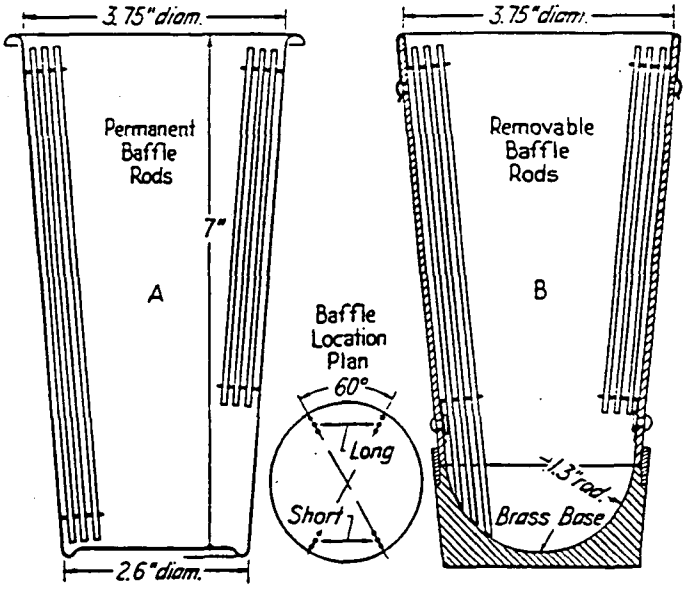
NOTE 6—A set of sieves giving uniform spacing of points for the ...h, as required in Section 17, may be used if desired. This set consists ... the following sieves:

3-in. (75-mm)	No. 16 (1.18-mm)
1½-in. (37.5-mm)	No. 30 (600-μm)
¾-in. (19.0-mm)	No. 50 (300-μm)
⅜-in. (9.5-mm)	No. 100 (150-μm)
No. 4 (4.75-mm)	No. 200 (75-μm)
No. 8 (2.36-mm)	

3.7 *Water Bath or Constant-Temperature Room*—A water bath or constant-temperature room for maintaining the soil suspension at a constant temperature during the hydrometer analysis. A satisfactory water tank is an insulated tank that maintains the temperature of the suspension at a convenient constant temperature at or near 68°F (20°C). Such a device is illustrated in Fig. 4. In cases where the work is performed in a room at an automatically controlled constant temperature, the water bath is not necessary.

3.8 *Beaker*—A beaker of 250-mL capacity.

3.9 *Timing Device*—A watch or clock with a second hand.



Metric Equivalents			
in.	1.3	2.6	3.75
mm	33	66	95.2

FIG. 2 Dispersion Cups of Apparatus

4. Dispersing Agent

4.1 A solution of sodium hexametaphosphate (sometimes called sodium metaphosphate) shall be used in distilled or demineralized water, at the rate of 40 g of sodium hexametaphosphate/litre of solution (Note 7).

NOTE 7—Solutions of this salt, if acidic, slowly revert or hydrolyze back to the orthophosphate form with a resultant decrease in dispersive ...n. Solutions should be prepared frequently (at least once a month) ...djusted to pH of 8 or 9 by means of sodium carbonate. Bottles containing solutions should have the date of preparation marked on them.

4.2 All water used shall be either distilled or demineralized water. The water for a hydrometer test shall be brought to the temperature that is expected to prevail during the hydrometer test. For example, if the sedimentation cylinder is to be placed in the water bath, the distilled or demineralized water to be used shall be brought to the temperature of the controlled water bath; or, if the sedimentation cylinder is used in a room with controlled temperature, the water for the test shall be at the temperature of the room. The basic temperature for the hydrometer test is 68°F (20°C). Small variations of temperature do not introduce differences that are of practical significance and do not prevent the use of corrections derived as prescribed.

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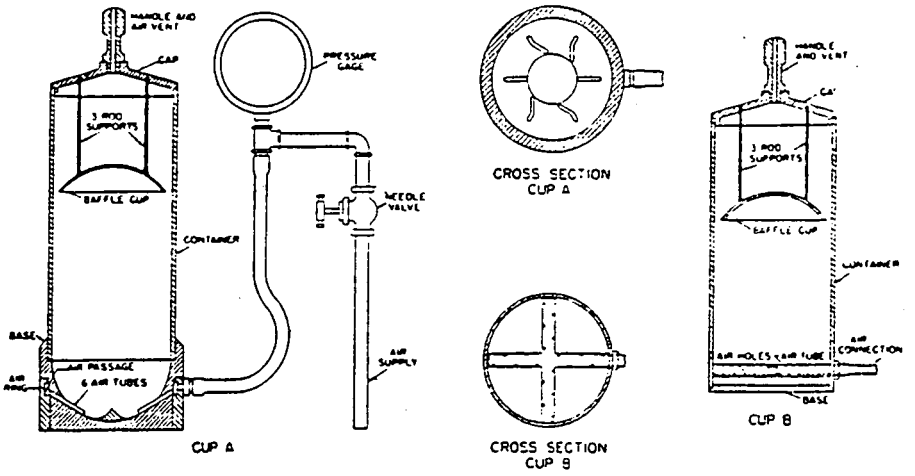


FIG. 3 Air-Jet Dispersion Cups of Apparatus B

5. Test Sample

5.1 Prepare the test sample for mechanical analysis as outlined in Practice D 421. During the preparation procedure the sample is divided into two portions. One portion contains only particles retained on the No. 10 (2.00-mm) sieve while the other portion contains only particles passing the No. 10 sieve. The mass of air-dried soil selected for purpose of tests, as prescribed in Practice D 421, shall be sufficient to yield quantities for mechanical analysis as follows:

5.1.1 The size of the portion retained on the No. 10 sieve shall depend on the maximum size of particle, according to the following schedule:

Nominal Diameter of Largest Particles, in. (mm)	Approximate Minimum Mass of Portion, g
⅜ (9.5)	500
¾ (19.0)	1000
1 (25.4)	2000
1½ (38.1)	3000
2 (50.8)	4000
3 (76.2)	5000

5.1.2 The size of the portion passing the No. 10 sieve shall be approximately 115 g for sandy soils and approximately 65 g for silt and clay soils.

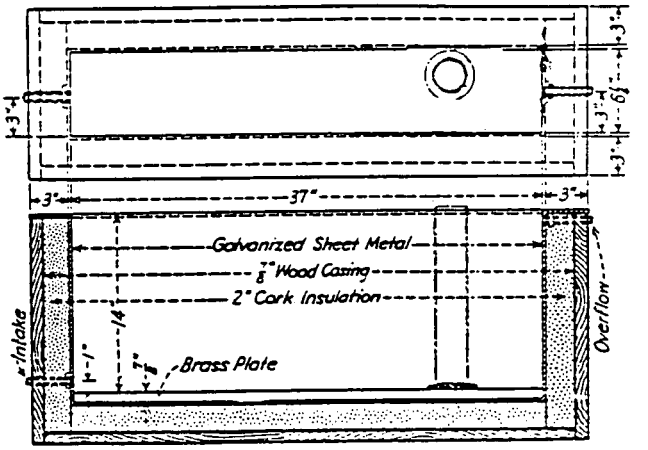
5.2 Provision is made in Section 5 of Practice D 421 for weighing of the air-dry soil selected for purpose of tests, the separation of the soil on the No. 10 sieve by dry-sieving and washing, and the weighing of the washed and dried fraction retained on the No. 10 sieve. From these two masses the percentages retained and passing the No. 10 sieve can be calculated in accordance with 12.1.

NOTE 8—A check on the mass values and the thoroughness of pulverization of the clods may be secured by weighing the portion passing the No. 10 sieve and adding this value to the mass of the washed and oven-dried portion retained on the No. 10 sieve.

SIEVE ANALYSIS OF PORTION RETAINED ON NO. 10 (2.00-mm) SIEVE

6. Procedure

6.1 Separate the portion retained on the No. 10 (2.00-mm) sieve into a series of fractions using the 3-in. (75-mm), 2-in. (50-mm), 1½-in. (37.5-mm), 1-in. (25.0-mm), ¾-in. (19.0-mm), ⅜-in. (9.5-mm), No. 4 (4.75-mm), and No. 10 sieves, or as many as may be needed depending on the sample, or upon the specifications for the material under test.



Metric Equivalents

in.	⅞	1	3	6¼	14	37
mm	22.2	25.4	76.2	158.2	356	940

FIG. 4 Insulated Water Bath

6.2 Conduct the sieving operation by means of a lateral and vertical motion of the sieve, accompanied by a jarring action in order to keep the sample moving continuously over the surface of the sieve. In no case turn or manipulate fragments in the sample through the sieve by hand. Continue sieving until not more than 1 mass % of the residue on a sieve passes that sieve during 1 min of sieving. When mechanical sieving is used, test the thoroughness of sieving by using the hand method of sieving as described above.

6.3 Determine the mass of each fraction on a balance conforming to the requirements of 3.1. At the end of weighing, the sum of the masses retained on all the sieves used should equal closely the original mass of the quantity sieved.

HYDROMETER AND SIEVE ANALYSIS OF PORTION PASSING THE NO. 10 (2.00-mm) SIEVE

7. Determination of Composite Correction for Hydrometer Reading

7.1 Equations for percentages of soil remaining in suspension, as given in 14.3, are based on the use of distilled or demineralized water. A dispersing agent is used in the water, however, and the specific gravity of the resulting liquid is appreciably greater than that of distilled or demineralized water.

7.1.1 Both soil hydrometers are calibrated at 68°F (20°C), and variations in temperature from this standard temperature produce inaccuracies in the actual hydrometer readings. The amount of the inaccuracy increases as the variation from the standard temperature increases.

7.1.2 Hydrometers are graduated by the manufacturer to be read at the bottom of the meniscus formed by the liquid on the stem. Since it is not possible to secure readings of soil suspensions at the bottom of the meniscus, readings must be taken at the top and a correction applied.

7.1.3 The net amount of the corrections for the three items enumerated is designated as the composite correction, and may be determined experimentally.

7.2 For convenience, a graph or table of composite corrections for a series of 1° temperature differences for the range of expected test temperatures may be prepared and used as needed. Measurement of the composite corrections may be made at two temperatures spanning the range of expected test temperatures, and corrections for the intermediate temperatures calculated assuming a straight-line relationship between the two observed values.

7.3 Prepare 1000 mL of liquid composed of distilled or demineralized water and dispersing agent in the same proportion as will prevail in the sedimentation (hydrometer) test. Place the liquid in a sedimentation cylinder and the cylinder in the constant-temperature water bath, set for one of the two temperatures to be used. When the temperature of the liquid becomes constant, insert the hydrometer, and, after a short interval to permit the hydrometer to come to the temperature of the liquid, read the hydrometer at the top of the meniscus formed on the stem. For hydrometer 151H the composite correction is the difference between this reading and one; for hydrometer 152H it is the difference between the reading and zero. Bring the liquid and the hydrometer to the other temperature to be used, and secure the composite correction as before.

8. Hygroscopic Moisture

8.1 When the sample is weighed for the hydrometer test, weigh out an auxiliary portion of from 10 to 15 g in a small metal or glass container, dry the sample to a constant mass in an oven at 230 ± 9°F (110 ± 5°C), and weigh again. Record the masses.

9. Dispersion of Soil Sample

9.1 When the soil is mostly of the clay and silt sizes, weigh out a sample of air-dry soil of approximately 50 g. When the soil is mostly sand the sample should be approximately 100 g.

9.2 Place the sample in the 250-mL beaker and cover with 125 mL of sodium hexametaphosphate solution (40 g/L). Stir until the soil is thoroughly wetted. Allow to soak for at least 16 h.

9.3 At the end of the soaking period, disperse the sample further, using either stirring apparatus A or B. If stirring apparatus A is used, transfer the soil - water slurry from the beaker into the special dispersion cup shown in Fig. 2, washing any residue from the beaker into the cup with distilled or demineralized water (Note 9). Add distilled or demineralized water, if necessary, so that the cup is more than half full. Stir for a period of 1 min.

NOTE 9—A large size syringe is a convenient device for handling the water in the washing operation. Other devices include the wash-water bottle and a hose with nozzle connected to a pressurized distilled water tank.

9.4 If stirring apparatus B (Fig. 3) is used, remove the cover cap and connect the cup to a compressed air supply by means of a rubber hose. A air gage must be on the line between the cup and the control valve. Open the control valve so that the gage indicates 1 psi (7 kPa) pressure (Note 10). Transfer the soil - water slurry from the beaker to the air-jet dispersion cup by washing with distilled or demineralized water. Add distilled or demineralized water, if necessary, so that the total volume in the cup is 250 mL, but no more.

NOTE 10—The initial air pressure of 1 psi is required to prevent the soil - water mixture from entering the air-jet chamber when the mixture is transferred to the dispersion cup.

9.5 Place the cover cap on the cup and open the air control valve until the gage pressure is 20 psi (140 kPa). Disperse the soil according to the following schedule:

Plasticity Index	Dispersion Period, min
Under 5	5
6 to 20	10
Over 20	15

Soils containing large percentages of mica need be dispersed for only 1 min. After the dispersion period, reduce the gage pressure to 1 psi preparatory to transfer of soil - water slurry to the sedimentation cylinder.

10. Hydrometer Test

10.1 Immediately after dispersion, transfer the soil - water slurry to the glass sedimentation cylinder, and add distilled or demineralized water until the total volume is 1000 mL.

10.2 Using the palm of the hand over the open end of the cylinder (or a rubber stopper in the open end), turn the cylinder upside down and back for a period of 1 min to complete the agitation of the slurry (Note 11). At the end of 1 min set the cylinder in a convenient location and take hydrometer readings at the following intervals of time (measured from the beginning of sedimentation), or as many as may be needed, depending on the sample or the specification for the material under test: 2, 5, 15, 30, 60, 250, and 1440 min. If the controlled water bath is used, the sedimentation cylinder should be placed in the bath between the 2- and 5-min readings.

NOTE 11—The number of turns during this minute should be approximately 60, counting the turn upside down and back as two turns.

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any soil remaining in the bottom of the cylinder during the first few turns should be loosened by vigorous shaking of the cylinder while it is in the inverted position.

10.3 When it is desired to take a hydrometer reading, carefully insert the hydrometer about 20 to 25 s before the reading is due to approximately the depth it will have when the reading is taken. As soon as the reading is taken, carefully remove the hydrometer and place it with a spinning motion in a graduate of clean distilled or demineralized water.

NOTE 12—It is important to remove the hydrometer immediately after each reading. Readings shall be taken at the top of the meniscus formed by the suspension around the stem, since it is not possible to secure readings at the bottom of the meniscus.

10.4 After each reading, take the temperature of the suspension by inserting the thermometer into the suspension.

11. Sieve Analysis

11.1 After taking the final hydrometer reading, transfer the suspension to a No. 200 (75-μm) sieve and wash with tap water until the wash water is clear. Transfer the material on the No. 200 sieve to a suitable container, dry in an oven at 230 ± 9°F (110 ± 5°C) and make a sieve analysis of the portion retained, using as many sieves as desired, or required for the material, or upon the specification of the material under test.

CALCULATIONS AND REPORT

12. Sieve Analysis Values for the Portion Coarser than the No. 10 (2.00-mm) Sieve

12.1 Calculate the percentage passing the No. 10 sieve by dividing the mass passing the No. 10 sieve by the mass of soil originally split on the No. 10 sieve, and multiplying the result by 100. To obtain the mass passing the No. 10 sieve, subtract the mass retained on the No. 10 sieve from the original mass.

12.2 To secure the total mass of soil passing the No. 4 (4.75-mm) sieve, add to the mass of the material passing the No. 10 sieve the mass of the fraction passing the No. 4 sieve and retained on the No. 10 sieve. To secure the total mass of soil passing the ⅜-in. (9.5-mm) sieve, add to the total mass of soil passing the No. 4 sieve, the mass of the fraction passing the ⅜-in. sieve and retained on the No. 4 sieve. For the remaining sieves, continue the calculations in the same manner.

12.3 To determine the total percentage passing for each sieve, divide the total mass passing (see 12.2) by the total mass of sample and multiply the result by 100.

13. Hygroscopic Moisture Correction Factor

13.1 The hydroscopic moisture correction factor is the ratio between the mass of the oven-dried sample and the air-dry mass before drying. It is a number less than one, except when there is no hygroscopic moisture.

14. Percentages of Soil in Suspension

14.1 Calculate the oven-dry mass of soil used in the hydrometer analysis by multiplying the air-dry mass by the hygroscopic moisture correction factor.

TABLE 1 Values of Correction Factor, a, for Different Specific Gravities of Soil Particles[A]

Specific Gravity	Correction Factor[A]
2.95	0.94
2.90	0.95
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.03
2.45	1.05

[A] For use in equation for percentage of soil remaining in suspension when using Hydrometer 152H.

14.2 Calculate the mass of a total sample represented by the mass of soil used in the hydrometer test, by dividing the oven-dry mass used by the percentage passing the No. 10 (2.00-mm) sieve, and multiplying the result by 100. This value is the weight W in the equation for percentage remaining in suspension.

14.3 The percentage of soil remaining in suspension at the level at which the hydrometer is measuring the density of the suspension may be calculated as follows (Note 13): For hydrometer 151H:

$$P = [(100\,000/W) \times G/(G - G_1)](R - G_1)$$

NOTE 13—The bracketed portion of the equation for hydrometer 151H is constant for a series of readings and may be calculated first and then multiplied by the portion in the parentheses.

For hydrometer 152H:

$$P = (Ra/W) \times 100$$

where:

a = correction faction to be applied to the reading of hydrometer 152H. (Values shown on the scale are computed using a specific gravity of 2.65. Correction factors are given in Table 1),

P = percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the suspension,

R = hydrometer reading with composite correction applied (Section 7),

W = oven-dry mass of soil in a total test sample represented by mass of soil dispersed (see 14.2), g,

G = specific gravity of the soil particles, and

G_1 = specific gravity of the liquid in which soil particles are suspended. Use numerical value of one in both instances in the equation. In the first instance any possible variation produces no significant effect, and in the second instance, the composite correction for R is based on a value of one for G_1.

15. Diameter of Soil Particles

15.1 The diameter of a particle corresponding to the percentage indicated by a given hydrometer reading shall be calculated according to Stokes' law (Note 14), on the basis that a particle of this diameter was at the surface of the suspension at the beginning of sedimentation and had settled to the level at which the hydrometer is measuring the density of the suspension. According to Stokes' law:

$$D = \sqrt{[30n/980(G - G_1)] \times L/T}$$

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where:

D = diameter of particle, mm,

η = coefficient of viscosity of the suspending medium (in this case water) in poises (varies with changes in temperature of the suspending medium),

L = distance from the surface of the suspension to the level at which the density of the suspension is being measured, cm. (For a given hydrometer and sedimentation cylinder, values vary according to the hydrometer readings. This distance is known as effective depth (Table 2)),

T = interval of time from beginning of sedimentation to the taking of the reading, min,

G = specific gravity of soil particles, and

G_1 = specific gravity (relative density) of suspending medium (value may be used as 1.000 for all practical purposes).

NOTE 14—Since Stokes' law considers the terminal velocity of a single sphere falling in an infinity of liquid, the sizes calculated represent the diameter of spheres that would fall at the same rate as the soil particles.

15.2 For convenience in calculations the above equation may be written as follows:

$$D = K\sqrt{L/T}$$

where:

K = constant depending on the temperature of the suspension and the specific gravity of the soil particles. Values of K for a range of temperatures and specific gravities are given in Table 3. The value of K does not change for a series of readings constituting a test, while values of L and T do vary.

15.3 Values of D may be computed with sufficient accuracy, using an ordinary 10-in. slide rule.

NOTE 15—The value of L is divided by T using the A- and B-scales, the square root being indicated on the D-scale. Without ascertaining the value of the square root it may be multiplied by K, using either the C- or CI-scale.

16. Sieve Analysis Values for Portion Finer than No. 10 (2.00-mm) Sieve

16.1 Calculation of percentages passing the various sieves used in sieving the portion of the sample from the hydrometer test involves several steps. The first step is to calculate the mass of the fraction that would have been retained on the No. 10 sieve had it not been removed. This mass is equal to the total percentage retained on the No. 10 sieve (100 minus total percentage passing) times the mass of the total sample represented by the mass of soil used (as calculated in 14.2), and the result divided by 100.

16.2 Calculate next the total mass passing the No. 200 sieve. Add together the fractional masses retained on all the sieves, including the No. 10 sieve, and subtract this sum from the mass of the total sample (as calculated in 14.2).

16.3 Calculate next the total masses passing each of the other sieves, in a manner similar to that given in 12.2.

16.4 Calculate last the total percentages passing by dividing the total mass passing (as calculated in 16.3) by the total mass of sample (as calculated in 14.2), and multiply the result by 100.

TABLE 2 Values of Effective Depth Based on Hydrometer and Sedimentation Cylinder of Specified Sizes[A]

Hydrometer 151H		Hydrometer 152H			
Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm	Actual Hydrometer Reading	Effective Depth, L, cm
1.000	16.3	0	16.2	31	11.2
1.001	16.0	1	16.1	32	11.1
1.002	15.8	2	16.0	33	10.9
1.003	15.5	3	15.8	34	10.7
1.004	15.2	4	15.6	35	10.6
1.005	15.0	5	15.5		
1.006	14.7	6	15.3	36	10.4
1.007	14.4	7	15.2	37	10.2
1.008	14.2	8	15.0	38	10.1
1.009	13.9	9	14.8	39	9.9
1.010	13.7	10	14.7	40	9.7
1.011	13.4	11	14.5	41	9.6
1.012	13.1	12	14.3	42	9.4
1.013	12.9	13	14.2	43	9.2
1.014	12.6	14	14.0	44	9.1
1.015	12.3	15	13.8	45	8.9
1.016	12.1	16	13.7	46	8.8
1.017	11.8	17	13.5	47	8.6
1.018	11.5	18	13.3	48	8.4
1.019	11.3	19	13.2	49	8.3
1.020	11.0	20	13.0	50	8.1
1.021	10.7	21	12.9	51	7.9
1.022	10.5	22	12.7	52	7.8
1.023	10.2	23	12.5	53	7.6
1.024	10.0	24	12.4	54	7.4
1.025	9.7	25	12.2	55	7.3
1.026	9.4	26	12.0	56	7.1
1.027	9.2	27	11.9	57	7.0
1.028	8.9	28	11.7	58	6.8
1.029	8.6	29	11.5	59	6.6
1.030	8.4	30	11.4	60	6.5
1.031	8.1				
1.032	7.8				
1.033	7.6				
1.034	7.3				
1.035	7.0				
1.036	6.8				
1.037	6.5				
1.038	6.2				

[A] Values of effective depth are calculated from the equation:

$$L = L_1 + \tfrac{1}{2}\,[L_2 - (V_B/A)]$$

where:

L = effective depth, cm,

L_1 = distance along the stem of the hydrometer from the top of the bulb to the mark for a hydrometer reading, cm,

L_2 = overall length of the hydrometer bulb, cm,

V_B = volume of hydrometer bulb, cm^3, and

A = cross-sectional area of sedimentation cylinder, cm^2

Values used in calculating the values in Table 2 are as follows:

For both hydrometers, 151H and 152H:

L_2 = 14.0 cm

V_B = 67.0 cm^3

A = 27.8 cm^2

For hydrometer 151H:

L_1 = 10.5 cm for a reading of 1.000

= 2.3 cm for a reading of 1.031

For hydrometer 152H:

L_1 = 10.5 cm for a reading of 0 g/litre

= 2.3 cm for a reading of 50 g/litre

17. Graph

17.1 When the hydrometer analysis is performed, a graph

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TABLE 3 *Values of K for Use in Equation for Computing Diameter of Particle in Hydrometer Analysis*

Temperature, °C	Specific Gravity of Soil Particles								
	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.01510	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.1323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.01290	0.01269	0.01249	0.01230	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

of the test results shall be made, plotting the diameters of the particles on a logarithmic scale as the abscissa and the percentages smaller than the corresponding diameters to an arithmetic scale as the ordinate. When the hydrometer analysis is not made on a portion of the soil, the preparation of the graph is optional, since values may be secured directly from tabulated data.

18. Report

18.1 The report shall include the following:

18.1.1 Maximum size of particles,

18.1.2 Percentage passing (or retained on) each sieve, which may be tabulated or presented by plotting on a graph (Note 16),

18.1.3 Description of sand and gravel particles:

18.1.3.1 Shape—rounded or angular,

18.1.3.2 Hardness—hard and durable, soft, or weathered and friable.

18.1.4 Specific gravity, if unusually high or low,

18.1.5 Any difficulty in dispersing the fraction passing the No. 10 (2.00-mm) sieve, indicating any change in type and amount of dispersing agent, and

18.1.6 The dispersion device used and the length of the dispersion period.

NOTE 16—This tabulation of graph represents the gradation of the sample tested. If particles larger than those contained in the sample were removed before testing, the report shall so state giving the amount and maximum size.

18.2 For materials tested for compliance with definite specifications, the fractions called for in such specifications shall be reported. The fractions smaller than the No. 10 sieve shall be read from the graph.

18.3 For materials for which compliance with definite specifications is not indicated and when the soil is composed almost entirely of particles passing the No. 4 (4.75-mm) sieve, the results read from the graph may be reported as follows:

(1) Gravel, passing 3-in. and retained on No. 4 sieve ..... %
(2) Sand, passing No. 4 sieve and retained on No. 200 sieve ..... %
  (a) Coarse sand, passing No. 4 sieve and retained on No. 10 sieve ..... %
  (b) Medium sand, passing No. 10 sieve and retained on No. 40 sieve ..... %
  (c) Fine sand, passing No. 40 sieve and retained on No. 200 sieve ..... %
(3) Silt size, 0.074 to 0.005 mm ..... %
(4) Clay size, smaller than 0.005 mm ..... %
  Colloids, smaller than 0.001 mm ..... %

18.4 For materials for which compliance with definite specifications is not indicated and when the soil contains material retained on the No. 4 sieve sufficient to require a sieve analysis on that portion, the results may be reported as follows (Note 17):

SIEVE ANALYSIS

Sieve Size	Percentage Passing
3-in.	.....
2-in.	.....
1½-in.	.....
1-in.	.....
¾-in.	.....
⅜-in.	.....
No. 4 (4.75-mm)	.....
No. 10 (2.00-mm)	.....
No. 40 (425-μm)	.....
No. 200 (75-μm)	.....

HYDROMETER ANALYSIS

0.074 mm	.....
0.005 mm	.....
0.001 mm	.....

NOTE 17—No. 8 (2.36-mm) and No. 50 (300-μm) sieves may be substituted for No. 10 and No. 40 sieves.

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Major Divisions (1)	(2)	Symbol: Letter (3)	Hatching (4)	Color (5)	Name (6)	Value as Subgrade When Not Subject to Frost Action (7)	Value as Su When Not S to Frost A (8)
COARSE-GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	GW		Red	Well-graded gravels or gravel-sand mixtures, little or no fines	Excellent	Excellent
		GP			Poorly graded gravels or gravel-sand mixtures, little or no fines	Good to excellent	Good
		GM d		Yellow	Silty gravels, gravel-sand-silt mixtures	Good to excellent	Good
		GM u				Good	Fair
		GC			Clayey gravels, gravel-sand-clay mixtures	Good	Fair
	SAND AND SANDY SOILS	SW		Red	Well-graded sands or gravelly sands, little or no fines	Good	Fair to goc
		SP			Poorly graded sands or gravelly sands, little or no fines	Fair to good	Fair
		SM d		Yellow	Silty sands, sand-silt mixtures	Fair to good	Fair to goc
		SM u				Fair	Poor to fa:
		SC			Clayey sands, sand-clay mixtures	Poor to fair	Poor
FINE-GRAINED SOILS	SILTS AND CLAYS LL IS LESS THAN 50	ML		Green	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	Poor to fair	Not suitabl
		CL			Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitabl
		OL			Organic silts and organic silt-clays of low plasticity	Poor	Not suitab.
	SILTS AND CLAYS LL IS GREATER THAN 50	MH		Blue	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitabl
		CH			Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitabl
		OH			Organic clays of medium to high plasticity, organic silts	Poor to very poor	Not suitab.
HIGHLY ORGANIC SOILS		Pt		Orange	Peat and other highly organic soils	Not suitable	Not suitabl

Note:

1. Column 2, division of GM and SM groups into subdivisions of d and u are for roads and airfields only. Subdivision is on basis of plasticity index is 5 or less; the suffix u will be used otherwise.
2. In column 13, the equipment listed will usually produce the required densities with a reasonable number of passes when moisture condi are listed because variable soil characteristics within a given soil group may require different equipment. In some instances, a com
   a. Processed base materials and other angular materials. Steel-wheeled and rubber-tired rollers are recommended for hard, angular m subject to degradation.
   b. Finishing. Rubber-tired equipment is recommended for rolling during final shaping operations for most soils and processed materi
   c. Equipment size. The following sizes of equipment are necessary to assure the high densities required for airfield construction:
      Crawler-type tractor -- total weight in excess of 30,000 lb.
      Rubber-tired equipment -- wheel load in excess of 15,000 lb, wheel loads as high as 40,000 lb may be necessary to obtain the re
      Sheepsfoot roller -- unit pressure (on 6- to 12-sq-in. foot) to be in excess of 250 psi and unit pressures as high as 650 psi m be at least 5 per cent of the total peripheral area of the drum, using the diameter measured to the faces of the feet.
3. Column 14, unit dry weight: are for compacted soil at optimum moisture content for modified AASHO compaction effort (CE 55).
4. In column 15, the maximum value that can be used in design of airfields is, in some cases, limited by gradation and plasticity requir

B-8-A

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Table 21

Characteristics Pertinent to Roads and Airfields

	Value as Subgrade When Not Subject to Frost Action (7)	Value as Subbase When Not Subject to Frost Action (8)	Value as Base When Not Subject to Frost Action (9)	Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	
and	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawl roller
-sand	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawl roller
mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber roller
	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber roller
y mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber roller
ands,	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawl roller
	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawl roller
	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor	Rubber roller moist
	Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber roller
	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber roller
nds, rock ds or city	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber roller
m plastic- s, silty	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber roller
-clays of	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber roller
liatomaceous tic silts	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheeps roller
city, fat	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepr roller
	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepa roller
soils	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compac

and airfields only. Subdivision is on basis of Atterberg limits; suffix d (e.g., GMd) will be used when the liquid limit is 25 or less and th

reasonable number of passes when moisture conditions and thickness of lift are properly controlled. In some instances, several types of equipm different equipment. In some instances, a combination of two types may be necessary.
red rollers are recommended for hard, angular materials with limited fines or screenings. Rubber-tired equipment is recommended for softer mat

operations for most soils and processed materials.
densities required for airfield construction:

as 40,000 lb may be necessary to obtain the required densities for some materials (based on contact pressure of approximately 65 to 150 psi). 250 psi and unit pressures as high as 650 psi may be necessary to obtain the required densities for some materials. The area of the feet shoul meter measured to the faces of the feet.
ified AASHO compaction effort (CE 55).
ses, limited by gradation and plasticity requirements.

B-8-B

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Potential Frost Action (10)	Compressibility and Expansion (11)	Drainage Characteristics (12)	Compaction Equipment (13)	Unit Dry Weight lb per cu ft (14)	Typical Design Values: CBR (15)	Typical Design Values: Subgrade Modulus k lb per cu in. (16)
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125-140	40-80	300-500
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110-140	30-60	300-500
Slight to medium	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	125-145	40-60	300-500
Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115-135	20-30	200-500
Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	130-145	20-40	200-500
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110-130	20-40	200-400
None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105-135	10-40	150-400
Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	120-135	15-40	150-400
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-130	10-20	100-300
Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100-135	5-20	100-300
Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheepsfoot roller; close control of moisture	90-130	15 or less	100-200
Medium to high	Medium	Practically impervious	Rubber-tired roller, sheepsfoot roller	90-130	15 or less	50-150
Medium to high	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	90-105	5 or less	50-100
Medium to very high	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	80-105	10 or less	50-100
Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	90-115	15 or less	50-150
Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	80-110	5 or less	25-100
Slight	Very high	Fair to poor	Compaction not practical	-	-	-

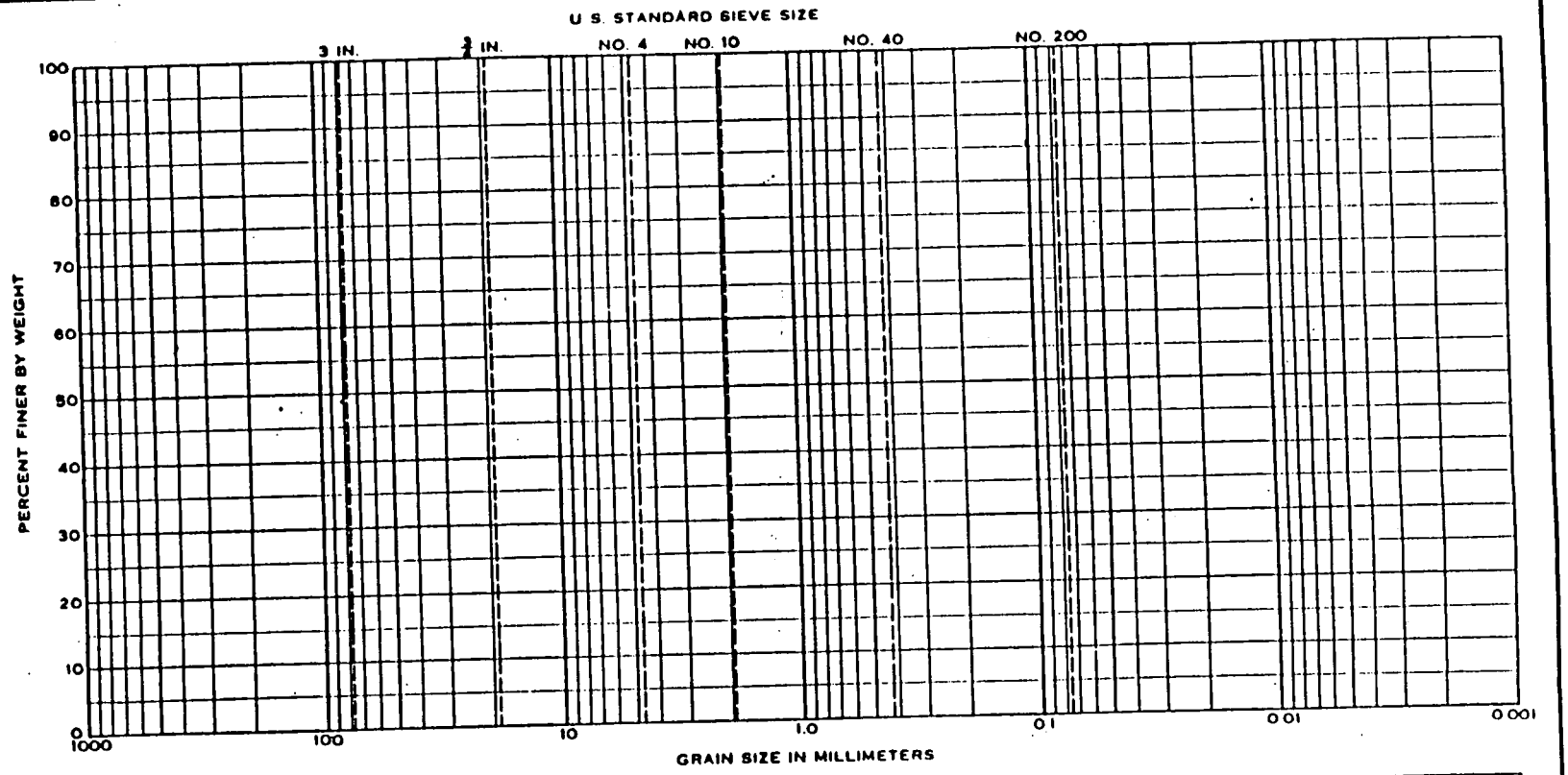
033159A

(e.g., GMd) will be used when the liquid limit is 25 or less and the

re properly controlled. In some instances, several types of equipment
necessary.
r screenings. Rubber-tired equipment is recommended for softer materials

erials (based on contact pressure of approximately 65 to 150 psi).
required densities for some materials. The area of the feet should

6-8-C



Sample No.	Elev or Depth	Classification	Nat WC	LL	PL	PI	

Project

Area

Boring No.

Date

062552 C

GRADATION CURVES

PLATE 1

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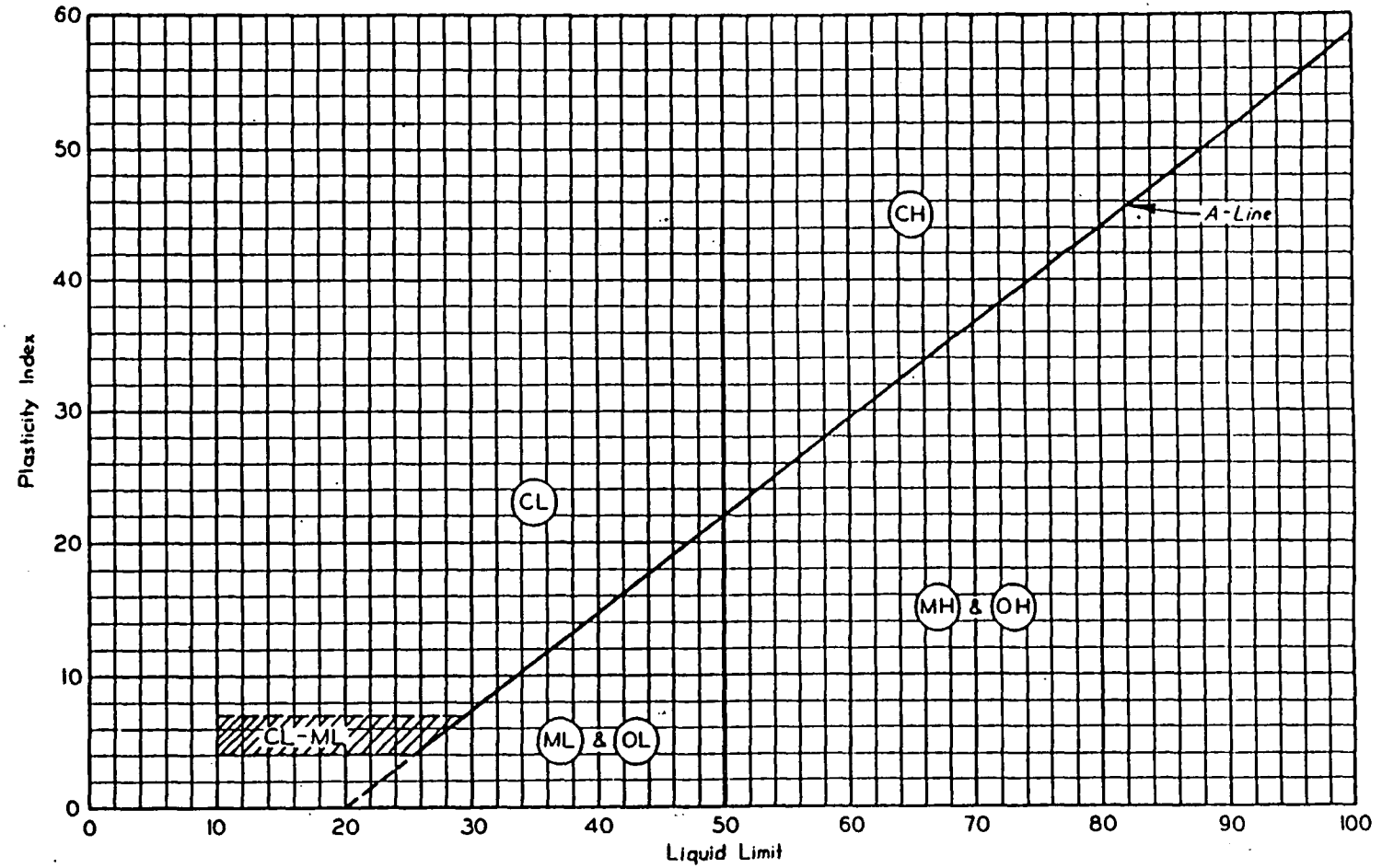
PLATE 2



PLASTICITY CHART

R-011953-C

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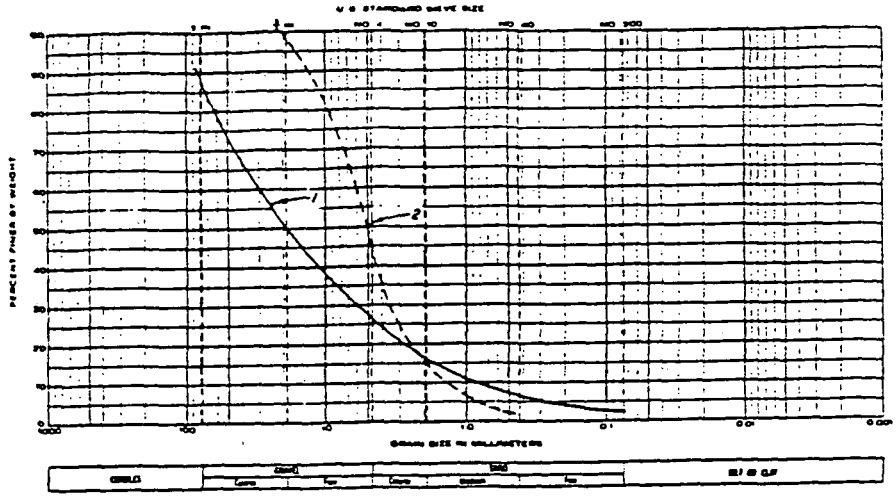
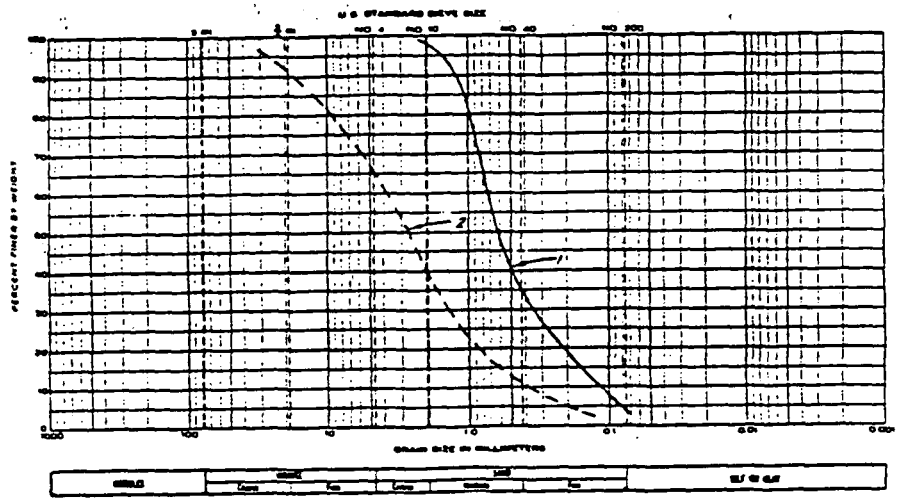


CURVE 1: Pit run gravel; nonplastic; well-graded; small percentage of fines.
CURVE 2: Sandy gravel; nonplastic; no fines. Curve is about the steepest one that will meet the criteria for GW group.

GW GROUP

FIG. 1



CURVE 1: Medium to fine sand; nonplastic; well-graded. Curve is about the steepest one that will meet the criteria for SW group.
CURVE 2:- Gravelly sand; nonplastic; well-graded.

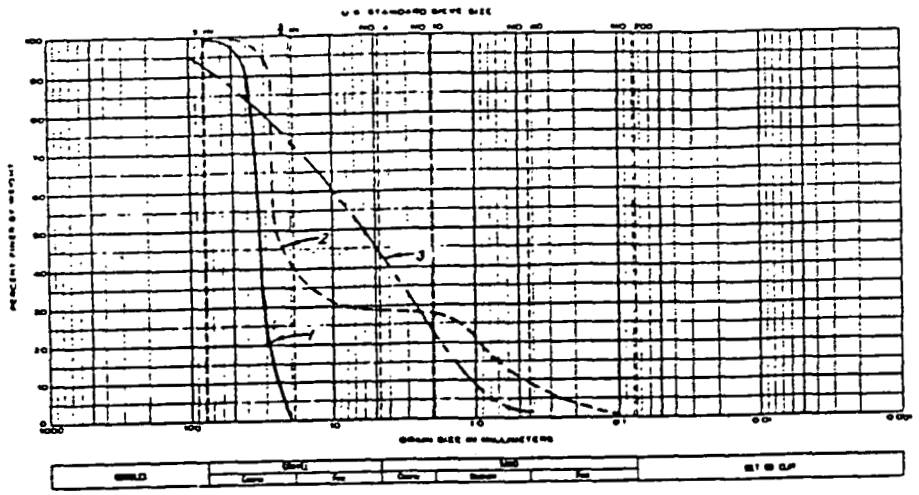
SW GROUP

FIG. 2

TYPICAL EXAMPLES
GW AND SW SOILS

062652-A

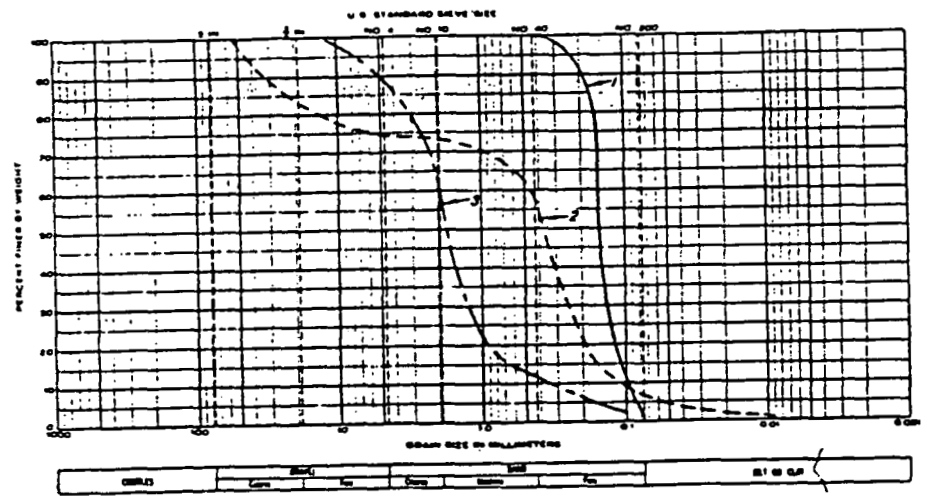
PLATE 3



CURVE 1: Uniform coarse gravel; nonplastic. Very uniform gradation.
CURVE 2: Gravel-sand mixture; nonplastic. Gravel is almost all of one size (3/4- to 1-in.), no fine gravel present. Poorly graded.
CURVE 3: Sandy gravel; nonplastic. All sizes are present, but gradation does not meet curvature criterion for GW.

GP GROUP

FIG. 1



CURVE 1: Uniform fine sand; nonplastic.
CURVE 2: Poorly graded gravelly sand mixture; nonplastic. Approximately 7 per cent fines makes this a borderline soil, symbol SP-SM.
CURVE 3: Coarse to medium sand; nonplastic. Approaching uniform gradation; does not meet curvature criterion for SW.

SP GROUP

FIG. 2

TYPICAL EXAMPLES
GP AND SP SOILS

062652-8

PLATE 4

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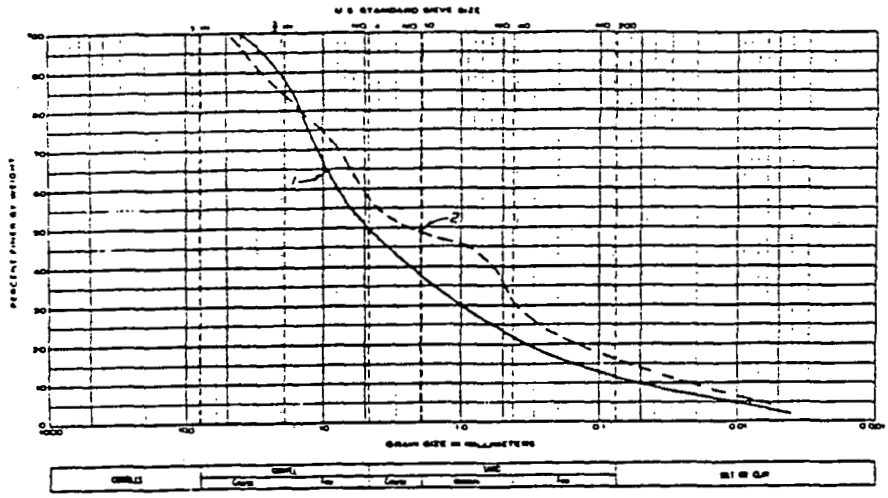
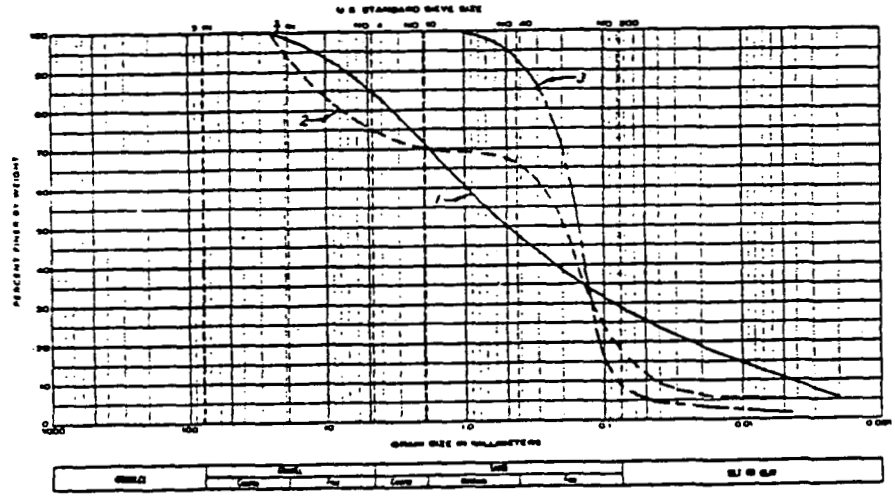


CURVE 1: Crushed limestone; LL-16, PI-8. Well-graded. Made excellent base course material.
CURVE 2: Gravel-sand-silt mixture; LL-32, PI-6. Poorly graded.

GM GROUP
FIG. 1



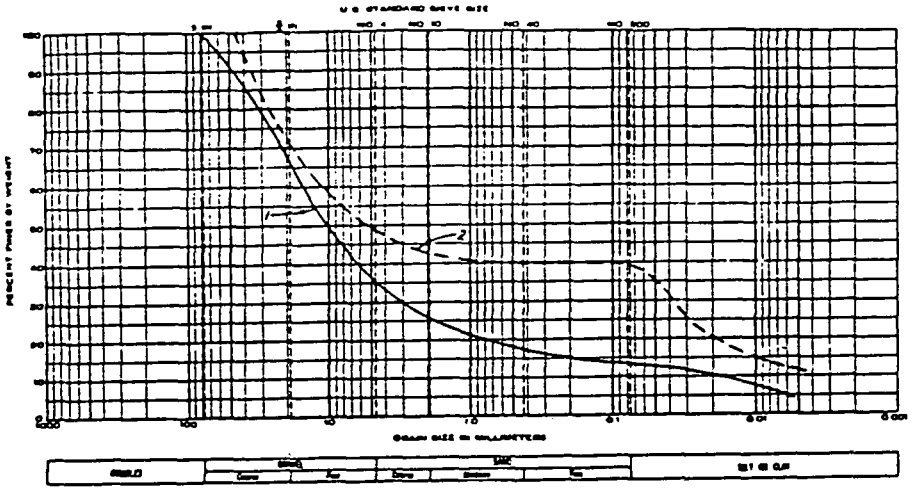
CURVE 1: Silty gravelly sand; nonplastic. Micaceous silt stabilized with sandy chert gravel.
CURVE 2: Mixture of gravel-sand and fine silty sand; nonplastic. Poorly graded mixture; note absence of coarse and medium sand.
CURVE 3: Silty fine sand; LL-22, PI-5. Uniform gradation, amount passing No. 200 sieve, and Atterberg limits classify soil as borderline in SP-SM-SC groups. Classify as SP-SM.

SM GROUP
FIG. 2

TYPICAL EXAMPLES
GM AND SM SOILS

062852-C

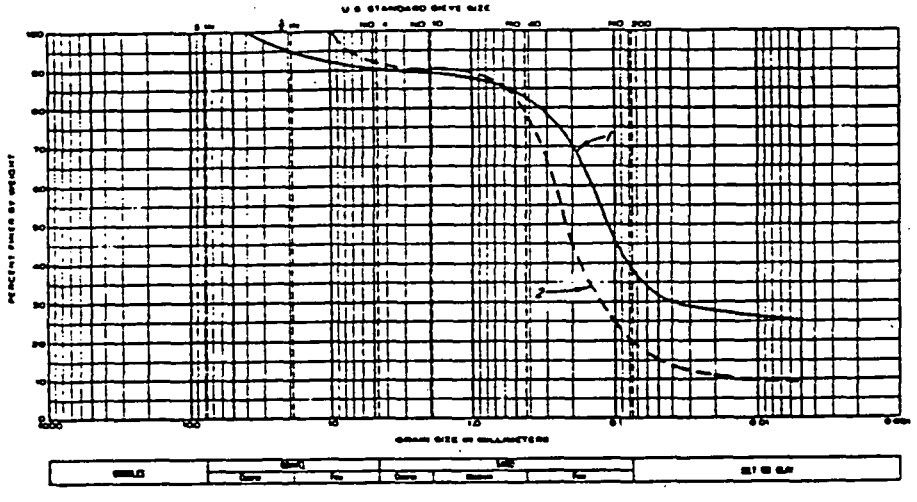
PLATE 5



CURVE 1: Clay-gravel (chert); LL-40, PI-19. Fairly low percentage of plastic fines.
CURVE 2: Natural mixture of gravel and clay; LL-46, PI-20. Very poorly graded; almost no sand sizes present.

GC GROUP

FIG. 1



CURVE 1: Clayey sand; LL-23, PI-10. Poorly graded mixture of sand-clay and fine silty sand.
CURVE 2: Limerock and sand mixture; LL-23, PI-8. Poorly graded.

SC GROUP

FIG. 2

TYPICAL EXAMPLES
GC AND SC SOILS

062652-D

PLATE 6

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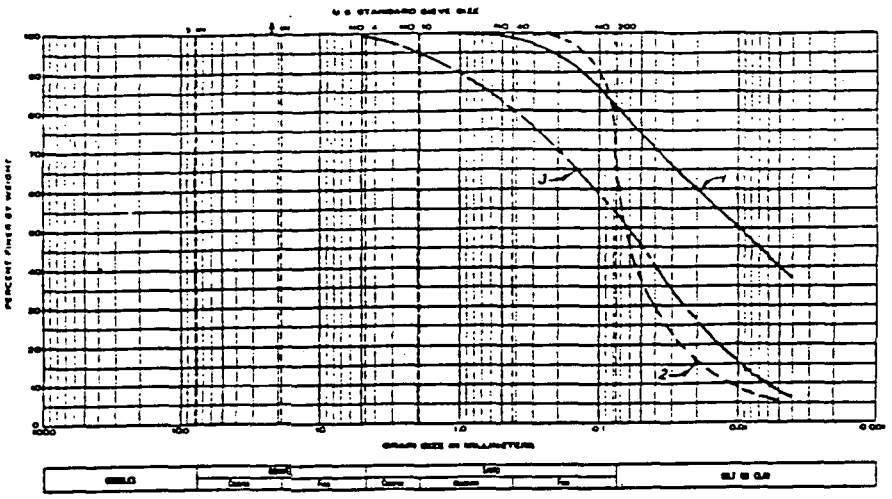
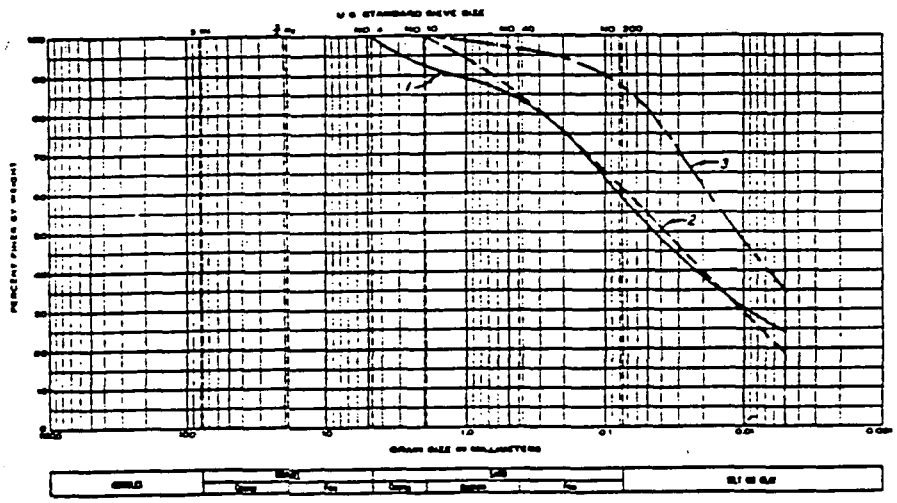


CURVE 1: Clayey silt; LL-46, PI-16.
CURVE 2: Uniform sandy silt; LL-30, PI-3.
CURVE 3: Sandy silt; LL-34, PI-3.
GENERAL: Both curves 2 and 3 have about the same plasticity but vary in grain size distribution.

ML GROUP
FIG. 1



CURVE 1: Micaceous sandy silt; LL-55, PI-6.
CURVE 2: Sandy silt; LL-47, PI-27.
CURVE 3: Clayey silt; LL-54, PI-24.
GENERAL: Both curves 1 and 2 have approximately the same grain size but are widely different in plasticity.

MH GROUP
FIG. 2

TYPICAL EXAMPLES
ML AND MH SOILS

062652-C

PLATE 7

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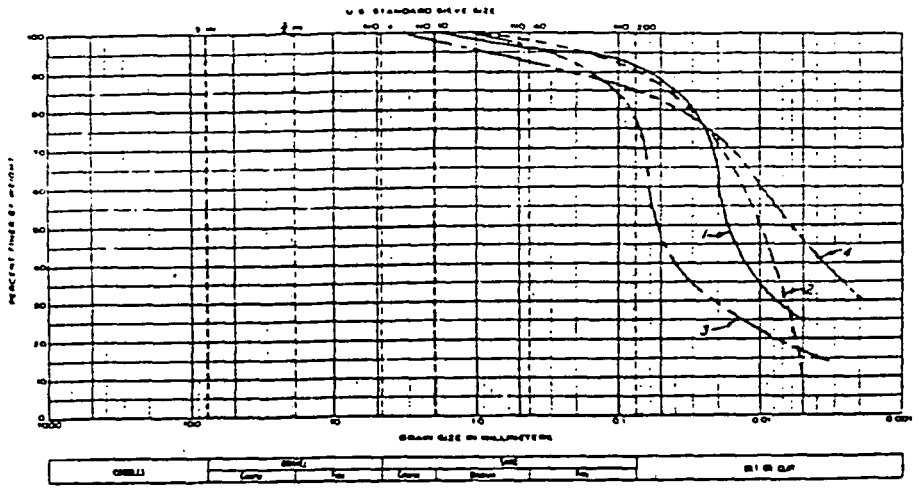
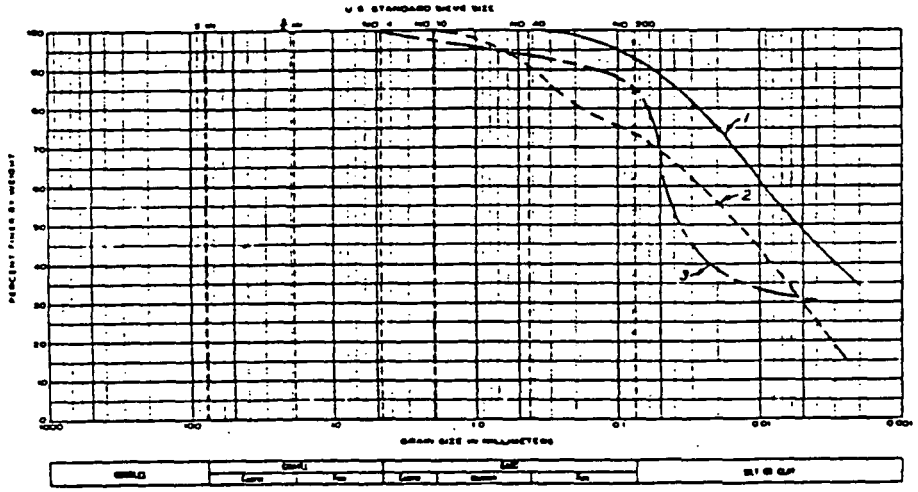


CURVE 1: Lean clay; LL-30, PI-13.
CURVE 2: Silty clay; LL-25, PI-4. Borderline, classify as CL-ML.
CURVE 3: Sandy clay; LL-31, PI-18.
CURVE 4: Clay; LL-44, PI-25.

CL GROUP
FIG.1



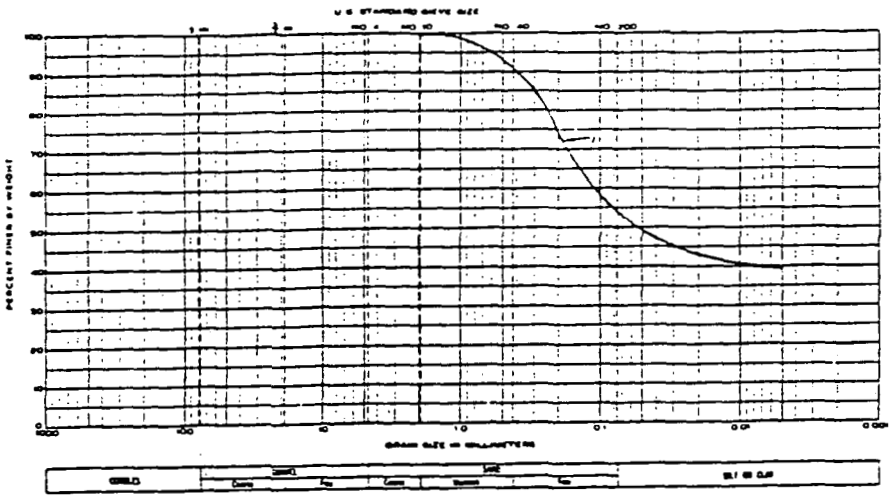
CURVE 1: Silty clay; LL-52, PI-25.
CURVE 2: Sandy fat clay; LL-75, PI-45.
CURVE 3: Sandy clay; LL-51, PI-29.

CH GROUP
FIG.2

TYPICAL EXAMPLES
CL AND CH SOILS

062652-F

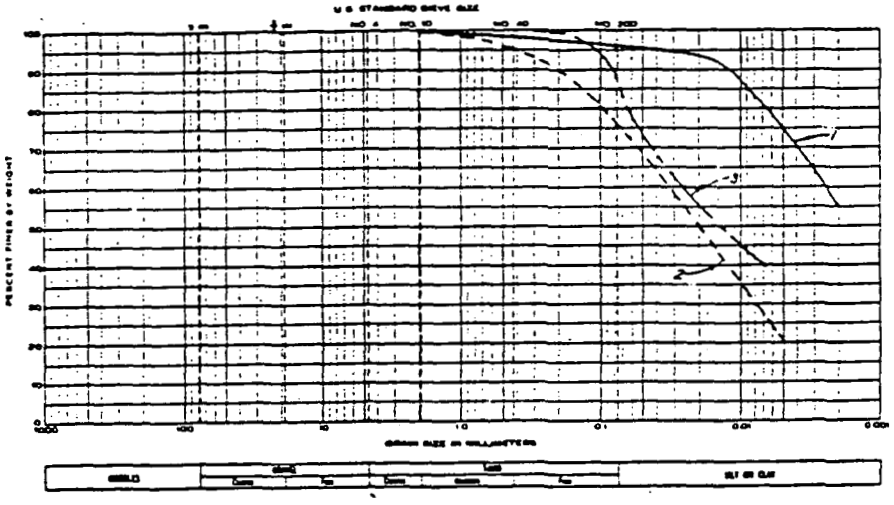
PLATE 8



CURVE 1: Organic sandy clay; LL-46, PI-15.

OL GROUP

FIG. 1



CURVE 1: *Organic clay (tidal flats)*; LL-95, PI-39.
CURVE 2: Alkali clay with organic matter; LL-66, PI-27.
CURVE 3: Organic silt; LL-70, PI-33 (natural water content); LL-53, PI-19 (oven dried).

OH GROUP

FIG. 2

TYPICAL EXAMPLES
OL AND OH SOILS

062652-C

PLATE 9

DOCUMENT MODIFICATION REQUEST (DMR)

INFORMATION ONLY

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

1. Date	25. DMR. No.
03/01/94	93-DMR- 00405

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
-21000-OPS-GT.2, Rev. 2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
Steve Paris/8543/4624/080-628	Drilling and Sampling Using Hollow-stem Auger Techniques

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	8	5.3.1	Change the 4th sentence of the 1st paragraph to read: "Once the core barrel has been removed from the borehole, opened, scanned, and measured, the VOA sample liner will immediately be capped with Teflon® paper, sealed with plastic caps, labeled, and placed in plastic bags prior to placement in a cooler with ice."

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. Toluene and several low-level aromatic hydrocarbons are detected during analysis of VOAs. These compounds are known to be associated with electrical tape. The use of electrical tape during sample handling, therefore, creates false positives in the analytical results.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
GEO	S.M. Paris	3/1/93
EQS	Mark Brooks (RR)	3/19/94
SME	T.P. Lovseth	3/4/94
RPM	Wanda Busby	3/14/94
EOM	Marla Broussard	3/15/94
SM	D.D. Stagg	3/17/94
SPP	S.R. Keith	3/15/94

16. Originator's Supervisor (print/sign/date)
Carol Bicher

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T.P. Lovseth/8706/5134/080	0243	ENV-GT	03/11/94	03/28/94

22. Accelerated Review?	23. ORC Review
Yes ☐ No ☒	ORC Review not required; This nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print, sign, date)
Stephen H. Singer — Stephen H Singer — 3/7/94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

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DOCUMENT MODIFICATION REQUEST (DMR)

INFORMATION ONLY

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

1. Date	25.
03/14/94	DMR. No. 94-DMR-000382 SUPD 3/15

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.2/Rev2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
Maurice Sell/X8693/NA/080-430	Drilling and Sampling Using Hollow-Stem Auger Techniques

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	2	2.0	Add the following paragraph to the end of Section 2.0: If the eventual purpose of the grouted surface casing placement is to support requirements to install a well, not a piezometer, the Project Manager should refer to SOP GT.6 and other contained related SOPs for further instruction. These procedures specify pre-installation approval for monitoring wells from Environmental Science and Engineering, Geosciences Division. Advanced notification of monitoring well installation is necessary for the state of Colorado, Division of Water Resources. Prior to invasive activities, SOP GT.24 requirements should be reviewed and followed to acquire soil disturbance approval from RFP Construction Management.
2	3A	4.2	Add the following reference to the list of SOPs: • SOP GT.24, Approval Process for Construction Activities on or near Individual Hazardous Substance Sites (IHSSs)
3	12	6.0	Add the following sentence to the beginning of the fourth paragraph in this section: If sufficient material is available to collect a planned QC sample, the QC sample will be collected and documentation will be recorded in the field log book and on the Daily Field Drilling Activities Report Form (GT-2A).
4	12A	6.0	Add the following sentence to the end of the fourth paragraph: The hollow stem auger barrel should be designed with ridges to incorporate two 3-inch stainless steel sample liners above the barrel shoe. This design will be used to collect a VOA soil sample and its replicate. Project or site-specific QC sample collection techniques will be addressed in either the field sampling plan, work plan, or Quality Assurance Addendum.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. Specify the advanced notification of the state of Colorado prior to the installation of monitoring wells.

2. Add required reference.

3. It is not clear about QC sampling if sufficient material is available. This is intended to clarify the ambiguity.

4. The liners inserted in hollow stem augers are not usually designed to accept two sample barrels simultaneously. Liners would have to be grooved to accomplish this method of sampling.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	Tim Lovseth	3/15/94
EQS	Mark Brooks (RR)	3/16/94
RPM	Wanda Busby	16-Mar-94
EOM	Marla Broussard	3-16-94
SM	D.D. Stagg	15 Mar 94
SPP	S.R. Keith	3/15/94

16. Originator's Supervisor (print/sign/date)
R.S. Luker 3.15.94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T.P. Lovseth/8706/5134/080	0202	ENV-GT	03/16/94	03/28/94

22. Accelerated Review?	23. ORC Review
Yes ☐ No ☒	Not required; this nonintent change was processed as an intent change to expedite the DMR process.

Responsible Manager (print, sign, date)
Stephen H. Singer 3/17/94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

93D00736.001

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DOCUMENT MODIFICATION REQUEST (DMR)

PAGE 1 of 1

Refer to 1-A01-PPG-001 for Processing Instructions.
***Print or Type** All Information (Except Signatures)*

INFORMATION ONLY

1. Date	25. DMR No.
11-2-93	93-DMR-000955 SEND

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.02/Rev. 2 RR 11/22/93	N/A

4. Originator's Name/Phone/Pager/Location	5. Document Title
P. A. Kiefer, X8698, 080	Drilling and Sampling Using Hollow-Stem Auger Techniques

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one): ☐ New ☐ Revision ☒ Intent Change ~~☒~~ Nonintent Change SEND 12-3-93 ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	3	4.2	Add reference as identified on attached.
~~2~~	~~8~~	~~5.2~~	~~Change where water level is recorded as identified on attached.~~ OK 11-10-93
3	14	8.0	Change requirements of Daily Field Drilling Activities Report as identified on attached
4	FORM GT.2A		Replace existing GT.2A with attached GT.2A. Insert example of a completed GT.2A. (attached)

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Replace GT.2A with a revised GT.2A that is a combination of GT.2A, GT.3A, GT.4A and FO.14E.

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER D.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	T. P. Lovseth Timothy Lovseth	11-10-93
SM	P. A. Kiefer	11-2-93
EQS	M. C. Brooks (RR)	12-13-93
EQM	C. M. Broussard	12-04-93
RPM	S. W. Busby	11-7-93

16. Originator's Supervisor (print/sign/date): D. D. Stagg 2Nov93

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T. P. Lovseth / 8706/5/34/080-223	0202	ER-GT	12/15/93	1-10-94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review: ORC Reviewed NOT Required

24. Responsible Manager (print,sign,date): ~~N. Hotchkiss~~ RR 12/13/93 Steve Singer 12/13/93

REVIEWED FOR CLASSIFICATION / UCNI
BY NA

RF-47940 (5/93)

125

DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

1. Date	25.
11/16/93	DMR. No. 93-DMR-000960

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
21700-OPS-GT.2/Rev. 2 RR 12/7/93	N/A

4. Originator's Name/Phone/Page/Location	5. Document Title
E.C. Mast/8589/4672/080 SUPD 12.16.93	EMD Operating Procedures, Volume III: Geotechnical, Procedure GT.2, Drilling and Sampling using Hollow-Stem Augering Techniques

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☒ Revision ☒ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	RR 11/22/93 11. Proposed Modifications
1	12 of 14	6.0	Add the following sentence to the end of the third paragraph of this section: RR 11/22/93 If insufficient sample material is available for the collection of a planned QC sample, the conditions that prevent the collection of the QC sample will be documented in the field log book and on the Daily Drilling Form (GT.3A) Field Activities Report. The Project Manager will be informed that QC samples were not collected as planned so that any impacts to the QA/QC goals established in applicable project plans can be evaluated.

12. Justification (Reason for Modification, ECN, TWI, etc.)

1. Field conditions often prevent the collection of field QC samples, particularly duplicates. No contingencies are provided in the existing procedure to account for such conditions.

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurrence prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
EG&G/RPM	Edward C Mast	11/16/93
EG&G/EQS	STEVEN LUKER Steven Luker for K.D. (QAPM) SL	11/17/93
QAPM	RR	12/2/93
SME	Tim Lovseth	12/2/93

16. Originator's Supervisor (print/sign/date)
Tim O'ROURKE 17-Nov-93

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
Tim Lovseth/8706/5134/080-223293	0243	486479 RR ER-GT 11/22/93	12/3/93	1-10-94

22. Accelerated Review?	23. OKC Review
Yes ☐ No ☒	Not Required

24. Responsible Manager (print, sign, date)
W. S. Busby W. S. Busby

REVIEWED FOR CLASSIFICATION/UCN
BY NA
DATE NA

93F00021.001

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INFORMATION ONLY

DRILLING AND SAMPLING USING HOLLOW-STEM AUGER TECHNIQUES

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.2, Rev. 2
	Page:	1 of 16
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
DRILLING AND SAMPLING USING
HOLLOW-STEM AUGER TECHNIQUES

Approved By:

(Name of Approver) Signature on file SCRD 1-7-94 (Date)

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PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.2, Rev. 2
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	Effective Date:	March 28, 1994
Category 2	Organization:	Environmental Management

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LIST OF EFFECTIVE PAGES

Pages	Effective Date	Change Number
1	07/27/92	DCN 92.03
1	05/27/93	DCN 93.03
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3	01/10/94	93-DMR-000955
3A	03/28/94	94-DMR-000382
8-9	03/28/94	94-DMR-000405
11	08/20/93	DCN 93.04
11	01/25/93	DCN 93.01
11A	07/27/92	DCN 92.03
11A	12/04/92	DCN 92.05
11A-C	03/17/93	DCN 93.02
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Form GT.2A	01/10/94	93-DMR-000955

TOTAL NUMBER OF PAGES (including forms): 24

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for drilling and obtaining samples of soil and rock from hollow-stem auger borings. In general, hollow-stem auger coring will be the preferred technique for obtaining environmental samples of subsoil and bedrock from boreholes at the RFP. Other types of samples may also be obtained from hollow-stem auger borings. This SOP describes hollow-stem auger drilling and sampling equipment and procedures, and decontamination that will be used for field data collection and documentation in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

If the eventual purpose of the grouted surface casing placement is to support requirements to install a well, not a piezometer, the Project Manager should refer to SOP GT.6 and other contained related SOPs for further instruction. These procedures specify pre-installation approval for monitoring wells from Environmental Science and Engineering, Geosciences Division. Advanced notification of monitoring well installation is necessary for the state of Colorado, Division of Water Resources. Prior to invasive activities, SOP GT.24 requirements should be reviewed and followed to acquire soil disturbance approval from RFP Construction Management.

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3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing drilling operations and logging alluvial and bedrock materials should be geologists with a minimum of a B.S. or B.A. degree in geology and have applicable field experience. Other qualified personnel may include geotechnical engineers or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person. The personnel will be trained to log according to the RFP "reference" cores and samples (see SOP GT.1, Logging Alluvial and Bedrock Material).

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1. Washington D.C. September 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.8, Handling of Drilling Fluids and Cuttings
- SOP FO.9, Handling of Residual Samples
- SOP GT.1, Logging Alluvial and Bedrock Material
- SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP GT.4, Rotary Drilling and Rock Coring
- SOP GT.5, Plugging and Abandonment of Boreholes

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- SOP GT.6, Monitoring Wells and Piezometer Installation
- SOP GT.10, Borehole Clearing
- SOP FO.14, Field Data Management
- SOP GT.24, Approval Process for Construction Activities on or near Individual Hazardous Substance Sites (IHSSs)

5.0 PROCEDURES FOR DRILLING AND SAMPLING

Hollow-stem augers are one type of continuous-flight auger used for advancing boreholes when discrete samples of the subsurface materials are obtained. They are particularly applicable for sampling materials with a tendency to cave in and for environmental sampling. The augers

consist of sections of steel tubing (up to 5 feet long) with steel helical flights around the outside. Segments of auger are added as the borehole advances, and samples are retrieved through the inside of the auger without having to remove the auger from the borehole during sampling.

With this technique, samples will be obtained either with standard split spoon or California drive samplers, or with a continuous core augering technique. The continuous coring technique can obtain up to 5-foot-long cores in a 5-foot-long sample barrel; however, at RFP, sampling will be conducted in increments of 2 feet to enhance sample recovery unless otherwise specified in the Field Sampling Plan (FSP). Drive sampling will normally obtain a 12- to 18-inch-long sample depending on the length of the sampler. Visual logging of the alluvial and bedrock materials will be performed according to SOP GT.1, Logging Alluvial and Bedrock Material. Sampling for chemical analysis is addressed in this SOP. All sampling equipment will be protected from the ground surface with clear plastic sheeting. All drilling and sampling activities will be conducted in accordance with the project Health and Safety Plan.

5.1 EQUIPMENT AND MATERIALS

The following equipment and materials are needed for hollow-stem auger drilling and soil sampling. Only the types of samplers required by the sampling specified in the Field Sampling Plan (FSP) will be required on a given project. Sample barrels will have permanent (welded or stamped) identification numbers on them.

- Drill rig equipped for drilling and sampling with hollow-stem augers
- Continuous core augering equipment (including 2-1/2- to 3-inch inside diameter sample barrel suitable for 2-foot sample rods)
- Standard split spoon sampler (ASTM D 1586)

- California spoon sampler
- Brass (or stainless steel) California liners (2-inch-diameter)
- 3-inch-long stainless steel volatile/semi-volatile organic analysis (VOA) sample liner for continuous auger core barrel
- Teflon® film (cut in 4-inch x 4-inch squares)
- Plastic caps for California and VOA liners
- Stainless steel mixing bowl and utensils
- Self-adhesive labels
- Ice chests (sample shuttles)
- High pressure steamer/sprayer
- Long-handled bristle brushes
- Wash/rinse tubs
- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Location map
- Weighted tape measure

- Water level probe
- Distilled water
- Drums for containment of cuttings
- Appropriate health and safety equipment
- Field book
- Boring log forms

5.2 DRILLING PROCEDURES

Boreholes will be drilled by using hollow-stem augers and the sampling equipment required by the FSP. All drilling equipment, including the rig, water tanks, augers, drill rods, samplers, etc., will be decontaminated before arrival at the work area site. Between boreholes, all down-hole equipment will be decontaminated, and sampling equipment will be decontaminated between samples. Equipment will be inspected for evidence of fuel oil or hydraulic system leaks (see SOP FO.3, General Equipment Decontamination, and SOP FO.4, Heavy Equipment Decontamination). If lubricants are required for downhole equipment, only pure vegetable oil will be used.

Before drilling, borings will have been located, numbered, and identified using stakes or paint sticks on paved surfaces. Buried metal objects will have been located by using geophysical methods, and utility clearance will have been accomplished according to SOP GT.10, Borehole Clearing.

After boreholes have been cleared and obstructions removed, an exclusion zone will be established according to the project Health and Safety Plan, and the drill rig will be set up. The boring will be advanced to the depth indicated and sampled according to the FSP.

For borings where environmental samples will be obtained in the bedrock, surface casing may be required. If surface casing is required, it will be installed according to SOP GT.3, Isolating Bedrock From the Alluvium With Grouted Surface Casing. The bottom of the surface casing will be embedded in the bedrock according to SOP GT.3. The embedment may vary for monitoring wells according to the FSP or project-specific work plan. After installing the casing, the bedrock will be drilled and sampled by using hollow-stem augers small enough to fit through the casing in boreholes designated for environmental sampling. In boreholes that are drilled only for geologic logging, hydraulic or geotechnical testing, or monitoring wells, the portion of the borehole below the casing may be drilled using conventional rotary or rock coring techniques (see SOP GT.4, Rotary Drilling and Rock Coring). This will normally allow for the use of a smaller diameter surface casing.

It is anticipated that most or all of the weathered bedrock can be drilled and sampled by using the continuous hollow-stem auger coring method. However, if bedrock that is sufficiently cemented to render this method ineffective is encountered in borings designated for environmental sampling, the cemented zone will be rock cored using filtered air as the drilling medium according to SOP GT.4, Rotary Drilling and Rock Coring. After the cemented zone is penetrated, the boring will continue with hollow-stem auger coring. If necessary, this may require reaming the cored section with air-rotary techniques.

The borings will be logged lithologically by examination and classification of the samples. Documentation will be completed by the site geologist according to Section 8.0 of this SOP. SOP GT.1, Logging Alluvial and Bedrock Material, describes procedures for material classification and borehole logging.

At the first indication of free water on the sampler or in samples, the time and estimated depth will be recorded. However, it is frequently difficult to determine the true water level in hollow-stem auger borings at the time of drilling, particularly when drilling in low-permeability soil or bedrock. Therefore, water levels will also be measured each day before drilling begins and recorded on Form GT.2A. In low-permeability deposits, it is possible for a borehole to be drilled below the groundwater level and not collect water for several hours or even days. It is, therefore, important to note moisture changes in the samples when evaluating groundwater conditions at the time of drilling. During the drilling and while the augers are being removed, the cuttings and unsaved portions of samples from the boring will be containerized according to SOP FO.8, Handling of Drilling Fluids and Cuttings, and SOP FO.9, Handling of Residual Samples.

5.3 SAMPLING PROCEDURES

5.3.1 Continuous Core Auger Sampling

The continuous coring method advances a split barrel that is contained within the lead auger. The augers rotate around the sampler and cut while the sample barrel is prevented from rotating. Continuous core samples are collected in the barrel. The barrel will be unlined except for a 3-inch long stainless steel VOA sample liner placed at the bottom end of the barrel directly behind the cutting shoe. Once the core barrel has been removed from the borehole, opened, scanned, and measured, the VOA sample liner will immediately be capped with Teflon® ~~lined plastic caps~~ paper, sealed with ~~electrical tape, plastic caps,~~ labeled, and placed plastic bags prior to placement in a cooler with ice. In order to obtain a composite sample for additional analyses, including semi-VOAs, the sampler will be closed and placed in a safe location, out of the direct sun, until a sufficient interval of samples have been obtained. Once the samples have been obtained, the core barrels will be opened and each sample will then be classified, logged, peeled, composited, and placed in appropriate containers for analytical testing according to SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples. Sample

94-DMF-000405

intervals and requirements for compositing will be defined in the FSP or project-specific work plan.

Sample peeling will involve discarding the portion of sample that was in direct contact with the sampler. Once the samples have been peeled, a linear scraping of the peeled samples will be placed in a stainless steel bowl and mixed with a stainless steel instrument. Soil particles (gravels) larger than the jar mouth will be discarded. Peeling and compositing will be conducted with separate decontaminated stainless steel instruments. If the core is not coherent, core samples need not be peeled before sampling because it is difficult to be certain what parts of a noncoherent sample were in contact with the sampler.

Samples for geotechnical testing will consist of approximately 3/4-filled pint-sized glass jars with air-tight lids placed in compartmented shipping cartons designed to prevent breakage of the jars. Sample peeling is not required for geotechnical samples.

5.3.2 Drive Sampling

Drive samples will be obtained in general accordance with ASTM Designation D 1586. After drilling to the predetermined depth, the standard split spoon or California sampler will be attached to the end of the drill rod and lowered to the bottom of the boring. The standard 140-pound hammer assembly will then be attached to the top of the drill rod. The depth to the bottom of the sampler will be recorded, and reference marks at 6-inch increments will be placed on the drill rod. The test consists of driving the sampler with the standard 140-pound hammer dropped 30 inches.

When using the 2-inch-outside-diameter (O.D.) standard split spoon sampler, drive the sampler through three 6-inch increments (or 100 blows, whichever occurs first), with the sum of the last two increments being the Standard Penetration Count or Blow Count or N-value, and the first 6-inch increment being considered as seating.

A California barrel with brass (or stainless steel) liners may be substituted for the standard split barrel. The integrity of the sample can generally be better maintained since thin-walled liners containing the sample can be removed from the barrel and sealed. Since the California sampler is shorter than the standard split spoon sampler, it will be driven only 12 inches, with blow counts recorded for each 6-inch increment. However, several blows are required before marking and counting blows to seat the sampler.

A California barrel has a 2.5-inch O.D. and a 2-inch inside diameter (I.D.) Modified California samplers with larger diameters are also available. The liners for a conventional California barrel have a 1.94-inch I.D. Although not precisely equivalent, the blow count obtained by using a 2-inch I.D. California barrel is frequently considered to be comparable to the N-value obtained using a standard barrel. Blow counts using larger samplers will not be equivalent, and larger hammers may be required to drive them under some conditions.

A rope and cathead arrangement or automatic trip hammer will be used to obtain drive samples. If a rope and cathead arrangement is used, excessive turns of the rope on the cathead must be avoided, since this will result in friction and drag between the rope and cathead. Two turns of the rope on the cathead will be used and sufficient slack in the rope provided during hammer free fall to prevent excessive friction.

Standard split spoon samples saved for geotechnical testing will consist of 3/4-filled pint-sized glass jars with airtight lids placed in compartmented shipping cartons designed to prevent breakage of the jars. Samples for VOA analytical testing will be obtained by placing a 3-inch long stainless steel VOA sample liner at the bottom end of the barrel directly behind the cutting shoe. Composite samples for additional analyses, including semi-VOAs, will consist of linear scrapes from three consecutive peeled samples (see Subsection 5.3.1) placed in containers described in SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples. For California liner samples, the geotechnical samples may be saved in the liners with plastic end caps.

5.3.3 VOC Sampling

DCN 93.04

- Three VOC samples will be taken per borehole. VOC sampling will be conducted in accordance with the project-specific work plan. Additional VOC samples will not be taken for elevated OVA readings.

- VOC samples will be collected from the base of every other 2-foot drive sample from the ground surface to the water table.

- A VOC sample will be collected in the bottom of the first drive sample below the water table.

DCN 93.01

- A final VOC sample will be collected from the base of the first drive within bedrock immediately below the alluvial material in unsaturated conditions.

- Additional VOC samples will be collected as follows:

  - If a lithologic feature or OVA reading indicates the possibility that VOC contamination exists, then a sample will be taken at the base of the next drive interval.

  - If the sampler is opened, scanned and a color change, free product, or other physical evidence indicating the possibility for contamination is observed in a location other than where a pretargeted VOC sample is located, a 3" section will be immediately cut, pulled, wrapped, placed in a wide mouth jar and sealed. The sample will be sent to the lab for subcoring and analysis.

5.3.4 Drum Characterization

When obtaining geotechnical samples strictly for the purpose of characterizing the environmental materials present in drums, the following procedures will apply.

DCN 92.03

During drilling operations, environmental materials accumulate in a mud pit and are then shoveled into drums. As drums are being filled, samples will be collected from the material filling the bottom, middle, and upper portion of the drum. The samples will be composited in a stainless steel bowl kept in a safe location out of the sun. The materials from up to four drums from a given borehole will be composited in this manner. The samples will then be placed in the appropriate containers for analytical testing.

When obtaining geochemical samples from drummed mixtures of bedrock and water resulting from drilling operations, a bailer will be used to obtain a sample from the bottom, middle, and upper portion of a drum. Materials from up to four drums from a given borehole will be composited in this manner. The samples will then be placed in the appropriate containers for analytical testing. (NOTE: In areas outside of IHSSs, no further characterization sampling will be done then is stipulated in the Work Field Sampling Plan.)

DCN 92.05

DCN 93.02

During drilling of boreholes, if a recent borehole (within one year) that has been sampled is located within 10 feet of the present borehole, no additional samples for drum characterization purposes only will be collected. All cored material will be saved in case it is needed for future analyses.

5.3.5 Kansas Type Sampler

This section contains procedures for collecting soil samples from depth without a drill rig utilizing a Kansas type sampler.

The equipment and supplies that are required are as follows:

- All Terrain Vehicle (Scorpion) with a Stanley sinker drill attached to the rear of the vehicle that is hydraulically powered from the systems mounted power take off or similar rig;
- Probe rods;
- One or two foot Kansas type sampler constructed of stainless steel with high strength alloy piston and screw-on top and bottom and reverse thread release pin;
- Extender rods, used for releasing piston stop pin on the sampler; and
- Appropriate sample liners or containers.

DCN 93.03

The following steps are required to obtain soil samples.

1. Assemble sampler with appropriate liners, if necessary.
2. Attach probe rods to sampler and hydraulically push and hammer sampler to the top of the desired sampling depth. If depth to first sample interval or depth between samples is more than about two feet, a pilot hole may be driven to the top of the desired sampling depth.

3. Insert extruder rods down the inside of the probe rods and thread it into the piston stop pin.

4. The piston stop pin is made up of two different types of threads. One being right hand thread and the other being a left thread. With this type of thread pattern the result will be that the extruder rods will thread into the piston stop pin. After the extruder rods have snugged up into the piston stop pin, the piston stop pin will then unscrew from the sampler. Once the piston stop pin has been unscrewed from the sampler, it along with the extruder rods will be withdrawn from the probe rods.

DCN 93.03

5. The sampler will then be pushed and hammered one or two feet depending upon the length of the sampler.

6. The sampler and probe rods are then withdrawn from the hole.

7. The sampler is then taken apart and the sample removed.

8. The sample will then be screened as specified in the Field Sampling Plan and logged. Note: typically, all the soil removed is sent to the laboratories; therefore, core cannot be logged at a later time and saved for a permanent record as discussed in GT.1 Logging Alluvial and Bedrock Material.

9. Samples saved for geotechnical testing will consist of 3/4-filled pint-sized glass jars with airtight lids or capped liners. Samples for VOC testing will be saved in capped liners. Samples for additional analyses, will be saved in either the containers described in SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Sampler or capped liners.

5.4 BORING COMPLETION AND ABANDONMENT

After the borehole has been advanced to its final depth, it will either be abandoned or completed as a monitoring well (see SOP GT.5, Plugging and Abandonment of Boreholes, and SOP GT.6, Monitoring Wells and Piezometer Installation).

The boring location stake will be left in the ground adjacent to the borehole, and a board or other cover placed over the hole until it has been grouted. All boreholes to be abandoned with a depth greater than 1 foot will be grouted the same day that abandonment is completed. The boring location stake will then be placed in the grout.

6.0 QUALITY ASSURANCE/QUALITY CONTROL SAMPLES

Quality Assurance (QA) and Quality Control (QC) activities will be accomplished according to applicable project plans as well as quality requirements presented in this SOP.

QA samples for soils fall into five categories:

- Duplicate
- Matrix spike
- Matrix spike duplicate
- Equipment rinsate
- Field blank

SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples describes the general handling of samples. Applicable project plans specify QA sample frequencies. If insufficient sample material is available for the collection of a planned QC sample, the conditions that prevent the collection of the QC sample will be documented in the field log book and on the Daily Field Drilling Activities Report Form (GT.2A). The Project Manager will be informed that QC samples were not collected as planned so that any impacts to the QA/QC goals established in applicable project plans can be evaluated.

If sufficient material is available to collect a planned QC sample, the QC sample will be collected and documentation will be recorded in the field log book and on the Daily Field

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Drilling Activities Report Form (GT-2A). Sample collection procedures will be the same as those described in Section 5.0 for duplicate, matrix spike, and duplicate matrix spike samples. These samples are intended to be as close to exact replicates of the original samples as possible. They are obtained immediately adjacent to the planned samples that they are intended to duplicate. The hollow stem auger barrel should be designed with ridges to incorporate two 3-inch stainless steel sample liners above the barrel shoe. This design will be used to collect a VOA soil sample and its replicate. Project or site-specific QC sample collection techniques will be addressed in either the field sampling plan, work plan, or Quality Assurance Addendum.

A rinsate sample from sampling equipment is intended to check for potential contamination of the sample by the sampling equipment. For the soil sampling operation, a rinsate sample will be

collected from sampling equipment with any liners in place before the sampling equipment is used. Approximately 3 liters of distilled water will be rinsed over a decontaminated sampler and collected in a large decontaminated stainless steel bowl. A decontaminated glass or stainless steel beaker will be used to dip the water from the bowl and fill the sample bottles. The rinsate samples will be analyzed for the same parameters as the soil samples.

Field blank samples are containers filled with clean water that are handled and moved the same as the other samples to check for potential cross-contamination resulting from field handling and movement procedures.

7.0 DECONTAMINATION

Generalized equipment decontamination procedures will include:

- Sampling equipment. Decontamination will be conducted between individual sampling points to minimize potential cross-contamination. Sampling equipment will be decontaminated according to SOP FO.3, General Equipment Decontamination. During drilling and sampling, decontaminated equipment will be placed on new plastic or racks until it is used. At least two sets of samplers will be available so that one set can be used while the other is being decontaminated.

- Drilling equipment. Decontamination of augers, drill stems, drill bits, and other down-hole equipment will be conducted after each boring is complete. Drill rigs will be decontaminated when moved out of a work area or when they become unusually dirty as a result of site or drilling conditions, at the discretion of the site or project manager. Decontamination of drilling equipment is described in more detail in SOP FO.4, Heavy Equipment Decontamination.

8.0 DOCUMENTATION

93-DMR-000955

All information required by this SOP will be documented on the Borehole Log Form (Form GT.1A) and the Hollow-Stem Auger Drilling Field Daily Field Drilling Activities Report Form (Form GT.2A). The Daily Field Drilling Activities Report Form will be filled out for each day of drilling at a given borehole location and, in situations where more than one boring is drilled and completed per day per drill rig, at least one form will be completed per boring. The borehole log will include information on subsurface material classification ~~and lithology~~. The Daily Field Drilling Activities Report will include the following information and have space for comments and documentation of general observations:

93-DMR-000955

- Project name ~~and bore identification~~
- Subcontractors
- Location code
- Date
- Weather conditions
- Drilling company and driller
- Geologist and other crew members
- Equipment descriptions (rig, augers, bits, etc.)
- Borehole depth ~~and diameter~~
- ~~Water level~~
- Sample number
- ~~Depth to bedrock~~
- QC Code
- ~~Decontamination~~
- Time
- ~~Samples and depths~~
- OVM and RAD readings

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- End-of-day status (in progress of drilling completed)
- Chronological record of activities

The above information shall be entered into the field data capture program (Datacap) (see procedure FO.14, Field Data management).

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM GT.2A (REV. 3.1)

DAILY FIELD DRILLING ACTIVITIES REPORT

Project Name:_____ Subcontractor:_____ Date:_____
Location Code:_____ Rig Type:_____
Drilling Co.:_____ Drilling Method:_____
Driller:_____ Drilling Fluid:_____
Geologist:_____ Bit Diameter:_____ IN
Crew Member(s):_____ Bit Type:_____
_____ Total Depth:_____ FT

Sample #	QC Code	Time	(C)omp (G)rab	Depths (FT): Start	End	Types:OVM_____ Reading (PPM)	α_____ β_____ Readings (CPM)	

End of Day Status: In Progress_____ Drilling Completed_____

Chronological Record of Activities and Comments:_____

Was there fluid in the hole at the beginning of the daily drilling operation? Yes____ No____
If yes, what was the water level? _____ FT
Weather:_____

Completed By:_____ Date:_____
Print Name Signature
Checked By:_____ Date:_____
Print Name Signature

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DOCUMENT MODIFICATION REQUEST (DMR)

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Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures).

1. Date	25. DMR No.
11-2-93	93-DMR-00956

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.03/Rev.2 RR 11/22/93	N/A

4. Originator's Name/Phone/Pager/Location	5. Document Title
P. A. Kiefer, X8698, 080 INFORMATION ONLY	Isolating Bedrock from the Alluvium with Grouted Surface Casing

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one): ☐ New ☐ Revision ☒ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	3	4.2	Add reference as identified on attached.
2	9,10	6.0	Change requirements of Daily Field Drilling Activities Report as identified on attached
3	FORM GT	3A	Eliminate. Information will be recorded on GT.2A

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Eliminate GT.3A, as all information will be recorded on GT.2A which is a combination of GT.2A, GT.3A, GT.4A and FO.14E.

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	T. P. Lovseth Timothy Lovseth	11-10-93
SM	P. A. Kiefer	11-2-93
EQS	M. C. Brooks (RR) Mary C. Brooks	12-13-93
EOM	C. M. Broussard M. C. Broussard	12-07-93
RPM	for W.S.Busby WSBusby	12-13-93

16. Originator's Supervisor (print/sign/date): D. D. Stagg Dennis D Stagg 22 Nov 93

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T.P. Lovseth/8706/5134/080-223	0202	ER-GT	12/15/93	1.10.94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review: ORC Review NOT Required

24. Responsible Manager (print,sign,date): Steve Singer Stephen H Singer 12/13/93

REVIEWED FOR CLASSIFICATION / UCNI
BY NA

150 RF-47940 (5/93)

DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
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INFORMATION ONLY

1. Date	25.
March 17, 1994	DMR. No. 94-DMR- 000418

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.3/Rev2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
J.A. Paschis/x8644/NA/080	Isolating Bedrock from the Alluvium with Grouted Surface Casing

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	2	2.0	Add the following paragraph after the first paragraph in Section 2.0: If the end-purpose of the drilling is to install and complete a monitoring well, not a piezometer, the Project Manager should refer to SOP GT.6 and other contained related SOPs for further instructions. These procedures specify pre-installation approval for monitoring wells from Environmental Sciences and Engineering, Geosciences Division. Advanced notification of monitoring well installation is necessary for the state of Colorado, Division of Water Resources. Prior to invasive activities, SOP GT.24 requirements should be reviewed and followed to acquire soil disturbance approval from RFP Construction Management.
2	3	4.2	Add the following reference to the list of SOPs: • SOP GT.24, Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. Specify the advanced notification of the state of Colorado prior to the installation of monitoring wells.

2. Add required reference.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	Tim Lovseth	3/16/94
EQS	Mark Brooks (RR)	4-4-94
RPM	Wanda Busby	3/21/94
EOM	Marla Broussard	3/24/94
ETT	Gary Anderson	5 APR 94
SPP	Steve Keith	3/29/94

16. Originator's Supervisor (print/sign/date)
Stephen H. Singer Stephen H. Singer 3/17/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
Tim Lovseth/8706/5134/080	0202	ENV-GT	03/21/94	4-22-94 SUBJ

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
Not required; this nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print, sign, date)
Mark E. Levin 4-1-94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

93D00729.001

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INFORMATION ONLY

ISOLATING BEDROCK FROM THE ALLUVIUM WITH GROUTED SURFACE CASING

EG&G ROCKY FLATS PLANT EMD MANUAL OPERATION SOP	Manual: Procedure No.: Page: Effective Date:	5-21000-OPS GT.3, Rev. 2 1 of 10 March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
ISOLATING BEDROCK FROM THE ALLUVIUM WITH GROUTED SURFACE CASING

Approved By:

(Name of Approver) Signature on file (Date) 3/11/92

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DCN 93.02

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PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

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EG&G ROCKY FLATS PLANT	**Manual:**	**5-21000-OPS**
EMD MANUAL OPERATION SOP	**Procedure No.:**	**GT.3, Rev. 2**
	Page:	**1A of 10**
	Effective Date:	**04/22/94**
Category 2	**Organization:**	**Environmental Management**

94-DMR-000418

LIST OF EFFECTIVE PAGES

Pages	Effective Date	Change Number
1	05/10/93	DCN 93.02
1A	04/22/94	94-DMR-000418
2-3A	04/22/94	94-DMR-000418
3	01/10/94	93-DMR-000956
5	05/10/93	DCN 93.02
5	08/20/93	DCN 93.04
5	02/10/93	DCN 93.01
6-9	05/10/93	DCN 93.02
9-10A	01/10/94	93-DMR-000956
Form GT.3	01/10/94	93-DMR-000957

TOTAL NUMBER OF PAGES (including forms): 17

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to install surface casing (where required) grouted into the top of bedrock to isolate the bedrock from the alluvium. The intent of implementing this SOP is to prevent cross-contamination from the alluvium into the bedrock. This may be required for environmental sampling of the bedrock in boreholes and for construction of bedrock monitoring wells. The following items are discussed in this SOP:

- Drilling methods for advancing boreholes
- Surface casing installation materials
- Surface casing installation procedures

If the end-purpose of the drilling is to install and complete a monitoring well, not a piezometer, the Project Manager should refer to SOP GT.6 and other contained related SOPs for further instructions. These procedures specify pre-installation approval for monitoring wells from Environmental Sciences and Engineering, Geosciences Division. Advanced notification of monitoring well installation is necessary for the state of Colorado, Division of Water Resources. Prior to invasive activities, SOP GT.24 requirements should be reviewed and followed to acquire soil disturbance approval from RFP Construction Management.

94-DMR-00048

This SOP describes the field procedures that will be used to install surface casing and document the procedures in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the installation of grouted surface casing will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1. Washington D.C. September 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination

EG&G ROCKY FLATS PLANT	**Manual:**	**5-21000-OPS**
EMD MANUAL OPERATION SOP	**Procedure No.:**	**GT.3, Rev. 2**
	Page:	**3A of 10**
	Effective Date:	**04/22/94**
Category 2	**Organization:**	**Environmental Management**

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- SOP GT.1, Logging Alluvial and Bedrock Material
- SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP GT.4, Rotary Drilling and Rock Coring
- SOP GT.10, Borehole Clearing
- SOP FO.14, Field Data Management
- SOP GT.24, Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)

5.0 PROCEDURES FOR INSTALLING SURFACE CASING

If required, surface casings will be installed in boreholes drilled and logged according to SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques, and SOP GT.1, Logging Alluvial and Bedrock Material. All drilling and sampling equipment will be decontaminated according to SOP FO.3, General Equipment Decontamination and/or SOP FO.4, Heavy Equipment Decontamination. Drilling and sampling equipment will be protected from the ground surface with clear plastic sheeting or placed on clean drill racks.

5.1 EQUIPMENT AND MATERIALS

The following is a list of equipment and materials used for surface casing installation:

- Drill rig with appropriately-sized augers
- Surface casing
- Cement of approved quality and American Colloid Pure Gold Bentonite grout (or approved equivalent)
- Rubber grout-displacement plug (1/2-inch diameter larger than inside diameter of casing)
- Tremie pipe and grout pump
- High pressure steamer/sprayer
- Mechanical grout mixer
- Weighted tape measure
- Water level probe
- Pipe cutter
- Appropriate documentation forms
- Drums for containment of cuttings
- Appropriate health and safety equipment

- Pre-approved water from a potable source (see SOP FO.3, General Equipment Decontamination)
- Plastic Sheeting

5.1.1 Casing Requirements

DCN 93.02

Surface casing will consist of new schedule 4080 poly-vinyl chloride (PVC) or steel well casing. PVC casing will be used for nominal casing diameters of 6 inches or less. Larger casings will be steel. Joints will be water-tight threaded couplings made without welds, solvents or lubricants. The casing will be embedded into the top of bedrock and extend to approximately 1 foot above the ground surface. ~~Casing centralizers will be attached to the casing to allow uniform grouting. At least 2 centralizers will be required, one within 5 feet of the bottom and the other within 5 feet of the top of the casing.~~ All surface casing will be free of foreign material and will be decontaminated according to SOP FO.3, General Equipment Decontamination. Decontaminated casing will be stored in plastic sheeting or kept on clean racks prior to use. Eight (8) inch PVC casing may be used when isolating bedrock from present landfill materials in boreholes that are for the purpose of sampling weathered bedrock only.

DCN 93.04

DCN 93.01

5.1.2 Grout Requirements

The grout mixture will consist of a cement and reduced pH bentonite grout (American Colloid Pure Gold or approved equivalent) mixed according to the manufacturer's recommendations. The mixture will contain 5 to 10 percent bentonite by weight and have a minimum density of 13 to 15 pounds per gallon after mixing. The density will be measured using a mud balance.

5.2 DRILLING METHODS

Boreholes will be drilled into the top of bedrock using hollow-stem augers. Alternatively, conventional rotary or reverse-circulation rotary methods may be used; however, due to the variability of these

methods, their use may be outlined in a project-specific work plan. Drilling equipment including the rig, augers, drill rods, and samplers will be decontaminated according to SOP FO.3, General Equipment Decontamination, and SOP FO.4, Heavy Equipment Decontamination. The borehole will be of sufficient diameter to allow 2 inches of grout between the casing and the borehole. Each borehole location will be cleared according to SOP GT.10, Borehole Clearing, before drilling.

~~The embedment of casing into the bedrock will be a minimum of 3 to 5 feet into the weathered bedrock. However, the intent is to place the bottom of the casing approximately 3 feet below the interface describing a substantial reduction in hydraulic conductivity. If the uppermost weathered bedrock is highly weathered and/or fractured, this embedment depth will be adjusted downward. Based on field experience at RFP, casing may be emplaced to depths of up to 60 feet in highly weathered or fractured bedrock to ensure a good seal. When very shallow, bedrock boreholes are augered to total depth in uncontaminated areas, surface casing will not be used. Instead, the borehole will be drilled and grouted in one day.~~

DCN 93.02

Surface casing will be emplaced to a depth that will isolate the upper hydrostratigraphic unit (UHSU). If the core samples indicate siltstone or sandstone immediately below the base of the UHSU, the auger hole will be terminated at the base of the UHSU. If claystone, surface casing will be embedded a minimum of 3 feet into the lower hydrostratigraphic unit (LHSU).

5.3 SURFACE CASING INSTALLATION AND SEALING PROCEDURES

~~Surface casing will be installed by placing the casing into the borehole, filling the casing with grout, and then forcing the grout from within the casing by pushing a rubber plug down the casing thus displacing the grout out through grout ports at the bottom of the casing. Implementing this SOP is intended to provide a uniform seal from the base of casing to the ground surface. Figure GT.3-1 depicts the casing installation described below.~~

DCN 93.02

DCN 93.02

~~Surface casing installation will begin after the borehole has been drilled into the top of bedrock to the required depth specified in the Field Sampling Plan (FSP) according to the following steps:~~

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DCN 93.021

~~FIGURE GT.3-1 SCHEMATIC DIAGRAM OF GROUTED SURFACE CASING~~

DCN 93.02

~~(1) Measure the borehole total depth using a weighted tape measure. The weight on the tape measure will be stainless steel in the event that it accidentally becomes embedded.~~

~~(2) Drill or cut three equally spaced 1 inch diameter holes, slots, or triangles (grout ports) into the wall of the casing immediately above the bottom of the casing. The distance between the bottom of the casing and the holes will not exceed the length of the rubber plug.~~

~~(3) Lower the surface casing into the borehole through the augers. Install the required centralizers at 5 feet below the top of the casing and 5 feet above the bottom of the casing while running the casing in the borehole.~~

~~(4) Remove the augers and pump the grout mixture into the casing using a tremie pipe until undiluted grout is present at the top of the casing.~~

~~(5) Place a rubber plug, intended for displacing grout from within the casing (1/2 inch diameter larger than the inside of the casing), inside the casing and force it down to the bottom of the casing by using drill rods or water pressure. Add RFP potable water to the inside of the casing as the plug is being forced down. The water will aid in equalizing the pressure of the grout on the rubber plug until the grout has set. Enough grout will be used to ensure that grout will rise to ground level when displaced from the casing.~~

~~(6) Place a protective cover over the top of the casing and allow the grout to set for at least 24 hours.~~

~~(7) Remove the water inside the casing by air-lift methods or bailing before the plug is drilled out and the borehole is advanced past the bottom of the casing.~~

~~Alternatively, surface casing may be installed by filling the borehole with grout as the augers are removed, placing the casing into the grout filled borehole after auger removal, and then forcing the grout from within the casing using a rubber plug. The first method is the preferred method at RFP because it reduces the waste volume of grout and it can be used in holes of all depths. The alternative method of placing the casing into the uncased, grout filled borehole can be used if large diameter surface casing (approximately greater than 6 inches) is required.~~

DCN 93.02

Place surface casing with threaded PVC cap or rubber plug on bottom end into borehole. Fill surface casing with potable water to ensure positive pressure. Following installation of surface casing in the borehole, a 2 to 3 foot thick bentonite seal consisting of 1/4-inch compressed bentonite pellets will be placed at the bottom of the annulus surrounding the surface casing. If the borehole annulus does not contain water, potable water will be added to hydrate the pellets prior to grouting. Following the installation of the bentonite seal the grout seal will be emplaced. The grout mixture will be emplaced in the annular space between the augers or drill casing and surface casing. Upon removal of each section of auger or drill casing, additional grout will be added to the annulus. The grout will be emplaced by means of a tremie pipe. The grout will be allowed to set for 24 hours.

6.0 DOCUMENTATION

All information required by this SOP will be documented on the Borehole Log Form (Form GT.1A) and the ~~Surface Casing Installation Field Activities Report form (Form GT.3A)~~ Daily Field Drilling Activities Report Form (Form GT.2A). Form GT.2A will be filled out for each day of drilling at a given borehole location: and, in situations where more than one boring is drilled and completed per day per drill rig, at least one form will be completed per boring. ~~The borehole log will include information on subsurface material classification and lithology.~~ The Daily Field Drilling

93-DME-03956

include the following information and have space for comments and documentation of general observations:

- Project name ~~and borehole identification~~
- Subcontractor
- Location code
- Date
- Weather conditions
- Driller and drilling company
- Geologist and other crew members
- Equipment descriptions (rig, etc.)
- Borehole depth ~~and diameter~~

93-IMP-00056

- Equipment descriptions (rig, etc.)
- Borehole depth ~~and diameter~~
- ~~Water level~~
- Sample number
- ~~Depth to bedrock~~
- QC Code
- ~~Casing diameter and depth~~
- Time
- ~~Type of Casing (schedule, wall thickness, grade, etc.)~~
- OVM and RAD readings
- ~~Casing stick up (measured height above ground level)~~
- ~~Centralizer types and depths~~
- ~~Quality and composition of grout (including cement/grout mix ratio and weight in lb/gallon)~~
- ~~Joint/coupling description~~
- End-of-day status
- Chronological record of activities

The above information shall be entered into the field data capture program (Datacap) (see procedure FO.14, Field Data Management).

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- ~~Water level~~
- Sample number
- ~~Depth to bedrock~~
- QC Code
- ~~Casing diameter and depth~~
- Time
- ~~Type of Casing (schedule, wall thickness, grade, etc.)~~
- OVM and RAD readings
- ~~Casing stick up (measured height above ground level)~~
- ~~Centralizer types and depths~~
- ~~Quality and composition of grout (including cement/grout mix ratio and weight in lb/gallon)~~
- ~~Joint/coupling description~~
- End-of-day status
- Chronological record of activities

The above information shall be entered into the field data capture program (Datacap) (see procedure FO.14, Field Data Management).

DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
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INFORMATION ONLY

1. Date	25.
5/2/94	DMR. No. 94-DMR-00935

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.4/Rev2	NA
4. Originator's Name/Phone/Page/Location	5. Document Title
Kelly O'Neill/8665/5473/080-293	Rotary Drilling and Rock Coring

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	2	2.0	Add the following sentence after the first sentence of the first paragraph in Section 2.0: "These procedures also are applicable for the use of sonic drilling methods where little or no water, air, or mud is required for circulation during penetration." Also add the words "sonic drilling", as indicated, into the same paragraph.
2	2	3.0	Change Section 3.0 to read: "Personnel overseeing rotary drilling, *sonic drilling*, and rock coring will..."
3	4	5.1	Insert the following sentence in the last paragraph before the last sentence: Sonic drilling methods require little or no water, air, mud, or other circulation medium for penetration.
4	8	5.3.3	Add the following as a new section: **5.3.3 Sonic Drilling Techniques** Sonic drilling is achieved by a drill head that transmits high-frequency pressure waves through steel drilling pipe to create a cutting action at the tip of the drill bit. Pressure waves are created by center-rotating, offset balanced roller-weights. The frequency of the drill string causes the column to vibrate elastically along its longitudinal axis. In the resonant condition, the drill string acts as a fly-wheel, transmitting maximum power to the drill bit. This power, combined with slow rotation to expose fresh material to the bit and slight downward pressure advances the drill string through soil and rock without the addition of a drilling medium. Because the drilling action and thin-wall design of the drill string either forces the displaced material into the wall of the borehole or into the core barrel, very little waste cuttings are generated. Samples will be obtained by vibrating the drill bit and rotating the core barrel to the desired depth, advancing the outer drill pipe, and then pulling the sample to the surface via the wireline. Once at the surface, the sample will be vibrated or hydraulically extracted from the core barrel into a plastic sleeve or clean sample tray. After a sample is collected, the core barrel will be decontaminated and readied to retrieve the next sample.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1-4. Change procedure to allow for use of sonic drilling technique.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	Tim Lovseth	5/6/94
EQS	Mark Brooks (RR)	5/13/94
RPM	Wanda Busby	5/9/94

16. Originator's Supervisor (print/sign/date)
Tim O'Rourke 2-May-94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
Tim Lovseth/8706/5134/080	0202	~~ENV GT~~ 489C5500	05/17/94	6-1-94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
Not required; this nonintent change was processed as an intent change to expedite the DMR process. 5/16/94

24. Responsible Manager (print, sign, date)
Steve Singer Stephen H. Singer 5/6/94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

DOCUMENT MODIFICATION REQUEST (DMR)

PAGE 1 OF 1

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures).

1. Date	25. DMR No.
11-2-93	93-DMR-00957

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.04/Rev. 2 INFORMATION ONLY	N/A

4. Originator's Name/Phone/Pager/Location	5. Document Title RR 11/22/93
P. A. Kiefer, X8698, 080	Rotary drilling and Rock Coring

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one) 12.15.93 SWD: ☐ New ☐ Revision ☒ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	3	4.2	Add reference as identified on attached.
2	9,10	7.0	Change requirements of Daily Field Drilling Activities Report as identified on attached
3	FORM GT	4A	Eliminate. Information will be recorded on GT.2A

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Eliminate GT.4A, as all information will be recorded on GT.2A which is a combination of GT.2A, GT.3A, GT.4A and FO.14E.

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

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13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	T. P. Lovseth	11-10-93
SM	P. A. Kiefer	11-2-93
EQS	M. C. Brooks (RR)	12-13-93
EOM	C. M. Broussard	12.09.93
RPM	for W. S. Busby	12-13-93

16. Originator's Supervisor (print/sign/date): D. D. Stagg 12-14-93

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T.P. Lovseth/8706/5134/080-223	0202	ER-GT	12/15/93	1-10-94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review: ORC Review NOT Required

24. Responsible Manager (print,sign,date): Steve Singer 12/13/93

REVIEWED FOR CLASSIFICATION / UCNI
BY NA

RF-47940 (5/93)

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DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

1. Date	25.
March 17, 1994	DMR. No. 94-DMR- 000 419

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.4/Rev2 INFORMATION ONLY	NA
4. Originator's Name/Phone/Page/Location J.A. Paschis/x8644/NA/080	5. Document Title Rotary Drilling and Rock Coring

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	2	2.0	Add the following paragraph after the first paragraph in Section 2.0: If the end-purpose of the drilling is to install and complete a monitoring well, not a piezometer, the Project Manager should refer to SOP GT.6 and other contained related SOPs for further instructions. These procedures specify pre-installation approval for monitoring wells from Environmental Sciences and Engineering, Geosciences Division. Advanced notification of monitoring well installation is necessary for the state of Colorado, Division of Water Resources. Prior to invasive activities, SOP GT.24 requirements should be reviewed and followed to acquire soil disturbance approval from RFP Construction Management.
2	3	4.2	Add the following reference to the list of SOPs: • SOP GT.24, Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. Specify the advanced notification of the state of Colorado prior to the installation of monitoring wells.

2. Add required reference.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	Tim Lovseth	3/18/94
EQS	Mark Brooks (RR)	4-4-94
RPM	Wanda Busby	3/21/94
EOM	Marla Broussard	3/24/94
ETT	Gary Anderson	5 APR 94
SPP	Steve Keith	3/29/94

16. Originator's Supervisor (print/sign/date)
Stephen H. Singer Stephen H Singer 3/17/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
Tim Lovseth/8706/5134/080	0202	ENV-GT	03/21/94	4-22-94 SEED

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
Not required; this nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print/sign/date)
Mark E. Levin 4/11-94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

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INFORMATION ONLY

ROTARY DRILLING AND ROCK CORING

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
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Category 2	Organization:	Environmental Management

TITLE:
ROTARY DRILLING AND ROCK CORING

Approved:
/s/ J. E. Evered 05/12/92
(Name of Approver) (Date)

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PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

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2	06/01/94	94-DMR-000935
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4	06/01/94	94-DMR-000935
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9-10	01/10/94	93-DMR-000957
Form GT.4A	01/10/94	93-DMR-000957

TOTAL NUMBER OF PAGES: 13

2.0 PURPOSE AND SCOPE

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This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for rotary drilling and rock coring, using air and water as drilling media. These procedures also are applicable for the use of sonic drilling methods where little or no water, air, or mud is required for circulation during penetration. It addresses equipment, field procedures, decontamination, and documentation that will be used for rotary drilling, sonic drilling, and rock coring, and describes documentation of these procedures in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

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If the end-purpose of the drilling is to install and complete a monitoring well, not a piezometer, the Project Manager should refer to SOP GT.6 and other contained related SOPs for further instructions. These procedures specify pre-installation approval for monitoring wells from Environmental Sciences and Engineering, Geosciences Division. Advanced notification of monitoring well installation is necessary for the state of Colorado, Division of Water Resources. Prior to invasive activities, SOP GT.24 requirements should be reviewed and followed to acquire soil disturbance approval from RFP Construction Management.

3.0 PERSONNEL QUALIFICATIONS

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Personnel overseeing rotary drilling, sonic drilling, and rock coring will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Ground-Water Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1. Washington D.C. September, 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.8, Handling of Drilling Fluids and Cuttings
- SOP GT.1, Logging Alluvial and Bedrock Material
- SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP GT.3, Isolating Bedrock from the Alluvium With Grouted Surface Casing
- SOP GT.6, Monitoring Wells and Piezometer Installation
- SOP GT.5, Plugging and Abandonment of Boreholes

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- SOP GT.10, Borehole Clearing
- SOP FO.14, Field Data Management
- SOP GT.24, Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)

5.0 EQUIPMENT AND PROCEDURES

5.1 GENERAL

Rotary drilling and rock coring methods that use air or water as the drilling media are common techniques employed to obtain stratigraphic, lithologic, hydrogeologic, geotechnical, and environmental data, as well as a means for monitoring well installation. In general, hollow-stem continuous-flight augers will be the preferred technique for drilling boreholes to collect environmental samples of soil and rock (see SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques). The use of air or water can alter analytical chemistry or physical property test results by altering sample moisture, by volatilizing contaminants (in the case of air), or by washing

them away (in the case of water). Using water when drilling can also alter the groundwater chemistry in the vicinity of the borehole, and needs to be accounted for during development of wells. Rotary drilling and rock coring may be used for advancing boreholes with or without environmental sampling in zones of hard material which cannot be penetrated with augers.

Samples obtained for analytical chemistry testing will be prepared and contained in general accordance with SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques. In general, air will be the drilling medium used when it is necessary to penetrate cemented zones of rock in auger borings drilled for environmental sampling. Water will typically be used as the drilling medium when drilling relatively deep bedrock wells and when obtaining rock core exclusively for geologic logging. Alternatively, dual-tube air percussion or ODEX drilling methods using water or air may be appropriate for some conditions. Sonic drilling methods require little or no water, air, mud, or other circulation medium for penetration. The appropriate work plan will outline drilling requirements for each project.

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5.2 EQUIPMENT AND MATERIALS

5.2.1 General Rotary Drilling Equipment

The following is a list of equipment and materials for rotary drilling:

- Drill rig with appropriately-sized drill bits and rods
- Portable recirculation tanks for water rotary
- Preapproved water for water rotary
- Conveyance equipment (pumps and hoses)
- Air compressor with appropriate air filter(s)
- High pressure steamer/sprayer
- Wash/rinse tubs
- Weighted tape measure

- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Water level probe
- Appropriate health and safety equipment
- Drums for containment of cuttings and fluids (see SOP FO.8, Handling of Drilling Fluids and Cuttings)
- Boring log form
- Field activities report form
- Pint-sized plastic jars with screw caps for cuttings (see SOP GT.1, Logging Alluvial and Bedrock Material)
- Black, waterproof (permanent) marking pens

5.2.2 Supplemental Equipment for Rock Coring

Additional equipment for rock coring will consist of the following:

- Core barrel assembly
- Wire line or core rods
- Coring log forms
- Core boxes with wooden blocks
- Measuring tape
- Camera (photography is security controlled at Rocky Flats Plant)
- Core barrel rack
- Plastic wrap for core

5.3 PROCEDURES

Boreholes will be drilled using a rig equipped with rotary drilling equipment capable of advancing the borehole to the depth specified in the Field Sampling Plan (FSP). All drilling equipment,

including the rig, water transportation tanks, bits, and drill rods, will be decontaminated according to SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination. These decontamination procedures will also be followed between boreholes for downhole equipment and between work areas of different contaminant characterization for the drilling rig. Drilling equipment will be inspected to ensure that hydraulic system and fuel leaks do not introduce organic contamination on site or into the borehole. Any leaks that may introduce such contamination will be repaired before drilling. If lubricants are required for downhole equipment, only pure vegetable oil will be used.

Borehole locations will be cleared before drilling according to SOP GT.10, Borehole Clearing. Drill fluids and cuttings will be handled according to SOP FO.8, Handling of Drilling Fluids and Cuttings. Boreholes will be abandoned according to SOP GT.5, Plugging and Abandonment of Boreholes. All procedures will be conducted according to the applicable Health and Safety Plan. Project-specific requirements will be addressed in a work plan.

5.3.1 Rotary Drilling Techniques

Conventional rotary drilling involves the introduction of a drilling medium (fluid) into the borehole through the drill rods and circulation of the medium back up the hole to remove drill cuttings. The hole is advanced by the cutting action of a rotating drill bit at the bottom of the hole. Reverse circulation methods are similar to conventional rotary methods, except that the drilling medium is injected down the annulus between an inner and outer double casing and returns back up the inside of the inner casing. Some reverse circulation methods use rotary techniques, some use non-rotating percussion techniques, and some use a combination of the two. When rotary drilling, samples of cuttings obtained to be saved for geotechnical testing or future geologic reference will be placed in pint-sized plastic jars with screw-on tops and saved in core boxes.

5.3.1.1 Water

Water used for rotary drilling will consist of RFP potable water. Water transportation tanks and conveyance equipment will be contaminant-free and dedicated for the use with preapproved water to ensure that the preapproved water introduced into the borehole is also contaminant-free. Portable decontaminated water recirculation tanks will be used for rotary operations. Excavated sumps or pits (lined or unlined) will not be used. If caving becomes a problem during drilling with water, super Gel-X (powdered bentonite) or biodegradable drilling additives such as guar gum may be added to the RFP potable water to stop uptake of water by the formation and to prevent hole loss. All drilling additives must be pre-approved by EG&G before use in a borehole, and they must be noted on the applicable documentation. Decontamination of tanks and conveyance equipment will also be conducted in accordance with SOP FO.3, General Equipment Decontamination and/or SOP FO.4, Heavy Equipment Decontamination.

5.3.1.2 Air

Conventional air compressors used for air rotary methods contain oil for lubricating moving parts and compress air and oil in their operation. To avoid introducing contaminants into the borehole, an EG&G-approved filtration system designed to provide oil-free air will be used. Depending on the requirements of the particular project, such a system may consist of an air-cooled aftercooler, a regenerative dryer, a coalescing filter, and a particulate afterfilter, all arranged in series. The particular filtration system design will depend on the compressor equipment, the project requirements, and anticipated ambient conditions. The filtration system will be matched appropriately to the compressor's capacity so that the reduction in the flow of air to the drilling equipment is tolerable. The filtration system components will be changed or monitored according to the requirements of the design during operation and a record of this kept on the field activities report form (see Section 7, Documentation).

Dust control measures may also be required according to the Field Operations Plan (FOP) and Health and Safety Plan (HSP). The airborne dispersion of cuttings can be controlled to some extent by circulating the return air through a vortex or cyclone. See SOP FO.1, Air Monitoring and Dust Control for more information.

5.3.2 Rock Coring

Continuous core samples collected using rock coring methods can be used to obtain relatively undisturbed samples of rock for stratigraphic, lithologic, hydrogeologic, and environmental data. Conventional rock coring methods use a diamond coring bit instead of a conventional tricone or granular rotary bit.

Continuous core samples will be extracted from the core barrel, placed on core racks, and logged by appropriate personnel according to SOP GT.1, Logging Alluvial and Bedrock Material. Rock core to be saved for geotechnical testing or further geologic observations will be placed in plastic core wrap and then placed in core boxes with appropriately-sized dividers to protect and preserve the orientation of the core during movement and storage. Coring equipment will also be decontaminated according to SOP FO.3, General Equipment Decontamination.

Air or water drilling media used for coring must be contaminant-free. Therefore, the provisions required in Subsections 5.3.1.1 and 5.3.1.2 for drilling fluids also apply to rock coring procedures.

5.3.3 Sonic Drilling Techniques

Sonic drilling is achieved by a drill head that transmits high-frequency pressure waves through steel drilling pipe to create a cutting action at the tip of the drill bit. Pressure waves are created by center-rotating, offset balanced roller-weights. The frequency of the drill string causes the column to vibrate elastically along its longitudinal axis. In the resonant condition, the drill string acts as a

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fly-wheel, transmitting maximum power to the drill bit. This power, combined with slow rotation to expose fresh material to the bit and slight downward pressure advances the drill string through soil and rock without the addition of a drilling medium.

Because the drilling action and thin-wall design of the drill string either forces the displaced material into the wall of the borehole or into the core barrel, very little waste cuttings are generated.

Samples will be obtained by vibrating the drill bit and rotating the core barrel to the desired depth, advancing the outer drill pipe, and then pulling the sample to the surface via the wireline. Once at the surface, the sample will be vibrated or hydraulically extracted from the core barrel into a plastic sleeve or clean sample tray. After a sample is collected, the core barrel will be decontaminated and readied to retrieve the next sample.

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6.0 DECONTAMINATION

Generalized equipment decontamination procedures will include:

- Sampling equipment. Decontamination will be conducted between individual sampling points to minimize potential cross-contamination. Sampling equipment will be decontaminated according to SOP FO.3, General Equipment Decontamination. During drilling and sampling, decontaminated equipment will be placed on new plastic sheeting or racks until it is used. At least two sets of samplers will be available so that one set can be used while the other is being decontaminated. When coring bedrock using water as a circulating medium, no decontamination of core barrels or measuring tapes is necessary between coring

runs. The core barrels and measuring tapes will be decontaminated after each boring is complete.

- Drilling equipment. Decontamination (augers, drill stems, drill bits, and other downhole equipment) will be conducted after each boring is complete. The drill rig will be decontaminated when moved to a new work area that has a different contaminant characterization. Decontamination of drilling equipment is described in SOP FO.4, Heavy Equipment Decontamination.

7.0 DOCUMENTATION

All information required by this SOP will be documented on the Borehole Log Form (Form GT.1A) and the ~~Rotary/Core Drilling Field Activities Report Form (Form GT.4A)~~ Daily Field Drilling Activities Report Form (Form GT.2A). The Daily Field Drilling Activities Report Form will be filled out for each day of drilling at a given borehole location and, in situations where more than one boring is drilled and completed per day per drill rig, at least one form will be completed per boring. The borehole log will include information on subsurface material classification and lithology. ~~Information on core length, core loss, percent of recovery, core breakage due to discontinuities, total core breakage, and rock classification and lithology will be recorded on the log form.~~ The Daily Field Drilling Activities Report will include the following information and have space for comments and documentation of general observations:

- Project name ~~and bore identification~~
- Location code
- Subcontractor
- Date
- Weather conditions
- Equipment descriptions (rig, bits, etc.)
- Drilling company and driller

- Geologist and other crew members ~~(with subcontractors)~~
- Borehole depth ~~and diameter~~
- ~~Water level~~
- Sample number
- ~~Depth to bedrock~~
- QC Code
- Time
- ~~Sampling types and depths~~
- OMD and radiological readings
- Drilling fluid used
- ~~Drilling fluid return/loss and pressures~~
- ~~Compressor/pump type~~
- End-of-day status (in progress of drilling complete)
- Chronological record of activities

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The above information shall be entered into the field data capture program (Datacap) (see procedure FO.14, Field Data Management).

DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures).

1. Date	25. DMR No.
11-18-93	93-DMR-000961

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.05, R2 INFORMATION ONLY	N/A

4. Originator's Name/Phone/Pager/Location	5. Document Title
P. A. Kiefer, X8698, 080	Plugging and Abondonment of Boreholes

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one): ☐ New ☐ Revision ☒ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	3	4.2	Add reference as identified on attached.
2	7,8	6.0	Change requirements of Well/Borehole Abandonment Form as identified on attached
3	FORM GT 5A (rev.2)		Replace existing GT.5A (rev. 2) with attached GT.5A (rev.3) Insert example of a completed GT.5A (rev.3)

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Replace GT.5A (rev.2) with a revised GT.5A (rev.3) which is a combination of GT.5A (rev.2) and GT.11A (rev.2)

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	T. P. Lovseth	11-22-93
SM	P. A. Kiefer	11-18-93
EQS	M. C. Brooks	12-3-93

16. Originator's Supervisor (print/sign/date): D. D. Stagg 22Nov93

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T. P. Lovseth	3003	ENV-GT	12/9/93	1-10-94

22. Accelerated Review? Yes ☐ No ☐

23. ORC Review: NOT ORC, REVIEW NOT REQUIRED

24. Responsible Manager (print,sign,date): Stephen H. Singer 12/17/93

REVIEWED FOR CLASSIFICATION / UCNI
BY N/A 12/16/93

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INFORMATION ONLY

PLUGGING AND ABANDONMENT OF BOREHOLES

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	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
PLUGGING AND ABANDONMENT
OF BOREHOLES

Approved By:

(Name of Approver) Signature on file (Date) / /

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PER R.B. HOFFMAN, CLASS
JUNE

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4	3/1/92	
5, 6, 6A	2/4/93	DCN-93.01 DCN-92.01
7	1/10/94	93-DMR-000961
8	3/1/92	
Form GT.5a (Rev. 3)	1/10/94	93-DMR-000961

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to plug and abandon (P&A) boreholes. Plugging refers to the physical process of filling the hole with grout while abandonment refers to the completion and documentation of all of the requirements of this SOP.

For the purpose of this SOP, a borehole is defined as a ground penetration that is drilled for the primary purpose of obtaining geologic and environmental information. Generally, a borehole will provide retrieval of cores, cuttings, and geophysical data. Boreholes may be uncased or partially or fully cased. This SOP addresses abandonment of boreholes immediately after completion of drilling; therefore, the depth, diameter, and other features of the borehole will be known. Unless the status of a borehole is changed, it will be plugged and abandoned immediately after the desired data are collected.

The status of a borehole may be changed to that of a well. For the purpose of this SOP, a well is defined as a surface penetration drilled for the purpose of installing a water well (i.e., for monitoring and/or production) or a cased penetration designed to obtain piezometric information. Abandonment of wells is addressed in SOP GT.11, Plugging and Abandonment of Wells. Abandonment of previous ground penetrations of unknown status is also addressed in SOP GT.11.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the plugging and abandonment of boreholes will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA. OSWER-9950.1. Washington D.C. September 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.5, Handling of Purge and Development Water
- SOP FO.8, Handling of Drilling Fluids and Cuttings
- SOP FO.9, Handling of Residual Samples
- SOP FO.14, Field Data Management

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- SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP GT.4, Rotary Drilling and Rock Coring

- SOP GT.10, Borehole Clearing
- SOP GT.11, Plugging and Abandonment of Wells

5.0 EQUIPMENT AND PROCEDURES

5.1 MATERIALS AND EQUIPMENT

The following materials and equipment may be used:

- Drill rig and associated equipment
- Reduced pH bentonite grout (American Colloid Pure Gold, or approved equivalent)
- Cement bentonite grout proportioned as 1 sack (94 pounds) of Portland cement, 5 pounds of powdered bentonite, and approximately 8 gallons of potable water
- Portable metal tanks for flushing and mixing
- High pressure steamer/sprayer
- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Drums for containment of borehole effluent and sediment
- Weighted tape measure
- Mirror and/or flashlight

- Health and safety monitoring equipment and personal protective equipment according to the Health and Safety Plan
- Borehole plugging and abandonment form
- Black waterproof (permanent) marking pens

5.2 PROCEDURES

Equipment for plugging and abandoning boreholes will be used according to the requirements of SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques and SOP GT.4, Rotary Drilling and Rock Coring. These requirements include the use of contaminant-free lubricants only (i.e., pure vegetable oil) and visual monitoring of equipment for hydraulic and/or fuel or oil leaks. All procedures will be conducted according to the applicable Health and Safety Plan. If necessary, project-specific requirements will be addressed in a work plan.

A grouted surface casing may have been placed in some boreholes prior to completion of drilling (see SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing). Steel casing will be removed during borehole abandonment. PVC casing may be left in place except for the upper 3 feet where cement grout will be placed. Steel casing will be decontaminated after removal. Abandonment procedures must not allow cross-contamination from the alluvium into the bedrock or surface soils. This will require grouting the portion of borehole in bedrock prior to casing removal. If difficulties are encountered removing casing, further measures, such as overdrilling, may be required according to SOP GT.11, Plugging and Abandonment of Wells.

Plugging will involve placing bentonite grout by a tremie pipe positioned at the bottom of the hole. The grout will be mixed in a powered mechanical grout mixer according to the manufacturer's recommendations. The grout will contain at least 30 percent solids by weight and have a minimum

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The following procedure will be utilized to abandon shallow (< 10 ft.) soil borings at OU-6 in which groundwater was not encountered. Plugging will involve placing bentonite groute by gravity into the boring. The grout will be manually mixed according to the manufacturer's recommendations. Plugging will involve placing bentonite grout by a tremie pipe positioned at the bottom of the hole. The grout will be mixed in a powered mechanical grout mixer according to the manufacturer's recommendations. The grout will contain at least 30 percent solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. A mud balance will be used to check the grout density for each borehole prior to pumping. The grout will be tremied using a side-discharge tremie pipe. The tremie pipe can be raised during grouting, but it will be maintained at least 5 to 10 feet below the upper level of the grout. The grout will be pumped until any other fluids have been displaced from the hole and undiluted grout is observed flowing from the hole. The tremie pipe will then be removed from the hole.

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For borings less than 10 feet deep, where groundwater was not encountered, plugging will consist of mixing grout according to the manufacturer's recommendations either manually or with a mechanical mixer. The grout will then be poured into the boring. After settlement of the bentonite grout, the hole will be cleaned out to a depth of approximately 3 feet and a cement bentonite grout will be placed from the ground surface to a depth of approximately 3 feet. This cement bentonite grout cap will be installed after 24 hours or more to allow for primary grout settlement. If the initial grout settlement is 3 feet or more, the upper grout surface will be rehydrated by adding water and waiting approximately 30 minutes prior to placing the cement bentonite grout cap. Alternatively, the dehydrated grout may be removed. A metal cap with the borehole ID and survey information will be embedded in the cement bentonite grout. The following information will be inscribed in the cap See the Field Sampling Plan (FSP) for survey requirements.

- Borehole number
- Survey coordinates
- Elevation
- Date

Upon completion of plugging, the rig and associated equipment will be decontaminated according to SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination. Remaining environmental materials will be handled according to SOP FO.8, Handling of Drilling Fluids and Cuttings. The ground surface at the site will be restored to near original lines and grades. Landscaping and/or pavement will be replaced.

6.0 DOCUMENTATION

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Information required by this SOP will be documented on the Borehole Log Form (Form GT.1A) and the Well/Borehole Abandonment ~~Field Activities Report~~ Form (Form GT.5A). ~~The Field Activities Report form will be filled out for each day of abandonment activities at a given borehole location and,~~ ~~i~~In situations where more than one boring is abandoned per day per drill rig, at least one form will be completed per boring. The boring log will include information on subsurface material classification, stratigraphy, and lithology. Environmental materials handling will be documented according to SOP FO.8, Handling of Drilling Fluids and Cuttings. The ~~Field Activities Report~~ Well/Borehole Abandonment Form will include, but not limited to, the following information and have space for comments and documentation of general observations:

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- Project name and ~~borehole identification~~ location code
- Date
- Weather conditions
- Drilling company and driller
- Geologist and other crew members (with subcontractors)
- Equipment descriptions (rig, tremie, pump, etc.)
- Borehole depth and diameter
- Water level in borehole prior to abandonment (if any)

- Volume of grout placed
- Type, length, and diameter of casing removed (if applicable)
- Type, depth, and diameter of casing left in place (if applicable)
- ~~End of day status (in progress or complete)~~
- Surface seal information (date set and depth)
- Chronological record of activities

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Information on Form GT.5A shall be entered into the field data capture program (Datacop) when released. See procedure FO.14, Field Data Management.

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM GT.5A (REV. 3)

WELL / BOREHOLE ABANDONMENT FORM

LOCATION CODE: 43892 DATE: 6-15-93
PROJECT NAME: OU2 - RFI/RI SUBCONTRACTOR: JE

EXAMPLE

Well Specifics (as applicable):

CONSTRUCTED DEPTH (FT): 44.0' BORING DIAMETER (IN): 7 5/8"
FIELD DEPTH (FT): 42.0' WATER LEVEL (FT): 22'
NUMBER OF SCREENS: 2
SCREEN TYPE(S): 10' Sch-40 PVC
SCREEN DIAMETER(S) (IN): 2"
SCREENED INTERVALS (FT): 18' - 38'
STICKUP OR FLUSH MOUNT: Stick up 2.0'
PENETRATES CONFINING LAYERS (Y/N): N
AQUIFERS MONITORED: Alluvium
REASON FOR ABANDONMENT: well damaged

Abandonment Specifics (as applicable)

ABANDONMENT START DATE: 6.14.93 END DATE: 6-15-93
FIELD BOOK ID NUMBER: OU2-17 PAGE NUMBER(S): 56-58
WEATHER CONDITIONS: clear, hot 70° - 85°
GEOLOGIST: J. Osterhaven
SITE PERSONNEL: T. Savko ('His)
B. Keeney (helper)

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DRILLER & DRILLING COMPANY: R. Hupp / Layne Environmental

RIG TYPE: Simco Core DRILLING METHOD: Hollow Stem
TREMIE & PUMPING EQUIPT.: 1" PVC / Moyno Pump
GROUT VOLUME PLACED (FT³): 547
CASING REMOVED (Y/N): N
TYPE: N/A DIAMETER (IN): N/A
LENGTH (FT): N/A
CASING LEFT IN PLACE (Y/N): N
TYPE: N/A DIAMETER (IN): N/A
LENGTH (FT): N/A
SURFACE SEAL DEPTH (FT): 3.0' DATE SET: 6-15-93
CONCRETE PAD INSCRIPTION: 43892 / 6-15-93
METAL ID PLATE INSTALLED (Y/N): Y
ABANDONMENT METHOD: Grout filled to surface

DISPOSITION OF MATERIALS REMOVED: Protective casing removed, transported to contractor yard for screening by Rpt's!
COMMENTS OR PROBLEMS ENCOUNTERED:
Grout mixed to 9.9#/GALLON

STATE WELL ABANDONMENT FORM SUBMITTED TO GEOSCIENCES (Y/N): Y
DATE FORM SUBMITTED: 6-15-93
Completed By: JAMES OSTERGREN Date: 6-15-93
Print Name Signature

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U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM GT.5A (REV. 3)

WELL / BOREHOLE ABANDONMENT FORM

LOCATION CODE:_____ DATE:_____
PROJECT NAME:_____ SUBCONTRACTOR:_____

Well Specifics (as applicable):

CONSTRUCTED DEPTH (FT):_____ BORING DIAMETER (IN):_____
FIELD DEPTH (FT):_____ WATER LEVEL (FT):_____
NUMBER OF SCREENS:_____
SCREEN TYPE(S):_____
SCREEN DIAMETER(S) (IN):_____
SCREENED INTERVALS (FT):_____
STICKUP OR FLUSH MOUNT:_____
PENETRATES CONFINING LAYERS (Y/N):____
AQUIFERS MONITORED:_____
REASON FOR ABANDONMENT:_____
_____

Abandonment Specifics (as applicable)

ABANDONMENT START DATE:_____ END DATE:_____
FIELD BOOK ID NUMBER:_____ PAGE NUMBER(S):_____
WEATHER CONDITIONS:_____
GEOLOGIST:_____
SITE PERSONNEL:_____
_____
_____
_____
DRILLER & DRILLING COMPANY:_____
_____
RIG TYPE:_____ DRILLING METHOD:_____
TREMIE & PUMPING EQUIPT.:_____
GROUT VOLUME PLACED (FT^3):_____
CASING REMOVED (Y/N):_____
TYPE:_____ DIAMETER (IN):_____
LENGTH (FT):_____
CASING LEFT IN PLACE (Y/N):_____
TYPE:_____ DIAMETER (IN):_____
LENGTH (FT):_____
SURFACE SEAL DEPTH (FT):_____ DATE SET:_____
CONCRETE PAD INSCRIPTION:_____
METAL ID PLATE INSTALLED (Y/N):_____
ABANDONMENT METHOD:_____
_____
DISPOSITION OF MATERIALS REMOVED:_____
_____
COMMENTS OR PROBLEMS ENCOUNTERED:_____
_____
_____
_____
STATE WELL ABANDONMENT FORM SUBMITTED TO GEOSCIENCES (Y/N):_____
DATE FORM SUBMITTED:_____

Completed By:_____ Date:_____

Checked By:_____ Date:_____
Print Name *Signature*

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DOCUMENT MODIFICATION REQUEST (DMR)

INFORMATION ONLY

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

1. Date	25.
04/20/94	DMR No. 94-DMR-00301

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.6, Rev. 2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
J.A. Paschis/X8644/NA/080-645	Monitoring Well and Piezometer Installation

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
			This procedure has 9 active DMRs/DCNs against it, and is currently being revised. However, in order to continue operations, this DMR is being issued in parallel with the revision.
1	2	2.0	Replace first paragraph with the following paragraph: This standard operating procedure (SOP) describes requirements for administrative documentation of new monitoring wells (and piezometers) and field procedures that will be used for installing monitoring wells and piezometers (open-pipe) at Rocky Flats Plant (RFP). This SOP contains the forms for documentation and describes the equipment for drilling, field procedures, well material specifications, and decontamination procedures that will be used to install monitoring wells and open-pipe piezometers in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.
2	3	4.1	Add the following reference: Revised and Amended Rules and Regulations of the Board of Examiners of Water Well Construction and Pump Installation Contractors, 2CCR 402-2. State of Colorado, Office of the State Engineer, Denver, Colorado, Revised Effective August 1, 1988.

12. *Justification (Reason for Modification, EJO#, TP#, etc.)*

1. Informs well requestor that information about new well installation is needed for well permitting to the Office of the State Engineer.

2. New reference cites CO regulatory statutes relative to well installation.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	R.G. Smith R.G. Smith	4/20/94
EQS	M.C. Brooks (RR) M.C. Brooks	5/17/94
RPM	W.S. Busby W.S. Busby	5/5/94
SPP	S.R. Keith S.R. Keith	5/16/94
EOM	M.C. Broussard M.C. Broussard	5/2/94

16. Originator's Supervisor (print/sign/date)
Stephen H. Singer Stephen H. Singer SH Singer 4/20/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
R.G. Smith/X8705/D5135/080-643	0202	ENV-GT	04/29/94	6-01-94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
ORC Review not required; this nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print, sign, date)
Mark E. Levin 4/20/94

REVIEWED FOR CLASSIFICATION/UCN
BY NA
DATE NA

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

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Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

25. DMR No. 94-DMR-000801

2. or 3. Document Number/Revision	3. Document Title
5-21000-OPS-GT.6/2	Monitoring Well and Piezometer Installation

8. Item	9. Page	10. Step	11. Proposed Modifications
3	3	4.2	Add the following references: • SOP FO.14, Field Data Management • SOP GT.24, Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)
4	3	5.0 & 5.1 (new)	Insert the following new Sections 5.0 and 5.1, and consecutively renumber the old Sections 5.0 and 6.0 to 6.0 and 7.0, respectively . **5.0 ADMINISTRATIVE DOCUMENTATION PRECEDING WELL INSTALLATION** The Well Installation Notification (WIN), Form GT.6B is to be completed to ensure that new well administrative controls are met by the inclusion of requestor information, installation methods, purpose, initial well permit data, environmental protection measures, and additional information. The requestor should supply information necessary for the Environmental Science and Engineering, Geosciences Division to prepare and file applicable well permits required by the state of Colorado. The information will be used in applying for the: 1) ***Notice of Intent to Construct***: well owner's notice to drill a well. (This must be submitted to the Division of Water Resources three days prior to invasive activities.); and, 2) ***Permit to Construct a Well***: application form issued and approved by Division of Water Resources permitting construction for purposes such as groundwater monitoring, production, or recovery. (Additional permits are required for the installation of a pump). An approved soil disturbance permit is also required by RFP Construction Management. These pre-drilling administrative procedures will be coordinated through the Geosciences Division. **5.1 INSTRUCTIONS FOR ADMINISTRATIVE DOCUMENTATION** After Work Plan approval, administrative tracking for new wells (and piezometers) requires the following steps be implemented as an essential part of the planning stage prior to well installation. These procedures are for the purpose of assigning location codes (well numbers), initiating well construction permits required by the Division of Water Resources, and acquiring soil disturbance permits. 5.1.1 Submit one Well Installation Notification (WIN), Form GT.6A for each new well or piezometer to Geosciences Division for approval. 5.1.2 Receive approved WIN form and copy of approved Notice of Intent to Construct. 5.1.3 Submit WIN form and apply for Soil Disturbance Permit to RFP Construction Management. 5.1.4 Receive approved Soil Disturbance Permit. 5.1.5 Receive notice from Geosciences Division that well permits have been approved by Division of Water Resources and well installation may proceed.

2. Justification (Reason for Modification, EJO#, TP#, etc.)

3. Internal references cite additional guidance procedures used for pre-installation of wells and data management.

4. Specific data requested is to complete information for well permitting to Office of the State Engineer and for well requestor to receive unique location code for well control; provides well requestor with procedural instructions applicable to well permit acquisition.

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

INFORMATION ONLY

25. DMR No. 94-DMR-00080

2. or 3. Document Number/Revision: 5-21000-OPS-GT.6/2

3. Document Title: Monitoring Well and Piezometer Installation

Item	9. Page	10. Step	11. Proposed Modifications
4 cont.			5.1.6 Following well installation, submit copies of Groundwater Monitoring Well and Piezometer Report, form GT.6B, Well Development form GW.2A, land survey coordinates and RFP Borehole Log form GT.1A to Geosciences Division as soon as possible. 5.1.7 If applicable, provide Geosciences Division supplemental information for end-use requirements of well to obtain additional well/pump permits.
5	16	7.0	Insert following as new 1st paragraph in front of existing 1st paragraph: **7.0 DOCUMENTATION** Provide the WIN form to the Geosciences Division as instructed in 5.1.1. Submit copies of applicable (Sections 5.1.6, and 8.0) records related to this administrative procedure to Geosciences Division.
6	17	8.0	Replace Form GT.6A, Groundwater Monitoring Well and Piezometer Report Form with Form GT.6B.
7	18	8.0	Add the following section to end of text, page 18, GT.6. **8.0 ADMINISTRATIVE DOCUMENTATION** The two forms for documenting well completion data and well installation notification for wells (and piezometers) follow this section. The Well Installation Notification form GT.6A is completed and submitted to the Geosciences Division. Field information documented on the Groundwater Monitoring Well and Piezometer Report form GT.6B should be entered in electronic data format as specified in SOP FO.14 Field Data Management form FO.14G. Upon completion of data entry and quality control check, Form GT.6B is delivered to the Operable Unit Project Manager.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

5. Informs well requestor of type and filing location of documents.

6. Replaces old form with new form required for RFEDS update.

7. Provides well requestor/installer guidance on the filing of completed forms.

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INFORMATION ONLY

MONITORING WELL AND PIEZOMETER INSTALLATION

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.6, Rev. 2
	Page:	1 of 18
	Effective Date:	06/01/94
Category 2	Organization:	Environmental Management

TITLE:
MONITORING WELL AND
PIEZOMETER INSTALLATION

Approved By:

/s/ J.E. Evered (Name of Approver) 05/12/92 (Date)

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DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

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EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
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DCN93.12

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LIST OF EFFECTIVE PAGES

Pages	Effective Date	Change Number
1-5	06/01/94	94-DMR-000801
7-18	06/01/94	94-DMR-000801
7	05/11/93	DCN 93.09
9	09/23/93	DCN 93.06
10	03/17/93	DCN 93.07
13	02/10/93	DCN 93.04
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15D-16	01/29/93	DCN 93.02
Form GT.6A	06/01/94	94-DMR-000801
Form GT.6B	06/01/94	94-DMR-000801

TOTAL NUMBER OF PAGES: 27 (including forms)

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes requirements for administrative documentation of new monitoring wells (and piezometers) and field procedures that will be used for installing monitoring wells and piezometers (open-pipe) at the Rocky Flats Plant (RFP). This SOP contains the forms for documentation and describes the equipment for drilling, field procedures, well material specifications, and decontamination procedures that will be used to install monitoring wells and open-pipe piezometers in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the installation of monitoring wells and piezometers will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004 October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

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RCRA Groundwater Monitoring Technical Enforcement Guidance Document. EPA, OSWER-9950.1, Washington D.C., September 1986.

Revised and Amended Rules and Regulations of the Board of Examiners of Water Well Construction and Pump Installation Contractors, 2CCR 402-2. State of Colorado, Office of the State Engineer, Denver, Colorado, Revised Effective August 1, 1988.

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4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.8, Handling of Drilling Fluids and Cuttings
- SOP FO.14, Field Data Management
- SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)
- SOP FO.16, Field Radiological Measurements
- SOP GT.1, Logging Alluvial and Bedrock Material
- SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP GT.4, Rotary Drilling and Rock Coring
- SOP GT.24, Approval Process for Construction Activities on or Near Individual Hazardous Substance Sites (IHSSs)

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5.0 ADMINISTRATIVE DOCUMENTATION PRECEDING WELL INSTALLATION

The Well Installation Notification (WIN), Form GT.6A is to be completed to ensure that new well administrative controls are met by the inclusion of requestor information, installation methods, purpose, initial well permit data, environmental protection measures, and additional information.

The requestor should supply information necessary for Environmental Science and Engineering, Geosciences Division to prepare and file applicable well permits required by the state of Colorado. The information will be used in applying for the: 1) *Notice of Intent to Construct*: well owner's notice to drill a well. (This must be submitted to the Division of Water Resources three days prior to invasive activities.); and 2) *Permit to Construct a Well*: application form issued and approved by Division of Water Resources permitting construction for purposes such as groundwater monitoring, production, or recovery. (Additional permits are required for the installation of a pump.) An approved soil disturbance permit is also required by RFP Construction Management. These pre-drilling administrative procedures will be coordinated through the Geosciences Division.

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5.1 INSTRUCTIONS FOR ADMINISTRATIVE DOCUMENTATION

After Work Plan approval, administrative tracking for new wells (and piezometers) requires the following steps be implemented as an essential part of the planning stage prior to well installation. These procedures are for the purpose of assigning locaiton codes (well numbers), initiating well construction permits required by the Division of Water Resources, and acquiring soil disturbance permits.

5.1.1 Submit one Well Installation Notification (WIN), Form GT.6A for each new well and piezometer to Geosciences Division for approval.

5.1.2 Receive approved WIN form and copy of approved Notice of Intent to Construct.

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5.1.3 Submit WIN form and apply for Soil Disturbance Permit fo RFP Construction Management.

5.1.4 Receive approved Soil Disturbance Permit.

5.1.5 Receive notice from Geosciences Division that well permits have been approved by Division of Water Resources and well installation may proceed.

6.0 EQUIPMENT AND PROCEDURES FOR MONITORING WELL AND PIEZOMETER INSTALLATION

Groundwater monitoring wells and open-pipe piezometers (observation wells) will be constructed in boreholes drilled and logged according to SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques, or SOP GT.4, Rotary Drilling and Rock Coring, and SOP GT.1, Logging Alluvial and Bedrock Material. The construction of monitoring wells is the same as that used for piezometers. The distinction between wells and piezometers is based on the intended use. Wells are used for obtaining samples of groundwater while piezometers are intended only for water level measurements. If different types of piezometers are required (e.g., isolated electronic or pneumatic piezometers), they will be addressed in another SOP or in a project-specific work plan. All drilling

and sampling equipment and materials will be protected from the ground surface with clear plastic sheeting or will be placed on clean drill racks.

Personnel installing monitoring wells need to be cognizant of the many factors influencing the screened intervals selected for wells. For example, water table wells should have screens of sufficient length at the appropriate depth to monitor the water table. Wells with slow recharge should have sufficient screen area to allow adequate sample volume. However, long screened intervals should generally be avoided since they are of limited value for characterizing discrete zones of contamination.

Selection of well screen intervals may also depend on the suspected presence of light or dense immiscible layers of contaminants floating on the water table or residing at the bottom of a hydrostratigraphic unit (HSU). Screened intervals across different HSUs should generally be avoided particularly where there is a potential for cross-contamination between HSUs to occur.

These factors must be addressed during project planning, and the Field Sampling Plan (FSP) will normally provide rationale for the planned sampling. Personnel installing monitoring wells should be familiar with the FSP and the rationale used in determining well screen intervals.

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6.1 EQUIPMENT AND MATERIALS

The following is a list of equipment and well materials for well installation:

- Drill rig with appropriately-sized drill bits, augers, and/or rods
- High pressure steamer/sprayer
- Sand bailer
- Long-handled bristle brushes
- Wash/rinse tubs

- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Weighted tape measure
- Water level probe
- Distilled water
- Drums for containment of cuttings
- Appropriate health and safety equipment
- Field book
- Location map
- Boring log form
- Groundwater observation well report

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6.2 DRILLING PROCEDURES

Boreholes for wells will be drilled by using a drill rig and drilling method capable of completing the well to the depth specified in the FSP. All drilling equipment, including the drill rig, water tanks, and all downhole equipment will be decontaminated according to SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination. Downhole equipment will be decontaminated between boreholes, and other equipment such as the drill rig will be decontaminated between different work areas.

Before drilling, test borings/wells will have been located, numbered, and identified by using stakes or paint sticks on paved surfaces. Drilling locations will be cleared for buried metal objects and utility interference according to SOP GT.10, Borehole Clearing. Boreholes will be advanced from the ground surface to a predetermined target depth given in the FSP. Boreholes drilled for wells will be logged stratigraphically by examination of the sample cuttings or core samples according to SOP GT.1, Logging Alluvial and Bedrock Material.

If hollow-stem augers are used for alluvial wells, the boreholes will be augured as little as possible into claystone bedrock (approximately one foot or less), since the claystone bedrock cuttings may tend to be smeared along the side of the borehole in the alluvium. Therefore, after the augers have been advanced to the bedrock contact, an appropriately-sized drive sampler will be driven 2 feet into the claystone bedrock to provide a pilot hole, no more than 1 inch greater than the outside diameter (O.D.) of the casing, for a 2-foot deep sediment sump. Where claystone smearing is not a problem, auger 2 feet into bedrock to provide a pilot hole for a 2-foot deep sediment sump. The sediment sump will be a 2-foot-long piece of blank casing installed immediately beneath the screen in all wells.

If a center bit is used instead of a continuous hollow-stem core sampler, a drive sample may be taken after the interval is drilled to ascertain if the alluvial/bedrock contact has been reached. After a maximum of a 1-foot drive sample, coring will resume if indicated. During the drilling process, the center bit will be removed slowly to prevent sand from entering (blowing into) the bottom auger. In the event of sand blow-in, RFP potable water may be added to the inside of the augers to equalize the hydrostatic pressure of the formation water. A record of the intervals drilled using a center bit and/or the amount of water placed in the well will be noted on the applicable log sheets. The amount of water placed in the well (if applicable) will be recorded so that it can be taken into account during well development.

The inside diameter (I.D.) of the augers will be approximately 4 inches or more larger than the O.D. of the casing, resulting in a 2-inch annulus around the casing. Similarly, a 2-inch annulus will be provided around well screens and casings when wells are constructed in open portions of boreholes. In open-hole installation (wells constructed in uncased boreholes), the use of stainless steel casing centralizers will be required to ensure the 2-inch annulus is maintained. Centralizers should be provided above and below the well screen, but not within the bentonite seal. Depending on the well depth and diameter, centralizers may also be required at intervals along the riser to provide a 2-inch grout annulus. When hollow-stem augers are used, centralizers will only be

required if the auger flights are not a sufficient size to ensure a 2-inch minimum annulus dimension on all sides of the screen.

During the drilling operation, the cuttings and formation water from the boring will be placed in environmental materials drums if required (see SOP FO.8, Handling of Drilling Fluids and Cuttings).

Single-cased wells will be used in the alluvial/unconfined aquifer. Double casing may be required for bedrock wells installed in areas of potentially contaminated alluvial groundwater. If required, surface casing will be installed through the alluvium according to SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing.

Boreholes for alluvial and bedrock wells will be drilled according to SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques or SOP GT.4, Rotary Drilling and Rock Coring.

94-DMR-000801

6.3 WELL MATERIALS AND INSTALLATION PROCEDURES

6.3.1 Materials

6.3.1.1 Well Casings

DCN93.09

Well casings will consist of new, threaded, flush-joint schedule 40 or schedule 80 poly-vinyl chloride (PVC) unless another type of casing (e.g., stainless steel) is required by the FSP or project-specific work plan. The well casing will extend from the top of the well screen to approximately 2 feet above ground surface. The tops of all well casings will be fitted with slip-on or threaded PVC caps which can be easily removed by hand. All joints within the casing string will be threaded. Heat-welded joints, solvents, and/or gaskets will not be used. According to the manufacturer's recommendations, O-rings will be used between joints or Polytetra fluoroethylene (PTFE) tape will be wrapped around

the joint threads to improve the seal. All well casings will be free of foreign material and will be steam cleaned with approved water before use. Steam-cleaned casings will be stored in plastic sleeves prior to use. Casing with stamped or stenciled nomenclature will not be used.

94-DMR-000801

6.3.1.2 Well Screens

Well screens will consist of new threaded PVC pipe (unless another material [e.g., stainless steel] is required by the FSP or a project-specific work plan) with 0.010-inch factory-machined slots or wrapped screen. All well screens will have an I.D. equal to or greater than that of the well casing. The wall thickness of PVC screen will be the same as that of the well casing. A 2-foot deep sediment sump will be used beneath the screen. A threaded cap or a slip-on cap secured with stainless steel screws will be provided at the bottom of the sump. Well screen with stamped or stenciled nomenclature will not be used.

94-DMR-000801

6.3.1.3 Filter Pack

The filter pack material will be chemically inert, rounded, silica sand of appropriate size for the well screen and host environment. Grain size analyses of the unconsolidated formations underlying the site have indicated a 16-40 gradation is appropriate, and it will be used on the site unless the FSP or project-specific work plan indicates otherwise. The filter pack will extend approximately 2 feet above the top of the screen unless otherwise specified. Where the thickness of the alluvium is insufficient, the top of the filter pack may extend 6 inches above the top of the screen. The final depth to the top of the filter pack will be measured directly by using a weighted tape measure and not by using volumetric calculation methods. The volume placed will be recorded.

94-DMR-000801

94-DMR-000801

DCN 93.04

6.3.1.4 Bentonite Seal

A bentonite seal will be installed above the filter pack. The seal will consist of a layer of commercially available bentonite pellets that is at least 3 feet thick when measured immediately after placement, without allowance for swelling.

6.3.1.5 Bentonite Grout

The annular space between the well casing and the borehole will be grouted from the top of the bentonite seal to ground surface. The grout will consist of high-solids reduced pH bentonite grout (American Colloid Pure Gold or approved equivalent) mixed in a powered mechanical grout mixer according to the grout manufacturer's recommendations. The grout may be mixed by hand for intervals less than 5 feet thick. The grout will contain at least 30 percent solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. The density will be checked with a mud balance.

Grout will be placed outside of the monitoring well casing using a side-discharge tremie pipe located just above the top of the bentonite seal. The grout will be pumped through the pipe until undiluted grout flows from the annular space at the ground surface. The tremie pipe will then be removed and more grout added to compensate for settling. After 24 hours, the site will be checked for grout settlement and more grout added to fill any depressions. The total volume placed will be recorded.

When excessive grout loss into landfilled materials occurs, grouting will be stopped and bentonite chips or pellets will be added to the annular space to seal off the area losing grout. A minimum of two feet of pellets or chips will be added, then grouting will resume as above. If grout loss continues or if grout is again lost further uphole, grouting will again be stopped and additional bentonite pellets or chips will be added until grout loss is stopped.

94-EMD-200801

6.3.2 Installation Procedures

6.3.2.1 Alluvial Piezometer and Monitoring Well Installation

Figure GT.6-1 shows a schematic diagram of the lower portion of an alluvial well completion. Monitoring well installation will begin after formation water and fine grained sediment have been bailed using a sand bailer until the water is relatively clear and free of sediments. If granular soils do not blow into the bottom auger, raising the augers 1 to 2 feet above the bottom of the hole can help with the removal of muddy water from outside of the augers. This will not work if the hole bottom caves or blows in.

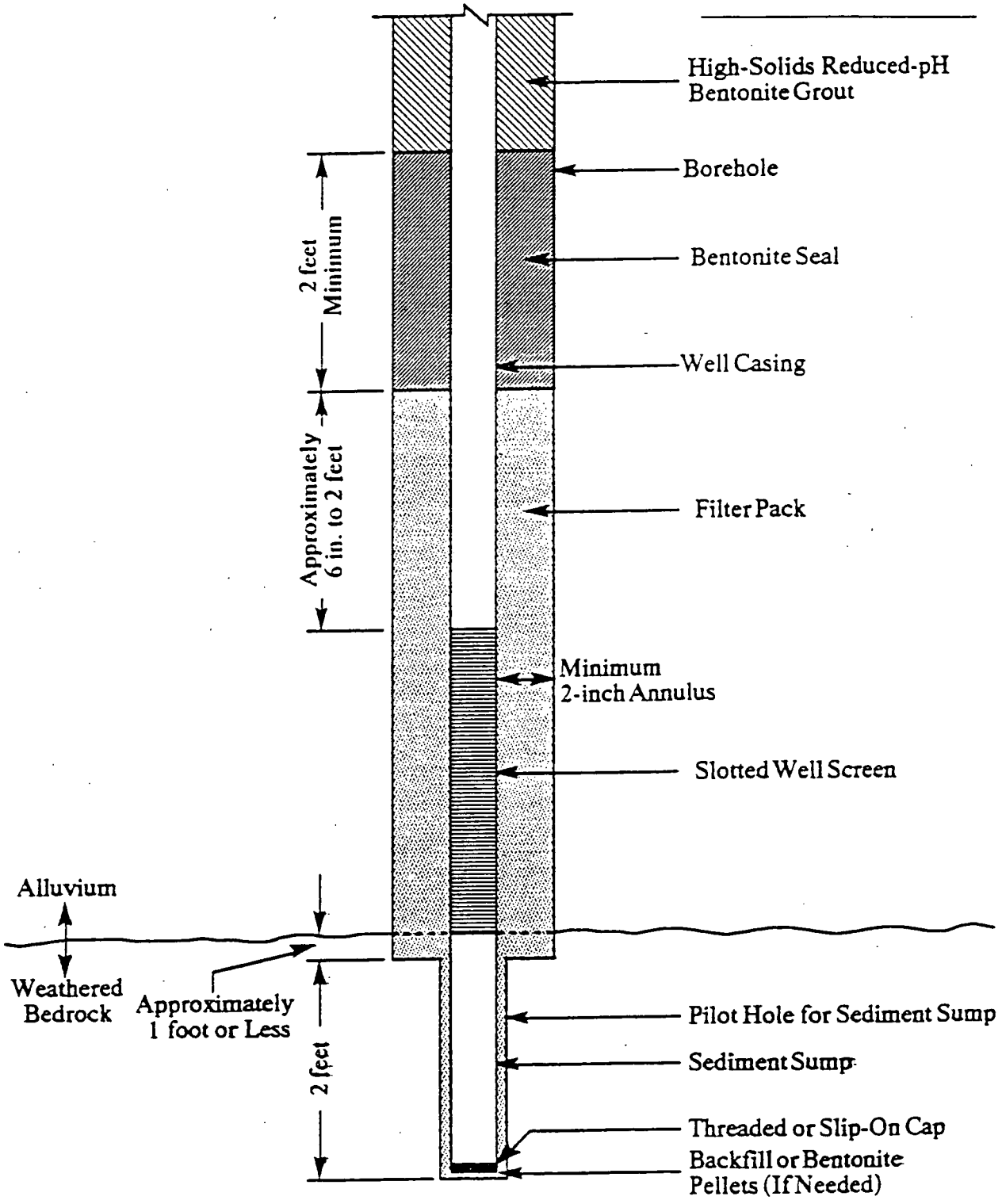
DCN 93.07

The borehole depth and the well assembly will be measured to the nearest 0.1 foot. The portion of the well casing cut off at the top will be measured and subtracted from the total length supplied to determine the total well assembly length. Before placing the well assembly into the borehole, any void spece between the bottom of the borehole and the bottom of the sediment sump will be backfilled with commercially available bentonite pellets.

Once the well assembly is in place, the filter pack will be added slowly to the zone below the water level in the borehole by tremie pipe. If filter pack material is placed in wells above the water level in the borehole, a tremie pipe will not be required inside of hollow-stem augers. A tremie pipe will be required for all filter placement in open hole completions. The filter pack will be added in 1- to 2-foot increments. Similarly, the augers will be raised in 1- to 2-foot increments so that the sand level is always at or slightly above the bottom of the augers. Depth measurements of the top of the filter material will be taken continuously in the well annulus as the filter is placed. The final depth to the top of the filter pack will be approximately 2 feet, but in no case less than 6 inches, above the top of the well screen. The top of the filter pack will be directly measured by a weighted tape measure. The weight on the tape measure will be stainless steel in the event that it accidentally becomes embedded in the filter pack. If bridging of the filter material occurs in the well annulus

FIGURE GT.6-1
SCHEMATIC DIAGRAM OF ALLUVIAL MONITORING WELL COMPLETION

NOTE: This figure illustrates guidelines for alluvial wells to show maximum bedrock penetration.



Not To Scale

or tremie pipe during placement, the bridged material will be broken loose mechanically by shaking the augers and/or well assembly. Bridged material in the annulus may also be broken loose by probing with a 1-inch-diameter tremie pipe. If both of these methods are unsuccessful, distilled water may be pumped through the 1-inch tremie pipe to dislodge the bridged material. A record of the amount of water placed in the well will be kept so that it can be taken into account during well development. The volume of filter material placed will also be recorded.

A minimum 2-foot bentonite pellet seal (before swelling) will be installed immediately above the filter pack. If the bentonite pellet seal will be placed below the water table, it will be installed through a tremie pipe. The bentonite pellets will be added slowly to reduce the chances for bridging of the pellets inside the tremie. The augers will be raised approximately 1 foot above the filter pack prior to adding the bentonite pellets. The top of the bentonite seal should never be above the base of the augers. If the bentonite seal is placed above the water level in the borehole, the pellets may be allowed to free-fall into the borehole if hollow-stem augers are being used. The bentonite will be hydrated using 5 gallons of distilled water after the base of the augers are raised approximately 1 foot above the top of the bentonite seal. The completed bentonite seal will be allowed to hydrate for approximately 30 minutes before proceeding with the grouting operation.

Bentonite grout backfill will be placed from the top of the bentonite seal to the ground surface. The grout mixture will conform to the specifications outlined in Subsection 5.3.1.5, Bentonite Grout. The grout will be tremied into the well annulus using a side-discharge tremie until it is completely full. The volume of grout placed will be recorded. The well casing will be checked for plumb by use of a weighted tape measure lowered from the center of the casing. If the tape measure touches the side of the casing prior to reaching the bottom, the casing will be shifted as much as possible to a vertical alignment and held in place while the grout sets up and hardens. After settlement of the bentonite grout has been allowed for 24 to 72 hours, the protective steel casing will be embedded in cement-bentonite grout or nonshrink concrete. The cement-containing grout will occupy the upper 1 1/2 to 3 feet of the well annulus to anchor the protective casing. This may

require removing some of the bentonite grout from the upper 1 1/2 to 3 feet of the well annulus. If the upper grout surface is dehydrated, it will either be removed or rehydrated by adding water and waiting approximately 30 minutes. When alluvial wells are installed in areas with minimal alluvial thicknesses and the bentonite seal is within 1.5 to 3 feet of the surface, no bentonite grout is needed, and the protective steel casing can be embedded in the required cement-bentonite grout.

94-DMR-000801

6.3.2.2 Bedrock Piezometer and Monitoring Well Installation

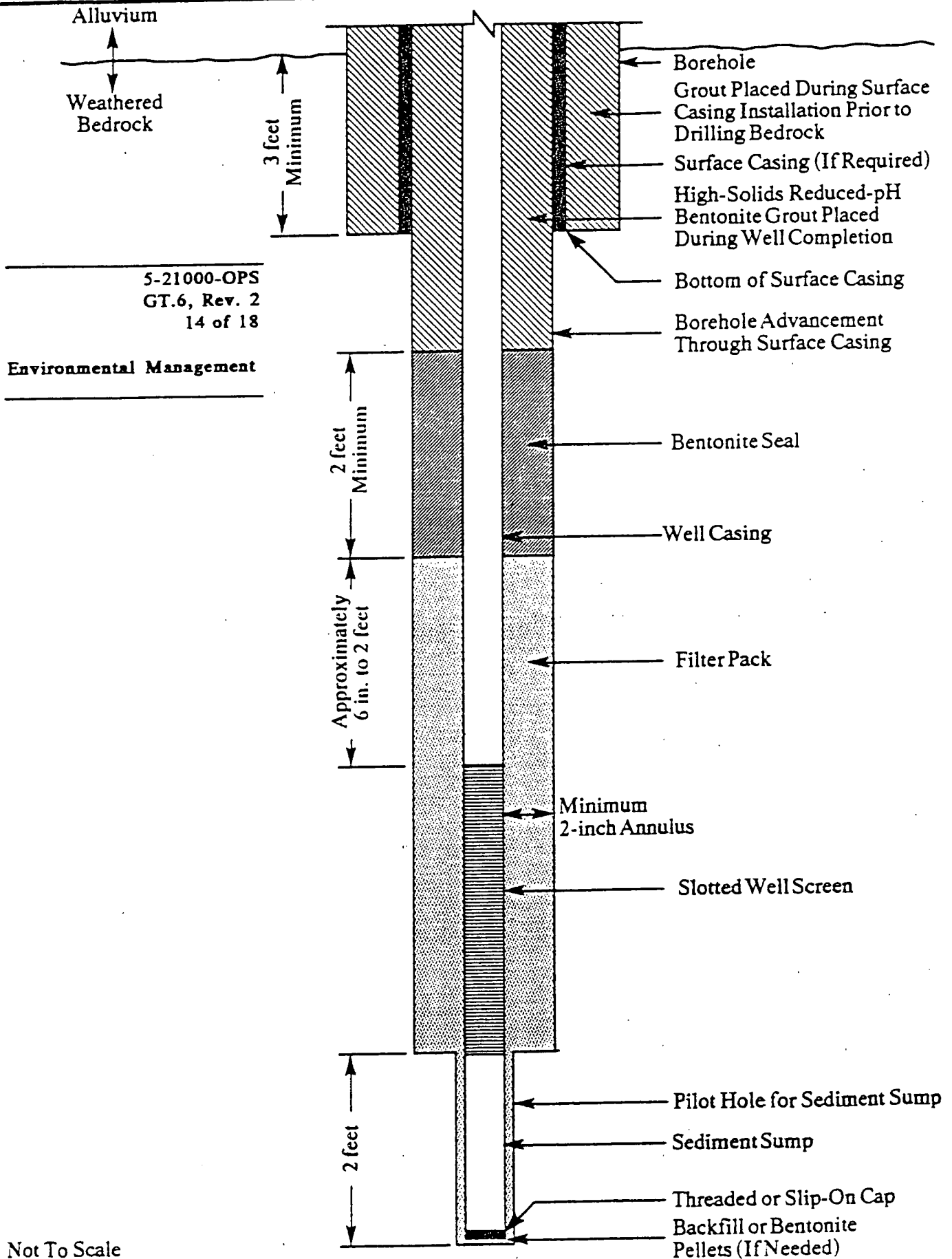
Figure GT.6-2 shows a schematic diagram of the lower portion of a bedrock well completion. Bedrock piezometers and monitoring well installations will be similar to the alluvial well installation procedures except that a surface casing may be provided through the alluvium to guard against potential cross-contamination of bedrock aquifers by contaminated alluvial groundwater. If required, the surface casing will extend from the ground surface to at least 3 feet below the alluvial/bedrock contact. This casing will be installed according to SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing.

If rotary drilling methods (see SOP GT.4, Rotary Drilling and Rock Coring) are required, the installation procedures will be similar except that the well may be completed in an open hole instead of inside of hollow-stem augers. The well string will be suspended approximately 2 inches above the bottom of the borehole prior to installing the filter pack. This will reduce bending of the well assembly and minimize the potential for collapse of the casing due to the weight of fluid in the annulus. Stainless steel centralizers will be placed at 20-foot-maximum spacing for wells completed in open holes.

ACN 93.04

Where wells cannot be completed in an open hole because of stability or other problems and/or the well cannot be completed within augers, the well may be installed through casing. This casing will be a diameter sufficient to provide a 2" annulus around the well casing and will consist of PVC or stainless steel. The casing will be advanced to the selected depth either using no additional fluids

FIGURE GT.6-2
SCHEMATIC DIAGRAM OF BEDROCK MONITORING WELL COMPLETION



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Not To Scale

DCN 93.04 94-Dmil-000801

or by circulating RFP potable water down through the casing. After reaching the selected depth, a sand bailer will be used to remove any accumulated fluids until the borehole is bailed clear or until fluids are relatively clear and free of sediment. The well assembly will then be advanced through the casing to the designated depth and the annulus between the casing and the well assembly will be used to tremie well materials. The well will be installed as per the alluvial wells installed through augers except that the casing will be used instead of augers.

6.3.2.3 Well Features at Ground Surface

DCN 93.06

Figure GT.6-3 shows a schematic diagram of well features at the ground surface. A 5-foot-long protective steel casing with a hinged and locking steel cap will be installed over the monitoring well riser that projects above the ground surface between 24 and 72 hours after initial grout placement, except when temperatures are below freezing. A shorter length protective steel casing (no less than 3-foot long) may be used when shallow screens are required. The protective casing will have a minimum 8-inch I.D. for 4-inch wells and a minimum 6-inch I.D. for 2-inch wells. The well designation will be welded on the protective casing. The bottom of the protective casing will be embedded 2 to 3 feet below the ground surface in concrete or cement grout. Prior to installing the protective casing, the well will be checked for alignment by lowering a 5-foot long, 1 1/2-inch diameter bailer down the entire depth of the well. If the bailer hangs up, the EG&G project manager will decide whether or not the well needs to be reconstructed.

DCN 93.12

In landfill areas, both the inner casing and outer protective casing shall be extended by means of attaching blank casing (also known as a riser) such that the top of the outer protective casing shall be about three feet above the new ground level. The top of the riser shall have threads to allow for subsequent additions of new blank casing as landfill operations cause the ground level elevation to rise (see schematic diagram GT.6-4 of riser construction).

The annulus between the well riser and the steel protective casing will be filled with nonshrink cement grout or concrete to a minimum of 12 inches above the ground surface, and a 1/4-inch-diameter hole will be drilled in the protective casing just above the grout or concrete surface to allow drainage.

At the same time the protective steel casing is grouted or concreted in place, an external concrete collar approximately 3-foot square will be placed around the protective casing at the ground surface. The well designation will be inscribed in the concrete before it sets. The collar will be graded to slope away from the casing in all directions. The concrete collar will be 5.5 inches thick or greater.

DCN 9314

When traffic conditions or vegetation warrant extra protection, four 3-inch-diameter steel posts will be installed. The posts will be located radially from the well casing at a distance of approximately 4 feet. They will be embedded in concrete 3 feet below the ground surface with a minimum of 3 feet sticking up above the ground. Installation is required within 72 hours of well installation. In areas of high vegetation, the posts will be flagged. Painted metal stakes shall be used to flag the location of the monitoring well or piezometer in high traffic areas. The stakes shall be installed in lieu of bumper posts.

DCN 93.12

When daytime temperatures are consistently below freezing, it is not feasible to excavate the upper most 1 1/2 to 3 feet of grout in order to install the surface well features since the grout is often frozen and difficult to remove. In addition, poured concrete may freeze before it cures causing cracking and necessitating replacement to ensure a surface seal. In these instances, the PVC well riser will be securely capped until warmer weather allows the setting of surface features. Wells installed during freezing weather will not be permitted to stand without surface features for more than two months.

DCN 93.05

6.4 WELL POINT INSTALLATION

This Section describes the procedures used for installing well points. Before installation, sites will be located, numbered, and identified using stakes (or paint sticks on paved surfaces). Refer to SOP GT.10, Borehole Clearing, for more information regarding clearing the sites of underground obstructions.

After test sites have been located and cleared, an exclusion zone will be established according to the project Health and Safety Plan. The procedure for installing well points at a specific location is as follows:

1. Decontaminate the rig and downhole equipment. See SOP FO.3, General Equipment Decontamination for specific details regarding decontamination.

2. Set up the rig to obtain a thrust direction as close to vertical as possible.

3. Advance threaded expendable point by either hydraulically pushing or hammering to desired depth.

4. At locations within an IHSS, monitor the breathing zone near the rig for volatile organic compounds.

5. Insert the end of the hand-perforated tubing (Polyethylene or Teflon) with a threaded stud attached into the probe rods. Thread this into the expendable drive point. Length of perforated tubing will range between one and five feet based upon magnitude of anticipated water level fluctuations.

6. Hydraulically withdraw probe rods from hole.

DCN 93.02

7. Place 10/20 silica sand filter pack to approximately six inches above the top of the screen while keeping tension on the tubing. Place at least six inches of granular bentonite seal above filter pack.

8. Install four-inch long, one-inch diameter PVC casing with threaded or slip cap as protective well-point surface casing. Protective casing will be nearly flush with the ground surface.

9. Install four-foot long, three-inch diameter steel post adjacent to protective casing to act as marker and traffic barrier. Post should be installed such that three feet are above ground.

10. Develop well point with peristaltic or inertia pump. Since these well points are only for measuring water levels, it is not necessary to measure all the parameters referenced in SOP GW.4, Well Development.

11. Survey top protection casing because well-point tubing is too flexible. Refer to SOP GT.17, Land Surveying, for more information regarding site surveying procedures.

DCN 93.02

94-DMR-00801

7.0 DOCUMENTATION

Provide the WIN form to the Geosciences Division as instructed in 5.1.1. Submit copies of applicable (Sections 5.1.6 and 8.0) records related to this administrative procedure to Geosciences Division.

The installation of monitoring wells and piezometers will be documented on groundwater monitoring well and piezometer report forms. Drilling information will be documented on the Rocky Flats Plant Borehole Log form (Form GT.1A) and on the Hollow-Stem Auger Drilling form (Form GT.2A), or on the Rotary/Core Drilling form (Form GT.4A). Besides the drilling and

borehole information required by these other SOPs, the following documentation will be recorded on the Groundwater Monitoring Well and Piezometer Report Form (Form GT.6A). Location references will use the State Plane Coordinate System and elevations will be in feet above mean sea level (USGS datum). All depth and height measurements will be from ground surface.

- Elevation of ground surface
- Height of top of protective casing
- Height of top of well casing
- Depth of protective casing
- Type and size of protective casing
- Depth of surface seal
- Type of surface seal
- Type and size of well casing
- Type/volume of backfill
- Depth of top of seal
- Type of seal
- Depth of top of filter pack/bottom of seal
- Type/volume of filter pack
- Depth of top of screened section
- Type and size of screened section
- Size of screen openings
- Depth of bottom of screened section
- Depth of bottom of filter pack
- Length of plugged blank section (sump) below screen
- Depth of bottom of plugged blank section (sump)
- Type of backfill below filter pack
- Diameter of borehole
- Depth of borehole

- Type and depths of centralizers if used
- Generalized stratigraphy and water level summary (based on rig geologist notes)

8.0 ADMINISTRATIVE DOCUMENTATION

The two forms for documenting well completion data and well installation notification for wells (and piezometers) follow the section. The Well Installation Notification Form GT.6A is completed and submitted to the Geosciences Division. Field information documented on the Groundwater Monitoring Well and Piezometer Report Form GT.6B should be entered in electronic data format as specified in SOP FO.14, Field Data Management Form FO.14G. Upon completion of data entry and quality control check, Form GT.6B is delivered to the Operable Unit Project Manager.

94-DM2-000801

U.S. DEPARTMENT OF ENERGY | ROCKY FLATS PLANT | Form GT.6A (Rev 0)

Well Installation Notification Form

Project Name	Location Code (Well Number) (Geosciences Use Only)	
Requestor (Person/Organization)	Phone Number	Pager ID

Approximate Well Location (Show on Back)

Approximate State Plane Coordinates _____ Northing, _____ Easting

_____ 1/4, _____ 1/4, Section _____, T _____, R _____

Land Owner

☐ DOE ☐ Other _____

Type of Well Installation

☐ Monitoring and Testing Only ☐ Production/Recovery ☐ Other _____

Purpose of Well	Driller License Number

Data Quality Objectives

Expected Date of Well Completion	Projected Life of Well ☐ < 1 Year ☐ > 1 Year	Future Uses

Target Aquifer

☐ Surficial Deposits – Unconfined ☐ Shallow Bedrock – Unconfined ☐ Deep Bedrock – Confined (Requires Special License)

Well Construction Details

☐ Other (Describe) _____

☐ Per SOP _____

Well Diameter (inches) (I.D.)	Casing Type	Screened Interval to ft.
Annular Seal Type and Interval	Estimated Total Depth	Pump Installation ☐ N/A ☐ Type/H.P. _____

Type of Well Installation

☐ Hollow Stem Auger ☐ Driven ☐ Sonic ☐ Fluid Rotary ☐ Air Rotary ☐ Other _____

Environmental Protection Measures Taken During Drilling

Requestor Signature	Date	Page ___ of ___

GEOSCIENCES USE ONLY

Well Installation Requirement	☐ Notice		☐ Permit
Pump Installation Requirement	☐ None		☐ Permit
Drilling Contractor Requirement	☐ None	☐ Special License	☐ Licensed
Well Abandonment	☐ Notice	☐ None	

Reviewer Signature	Date

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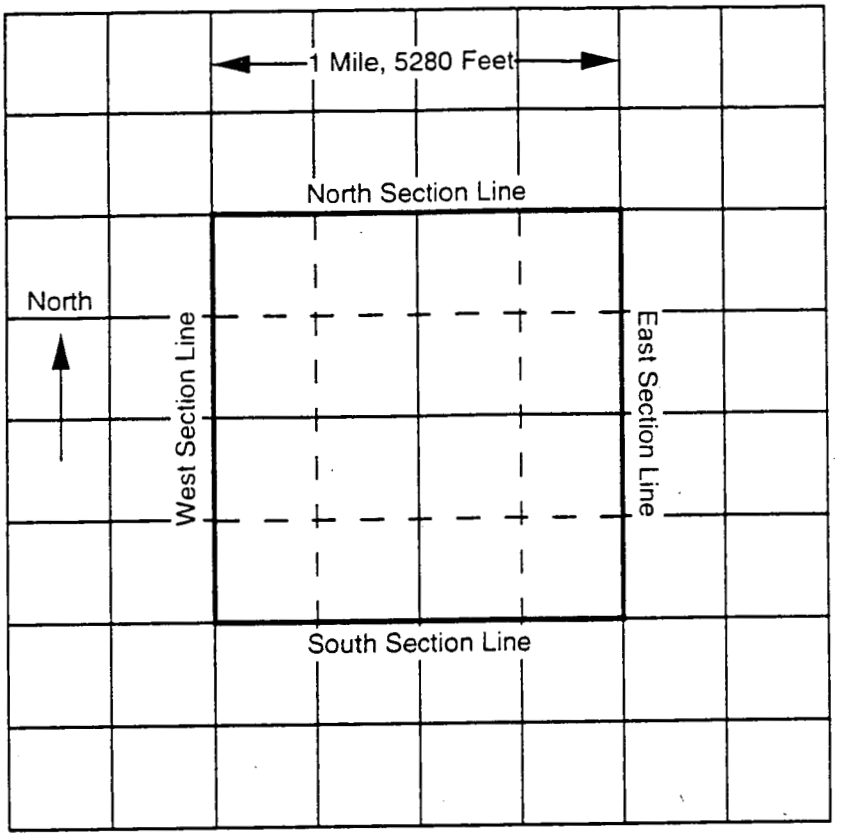
10/15/93

The Location of the Proposed Well

Use the CENTER SECTION (1 section, 640 acres) for the well location.



The scale of the diagram is 2 inches = 1 Mile
Each small square represents 40 acres.

Key:	
Requestor's Well	○
Nearest RFP Well and RFP Well Number:	□

Form GT.6A (Rev 0)

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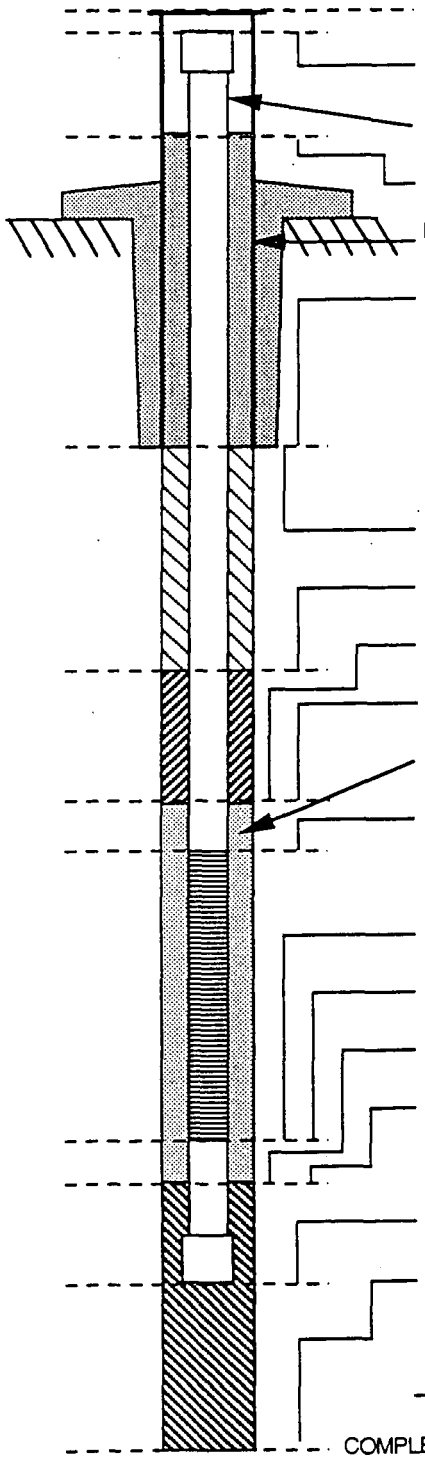
U.S. Department of Energy Rocky Flats Plant

Form GT.6B
(Rev. 3)
ORR 3/31/94

Groundwater Monitoring Well and Piezometer Report

LOCATION CODE: _____ PROJECT NAME: _____ PROGRAM: _____
SCREENED FORMATION: _____ DRILLING CONTRACTOR: _____
DRILLING METHOD: _____ DATE DRILLED: _____ DATE COMPLETED: _____
RIG GEOLOGIST: _____ LOGGING GEOLOGIST: _____
COMPLETED DEPTH (FT): _____ ESTIMATED DEPTH TO BEDROCK (FT): _____
BOREHOLE DIAMETER IN SCREENED INTERVAL (IN): _____

QUANTITY OF FLUIDS LOST DURING DRILLING (GAL): _____
INITIAL WATER LEVEL (FT): _____ DATE MEASURED: _____
COMPLETED WATER LEVEL (FT): _____ DATE MEASURED: _____



PROTECTIVE CASING, TOP (FT): _____ (FROM GROUND SURFACE)
SURFACE CASING (STICKUP), TOP (FT): _____
SURFACE CASING, I.D. (IN): _____ TYPE: _____
SURFACE SEAL, TOP (FT): _____ TYPE: _____
PROTECTIVE CASING, I.D. (IN): _____ TYPE: _____
PROTECTIVE CASING, BOTTOM (FT): _____

IF APPLICABLE
SECONDARY CASING, TOP (FT): _____ BOTTOM (FT): _____
SECONDARY CASING, I.D. (IN): _____ TYPE: _____

CENTRALIZER, O.D. (IN): _____ TOP (FT): _____ BOTTOM (FT): _____
GROUT SEAL, TOP (FT): _____ TYPE: _____
BENTONITE SEAL, TOP (FT): _____ TYPE: _____
BENTONITE SEAL, BOTTOM (FT): _____
FILTER PACK, TOP (FT): _____
FILTER PACK TYPE: _____ BRAND: _____
SURFACE CASING, BOTTOM (FT): _____ SCREEN, TOP (FT): _____
SCREEN SLOT SIZE (.000 IN): _____ SCREEN, I.D. (IN): _____
SCREEN, BOTTOM (FT): _____ TYPE: _____ BRAND: _____
SUMP, TOP (FT): _____ TYPE: _____
FILTER PACK, BOTTOM (FT): _____
BACKFILL, TOP (FT): _____ TYPE: _____
BACKFILL, BOTTOM (FT): _____
SUMP, BOTTOM (FT): _____
TOTAL DEPTH (FT): _____

ALL MEASUREMENTS WILL BE MADE FROM GROUND SURFACE.

REMARKS: _____

COMPLETED BY: _____ DATE: _____

CHECKED BY: _____ DATE: _____

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DOCUMENT MODIFICATION REQUEST (DMR)

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2.18.94

Refer to 1-A01-PPG-001 for Processing Instructions
Printor Type All Information (Except Signatures)

INFORMATION ONLY

24. Date	25.
02-04-94	DMR No. 94-DMR-000276

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.07, Rev. 2	N/A

4. Originator's Name/Phone/Pager/Location	5. Document Title
P. A. Kiefer, X8698, 080	Logging and Sampling of Test Pits, Trenches, and Construction Excavations

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one): ☐ New ☐ Revision ■ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	4	4.2	Add reference as identified on attached.
2	8	5.2.2	Remove form GT.7B, as identified on attached
3	9	5.2.3	Make changes as identified on attached
4	12,13	7.0	Make changes as identified on attached
5	FORM GT.7A (rev.2)		Replace existing GT.7A (rev.2) with attached GT.7A (rev.3).
6,7	FORMS GT.7B and GT.7C		Eliminate forms GT.7B and GT.7C from procedure.

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Replace GT.7A (rev.2) with a revised GT.7A (rev.3) which is a combination of GT.7A (rev.2), GT.20A (rev.2) and FO.14I. Eliminate GT.7B and GT.7C. These forms are not utilized.

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	M. Z. Litaor	2-4-94
SM	P. A. Kiefer	2-4-94
EQS	RR M.C. Brooks	2-21-94

16. Originator's Supervisor (print/sign/date): D. D. Stagg 2/4/94

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
M.Z. Litaor/8583/NA/080	3003	ENV-GT	02/25/94	

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review: ORC Review Not Required

24. Responsible Manager (print,sign,date): ~~Bruce Peterman~~ Mark Levin RR 2/23/94

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REVIEWED FOR CLASSIFICATION / UCNI
BY NA

DF-47940 (5/93)

INFORMATION ONLY

LOGGING AND SAMPLING OF TEST PITS, TRENCHES, AND CONSTRUCTION EXCAVATIONS

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.7, Rev. 2
	Page:	1 of 13
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
LOGGING AND SAMPLING OF TEST PITS, TRENCHES, AND CONSTRUCTION EXCAVATIONS

Approved By:

(Name of Approver) 5/12/92 (Date)

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REVIEWED FOR CLASSIFICATION/UCNI
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Date March 17, 1992

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes equipment, decontamination, and procedures that will be used for field data collection and documentation during logging and sampling of test pits, trenches, and construction excavations in order to attain acceptable standards of accuracy, precision, comparability, representativeness, and completeness.

Open excavations, long and narrow if a trench, or rectangular if a pit, may be used for shallow geological and environmental subsurface investigations and/or sampling purposes. Trenches or pits will be excavated manually or with a machine such as a backhoe, clamshell, trencher excavator, or bulldozer. Samples may be obtained using a variety of sampling equipment that will be specified in the project-specific work plan.

Occasionally, construction activities expose portions of the subsurface and open up windows of opportunity to collect geologic data. While the collection of geologic data may not be the primary function of these activities, it may be possible, by working with construction personnel, to collect significant amounts of geologic data. This SOP will also provide guidance for data collection in this situation.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel logging and sampling test pits, trenches, and construction excavations will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Soil Sample Collection--Surface. Colorado Department of Health Radiation Counting Facility, Operating Procedure. July 1, 1989.

Klute, A., Ed. "Methods of Soil Analysis, Part 1, Agronomy 9". Soil Science Society of America, 1986.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples
- SOP FO.14, Field Data Management
- SOP GT.1, Logging Alluvial and Bedrock Material
- SOP GT.8, Surface Soil Sampling
- SOP GT.10, Borehole Clearing

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5.0 EQUIPMENT AND PROCEDURES

5.1 MATERIALS AND EQUIPMENT

The following is a list of equipment and materials that may be needed to perform trenching and trench sampling:

- Backhoe (or other appropriate excavation equipment)
- High pressure steamer/sprayer
- 2- to 3-inch-diameter stainless steel, thin-walled tube (Shelby tube) samplers
- Sample jars and labels
- Extension rods with slide hammer apparatus to drive tube samples
- Teflon® sheeting
- Plastic caps for tube samplers
- Electrical tape
- 4-mil polyethylene sheeting
- Coolers
- Ice (H_2O or blue ice)
- Chain-of-custody forms
- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Tap water
- Distilled water
- Plastic buckets
- Scrub brush
- Stainless steel bowl
- Stainless steel long-handled spoon
- Stakes
- Gridded paper

- Tape measure
- Camera and film (photography is security controlled)
- Location map(s)
- Compass
- Personal health and safety equipment, as described in the Health and Safety Plan (HSP)
- Black waterproof (permanent) pens
- Clipboard and field notebook
- Logging forms
- Photolog form(s) (Form GT.7C)

5.2 PROCEDURES

5.2.1 Excavation

Prior to excavating, locations will be cleared according to SOP GT.10, Borehole Clearance. All excavations that are deeper than 4 feet must be examined, and measures taken to comply with OSHA regulations prior to personnel entry. All activities will be conducted in accordance with the Health and Safety Plan (HSP).

For the RFP site-wide Surficial Soil Program (SSP), pit dimensions will be approximately 9 to 15 feet long, 3 to 5 feet wide, and 4 feet deep.

Excavated material will be selectively stockpiled near the excavation to allow backfilling of the material in the general order in which it was removed. Material excavated from within an Individual Hazardous Substance Site (IHSS) will be stockpiled within the IHSS boundaries to avoid expansion of the IHSS. Depending on sampling requirements outlined in the Field Sampling Plan

(FSP), samples may be obtained from the excavation bottom at different depths as excavation proceeds, or the pit may be excavated to its final depth and then sampled from the sides.

Pits and trenches will normally be backfilled the same day as excavation, immediately after completion of sampling and/or logging. If pits are left open overnight, the pit and stockpile will be covered and barricaded for personnel safety and prevention of windblown dispersal of soils.

5.2.2 Logging

Classification of soils and bedrock, and logging of pits, trenches, and construction excavations will be conducted in general accordance with SOP GT.1, Logging Alluvial and Bedrock Material.

Since the descriptions are done in the field, it is not possible to accurately determine the grain size distribution by the means described in SOP GT.1. Field descriptions are to be done visually utilizing the classification schemes set forth in SOP GT.1. If required by the project-specific work plan, descriptions will be verified by taking samples for each described lithology and sending them to a geotechnical laboratory for analysis. Analyses done on the samples may include sieving, hydrometer analysis, moisture-density, and Atterberg limits. Samples should be taken at regular intervals as determined in the field sampling plan, or at changes in lithology and stratigraphy.

In addition to the information recorded in accordance with SOP GT.1, logging is to include the determination of the alluvial/bedrock contact, measured thicknesses of lithologic units, bedding, internal structures, moisture content, location and orientation of fractures, slickensides, geomorphic, and structural features. Care will be taken to remove material from the sides of the excavation which is not in place so that accurate descriptions can be made.

Reference stakes or reference lines between stakes will be used to help measure the pit dimensions and stratigraphy. In small excavations, if the stratigraphy is consistent around the periphery of the pit or on both sides of a trench, a borehole log may be sufficient to document the conditions. However, if relatively complex conditions are exposed, or if the excavation is of a large scale, it is necessary to create a "map" of the exposed surface. This map is to be drawn to scale and will include all of the information required by this SOP. Locations and depths recorded on the map are to be measured from fixed positions which have been surveyed. Depths will be measured by extending a tape measure vertically into the trench or excavation. In cases where the walls of the excavation are not vertical, the depth measurements will need to be corrected to true vertical.

Any visual signs of contamination will also be noted in the map and/or on the log. The map will include a plan view showing the pit orientation with a north arrow and will indicate the side(s) that is mapped.

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~~Trench or excavation maps and profiles will be recorded on the Profile Sketch Form (Form GT.7B) unless a larger format is desired or required to show more detail.~~

For the RFP site-wide SSP, soil profiles in the test pits will be described and logged using Soil Conservation Service (SCS) protocols. These protocols will be implemented by a qualified professional using Appendix GT.7A.

5.2.3 Sampling

Prior to sampling, the surface to be sampled (bottom or side) will be peeled with a stainless steel instrument to expose an undisturbed surface. Peeling will remove material possibly cross-contaminated during the excavation process by materials from other depths within the pit. If the trench or pit sides are sampled, peeling will start at the top and proceed downward and then

sampling will start at the bottom and progress upward. Alternatively, each sample location may be individually peeled immediately prior to obtaining the sample.

After peeling, sampling will be conducted by driving stainless steel thin-walled (Shelby) tubes, or by using a stainless steel spoon or scoop, to remove soils from the pit and then placing them in a container. In general, sample containers will be consistent with those described in SOP FO.13, Containerization, Preserving, Handling, and Shipping of ~~Soil and Water~~ Samples. However, Volatile Organic Analysis (VOA) samples may be obtained in stainless steel drive tubes and then immediately capped with Teflon®-lined plastic caps sealed with electrical tape.

Samples obtained for geotechnical purposes only (i.e., sieve analysis, hydrometer analysis, moisture density, and Atterberg limits) may not need the same rigorous specifications regarding sampling equipment and sample containers. All sample containers will be labeled immediately with the following information:

- ~~Station number~~ Location code
- Sample number
- Depth
- Analysis to be performed
- Date
- ~~Company~~ Subcontractor name and address

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For the RFP site-wide SSP, a rectangular-shaped wooden board will be placed on the ground surface and the lip of the pit above the pit face to be sampled. The depth below the surface for sample intervals will be measured from the base of the board.

For the RFP site-wide SSP, soil samples will be collected for each sampling interval from the bottom of the pit face to the top. Soil material will be collected from each interval by exposing

fresh material in the form of a horizontal cavity and taking sample material from within the cavity. An exception to the bottom-to-the-top sampling sequence will be made for near-surface intervals when the soil materials are too loose to permit discrete sampling. To sample these near-surface intervals, the sampler will start at the ground surface and use a knife and spatula to cut a rectangular area that is approximately 25 cm away from the plane the pit face, 20 cm parallel to the plane of the pit face, and 3 cm down into the pit. The soil material will be carefully removed from this rectangular area and retained as the sampled material. Sampling of loose materials will continue in this fashion down the pit face to the interval above the last discretely sampled interval.

In general, soil samples will be sampled for the following physical and chemical parameters:

- Physical parameters
  - Bulk density
  - Particle size distribution
  - Specific surface
  - Clay mineralogy

These parameters will be analyzed according to the applicable chapters of "Methods of Soil Analysis, Part 1" (1986). Clay mineralogy will be analyzed using the applicable chapters in "Minerals in Soil Environments", 2nd Ed., Soil Science Society of America, 1989.

- Chemical parameters
  - pH
  - Specific conductance
  - Organic matter
  - Calcium carbonate content
  - Exchangeable cations
  - Cation exchange capacity

- Sesquioxide content

Organic C determination will be determined by the Walkley-Black Procedure taken from the "Methods of Soil Analysis" (1982) on pages 570-571 (see Appendix GT.7B). Pretreatment for the removal of inorganic C in calcareous soils is outlined in the "Methods of Soil Analysis" (1982) on pages 561-563 (see Appendix GT.7C). Calcium carbonate content will be determined by the Manometric Method taken from the "Method of Soil Analysis" (1982) on pages 182-187 (see Appendix GT.7D). Soil pH and electrical conductivity will be determined by using a saturated paste technique taken from the "Methods of Soil Analysis" (1982) on pages 168-172 (see Appendix GT.7E). Exchangeable cations will be determined by the method described in "Methods of Soil Analysis" (1982) on pages 159-164. Cation exchange capacity will be determined by the method described in "Methods of Soil Analysis" (1982) on pages 149-157. Sesquioxides will be determined by the methods described in "Methods of Soil Analysis" (1986) on pages 101-142.

After a sample has been collected, the soil layers beneath the sampled layer will be scraped to expose a fresh face to prevent possible cross-contamination from falling soil material of the upper layer.

5.2.4 Trench Backfilling and Site Restoration

After completion of sampling and logging, the original soils will be replaced in the pit or trench at their original depths to the extent practical so that the soil from the bottom of the trench will be placed on the bottom and the topsoil will be replaced on the top. This can generally be accomplished by replacing the excavated material in layers of less than 8 inches on uncompacted thickness and making several passes over the soil lift with compaction equipment designed to compact soil. Backfill in outlying areas need not be compacted beyond tamping with a backhoe bucket. All excavation will be restored to near original line, grade, and aesthetics.

5.2.5 Surveying

Pit locations will be surveyed either before or after excavation. Surveying will involve obtaining horizontal coordinates of a stake near the center of the pit and an elevation of the ground surface at the stake. Required accuracies will be given in the FSP.

6.0 DECONTAMINATION

Excavation equipment will be decontaminated prior to excavating each trench or pit and at the conclusion of the operation. Sampling and peeling equipment will be decontaminated prior to collecting each sample. Care should be taken to inspect and monitor all excavation equipment, especially the backhoe, to ensure that no hydraulic and/or fuel leaks add contaminants to the site.

Specific decontamination procedures are described in SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination..

7.0 DOCUMENTATION

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All information required by this SOP will be documented on the Borehole Log Form (Form GT.1A); the ~~Field Activities Report, Pits, Trenches, and Construction Excavations~~ Pit Soil Profile Description Form (Form GT.7A)~~; the Profile Sketch Form (Form GT.7B); and the Photolog Form (Form GT.7C)~~. ~~The Soil Profile Description Form (Form GT.20A) will be used to document the soil profile description.~~ The ~~Field Activities Report~~ Pit Soil Profile Description Form will be filled out for each day of excavation at a given location, and, in situations where more than one pit or trench is excavated and completed per day, at least one form will be completed per pit or trench. The Borehole Log Form will include information on subsurface material classification and lithology.

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Information from the Pit Soil Profile Description (Form GT.7A) shall be entered into the field data capture program (Datacap) when released. See SOP FO.14, Field Data Management.

~~The Profile Sketch Form will show graphical stratigraphy if warranted by the complexity of the conditions exposed, or by the FSP.~~ At least one color photograph will be taken of each trench or pit, and multiple photographs will be obtained if conditions vary across the pit or trench, or if the excavation is of a large scale. Care will be taken to include ~~station numbers~~location codes, survey markers, depth markers, and scales to orient the photograph. All photographs taken at the RFP must conform to plant security controls. ~~The roll number, frame number, orientation, and location of each photograph will be recorded on the Photolog Form.~~ A visual scale and color reference chart will be included in all photographs. An 8-inch by 10-inch print will be stapled to the photolog form. The ~~Field Activities Report~~ Pit Soil Profile Description Form will include the following information and have space for comments and documentation of general observations:

- Project name and ~~site identification~~location code
- Date
- ~~Weather conditions~~Classification
- ~~Equipment descriptions (backhoe, shovel, etc.)~~Coordination
- ~~Excavator and c~~Subcontractor
- ~~Geologist and other crew members~~Elevation
- ~~Subcontractors~~Aspect
- Slope (% and position)
- Pit/trench horizontal dimensions and orientation
- ~~Pit/trench depth~~Parent material
- ~~Water level~~Drainage
- Sampling information (sample numbers, QC code types, and depths, horizon, boundary, color, coarse fragment, texture, structure, consistency, clay film, reactions, roots/pores)

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- ~~Environmental materials types, volumes, and drums used (if applicable)~~
- ~~Site restoration~~
- Chronological record of activities

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U.S. DEP. ENT OF ENERGY ROCKY FLATS PLANT FORM (REV. 3)

PIT SOIL PROFILE DESCRIPTION FORM

PROJECT NAME:_____ PROJECT CHARGED:_____ SUBCONTRACTOR:_____ DATE:_____

CLASSIFICATION:_____ COORDINATION E:_____ N:_____ LOCATION CODE:_____

ELEVATION:_____ ASPECT:_____ SLOPE(%):_____ SLOPE POSITION:_____

PARENT MATERIAL:_____

DRAINAGE:_____

PIT HORIZON DIMENSIONS & ORIENTATION:_____

NOTES:_____

Sample Number	QC Code	Horizon	Depth (cm) Start / End		Boundary	Color D or M	Coarse Fragment	Texture	Structure	Consist.	Reaction	Clay Film	Roots/ Pores

Completed By:_____ Date:_____
Print Name Signature

Checked By:_____ Date:_____
Print Name Signature

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APPENDIX GT.7A
SOIL SURVEY MANUAL

United States Department of Agriculture
Soil Conservation Service
P.O. Box 2890
Washington, D.C.
20013

June 9, 1981

SOIL SURVEY MANUAL
430-V
ISSUE 1

Purpose. To establish the Soil Survey Manual as a separate directive in the SCS Directives System and to issue Chapter 4 and a Contents page and tabulation sheet for the Manual.

Effective Date. This directive is effective when received.

Background. Chapters 3, 5, 7, and 10 of the Soil Survey Manual (Agriculture Handbook 18) were distributed as National Soils Handbook Notices 55, 59, 60, and 63. Recipieuts were instructed to file chapters of the manual in a 3-ring binder separate from the National Soils Handbook. National Soils Handbook Notices will no longer be used to issue chapters of the Soil Survey Manual. Future chapters will be sent out by transmittals such as this one. This manual will be included in the SCS Directives System until it is ready to be issued as a hardbound publication.

Information contained in Chapter 4 replaces the corresponding information in the August 1951 edition of the "Manual" and the May 1962 "Supplement to the Manual." The manual should not be supplemented with state or TSC directives.

Changes from past convention include the following:

1. Certain horizon designations have been changed or definitions modified in order to conform as closely as possible to other systems which are commonly referenced internationally.

2. Hydraulic conductivity classes are lowered to more accurately reflect the rates measured in the field for the respective classes.

3. A section on "Soil-Water Relations" is added in which definitions of three soil-water states are included. Descriptions of the soil-water states of a soil provide important information on which to base both farm and nonfarm interpretations. Soil drainage classes are retained, but their defintions are modified so the class limits can be set locally to meet state or multistate needs. In reality this is not a change from how soil drainage classes were applied by most states in the past.

DIST: SSM

MORE

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(430-V-SSM, May 1985)

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Chapter 1

Soil and Soil Survey

When soil survey began in the United States in 1899, an organized science of soil did not exist. This is not to say that nothing was known about soils. Indeed, farmers had learned a great deal through experience over the centuries, and much of their knowledge had been brought together in several compilations. Some, including L. J. M. Columella's treatise on husbandry, had been published as early as ancient Roman times. With the rise of agricultural chemistry during the nineteenth century, much that was useful was learned about the soil. Yet it was not until near the end of the nineteenth century that the knowledge about soils gained from farming, from agricultural chemistry, from biology, and from geology was coordinated. It could not be coordinated without some unifying concept of the soil itself.

Early Concepts

The first scholar to study soils in the United States was Edmund Ruffin of Virginia. He worked hard and successfully to find the secret of liming and learned to determine what we now call exchangeable calcium. After a brief essay in the American Farmer in 1822, he published the first edition of An Essay on Calcareous Manures in 1832. Although his writings were widely read in the Southern states, much of what he had learned about soils had to be rediscovered.

With a few exceptions,[1] the concepts of soil held at the time soil survey began were based on the ideas developed by the German chemist Justus von Liebig and modified and refined by agricultural chemists and plant physiologists working on samples of soil in laboratories and greenhouses and on small field plots. The soils were rarely examined below the layer turned in regular tillage. These chemists held the "balance-sheet" theory of plant nutrition. Soil was considered a more or less static storage bin for plant nutrients, which could be used and replaced. This concept still has value when applied within the framework of modern soil science. The removal of nutrients from soil by harvested crops and their return in manure, lime, and fertilizer are important to soil productivity, but a great deal more is needed to understand soils.

The early geologists generally accepted this theory of soil fertility and applied it within the framework of their own discipline. They described soil as disintegrated rock of various sorts—granite, sandstone, till, and the like. They went further, however, and showed how the weathering processes modified this material and how geologic processes shaped it into landforms such as glacial moraines, alluvial plains, loess plains, and marine terraces. N. S. Shaler's monograph on the origin and nature of soils[2] went about as

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far as possible with this geological concept of soils, although many details were added by G. P. Merrill.[3]

Near the end of the nineteenth century, Professor Milton Whitney inaugurated the National Soil Survey Program.[4] Professor Whitney and his coworkers in the new soil research unit of the United States Department of Agriculture became impressed by the great variations among natural soils—persistent variations that were in no way related to the effects of agricultural use. Whitney and his coworkers emphasized soil texture and the capacity of the soil to furnish plants with moisture as well as nutrients. Professor F. H. King of the University of Wisconsin was also emphasizing the physical properties of soils about this time.[5]

Early soil surveys were made to help farmers locate soils responsive to management and to help them decide what crops and management practices were most suitable for the particular kinds of soil on their farms. Soils were conceived as mainly the weathering products of recognized geologic formations, defined by landform and lithologic composition. Many of the early workers were geologists because only geologists were skilled in field methods and in scientific correlation appropriate to the study of soils. Most of the soil surveys published before 1910 were strongly influenced by these concepts. Those published from 1910 to 1920 gradually added greater refinements and recognized more soil features while retaining fundamentally geological concepts.

The early field workers soon learned that many important soil properties are not definitely related to either landform or kind of rock. They noted that naturally poorly drained soils have different properties than naturally well drained soils and that many sloping soils are unlike level ones. As early as 1902, soil structure was described in the soil survey of Dubuque County, Iowa. The 1904 soil survey of Tama County, Iowa, reported that soils that had formed under forest contrasted markedly with soils that had formed under grass on similar parent material.

Yet for several years the geological concept dominated field work and the balance-sheet theory of plant nutrition dominated the laboratory, and both were taught in many classrooms until the late 1920's. As a consequence, many special concepts were formed that broke down in contradiction when applied to the great continental area of the United States.

Broader and more generally useful concepts of soil were being developed by some American soil scientists, especially E. W. Hilgard. The necessary data for formulating these broader concepts came rapidly from the field work of the soil survey during the first decade of its operations. After Hilgard, the longest step toward a more satisfactory concept of soil was made by G. N. Coffey.[6] He "...concluded that an ideal classification should be a hierarchal system based on inherent differences in the soil itself as 'a natural body having a definite genesis and distinct nature of its own and occupying an independent position in the formations constituting the surface of the earth.'"[7]

Meanwhile, beginning in 1870, the Russian school of soil science under the leadership of V. V. Dokuchaiv and N. M. Sibertsev was developing a new

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concept of soil.[8] The results of this work became generally available to Americans through the publication of K. D. Glinka's textbook in German in 1914 and especially through its translation into English by C. F. Marbut in 1917.[9] The Russian workers conceived of soils as independent natural bodies, each with unique properties resulting from a unique combination of climate, living matter, parent material, relief, and time. The properties of each soil reflect the combined effects of the particular set of genetic factors responsible for its formation.

This was a revolutionary concept. Properties of soils no longer were based wholly on inferences from the geologic nature of the rocks or from climate or from other environmental factors, considered singly or collectively; rather, by going directly to the soil itself the integrated expression of these factors could be seen in the soils' morphology. This concept required that all properties of soils be considered collectively in terms of a completely integrated natural body, rather than as separate properties. In short, it made possible a <u>science</u> of soil.

The early enthusiasm for the new concept and for the rising new discipline of soil science led some to suggest that the other sciences were unnecessary for study of soil. Some extreme statements in this tone were made, perhaps to declare a certain sense of autonomy and freedom from the older concepts of geology and agricultural chemistry. Certainly the reverse is true, for besides laying the foundation for a soil science with its own principles, the new concept makes the other sciences even more useful. Soil morphology provides a firm basis on which to classify the results of observation, experiments, and practical experience and to develop principles that predict the soils' behavior.

Under the intellectual leadership of Marbut,[10] this new concept was broadened and adapted to conditions in the United States. As first expounded, this concept emphasized individual soil profiles—soils at points on the earth's surface—even to the subordination of external soil features and surface geology. However, by emphasizing points, soil scientists at first tended to overlook the soils' natural variability, which can be substantial even within a small area. Overlooking the variability of soils seriously reduced the value of the soil maps. This weakness soon became evident in the United States, perhaps because of the emphasis here on making detailed soil maps for their practical predictive value. Progress in transforming the profile concept into a more reliable predictive tool was rapid because a large body of important field data had already been accumulated. By 1925 a large amount of morphological and chemical work was being done on soils throughout the country. The data available by 1930 were summarized and interpreted in accordance with this concept, as viewed by Marbut, in his work on the soils of the United States.[11]

Further, early emphasis on genetic soil profiles was so great as to suggest that material lacking a genetic profile, such as fresh alluvium, was not soil. A sharp distinction was drawn between rock weathering and soil formation. Although a distinction between these sets of processes is useful for some purposes, rock weathering and soil formation are commonly indistinguishable.

Marbut always emphasized strongly that classification of soils should be based on morphology instead of on theories of soil genesis, since theories are both ephemeral and dynamic. He perhaps overemphasized this point. Because some workers assumed that soils had certain characteristics without examining the soils, Marbut tried to make clear that examination of the soils themselves is essential in developing a system of soil classification and in making usable soil maps. In spite of this, Marbut's own work reveals his personal understanding of the contributions of geology to soil science. His soil classification of 1935 depends heavily on the concept of a "normal soil": the product of equilibrium on a landscape where downward erosion keeps pace with soil formation.

The soil surveys published between 1920 and 1930 reveal a marked transition from earlier concepts to emphasis on soil profiles and soils as independent bodies. The maps retained the significant boundaries related to geology, as soil maps do today, and many of the surveys of that period provide excellent general maps for evaluating engineering properties of geologic material. In addition, the maps and texts of the period show more recognition of other soil properties significant to farming and forestry than do earlier surveys and have value for broad generalizations about farming practices in large areas.

The concept of soil was gradually broadened and extended during the years following 1930. This revision essentially was a matter of consolidation and balance. The major emphasis had been on the soil profile. After about 1930, morphological studies were extended from single pits to long trenches or a series of pits in an area of a soil. The morphology of a soil came to be described by ranges of properties deviating from a central concept instead of by a single "typical" profile.

Clarification and broadening of the concept of soil also grew out of increasing emphasis on detailed soil mapping. Concepts changed with increased emphasis on predicting crop yields for each kind of soil shown on the maps. Many of the older descriptions of soils had not been quantitative enough and the units of classification had been too heterogeneous for making the yield and management predictions needed for planning the management of individual farms.

The use of aerial photographs for soil mapping, which began during the late 1920's and early 1930's, greatly increased the precision of plotting soil boundaries. To meet the needs for planning the management of individual fields and farms, greater precision of interpretation was also required. Changing objectives of soil surveys brought changes in methods and techniques that made surveys more useful. The associated change in perspective forced reconsideration of the concept of soil itself.

During the 1930's, soil formation was explained in terms of loosely conceived processes, such as "podzolization," "laterization," "calcification." These were presumed to be unique processes responsible for the observed common properties of soils of a region. Since 1940, time has assumed much greater significance among the factors of soil formation, and geomorphological studies have become important in determining the time that soil material at any place has been subjected to soil-forming processes.

Meanwhile, advances in soil chemistry, soil physics, soil mineralogy, and soil biology, as well as in the basic sciences that underlie them, have added new tools and new dimensions to the study of soil formation. As a consequence, the formation of soil has come to be treated as the aggregate of many interrelated physical, chemical, and biological processes. These processes are subject to quantitative study as physics, chemistry, mineralogy, and biology. The focus of attention also has shifted from the study of gross attributes of the whole soil to the detail of individual parts, including grain-to-grain relationships.

In both Marbut's classification and the 1938 classification developed by the U. S. Department of Agriculture, the classes were described mainly in qualitative terms. Classes were not defined in quantitative terms that would permit application of the system consistently by different scientists. Neither system definitely linked the classes of its higher categories to the soil series that were used in soil mapping. Both systems reflected the concepts and theories of soil genesis of the time, which were themselves predominantly qualitative in character. Modification of the 1938 system in 1949 corrected some of its deficiencies, but also illustrated the need for a reappraisal of concepts and principles. More than fifteen years of work culminated in a completely new soil taxonomy. This became the official classification system of the U. S. National Cooperative Soil Survey in 1965 and was published as Soil Taxonomy in 1975.

Though the categories and classes of the new taxonomy are direct consequences of new and revised concepts and theories, its major contribution does not come primarily from the superiority of its classes and categories over those of previous systems. The classes and categories will undoubtedly change as new knowledge is obtained. The most significant contribution comes from defining class limits quantitatively. The theories on which the system is based are tested every time the taxonomy is applied. More importantly for soil survey, the application of quantitatively defined classes to bodies of soil can produce quantitatively defined map units. These, in turn, can be interpreted with more precision than was formerly achieved. Further, this taxonomy permits simplification and acceleration of soil correlation.

In addition to the new soil classification system, several other techniques have contributed to increased precision of soil survey. The use of aerial photographs as mapping bases became almost universal in detailed soil mapping during the late 1930's and early 1940's. Using aerial photographs has greatly increased the precision with which soil boundaries can be delineated on maps. At the same time, the scale of published maps was increased from about 1:62,500 to mainly 1:24,000 to 1:15,840. The smallest area that can be delineated legibly at a scale of 1:62,500 is about 4 ha; areas of 1 ha can be delineated legibly at a scale of 1:15,840.

One additional factor has had an immense impact on soil survey, especially during the 1960's. Prior to about 1950, the primary applications of soil surveys were farming, ranching, and forestry. Applications for highway planning were recognized in some states as early as the late 1920's, and soil interpretations were placed in field manuals for highway engineers of some states during the 1930's and 1940's. Nevertheless, the changes in soil

surveys during this period were mainly responses to the needs of farming, ranching, and forestry. During the 1950's and 1960's nonfarm uses of the soil increased rapidly, creating immense problems and a great need for information about the effects of soils on those uses.

Cooperative research with the Bureau of Public Roads and state highway departments beginning about 1950 established a firm basis for applying soil surveys to road construction. Working together, soil scientists and engineers and others have developed interpretations of soils for roads and other nonfarm uses. These interpretations, which have become standard parts of published soil surveys, require different information about soils. Some soil properties that are not important for growth of plants are of overriding importance in evaluating soils for building sites, sewage disposal systems, highway construction, pipelines, recreation, or other uses. Many of these uses of soil require very large capital investments per unit area; errors can be extremely costly. Consequently, precision in the location of soil boundaries, in identification of the areas delineated, and in quantitative definition of map units has assumed even greater importance.

The Modern Concept of Soil

Soil is "the collection of natural bodies on the earth's surface, in places modified or even made by man of earthy materials, containing living matter and supporting or capable of supporting plants out-of-doors. Its upper limit is air or shallow water. At its margins it grades to deep water or to barren areas of rock or ice. Its lower limit to the not-soil beneath is perhaps the most difficult to define. Soil includes the horizons near the surface that differ from the underlying rock material as a result of interactions, through time, of climate, living organisms, parent materials, and relief. In the few places where it contains thin cemented horizons that are impermeable to roots, soil is as deep as the deepest horizon. More commonly soil grades at its lower margin to hard rock or to earthy materials virtually devoid of roots, animals, or marks of other biologic activity. The lower limit of soil, therefore, is normally the lower limit of biologic activity, which generally coincides with the common rooting depth of native perennial plants."[12]

The "natural bodies" of this definition include all genetically related parts of the soil. A given part, such as a cemented layer, may not contain living matter or be capable of supporting plants; but it is still a part of the soil if it is genetically related to the other parts and if the body as a unit contains living matter and is capable of supporting plants.

By omitting any reference to soil formation, the definition includes as soil all natural bodies that contain living matter and are capable of supporting plants even though they do not have genetically differentiated parts. A fresh deposit of alluvium or earthy manmade fill is soil if it can support plants. If fill cannot support plants, it is not soil.

To be soil, a natural body must contain living matter. This excludes former soils now buried below the effects of organisms. This is not to say that buried soils may not be characterized by reference to taxonomic

classes. It merely means that they are not now members of the collection of natural bodies called soil.

Not everything "capable of supporting plants out-of-doors" is soil, however. Bodies of water that support floating plants such as algae are not soil, but the sediment below shallow water is soil if it can support bottom-rooting plants such as cattails or reeds. The above-ground parts of plants are also not soil, though they may support parasitic plants. Rock that supports mainly lichens on the surface or plants only in widely spaced cracks is also excluded.

The transition from not-soil to soil can be illustrated by recent lava flows in warm regions under heavy and very frequent rainfall. Plants become established very quickly in such climates on the broken types of basaltic lava, even through there is very little earthy material. The plants are supported by the porous rock filled with water containing plant nutrients. Organic matter soon accumulates, but even before it does the dominantly porous broken lava in which plant roots grow is soil.

More than 40 years ago, Marbut wrote "The soil consists of the outer layer of the earth's crust...."[13] Marbut's definition implies a concept of soil as a continuum. The current definition refers to "the collection of natural bodies on the earth's surface," which implies the division of that continuum into discrete, defined parts that can be treated as members of a population. The perspective of soil has changed from one in which the whole was emphasized and its parts were loosely defined to one in which the parts are sharply defined and the whole is an organized collection.

Pedon and Polypedon

In soil surveys the individual parts that make up the soil continuum are classified. The classes are defined to include bodies of soil of significant kinds and sizes. The classes are concepts, not real soils, but they are related to their representatives in nature: the pedon and the polypedon.

Pedon.--The basic soil unit is the pedon, a small element in the soil continuum. It is the smallest unit of soil that can be classified. It consists of material that has been modified by climate, living organisms, time, and relief. A pedon is large enough to include representative variations in the shape and relation of horizons and in the composition of the soil. Not only is the pedon the basic soil body, but it also serves as a standard unit for describing soil and for obtaining samples for laboratory work.

A pedon extends down to the lower limit of soil. It extends through all genetic horizons and, if the genetic horizons are thin, into the upper part of the underlying regolith. The pedon includes the rooting zone of most native perennial plants. For purposes of most soil surveys, a practical lower limit of the pedon is bedrock or a depth of about 2 m, whichever is shallower. A depth of 2 m provides a good sample of major soil horizons, even in thick soil; it includes much of the volume of soil penetrated by plant roots; and it permits reliable observations of soil properties.

The surface of a pedon is roughly polygonal and ranges from 1 m^2 to 10 m^2 in area, depending on the nature of the variability in the soil. Where the cycle of variations is less than 2 m and all horizons are continuous and nearly uniform in thickness, the pedon has an area of approximately 1 m^2. Where horizons or other properties are intermittent or cyclic over an interval of 2 to 7 m, the pedon includes one-half of the cycle (1 to 3 1/2 m). If horizons are cyclic over an interval greater than 7 m, each cycle is considered to contain more than one soil.

The minimum size of a pedon is large enough that individual peds or coatings or a vertical hole a few centimeters in diameter filled with soil material is not called a soil. The range in size, 1 to 10 m^2, permits consistent classification by different observers where important horizons are cyclic or repeatedly interrupted over short distances.

Polypedon.—A group of contiguous pedons of a single soil series makes up a polypedon. The limits of properties of a soil series mark the boundary of a polypedon (figure 1-1). The range of internal properties of a polypedon is estimated by selecting and studying many of its constituent pedons. If any group of contiguous pedons within the boundary of a polypedon exceeds the defined limits of the soil series, the group constitutes another polypedon that is a member of another series. Thus, one polypedon can surround another.

The minimum area of a polypedon approaches that of a single pedon, but a polypedon is enough larger that it represents ranges in most characteristics much better than any single pedon. No maximum area is specified. The range in properties of a polypedon does not necessarily cover the entire range of a soil series; a single polypedon generally covers only part of the range. A soil series is composed of many polypedons that may be far apart.

Polypedons link the real bodies of soil in nature to the mental concepts of taxonomic classes. Polypedons are delineated on maps as accurately as technique, scale, and soil patterns permit.

Factors that Control the Distribution of Soils

Properties of soil vary from place to place, but this variation is not random. Natural soil bodies are the result of climate and living organisms acting on parent material, with relief exerting a modifying influence and with time required for soil-forming processes to act. For the most part, soils are the same wherever all elements of the five factors are the same. Under similar environments in different places, soils are similar. This regularity permits prediction of the location of many different kinds of soil.

The effects of soil-forming factors on the soil are recognized at different geographic scales. When soils are studied in small areas, the likely conclusion is that relief, parent material, and time are most important. Local differences are associated mainly with differences in these factors. In the humid region, for example, wet soils and the properties associated with wetness are common in low-lying places, and better drained

soils form in higher lying areas. The correct conclusion is that relief is important. In arid regions, the differences associated with relief may be salinity or sodicity, but the conclusion is the same. In a local environment, different soils are associated with contrasting parent materials, such as residuum from shale and from sandstone, and the correct conclusion is that parent material is important. Alluvial soils on a flood plain differ from alluvial soils on higher and older terraces, and the correct conclusion is that time is important. These kinds of relationships are observed repeatedly while mapping a small area.

With some notable exceptions such as the contrasting patterns of vegetation in transition zones, local differences in vegetation are closely associated with differences in relief, parent material, or time. The effects of microclimate on vegetation may be reflected in the soil, but such effects are likely associated with differences in relief.

Properties determined by climate and vegetation generally persist throughout a region even though the local factors associated with relief, parent material, and time influence the soil as well. If a scientist's experience is confined to a single environmental region, understanding the impact of climate and vegetation on soils is unlikely. In spite of local differences, most of the soils in an area typically have some properties in common. The low base status of many soils in humid regions stands in marked contrast to the typical high base status in arid regions. To one who has studied soils only on old landscapes of humid regions, however, low base status is so commonplace that little significance is attached to it. The properties of soils of subhumid temperate grasslands contrast with those of soils of humid temperate forests, of the humid tropics, and of other regions. The common properties of the soils of any region are "normal" to one who has studied soil only in that region, but the scientist who studies soil from region to region is much impressed with the differences in soil properties associated with large-scale differences in climate and vegetation.

The regional patterns of climate and vegetation can be used to predict the kinds of soil in large areas. The local patterns of relief, parent material, and time, and their relationships to vegetation and microclimate, can be used to predict the kinds of soil in small areas. Soil surveyors learn to use local features, especially relief and associated vegetation, as marks of unique combinations of all five factors. These features are used to predict boundaries of different kinds of soil and to predict some of the properties of the soil within those boundaries. But scientists working on a local survey must be fully aware of the regional effects of climate and vegetation on the soils they study. Otherwise their outlook becomes provincial and the commonplace is not recorded.

Geographic order suggests relationships. Within a landscape, running water, with weathering and gravitation, commonly sculptures landforms. Over the ages, earthy material has been removed from some landforms and deposited on others. The landforms are interrelated within the landscape. Each landform has a high degree of unity; the entire area has unity through the interrelationships of the landforms.

Each distinguishable landform may have one kind of soil or several. Climate, including its change with time, commonly has been about the same

throughout the extent of a minor landform. The kinds of vegetation associated with climate also likely have been fairly uniform. Relief varies within some limits characteristic of the landform. The time that the material has been subjected to soil formation has probably been about the same throughout the landform. The surface of the landform may extend through one kind of parent material and into another. Of course, position on the landform may have influenced soil-water relationships, microclimate, and vegetation.

A catena is a group of geographically associated, unlike soils that differ in relief. In the United States, the term is applied to a group of soils that formed in similar parent materials but that differ in relief and associated degree of wetness. The term "catena" has been used in a somewhat broader sense in East Africa for a group of soils occupying a significant range of relief features but formed in either similar or unlike parent materials.

Just as different kinds of soil are commonly associated in a landscape, several landscapes are commonly associated in still larger areas. These areas cover thousands or tens of thousands of square kilometers. Many can be identified on photographs taken from satellites. From this vantage point broad geomorphic units such as the East Gulf Coastal Plain, the Allegheny Plateau, the Laramie Basin, and the Great Valley of California are apparent. These broad units usually have some unity of landscape, which is characterized by such terms as "plain," "plateau," and "mountain." These geomorphic units are composed of many landforms characteristic of a large number, commonly hundreds, of kinds of soil.

The main relief features of a geomorphic unit are usually the joint products of deep-seated forces and a complex set of surface processes acting over long spans of time. Within a geomorphic unit, groups of minor landforms are shaped principally by climate-controlled processes. The climate and biological factors, however, vary much less within a geomorphic unit than across a continent.

Still broader than the geomorphic units are great morphogenetic regions having distinctive climates. For example, one classification recognizes glacial, periglacial, arid, semiarid-subhumid, humid-temperate, and humid-tropical climatic regions associated with distinctive sets of geomorphic processes. Other major regions characterized by seasonal climatic variation are also recognized. These geomorphic-climatic regions are related to soil moisture and soil temperature regimes.

The great climatic regions are divided into major geomorphic units. Minor landforms and associated landscapes of soil are small parts of these units and are commonly of relatively recent origin.

The minor landforms of concern in soil mapping include constructional units, such as glacial moraines, and elements of local sequences of graded erosional and constructional land surfaces. These bear the imprint of local base level controls under climate-induced processes. Most surfaces that have formed within the last ten thousand years have been subject to climatic and base-level controls similar to those of the present. Older surfaces may

retain the imprint of climatic conditions and related vegetation of the distant past. In many places those conditions differed significantly from that of the present. Most minor landforms of the present started to form during the Quaternary Period; some started in late Tertiary time. Understanding the attributes of landforms in the present requires understanding climatic changes locally and worldwide far into the past.

The implications and consequences of geomorphic processes are so important in mapping soils that a prime requirement for soil survey work is a strong knowledge of geomorphology. Soil scientists must have a working knowledge of local geomorphic relationships in areas where they map and must understand the interpretations of landforms and land surfaces made by geomorphologists. The intricate interrelationships of soil and landscape can be best studied by collaboration between soil scientists and geomorphologists.

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Figures

Figure 1-1.—Diagram of a polypedon as a unit soil body on the earth's surface. Its margins represent the geographic limits of the properties of a soil series. (Courtesy Walter M. Simonson.)

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Footnotes

[1]E. W. Hilgard was one of the first true pedologists in the United States, but during his lifetime he never received the credit that his accomplishments deserved. See for example—

Geology and Agriculture of the State of Mississippi. 391 pp., 1860.

A Report on Cotton Production in the United States; Also Embracing Agricultural and Physiogeographical Descriptions of the Several Cotton States and California in volumes 5 and 6 of the 10th Census of the United States, 1884.

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[2]N. S. Shaler. The Origin and Nature of Soils. U.S. Geol. Surv. Annl. Rpt. 12, pp. 213-345, illus., 1891.

[3]O. P. Merrill. A Treatise of Rocks, Rock-Weathering and Soils. New ed., 411 pp., illus., 1906.

[4]H. Jenny. E. W. Hilgard and the Birth of Modern Soil Science. Pisa, Italy, 144 pp., illus., 1961.

[5]For example: F. H. King. A Textbook of the Physics of Agriculture. Ed. 3, 604 pp., illus., 1910.

[6]G. N. Coffey. A Study of the Soils of the United States. U.S. Dept. Agric., Bur. Soils Bull. 85, 114 pp., illus., 1912.

[7]M. G. Cline. Historical Highlights in Soil Genesis, Morphology and Classification. Soil Sci. Soc. Am. J. 41:250-254, 1977.

[8]K. K. Gedroiz. Soil-Absorbing Complex and the Absorbed Soil Cations as a Basis of Genetic Soil Classification. Nossov Agr. Expt. Sta. Paper 38, 29 pp., Leningrad. Trans. by S. A. Waksman. (In papers on soil reaction 1912-25.)

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S. S. Neustruev. Genesis of Soils. Russ. Pedol. Invest. 3, Acad. Sci., 98 pp., Leningrad, 1927.

[9]K. D. Glinka. The Great Soil Groups of the World and Their Development. Trans. from the German by C. F. Marbut. 235 pp., 1917.

[10]C. F. Marbut. The Contribution of Soil Surveys to Soil Science. Soc. Prom. Agr. Sci. Proc. 41:116-142, illus., 1921.

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Soil Science Society of America. Life and Work of C. F. Marbut. 271 pp., illus., 1942.

[11]C. F. Marbut. Soils of the United States. In Atlas of American Agriculture, pt. III. Advance Sheets, No. 8. U.S. Dept. Agric., 1935.

[12]United States Department of Agriculture. Soil Taxonomy: A Basic System of Classification for Making and Interpreting Soil Surveys. U.S. Dept. Agric. Handb. 436, 1975. p. 1.

[13]C. F. Marbut. Soils of the United States. p. 11.

[14]A landform is any feature of the earth's surface produced by natural causes. A landscape is a collection of landforms. The terms are relative: a hill is a landform, but it is also a landscape if the individual parts—summit, shoulder, side, footslope—are each considered landforms.

*U.S. GOVERNMENT PRINTING OFFICE : 1984 0-420-971/SCR-421

Chapter 2

Soil Surveys

Nature, Purposes, and Uses

A soil survey is a field investigation of the soils of a specific area, supported by information from other sources. The kinds of soil in the survey area are identified and their extent shown on a map, and an accompanying report describes, defines, classifies, and interprets the soils. Interpretations predict the behavior of the soils under different uses and the soils' response to management. Predictions are made for areas of soil at specific places. Soils information collected in a soil survey is useful in developing land-use plans and alternatives involving soil management systems and in evaluating and predicting the effects of land use.

Soil surveys began in the United States as a result of the U.S. Department of Agriculture Appropriations Act for fiscal year 1896. The act authorized funds for "Investigation in relation to agricultural soils, Division of Agricultural Soils" and "Investigation of the relation of soils to climate and organic life; for the investigation of the texture and composition of soils in field and laboratory."

In 1899 the U.S. Department of Agriculture completed field investigations and soil mapping of portions of Utah, Colorado, New Mexico, and Connecticut. Reports of these soil surveys and similar works were published by legislative directive. At the same time, the State of Maryland was completing a soil survey of Cecil County using similar procedures but financed by the state. Since then many soil surveys have been initiated, completed, and published cooperatively by the Department of Agriculture with state agencies and with other federal agencies. The total effort is the National Cooperative Soil Survey.

The early soil surveys were directed toward the investigation of soils used for farming, ranching, and forestry. As experience was acquired in the use of soil surveys, predictions were made about other uses, such as highways, airfields, and residential and industrial developments. As the making and the use of soil surveys expanded, the knowledge about soils--about their nature, occurrence, and behavior for defined uses and management--also increased. The Highway Department of Michigan was applying soil survey experience to assist in planning highway construction in the late 1920's. At about the same time soil surveys in North Dakota were used in tax assessment. Beginning in the 1930's, the Soil Conservation Service used soil surveys for resource conservation planning of farms and ranches with emphasis on control of soil erosion. In the 1950's Fairfax County, Virginia, made extensive use of soil survey information in urban land

development. During the late 1950's, soil survey information was applied to subdivision design in suburban areas of Chicago. Soil surveys were an important base for resource information in regional land use planning in southeastern Wisconsin. Rural land zoning has also relied on soil surveys.

Soil surveys are needed for all these purposes because there are many thousands of different kinds of soil--as many as there are significant combinations of the genetic factors. The properties of each soil can be learned through observation and research in the field and in the laboratory. The history of a soil and evidence of its potentials for use are contained in these properties, considered collectively. The influence on soil behavior of any one property, or of a variation in any one, depends on the others in the combination. The soil survey applies its findings to the practical problems of using soils within this perspective.

The different kinds of soil shown on a soil map have sets of interrelated properties that are characteristic of soil as a natural body. This definition is intended to exclude maps showing the distribution of a single soil property such as texture, slope, or depth, alone or in combinations; maps that show the distribution of soil qualities such as productivity or erodibility; and maps of soil-forming factors, such as climate, vegetation, or geologic material. A soil map delineates areas occupied by different kinds of soil, each of which has a unique set of interrelated properties characteristic of the material from which it formed, its environment, and its history. The soils mapped by the National Cooperative Soil Survey are identified by names that serve as references to a national system of soil taxonomy.

The geographic distribution of many individual soil properties or soil qualities can be extracted from soil maps and shown on separate maps for special purposes, such as showing predicted soil behavior for many uses. The number of such interpretative maps that can be derived from a soil map is large, and each such map would differ from the others according to its purpose. Rarely can a map made for one specific interpretation serve a different purpose.

Maps to show one or more soil properties can be made directly from field observations without making a basic soil map. Such maps serve their specific purposes but have few other applications. Predictions of soil behavior can also be mapped directly. However, most such interpretations need to be changed with changes in land use and in the cultural and economic environment. A map showing productivity of crops on soils that are wet and undrained, for example, has little value after drainage systems have been installed. If a soil map is made accurately, interpretative maps can easily be revised as needed. But if only "judgment" maps are made, without a soil map, any significant change in the enterprise or the cultural or economic environment requires that the fieldwork be done again. In planning soil surveys, this point needs to be emphasized. Occasionally "short-cut" inventories are made for some narrow objective, perhaps at a cost lower than that of a soil survey. Such maps quickly become obsolete. They cannot be revised without fieldwork because vital data were ignored, facts

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were mixed with interpretations, or boundaries between significant soil units were omitted.

The basic objective of soil surveys is the same for all kinds of land, although the number of map units, their composition, and the detail of mapping vary with the complexity of the soil patterns and the specific needs of the users. Thus a soil survey is matched to the soils and the soil-related problems of the area. Although soil surveys help us to increase our general knowledge about soils, they are most commonly made for more practical purposes. They satisfy a need for soils information about specific geographic areas for state, county, and community land use plans, resource conservation plans for farms and ranches, development of reclamation projects, forest management, preliminary planning for engineering projects and works, and many other purposes.

Although soil surveys can be made to satisfy a single purpose, this is rarely done. Most commonly they are made for areas sufficiently large to have more than one kind of important land use and many users with varied interests and needs. These needs may be few and noncomplex in areas of extensive land use that is not expected to change. These needs may be many and complex in areas of intensive use where many land use changes are expected.

Predictions for uses of soils other than farming, grazing, wildlife habitat, and forestry have tended to concentrate on limitations of soils for the intended uses. Where investment per unit of area is high, modifying the soil to improve its suitability for the intended use may be economically feasible. Soil scientists work with engineers and others to develop ways of improving soils for specific uses. These kinds of predictions are increasing in importance in areas where the demands on soil resources are high.

Information about soils can also be used for more general land-use planning. Land-use planning is the setting of policies and preparation of programs that influence the use of land. Land-use planning may be done at different levels of detail, from small tracts to regions of several million acres. The term "land" connotes real estate in defined tracts. "Land" includes more than soil. The predictions of soil surveys serve as a basis for judgment about land use and management but are not themselves recommendations. Valid recommendations for land use and management depend on much more than just soil.

The information assembled in a soil survey is used to predict or estimate the potentials and limitations of soils for many specific uses. The information must be interpreted in forms that can be used by professional planners and others. It is only part of the information they must use to make workable plans, but it is an important part.

Soil surveys are used to appraise potentials and limitations of soils in local areas having a common administrative structure. Planning at this level is sometimes called <u>community planning</u>, for it applies to community

units such as villages, towns, or townships, to counties or parishes, and tc trade areas that include more than one local political unit.

Soil surveys are also used to evaluate soil resources in multicounty or multistate areas that have problems that cannot be resolved by local political units. Regional planning deals with land use in broad perspective and necessarily appraises the potential of large areas. Regional planning is done in less detail than community planning. Soil surveys and their interpretations for regional planning are correspondingly less detailed and less specific. Soil maps and their interpretations for regional planning must provide graphic presentations of the predominant kinds of soil of similarly large areas.

Soil surveys provide the basic information about soil resources needed for planning development of new lands or conversion of land to new uses. The failures of trial-and-error land settlements had much to do with the start of the soil survey in the United States. Soil surveys are used to avoid waste caused by ignorance of soil limitations when major changes of land use are contemplated and when new lands are to be brought into use.

Soil survey information is important in planning specific land uses and the practices needed to obtain desired results. For example, if recreational use is being considered, a soil survey can indicate the limitations and potentials of the soils for recreation. The soil survey can furnish much information useful to a landscape architect in designing the area. A contractor can use the soil survey in planning the grading and in implementing an erosion control program during construction. A horticulturist can use it in selecting suitable vegetation.

Soil surveys provide a basis for decisions about the kind and intensity of management operations needed, including those operations that must be combined for satisfactory soil performance. For instance, soil survey information is useful in planning, designing, and implementing an irrigation system for a farm. The kind of soil and associated characteristics help in determining length of run, water application rate, soil amendment needs, leaching requirements, a general fertilization program, drainage requirements, and field practices for maintaining optimum soil conditions for plant growth.

Soil surveys are also useful in helping to locate possible sources of sand and gravel or of topsoil. They assist in siting agricultural research fields and plots and in the transfer of experiment results to other areas with similar soils. Much knowledge about use and management of soils has been spread by applying experience from one location to other areas with the same or similar soils and related conditions.

The hazards of nutritional deficiencies for plants, and even for animals, can be predicted from soil maps if the relationships of deficiencies to soils have been established. In recent years, important relationships have been worked out between many soils and deficiencies of such elements as copper, boron, manganese, molybedenum, iron, cobalt, chromium, selenium, and zinc. The relationships between soils and

deficiencies of phosphorus, potassium, nitrogen, magnesium, and sulfur are more widely known. Relationships of soils to some toxic chemical elements have also been established. By no means have all of the important soils been characterized, especially for the trace elements, and much more research is needed.

Land appraisal.--Many attributes of land contribute to its value. Soil is one of these. The relative importance of soil varies widely among the many uses of land. Where the soil is a factor of production, as in farming, ranching, or forestry, its capacity to produce and its requirements for production are elements of land value. Where capital investments are so high that the cost of modifying or replacing the soil is insignificant, soil has little influence on land value.

Soil surveys provide detailed information about the soil component of land, and this information cannot be obtained from any other source. Soil surveys can be interpreted specifically in terms of soil qualities that bear directly on land values for many different purposes. The interpretations are used most often, however, in assessing farmland for taxation and equalization, in appraising land for loans, and in guiding land buyers.

The soil is only one of the elements that must be considered for appraisal of land value within the total economic and institutional environment of an area. Many of the other elements that determine value of real estate can change with time. One of the important attributes of soil surveys is the fact that their record of the kinds of soil remains valid. A survey can easily be reinterpreted as economic or institutional conditions change.

Other uses.--In addition to their many widely recognized uses, soil surveys serve many other purposes.

Soil surveys provide essential data and information for the compilation of general soil maps. Many soil surveys are done for purposes that require relatively intense field investigation and map scales of about 1:12,000 to 1:24,000. However, a smaller scale soil map with more broadly defined units may be better for some uses, such as developing land-use plans for large areas. This map can be made by grouping units of the large-scale soil maps and generalizing the map detail. The resulting map units are more useful for the intended use. The scale of the general soil map is usually selected to be the same as the land-use planning map.

Soil surveys also provide information for compiling schematic soil maps of areas that are largely unsurveyed. Schematic soil maps are made by predicting the kinds of soil in an area from existing information, largely or entirely without the benefit of preexisting soil survey maps or field investigations. Scattered soil surveys in these areas provide some soil information that can be projected by photo interpretation or other means to unsurveyed areas. In some areas it is possible to generally predict with some reliability the occurrence of kinds of soil from related physiographic, geographic, geologic, or vegetative features. Although schematic soil maps are not as reliable as large-scale, more detailed soil maps based on field

investigations, they are useful where the other information is not available.

Soil surveys have served as a basis for educational programs to inform people of the important place soil resources have in maintaining a quality environment (Chapter 12).

Small-scale soil maps provide a basis for comparison of broadly defined capabilities and limitations that relate to the soil on regional, national, and even worldwide scales. International cooperation among soil scientists has accomplished much in relating the different soil classification systems of various countries to one another. This permits extending the findings of research on soils of one country to similar kinds of soil elsewhere. Since 1960, many people in many parts of the world have been working with the soil taxonomy that is used for the soil surveys of the United States. Many have contributed ideas and data that form the basis of this system. As a result, the uses of soil survey data have been extended far beyond the boundaries of the countries where the data were obtained.

Orders of Soil Surveys

All soil surveys are made by examining, describing, and classifying soils in the field and delineating their areas on maps. Some surveys are made to serve users who need precise information about the soil resources of areas a few hectares or less in size. They require refined distinctions among small, homogeneous areas of soil. Other surveys are made for users who need a broad perspective of heterogeneous but distinctive areas of thousands of hectares. A soil survey made for one group of users may not serve the other group well.

The elements of a soil survey can be adjusted to provide the most useful product for the principal intended purposes. Different intensities of field study, different degrees of detail in mapping, different phases or levels of abstraction in defining and naming map units, and different map unit designs produce a wide range of soil surveys. Adjustments in these elements form the basis for differentiating five orders of soil survey (Table 2-1).

Recognition of these different levels of detail is helpful for communicating about soil surveys and maps, even though the levels cannot be sharply separated from each other. The orders are intended to aid in the identification of the operational procedures used to conduct a soil survey. They also indicate general levels of quality control applied during the survey, which affect the kind and precision of subsequent interpretations and predictions.

Orders of soil survey differ in the following elements: 1/

I. The kind of soil survey legend that is used, which is characterized by--

   A. The kinds of map units (consociations, complexes, associations, and undifferentiated groups)

   B. The kinds of soil taxa used to identify the map units (soil series, subgroups, great groups, suborders, and orders, and phases of them)

II. The standard for purity of delineated soil areas, including--

   A. The minimum area of a limiting dissimilar soil that must be delineated separately (and thus excluded from areas identified as another kind of soil)

   B. The maximum percentage of limiting dissimilar inclusions that is permissible in a map unit.

III. The kinds of field operations necessary to identify and delineate areas of the map units within prescribed standards of purity

IV. The minimum map scale required to accommodate the map units of the legend, the standards of purity, and the map detail justified by field methods

Mapping legends are adjusted to provide the degree of refinement of map units required by the objectives of the survey. A map unit can be identified as a consociation (an area dominated by a soil of a single taxon such as a series or a suborder) or as a group (geographic mixture) of taxa, such as associations or complexes. A group may be more heterogeneous, and less refined, than a consociation at the same level of classification. A soil series has a much more narrowly defined set of soil properties than a suborder and so is a more refined distinction. Thus, phases of soil series are used as map units if users need precise information about small areas of soils. Phases of suborders might be used as soil map units if a very broad perspective is need of the soil resources of very large areas.

Standards of purity are adjusted according to the precision required by the survey objectives. Probably all delineations contain some kinds of soil besides that identified in the map unit name. These inclusions reduce purity. Different kinds of inclusions, however, have different effects on the value of the map for use. The inclusions that most detract from purity are those that are distinctly more limiting for use than the named soil. These are called limiting dissimilar soils. Not only the amount of such limiting soils but also the size of their individual areas is important. Soil survey standards for both are set at levels that do not seriously detract from the validity of interpretations based on the named soil.

Standards of purity are attained by adjusting the field operations. If the standards require that areas of limiting dissimilar soils as small as 0.1 ha be delineated, for example, the area must be traversed at intervals close enough to find areas that small and the soil must be examined at enough places along each traverse to detect them.

The map scale must be large enough that areas of the minimum size can be delineated legibly. Figure 2-1 illustrates the effect of scale on legibility of maps.

The choice of map scale also depends on the user's perspective. Users who need precise information about small areas focus their attention on a small part of the map and on a relatively few delineations. They are not distracted by boundaries and symbols on other parts of the map. Consequently, the map scale can usually be the smallest that will permit legible delineation of the smallest areas.

Map users who want a broad perspective of large areas, however, are usually concerned with comparisons among delineations of all, or a large part, of the map. Many closely spaced boundaries and symbols are confusing. Consequently, delineations on maps for such uses are generally larger and fewer in number. Although such maps are usually at small scale, the scale is commonly larger than the minimum that would permit legible delineation of the smallest areas.

Table 2-2 shows the relationships between map scales and the smallest delineations that can be made legibly at those scales. The difference between the smallest delineation that could be made and the smallest that is commonly made increases as map scale decreases.

When the elements of the soil survey are skillfully coordinated with the purposes for making the survey, the needs of the users can be met. The order of a survey is a consequence of field procedures, the minimum size of delineation, and the kinds of map units that are used. Table 2-1 is a key for identifying kinds of soil surveys.

First order surveys are made for very intensive land uses requiring very detailed information about soils, generally in small areas. The information can be used in planning for irrigation, drainage, truck crops, citrus or other specialty crops or experimental plots, individual building sites, and other uses that require a detailed and very precise knowledge of the soils and their variability.

Field procedures permit observation of soil boundaries throughout their length. The soils in each delineation are identified by transecting or traversing. Remotely sensed data are used as an aid in boundary delineation. Map units are mostly consociations with some complexes and are phases of soil series or are miscellaneous areas. Some map units named at a categorical level above the series may be appropriate. Delineations have a minimum size of about 1 hectare (2.5 acres) or less, depending on scale, and contain a minimum amount of contrasting inclusions within the limits

permitted by the kind of map unit used. Base map scale is generally 1:15,840 or larger.

Second order surveys are made for intensive land uses that require detailed information about soil resources for making predictions of suitability for use and of treatment needs. The information can be used in planning for general agriculture, construction, urban development, and similar uses that require precise knowledge of the soils and their variability.

Field procedures permit plotting of soil boundaries by observation and by interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals, and the soils in each delineation are identified by transecting or traversing. Map units are mostly consociations and complexes. Occasional undifferentiated groups or associations are also used. Components of map units are phases of soil series or are miscellaneous areas; map units named at a categorical level above the series can be used. Delineations are variable in size, with a minimum of 0.6 to 4 hectares, (1.5 to 10 acres) depending on landscape complexity and survey objectives. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:12,000 to 1:31,680, depending on the complexity of the soil pattern within the area.

Third order surveys are made for extensive land uses that do not require precise knowledge of small areas or detailed soils information. Such survey areas are usually dominated by a single land use and have few subordinate uses. The information can be used in planning for range, forest, recreational areas, and similarly extensive land uses and in community planning.

Field procedures permit plotting of most soil boundaries by interpretation of remotely sensed data. Boundaries are verified by direct observations. The soils are identified by transecting representative areas and applying the information to like areas. Some additional observations are made for verification. Map units are mostly associations, but complexes, consociations and undifferentiated groups can be used. Components of map units are phases of soil series or of taxa above the series, or miscellaneous areas. Delineations have a minimum size of about 1.6 to 256 hectares, (4 to 640 acres) depending on the survey objectives and complexity of the landscapes. Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:20,000 to 1:250,000, depending on the complexity of the soil pattern and intended use of the maps.

Fourth order surveys are made for extensive land uses that need general information for broad statements concerning land-use potential and general land management. The information can be used in locating, comparing, and selecting suitable areas for major kinds of land use, in regional land-use planning, and in selecting areas for more intensive study and investigation.

Field procedures permit plotting of soil boundaries by interpretation of remotely sensed data. The soils are identified by transecting representative areas to determine soil patterns and composition of map units and applying the information to like areas. Most map units are associations, but some consociations and undifferentiated groups may be used in some surveys. Components of map units are phases of soil series or of taxa above the series or are miscellaneous areas. Minimum size of delineations is at least 40 to 4,000 hectares, (100 to 10,000 acres) and contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base map scale is generally 1:100,000 to 1:1,000,000.

Fifth order surveys are made to collect soils information in very large areas at a level of detail suitable for planning regional land use and interpreting information at a high level of generalization. The primary use of this information is selection of areas for more intensive study.

Field procedures consist of mapping representative areas of 39 to 65 square kilometers (15 to 25 square miles) to determine soil patterns and composition of map units. This information is then applied to like areas by interpretation of remotely sensed data. Soils are identified by a few on-site observations or by traversing. Most map units are associations, but some consociations and undifferentiated groups may be used. Components of map units are phases of taxa at categorical levels above the series and miscellaneous areas. Minimum size of delineations is about 1,000 to 4,000 hectares (2,500 to 10,000 acres). Contrasting inclusions vary in size and amount within the limits permitted by the kind of map unit used. Base-map scale ranges from about 1:500,000 to 1:1,000,000 or smaller. 2/

Use of two orders of soil survey in the same project

Some soil survey areas have two or more separate and distinct parts that have different needs. For example, one part may be mapped to make predictions that pertain to irrigated farming but the other to make predictions that relate to range management. The irrigated part should be mapped at the intensity required for a 1st order or 2nd order soil survey, and map units are mostly consociations of narrowly defined phases of soil series. The part used for grazing, however, can be mapped as a 3rd order survey using associations, complexes, and some consociations of more broadly defined phases of soil series or of taxa above the series. Some map units of the two parts will consist of the same kinds of soil, but great care is exercised to ensure that map units for the two different orders of soil survey maps do not have the same names or symbols.

Large separate and distinct areas that are within the same project but surveyed by different methods are distinguished clearly by boundaries on the published soil map or on a small-scale inset map. Each part is identified by a note printed parallel to the line separating the areas of each survey order. The two parts have separate legends. The parts are considered as distinctly different orders of soil survey, but the results are reported in the same publication. The same map scale or different scales

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may be used for the different survey orders, depending on the intended uses.

Many 2nd order surveys delineate some map units by methods that are less intensive, even though the areas mapped at different intensities are intermingled on the map. For example, within an otherwise detailed soil map, the delineations of very steep or very stony soils are commonly investigated at the intensity normally used in a 3rd order survey. This is noted in the discussion about soil survey procedures.

Still other soil surveys include areas consisting of two or more distinctive soils that could be mapped separately by detailed soil survey methods; however, the cost of making the separation cannot be justified. For example, a survey area that is mostly productive soils suitable for general farming may contain large areas of unproductive sandy soils covered with nearly impenetrable brush. Although the sandy areas contain contrasting kinds of soil that could be delineated separately, the cost of detailed mapping to separate the two kinds of soils may exceed the expected return. The outer boundaries of the sandy areas are plotted in as much detail and with as careful investigations as any other boundaries of the soil survey, but the sandy areas themselves are mapped by 3rd or 4th order methods. Transects are made, and the composition of the areas is defined in terms of the kinds, proportions, and patterns of the individual soils. The delineations are described in the text of the published soil survey as soil associations mapped by methods of the appropriate survey order.

Soil Maps Made by Other Methods

Even though most soil maps published by the National Cooperative Soil Survey are made by field investigations, some are compiled from other sources. These kinds of soil maps are described in the following sections.

Generalized soil maps

Some users need soils information about areas larger than individual fields or tracts, as large as perhaps several square kilometers, but a detailed map tends to obscure the broad relationships. Generalized soil maps are made to reveal geographic relationships that cannot be seen readily on detailed maps. Most soil survey reports include a general soil map for the area. The scale of these maps depends on the intended uses. 3/

Generalized soil maps are made by combining the delineations of existing soil survey maps to form larger map units. Scrutiny of a detailed map usually will find large areas in which a few soil series, commonly two or three, are consistently associated. A detailed map is generalized by enclosing those larger areas within which a few kinds of soil predominate in relatively consistent proportions and patterns. These larger areas are described in terms of the dominant soils. The map is interpreted to show the combined effects of the constituent soils of each map unit.

Generalized soil maps are valuable for appraising the basic soil resources of whole counties, for assisting farm advisors in the geographic emphasis of their educational programs, and for guiding commercial interests. Increasingly, these maps are compiled for county and regional land-use planning. They are valuable for predicting the general suitability of large areas of soils for residential, recreational, wildlife, and other nonfarm uses, as well as for agriculture. They are useful to provide first estimates for alternative routes for roads and pipelines where the least problems with soils are expected. They provide valuable soils information as one basis for zoning.

Soil maps that are already less detailed can be generalized further for purposes that require very broad perspective. For example, 3rd order soil surveys for individual counties at scales of less than 1:250,000 can be combined and generalized to provide maps of states or regions at a scale of 1:1,000,000 or smaller. Soil maps that show the soils of areas of a few kilometers can be converted to maps having delineations of a few hundred square kilometers or more. Areas defined as associations of soil series or their phases are combined in this process into larger areas that can be defined in terms of associations of taxa at higher categories. These broad soil associations can be divided into phases to specify ranges in physiography, soil texture, or other features if such distinctions are useful. Soil maps at such levels of abstraction are used for very broad regional planning and other uses that focus on areas of hundreds of square kilometers.

Schematic soil maps

Schematic soil maps are also compiled, but they differ from generalized soil maps in being compiled from information other than pre-existing soil maps. Scale is commonly 1:1,000,000 or smaller, although useful maps are sometimes made at larger scales. Schematic soil maps are commonly made as a preliminary step to locate areas where further investigation is justified. For many areas, especially in undeveloped regions, a schematic soil map is useful in advance of an organized field survey. Some maps serve as continuing references on soils in areas where more intensive studies are not feasible.

Schematic soil maps are made by using many sources of information to predict the geographic distribution of different kinds of soil. First, all available data are assembled. Information about climate, vegetation, geology, landforms, and other factors related to soil are gathered and studied. Data obtained by remote sensing techniques, including aerial photography, may provide useful information. Any available information about the soil is used to the extent justified by its quality. Some soils information exists for most parts of the world, but in wild areas the information may be mainly notes by travelers and rough maps interpreted from aerial photographs without verification on the ground.

A soil is the unique result of five interrelated factors: climate and living organisms, conditioned by relief, acting on parent material for periods of time. If good geographic data about these factors are available, surprisingly good soil maps can be compiled by experienced soil

scientists familiar with the combinations of factors that produce different kinds of soils. The boundaries and the kinds of soil within them are predicted without significant verification by field investigations.

Obviously, all degrees of verification can exist between schematic soil maps with no direct information about soils and maps for which predictions are verified at enough places to lend substantial confidence to the product. Schematic soil maps merge with 5th order (exploratory) soil surveys without a sharp line of distinction.

Table 2-1
Key for Identifying Kinds of Soil Survey

Level of data needed	Field procedures	Minimum size delineation Hectares [1]	Typical components of map units	Kinds of map units [2]	Appropriate scales for field mapping and Publication	Kind of soil survey
Very intensive (i.e., experimental plots, individual building sites)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are observed throughout their length. Remotely sensed data is used as an aid in boundary delineation.	1 or less	Phases of soil series; miscellaneous areas	Mostly consociations; some complexes	1:15,840 or larger	1st order
Intensive (i.e., general agriculture, urban planning)	The soils in each delineation are identified by transecting or traversing. Soil boundaries are plotted by observation and interpretation of remotely sensed data. Boundaries are verified at closely spaced intervals.	0.6 to 4	Phases of soil series; miscellaneous areas; few named at a level above the series	Consociations and complexes; some undifferentiated and associated	1:12,000 to 1:31,680	2nd order
Extensive (i.e., rangeland, forest land, community planning)	The soils are identified by transecting representative areas with some additional observations. Boundaries are plotted mostly by interpretation of remotely sensed data and verified with some observations.	1.6 to 256	Phases of soil series and levels above the series; miscellaneous areas	Mostly associations or complexes; some consociations and undifferentiated groups	1:20,000 to 1:250,000	3rd order
Extensive (i.e., regional) planning)	The soils are identified by transecting representative areas to determine soil patterns and composition of map units. Boundaries are plotted by interpretation of remotely sensed data.	40 to 4,000	Phases of levels above the series; miscellaneous areas; phases	Mostly associations; some consociations, complexes, and undifferentiated groups	1:100,000 to 1:1,000,000	4th order
Very extensive (i.e., selections of areas for more intensive study)	The soil patterns and composition of map units are determined by mapping representative areas and applying the information to like areas by interpretation of remotely sensed data. Soils are verified by occasional onsite investigation or by traversing.	1,000 to 4,000	Phases of levels above the series; miscellaneous areas	Associations; some consociations and undifferentiated groups	1:500,000 to 1:1,000,000 or smaller	5th order

[1] This is about the smallest delineation allowable for readable soil maps (see table 2-2). In practice, the minimum size delineations are generally larger than the minimum size shown.

[2] Where applicable, all kinds of map units (consociations, complex, association, undifferentiated) can be used in any order of soil survey, and they are not identified as a particular order of map unit.

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Table 2-2
Guide to Map Scales and Minimum Delineation Size

Map scale		Inches per mile	Minimum size delineation[1]	
			acres	hectares
1:500		126.7	0.0025	0.001
1:2,000		31.7	0.040	0.016
1:5,000		12.7	0.25	0.10
1:7,920		8.00	0.62	0.25
1:10,000		6.34	1.00	0.41
1:12,000		5.28	1.43	0.57
1:15,840		4.00	2.5	1.0
1:20,000		3.17	4.0	1.6
1:24,000	(7 1/2')	2.64	5.7	2.3
1:31,680		2.00	10.0	4.1
1:62,500	(15')	1.01	39	15.8
1:63,360		1.00	40	16.2
1:100,000		0.63	100	40.5
1:125,000		0.51	156	63
1:250,000		0.25	623	252
1:300,000		0.21	897	363
1:500,000		0.127	2,500	1,000
1:750,000		0.084	5,600	2,270
1:1,000,000		0.063	10,000	4,000
1:5,000,000		0.013	249,000	101,000
1:7,500,000		0.0084	560,000	227,000
1:15,000,000		0.0042	2,240,000	907,000
1:30,000,000		0.0021	9,000,000	3,650,000
1:88,000,000		0.0007	77,000,000	31,200,000

[1]The "minimum size delineation" is taken as a 1/4-inch square area (1/16 sq. in.). Cartographicaly, this is about the smallest area in which a symbol can be printed readily. Smaller areas can be delineated, and the symbol lined in from outside, but such very small delineations drastically reduce map legibility.

Figure 2-1. The same map printed at three scales: A, 1:20,000; B,1:31,680; C, 1:63,360 (equivalent to 3, 2, and 1 inch to 1 mile). The numbers within individual delineations are the acreages of the areas represented. One acre equals about 0.4 ha.

Footnotes

1/ Many of the terms used here to describe orders of soil surveys are explained in other parts of this Manual. Chapter 5 explains "delineations," "map units," "phase," "complex," "consociation," "association," "group," "similar soil," "dissimilar soil," "limiting dissimilar soil," and "inclusion"; soil survey legends are discussed in Chapter 6. Chapter 3 explains maps and map scales, and Chapter 7 explains mapping procedures. The levels of soil classification are explained in Chapter 5 of Soil Taxonomy.

2/ An example is the "Exploratory Soil Survey of Alaska" (Charles E. Kellogg and Iver J. Nugard, U.S. Dep. Agric., Agric. Monogr. 7, 1951). For comparison, the map of "The Soils of the Rosetown Map Area" in Saskatchewan (J. G. Ellis, D. F. Acton, and H. C. Moss; Univ. Saskatchewan, Ext. Div., Ext. Publ. 202; 1970) was made at an intermediate scale with intensive field verification and much preexisting information about the soils. (This survey uses somewhat different conventions for naming soils than those described in this Manual.)

3/ The general soil map of Shawnee County, Kansas, (U.S. Dep. Agric., Soil Conserv. Serv.; 1970) for example, has a scale of about 1:190,000. That in the published soil survey of Gwinnet County, Georgia, (U.S. Dep. Agric., Soil Conserv. Serv.; 1967) has a scale of about 1:62,500. Some generalized soil maps are made for special publications. An example is the map compiled from existing maps to a scale of 1:250,000 prepared for town and country planning in a five-county area in New York where farm and nonfarm uses are competing for the land (Gerald W. Olson, John E. Witty, andRaymond L. Marshall; Soils and Their Use in theFive-County Area Around Syracuse; New York State Coll. Agric., Cornell Misc. Bull. 80; 1969).

Chapter 3

Preparing for Mapping

Planning of a soil survey should start well in advance of field mapping. Many technical details are involved. Besides the soil scientists in the field and laboratory, experts in many different specialties may be involved, including geologists, engineers, plant scientists, photogrammetrists, cartographers, draftsmen, editors, and others.

This chapter describes what needs to be done before mapping begins. It discusses work plans, staffing, equipment and supplies, base maps and related cartographic material, and preliminary fieldwork.

The United States Department of Agriculture is responsible for Federal leadership of the National Cooperative Soil Survey. The Department cooperates with an agency in each of the States, most commonly the agricultural experiment station of the land grant university, under a formal memorandum of understanding. Other agencies--local, State, or Federal--cooperate on individual surveys under separate formal agreements. These agreements may be made by either the Federal or the State cooperator within the framework of the memorandum of understanding. Because participation of a third party can affect the interests of both of the principal cooperators, the one making such an agreement must first consult with the other. The agreements take a variety of forms, depending on procedures of the agencies concerned. They cover a variety of contributions including financial assistance, personnel, equipment, and technical services.

Other agencies, firms, and individuals make surveys of soil or of soil conditions independently of the National Cooperative Soil Survey. Many surveys of small tracts of land are made by private consultants. Some agencies make special surveys of soil conditions for specific purposes. Most of these would not be "soil surveys" as described in this Manual. Some agencies other than the principal cooperators map soils as integral parts of their programs and adhere to standards of the National Cooperative Soil Survey so that their work maybe included in the national program.

Soil surveys in each State are scheduled in long term plans. Any local, State, or Federal agency may propose a new soil survey. New surveys are added to the schedule according to established priorities.

The Memorandum of Understanding

The memorandum of understanding between the responsible Federal agency and the principal State cooperator describes the basis of their collaboration in general terms. Specific commitments and obligations are defined in a memorandum of understanding for each survey area.

The memorandum of understanding clearly states the reasons for making the soil survey, what the work will entail, how it will be done, the scale to be used in the field and for publication, and who is responsible for the various aspects of operations. The memorandum is signed by authorized representatives of each cooperating agency.

The contents and format of soil survey area memoranda of understanding vary in detail, but the following items are significant parts of most:

1. Description of the area to be surveyed. The survey area may be described by giving the name and size where it corresponds with a defined land area, such as a county or other political subdivision. For some areas, the location and boundaries have to be defined geographically, perhaps by a sketch map. A brief description of the physical features of the area is included as background.

2. Mapping specifications. Guidelines for designing map units and determining their composition should be provided. If different levels of intensity of field investigation are to be used, guidelines should explain their relationship to purpose of the survey, map unit composition, and interpretations. The minimum size of each kind of map unit should be stated.

3. Cooperating agencies. The memorandum of understanding identifies all of the cooperating agencies, indicates which has major responsibility for providing leadership, and specifies the contributions that each will make. For some soil surveys, it specifies what personnel, equipment or facilities, financial contributions, or services will be provided by each agency. For other surveys, a more general indication of each agency's role is adequate. The role and function of each agency must be clearly understood and recorded in writing in whatever detail is necessary for orderly operations.

4. Purposes of the survey. Soil surveys should provide information for the specific needs of the survey area. The memorandum of understanding should clearly specify the principal purposes of the survey, such as evaluating areas for residential development, selecting areas suitable for recreation, growing high value cash grain crops, or planning on individual farms. This information is necessary to determine map scale and to inform the soil scientists who will do the mapping and make the interpretations.

5. Staff. The number, and names, if possible, of soil scientists and others who will be assigned to the survey, and the agency employing each should be listed. The name and agency of the party leader should be given, for the party leader, more than on anyone else, is responsible for the quality of the product and the efficiency of the work.

6. Equipment. Special equipment that may be needed and the agency that will provide it, as well as the kinds of vehicles to be used for transport should be described. Tools, equipment, and supplies that are used routinely in most soil surveys need not be listed unless there is a special reason to do so.

7. Kind of mapping base for fieldwork and publication. The memorandum of understanding specifies the kind of mapping base to be used (aerial photographs, topographic maps, or others) and the scale, source and issue date of the maps. Those who have the most need for the survey information participate in the selection. A satisfactory mapping base is selected from possible alternatives at this stage, and that selection should not be changed during the survey. The mapping base must satisfy the survey objectives yet be as economical as possible for all operations. Poor mapping bases increase field costs. The scale must be adequate for the objectives. A scale that is too large, or a change in scale after mapping has started, greatly increases publication cost.

8. Laboratory and other special studies. Special studies are planned at the beginning of the survey if possible. The agencies responsible are specified, and representatives of the laboratories that will do the work participate in the decisions.

9. Interpretations. The purposes for making a soil survey imply what interpretations are essential. The major interpretations to be made and the individuals or agencies responsible should be identified. Special studies to provide data necessary for interpretation and the individuals or agencies responsible are also specified. Any plans for prepublication issue of interpretive maps or reports are included.

10. Publication plans. Plans for preparation of the text are indicated. The names of the individuals responsible for writing the report and the agencies responsible for final publication are given.

11. Schedule. The memorandum of understanding includes the date fieldwork will start and estimated dates that (1) fieldwork will be completed, (2) field maps will be available for final compilation, and (3) the text will be available for editing. An estimated publication date is also given.

12. Other items. Existing reference material about soils, relief, geology, or vegetation may be cited. Required preliminary studies are described. Special conditions in the area, special arrangements for conducting the survey, and other important factors are also noted.

After it is approved the memorandum of understanding may have to be amended during the course of the survey to accommodate unforeseen circumstances. All cooperators must agree to any amendments, and authorized representatives of each agency must sign the amendment document.

The signed memorandum, with any amendments, is a record of the reasons, staff, materials, methods, and responsibilities for surveying the soils of an area. Its essential elements are the same as those for any well-conceived research plan, and it serves the same functions. It is the document that governs the soil survey from start to completion.

Staffing

A party leader is in charge of and is responsible for the survey. Additional soil scientists are assigned as needed to assist in mapping the area, in collecting technical data, and in performing other duties. In some survey areas, unskilled labor can be effectively used for manual tasks. Timely short-term assignment of professionals in other disciplines is helpful in making interpretations and in meeting the purposes of the soil survey.

Quality and efficiency of soil surveys are usually increased if the same soil scientists complete the work within a few years. Over a short timespan, concepts and procedures can be kept consistent and a map of uniform quality can be produced. Also, a single party leader usually can direct the entire survey, and few or no changes will be made in the staff.

The party leader

The party leader is responsible for supervising fieldwork and for keeping its quality high. Supervisory staff can help, and they can appraise the effectiveness of a leader; but they cannot give day-to-day direction of the survey and maintain its standards.

A party leader continually tests the mapping legend. Soil mapping and legend testing must be done in the field. The party leader works with the other members of the field party to solve the problems they encounter in mapping. Other members of the field party and users of the survey are also consulted in interpreting the soils and testing the legend against the objectives of the survey.

As mapping progresses, the party leader reviews the field work of the field party for uniformity of detail, soil identification, accuracy of soil boundaries, and cartographic legibility. He determines that the delineations are adequate for the objectives and that they do not contain unneeded detail. He reviews samples of mapping of each member of the party and, with them, decides what adjustments are needed.

The party leader commonly trains some of the field staff, thereby contributing to the quality of mapping. Inexperienced soil scientists must be trained. A beginning soil scientist does not have the skill necessary for independent mapping, and this skill must be developed. As new people gain experience, continued field checks of their mapping are needed. Experienced workers from other areas must learn the soil relationships in the survey area.

The party leader must see that the field sheets are legible, complete, and joined. He is usually responsible for writing much of the text and assembling the manuscript for the published soil survey, although others, both soil scientists and specialists in other disciplines, may supply field notes and may write various sections of the manuscript under the party leader's direction. The party leader has the major responsibility for interpretations of the soils, though specialists in other disciplines contribute important parts.

From the start of a survey until the maps and text are submitted for publication, the duties of a party leader focus on maintaining internal quality and accuracy. In addition, a party leader works with supervisory staff to insure that the mapping, the classification and interpretations, and the material for publication conform to standards of the National Cooperative Soil Survey.

Survey party staff

The number of persons needed for a soil survey depends on many factors. The scheduling of the work and the projected date of completion dictate input of personnel over a specified period of time. Factors such as the complexity of the soil patterns, the kind of survey and the refinement of map units required for its objectives, the accessibility of the areas to be mapped and the ease or difficulty of traverse, and the experience and proficiency of mappers determine the rate of progress. Characterization and interpretation of soil, assembly of field notes, and preparation of manuscript maps and texts for publication also require personnel and time. The cooperating agencies must either provide the personnel needed to complete the work by the specified time or adjust the projected date of completion to the personnel available.

The abilities of workers are important factors. Because an inexperienced worker can at first do only a limited amount of mapping of acceptable quality and because an experienced soil scientist's time is required for training the new worker, the net accomplishment is usually very small for the first six months of the new person's time. Time must be allowed for even experienced surveyors to learn the relationships among soils and landscapes in a new area, especially if

their experience has been in different environments. Activities other than mapping also require special skills and knowledge that are acquired through experience as well as training.

The stamina of workers is an important consideration. Fieldwork is physically demanding. In areas of rugged relief or dense vegetation only those who are in good physical condition can work efficiently.

Some surveys can be accelerated by judicious use of subprofessional assistants for routine work, such as inking field maps, tabulating data, and measuring the area of map units. In some surveys, subprofessional workers can assist professional soil scientists directly in mapping. Technicians can be trained to map areas and to collect survey data and information under supervision of the party leader. In some surveys unskilled labor can be used effectively for making excavations, cutting lines through dense vegetation, and other tasks.

Many factors must be considered in determining the staff required for a soil survey. The personnel needs must be reflected in the schedule and in personnel estimates in the memorandum of understanding.

Equipment

Many kinds of equipment are used in soil survey field operations. Equipment for transportation, for describing and sampling soils, and for mapping are described in this section. Some specialized kinds of equipment are described in the sections that deal with their use.

Transportation

Field operations of the soil survey require transporting workers, equipment, supplies, and soil samples. Vehicles are provided to the soil survey party for their daily operations. The time spent by soil scientists traveling to and from the field is large and mainly unproductive. Enough vehicles are provided to keep travel time as small as possible.

Additional equipment used for special purposes or for short periods is usually rented or supplied as needed. A passenger van, for example, may be furnished by one of the agencies during a field review. Aircraft may be rented to visit areas not readily reached by ground transport.

The uses of vehicles vary widely from one area to another. In some areas, travel is mainly on roads; in other areas, vehicles must be used to travel across country during mapping or to reach remote sites for soil studies. Some vehicles must carry power equipment or pull trailers. All vehicles that are provided for use should carry workers efficiently and in comfort and safety, hold the equipment used regularly and have some reserve capacity to accommodate an extra load, and protect workers and equipment from adverse weather.

In areas with good roads in which little off-road travel is required, passenger vehicles with large trunks are adequate.

In many areas, pickup trucks are desirable. Trucks are available with optional equipment that may be useful in some areas. Optional equipment includes four-speed transmissions for mountainous and off-road travel; four-wheel drive for off-road travel under adverse conditions; high clearance for travel over rough or

stony areas; oversize radiators for use in hot climates, for use where the truck engine will be idled for long periods, or for use with power probes, augers, or winches powered by the truck engine; special tires and wheels for unusual wet, rocky, or sandy conditions; and special bodies or truck beds for mounting and storing special equipment (figure 3-1). In some remote areas vehicles might be equipped with two-way radios. The various kinds of optional equipment have various disadvantages and limitations such as increased initial cost, increased operating and maintenance cost, increased downtime for the truck, difficulty in obtaining replacement parts, a decrease in the truck's handling qualities, and a decrease in its road speed.

Specialized vehicles are necessary in some areas. Tracked vehicles (figure 3-2) and all-terrain vehicles (ATV's) may be needed in very rugged areas. Marsh buggies with large buoyant tires and airboats are used in swamps and marshes. Snowmobiles provide access in winter to some northern swamps where travel is impossible or impractical in other seasons. Trailbikes can be used in areas that could otherwise be reached only by walking. Specialized vehicles must be reliable in relatively inaccessible areas. The equipment must be transported to the use area. Costs of buying or renting the equipment, maintaining it, and training operators can be high. Time is needed for transport, maintenance, and training. Some kinds of equipment are hazardous to operate. Sensitive ecosystems may be damaged by the equipment.

Aircraft, particularly helicopters, are used in some soil surveys to transport workers and equipment and to provide broad views of landscape and vegetation. Aircraft are useful for photographing landscapes, soil patterns, and land use. Availability, cost, and lack of convenient landing sites are the main limitations.

Tools for examining the soil

A soil scientist examines often in the course of mapping the soil. His most important tools are a spade and a soil auger. A spade or shovel is used to expose soil sections for examination, sampling, and photography. In some areas, a spade is used routinely to examine the soil. Augers are used in most areas for routine mapping. They are faster and more convenient than spades. In soils free of rock fragments, probes provide samples with structure intact. Where a probe or auger is regularly used for examining the soil, some profiles need to be exposed with a spade and examined as a check. Power equipment is often used to save time and effort. Various small instruments may be used to examine the soil.

Spades, shovels, picks, and bars.--For collecting samples, especially after a preliminary excavation has been made, a flat-bladed, squarepointed spade (figure 3-3A) is most convenient. The best spade for ordinary use in mapping is a tile spade or a post-hole spade (figure 3-3B, C) that has been modified by cutting off the sharp corners. A tile spade has a rounded point and tapers at the end. It is superior to a post-hole spade for stony and gravelly soils. The blades of post-hole and tile spades are commonly 30 to 45 cm long. Where deep holes are required, a long-handled spoon-type shovel is useful.

A heavy crowbar and pick may be needed to penetrate dry, cemented, or compact layers. A mattock is especially useful for making holes in soils that are hard, dry, stony, or gravelly. A small army-issue trenching pick will serve satisfactorily in some soils, but commonly the heavier conventional mattock with a long handle is better. One prong is sharply pointed and the other is made as a chisel. For moist soils and those containing many woody roots, the chisel point is

useful; for dry soils, the sharp point is more effective. A geologist's hammer, one end of which can be used as a pick, is also useful in examining rocks and the soil in cuts.

A post-hole digger is useful for removing deep soil material for examination. A digger is heavy and is used mainly for sampling at the botton of pits where digging is difficult. It removes the soil with less disturbance of structure than most kinds of augers.

Augers.--The screw, or worm, soil auger (figures 3-3D and 3-4A) is essentially like a wood auger and ranges from about 2½ to 4 cm in diameter. The worm part is about 15 cm long, and the distance between flanges is about the same as the diameter. If the distance between flanges is less, removing the soil with the thumb is difficult. In clayey soils, a 2½ cm bit may work better than the larger ones. The shaft is commonly 100 to 150 cm long, with extra lengths that can be added for deep boring. The bit will become tapered as it wears and should be replaceable. A scale can be marked on the shaft of the auger to measure depth to the tip.

Screw augers made especially for examining soils are available, but they can also be made from a wood auger bit and lengths of pipe. The auger bit is welded to a steel rod or iron pipe with a crosspiece at the top for a handle.

A screw auger is easily carried, can be used to examine gravelly or stony soils, and can bore holes rapidly. It cannot be used in dry or sandy soil because the soil material will not adhere to the bit. It is hard to pull from the bored hole. The extracted soil material is disturbed more by a screw auger than by other augers and probes.

Several kinds of barrel augers are used. Barrel augers are variously known as post-hole augers, bucket augers, orchard augers, core augers, and other names. They have a cylinder, or barrel, to hold the soil, which is forced into the barrel by cutting lips at the lower end (figure 3-4B). The upper end of the cylinder is attached to a length of pipe with a crosspiece for turning at the top. Although both ends of the cylinder are open, the soil usually packs enough to stay in while the auger is removed from the hole. A few taps of the cylinder on the ground or on a board loosens the soil for removal. Barrel augers with special closed cutting blades are available for use in sandy soils, very wet loose soils, and very dry soils. Tips should be made of hardened steel to resist wear.

Barrel augers disturb the soil less than screw augers. Soil structure, porosity, consistence, and color can be observed better. Barrel augers work well in loose or sandy soils and in compact soils. They are not well suited to use in wet or moist clayey soils, though an open-sided barrel is available that works well. They also work poorly in stony and gravelly soils. Barrel augers bore more slowly than screw augers or probes, and they are generally more bulky to carry. They are easy to pull from the hole. Tips wear excessively if not made of hardened steel. Where animals are grazing, the holes must be filled.

The Dutch mud auger (figure 3-4D) is a modified barrel auger having two connected straps with lips. The cylinder is about 5 to 10 cm in diameter. The cutting blades are so constructed that the soil is loosened and forced into the cylinder of the auger as it cuts into the soil. The Dutch mud auger works well in moist or wet soils of moderately fine or fine texture. It works poorly in other moist or wet soils and in all dry soil.

Soil augers are simple in design and somewhat crude in appearance, but considerable skill is required to use them effectively and safely. They must be pulled from the soil by using a technique that puts stress on the leg muscles, rather than the back muscles, to avoid serious back injury. Twisting the auger firmly while pulling takes advantage of the inclined plane of the screw to break the soil loose. A pair of pipe wrenches is needed to add and remove lengths of shaft and bits.

Probes.--Probes consist of a small-bore tube having a tempered sharp cutting edge slightly smaller in bore but larger in outside diameter than the barrel (figure 3-4C). Approximately one-third of the tube is cut away above the cutting edge so that the soil can be observed and removed. Probes are about 2.5 cm in diameter and about 20 to 40 cm long. The tube is attached to a shaft with a "T" handle at the opposite end. Shaft length can be varied by adding or removing sections. Probes can be used to examine the soil to a depth of 2 m. A pedal that attaches to the shaft is available, allowing the operator to apply body weight. Some workers carry rubber or plastic mallets to drive the tube into the soil. A pair of pipe wrenches is needed to add and remove lengths of shaft.

Probes work well in moist, medium textured soils that are free of gravel, stones, and dense layers. Under these conditions, the soil can be examined faster than with an auger. Probes are very difficult to use in dry or dense soil, in soil having other than medium texture, and in soil containing gravel or stones. Probes disturb the soil less than augers, but they retrieve less soil for examination. Probes are light and easily carried, and they pull from the hole more easily than screw augers. Often a special punch or dowel must be used to clear the tube.

Use of a soil probe is the fastest method to collect samples of surface layers for analysis. Probes used with power equipment (figure 3-1) have wide applications in soil surveys.

Examinations of deep deposits of peat are made with special tubelike samplers. A peat sampler designed by the Macaulay Institute for Soil Research, Aberdeen, Scotland, takes a relatively undisturbed volume that can be used for measurement of bulk density. The Davis peat sampler (figure 3-4E), another design, consists of 10 or more sections of steel rods, each 60 to 120 cm long, and a cylinder of brass or duraluminum, approximately 35 cm long with an inside diameter of about 1.9 cm. The cylinder has a plunger, cone-shaped at the lower end, and a spring catch near the upper end. The sampler is pressed into the peat until the desired depth for taking the sample is reached. Then the spring catch is released, allowing the plunger to be withdrawn from the cylinder. With the plunger withdrawn, the cylinder is filled by forcing it further downward. The cylinder protects the sample from contamination and preserves its structure when the sampler is removed. With this instrument, one can avoid the error of thinking that firm bottom has been hit when actually a buried log is encountered.

Power equipment.--Power equipment is used for rapid excavation or for extracting cores and samples rapidly and from depths that are difficult to reach with hand tools. The use of power equipment results in large savings in time and permits deeper and larger excavations with better exposure of the various horizons than can be attained with hand tools. However, not all sites are accessible to power equipment. Most of this equipment is powered by the motor of the tractor or truck on which the equipment is mounted, though some of the heavier types have separate power units.

A backhoe (figure 3-5) is used to expose vertical sections of soil. The width of the bucket, or shovel, ranges from 30 cm on the smaller models to more than 75 cm on the larger ones commonly used. Backhoes are available that mount on the back of small trucks, but the larger ones are mounted on tractors. Excavations can be made to depths of 2 or 3 m rapidly, performing in a matter of minutes a task that would take two people most of a day. Backhoes can be used effectively in gravelly and stony soils as well as in soils that are stone free.

Backhoes have limitations. Special arrangements must be made to transport equipment that is not truck mounted. Time must be taken for maintenance. Operators must be trained and safety standards must be met. Property owners generally do not want large equipment on their property. There is a tendency to dig pits so deep that side walls might cave in--which is dangerous for anyone in the pit. Rental costs are high, and in many areas machines are not available for rent.

Power augers are commonly mounted on a small truck and are powered by the truck's engine. Some have independent power plants and can be mounted on a trailer. The auger can be raised to permit soil to be taken from the bit for examination and can be reinserted in the hole for continued sampling. The bits are 5 cm to more than 15 cm in diameter and are generally threaded over lengths of 50 cm or more. Some augers, such as that in figure 3-6, are threaded throughout their length and have extensions that permit sampling to depths of a few meters. Power augers can be equipped with barrel-type bits. The barrels are usually larger and heavier than those on hand augers. Most power barrel augers have a cylinder that can be opened for removing the sample.

Power-operated probes (figures 3-1 and 3-7) are used in moist soils that have few stones. They are usually mounted on a truck and are forced into the soil by hydraulic drivers powered by the truck's engine and acting against the weight of the truck and its load. The tubes are usually 2.5 to 10 cm in diameter. They can effectively remove undisturbed cores of soil to depth of 2 m or more. The top of the tube can be taken off and the tube is open on one side, permitting the core to be removed. Power probes are especially useful in moist stone-free soil material, such as loess. They function poorly in dry or stony soils and in soils having cemented layers.

Equipment is available that anchors the truck to the ground by means of a screw. Anchoring allows undisturbed cores to be taken at greater depth and over a larger range of soil conditions.

Power equipment for extracting samples for examination or analysis is almost indispensable in soil surveys that require systematic sampling of deep layers, as in many areas where landscapes have low predictive value. In dry areas, deep layers that have no influence on present vegetation can be very important to success of irrigation farming. Power equipment has made surveys of such areas much more rapid and much less physically demanding on field workers.

Power augers and probes have limitations. Generally, holes can only be bored or probed when the truck is level. If the truck is not equipped with four-wheel drive, off-road operation in wet areas is curtailed. Fences slow off-road movement. Equipment and maintenance costs are high. Operators must be trained and safety standards met. Power augers mix the soil so that depths to different layers cannot be measured accurately.

Dense soils and soils containing large amounts of rock fragments are difficult to examine. The difficulty in digging pits affects classification. Electrically powered jackhammers that quickly loosen compact or skeletal material are available. The loosened material can be thrown from the pit with a shovel. The jackhammers are similar to those used in street repair. A chisel bit is used. The power source is the truck generator or an independent gasoline-powered generator. Use of jackhammers is limited to areas that can be reached by truck. The initial cost is high.

Scheduling of any power equipment is important to insure maximum use while the equipment is available and weather and soil moisture conditions are advantageous.

Small implements.--Many kinds of small implements are used for examining soil. Different persons have different preferences, but certain general types of implements are essential almost everywhere.

Some kind of small tool is usually needed for probing and digging in the exposed profile. Some kind of large knife is most common. A sheath knife having a blade about 10 to 15 cm long and 2 1/2 to 5 cm wide at the widest place--the kind available for hunting or camping--can be used for probing the soil, for cutting through peds to observe the interior, as a spatula for removing small amounts of material, for cutting roots, for scraping the vertical or horizontal sections of the pedon, and for a variety of other purposes. Trowels, spatulas, putty knives, and other small instruments are used similarly.

A geologist's or mason's hammer is useful, especially for breaking cemented layers and examining rock fragments and very strongly cemented nodules. The chisel-shaped end of the head can also be used for digging unconsolidated material.

Various small instruments for measurement and observation are essential. Some kind of scale for measuring length is indispensable. Graduated steel tapes that retract into a small case are most useful. A hand lens is very important. A 10X lens is most common, but lenses having magnifications ranging from 4X to more than 50X are used. Some, mounted in a pen-sized tube, have high magnification but a small field, and some of these have battery-powered lights for illuminating the sample. A pocket magnet for separating magnetic material is useful in some areas. A soil thermometer is needed by most field scientists. Those having a metal probe and a dial on which the temperature is read are especially suitable for use in soil.

A grid for area measurements or for point counts of features like stones is an important part of a soil scientist's kit. The grid may be simply a piece of wire mesh with the spacing of wires chosen to fit the scale at which measurements are to be made. A hand tally or counter is useful for point counts; it is also useful for recording paces in measuring distance. Standard color charts and standard charts for estimation of proportionate area are also necessary components of the kit.

Mapping equipment

Various small pieces of equipment and instruments are used in mapping. The choices of field workers vary, but certain kinds of equipment are essential.

Various kinds of metal or wood clipboards or folders are used for holding the map. Some surveyors use an aluminum folder with a spring clip and a covering flap hinged at one edge. If the field sheets are large, a rotary map cylinder is useful.

The part of the map being used is exposed on the board, and the unused part is rolled into a cylinder attached to the edge of the board. The cylinder protects the unused part of the map and provides a work surface. Some field scientists make these mapholders to suit their own preferences (figure 3-8).

The use of aerial photographs as mapping bases has almost eliminated the need for compasses for finding bearings. In areas where keeping located is difficult, a compass must be used to orient the map and to take bearings from which the soil scientist can plot location. A traverse board consists of a map board that has a compass attached at one edge and that rotates on a tripod.

In mountainous areas, an altimeter can be used to determine elevation and establish location relative to contours on topographic maps. Altimeters measure altitude by measuring changes in barometric pressure as related to elevation and must be adjusted at a point of known elevation to the barometric pressure at the time.

An instrument is needed for measuring slope gradient. The Abney hand level (figure 3-9) is commonly used. For convenience, the scale is graduated in percentage of slope or in both percentage and degrees. This instrument consists of a small spirit level pivoted above a graduated arc and is operated by rotating the level until the bubble, visible through the eyepiece by means of mirrors, indicates that the level is horizontal. The barrel of the level is then sighted parallel to the soil surface and gradient is read directly from the graduated arc.

Clinometers are used in some places to measure slope gradient. In a clinometer, a weighted string swings across a graduated arc. Clinometers are lighter in weight, more convenient to carry, and slightly faster to use than an Abney level.

A scale for measuring distances on the map is needed. A supply of pencils of different hardnesses should be carried. The hardness chosen is determined by temperature and humidity and by the material of the mapping base. If aerial photographs are used, the pencils should leave a fine dark line that does not smudge easily on handling, but it should not be hard enough to cut the emulsion. Because soil boundaries must be adjusted and the symbols changed frequently, the pencils should make marks that can be erased without smudging and without damaging the mapping base.

Selecting the Mapping Base

The quality of the cartographic material used in mapping and for publication affects the accuracy of map unit boundaries and soil identification, the rate of progress, the methods and costs of map construction, and the quality of the published map. Assembly of cartographic materials should begin as soon as an area is selected for survey.

Nearly all mapping bases used in soil surveys are now derived either directly or indirectly from aerial photographs or other remote sensing techniques. Ground control is obtained by scaling from U.S. Geological Survey maps or other existing maps. Most of the information for the ground control network is obtained from aerial photographs and other remote imagery or from USGS topographic maps or other existing maps. Prints of the photographs are the usual bases for soil mapping, but other kinds of base maps are used to some extent.

All available photography is evaluated in relation to both mapping in the field and compiling maps for publication. Sets of photographs of an area taken over a period of years are valuable references. Soil patterns can be evaluated under different vegetation and soil conditions. Generally, using older photography as the mapping base is expensive, even if the quality and scale are satisfactory. Mapping usually must be transferred to a more recent base for publication because land use has changed significantly or because the older map sheets are not the correct dimensions for printing and binding.

For most surveys, purchasing new or recent photography and preparing field sheets at the dimension and scale that will be used for publication is more economical. Some of the costly steps of map compilation are eliminated. High-altitude aerial photographs are particularly suitable, as are orthophotographs. These kinds of photography are precise enough that preparation of a costly controlled mosaic is not necessary.

Plans for the survey must consider all costs of map construction--fieldwork, compilation, finishing, and publication. Plans must be made for in advance of field operations, especially if contracts are to be let for new photography. Completion of aerial photography contracts can be delayed for a long time by adverse weather conditions.

In ordering new photography, time must be allowed for preparing specifications, awarding contracts, photographing the area, and inspecting and accepting the work. The cost of original aerial photography varies greatly. For example, in 1979, costs for flying a 1:20,000 scale aerial survey ranged from $2.24 to $2.90 per square mile. Reproductions from original aerial film held by Federal agencies cost $1.00 for each contact print at a scale of 1:20,000 and $3.50 for each enlargement at a scale of 1:15,840.

Enabling aerial photography contractors to keep their equipment and personnel busy throughout the year and to take advantage of favorable seasonal conditions reduces the cost of aerial photography. Such factors as geographic latitude and solar altitude must be considered in scheduling flights so that objectionable shadows are reduced or eliminated. The ground surface is best shown when it is free from snow and when trees are free of leaves and other vegetation is at a minimum. This requirement further limits the flying season in the northern half of the United States. Moisture conditions are important in revealing soil patterns. In areas of the central United States where annual row crops are the main type of crop, the ground cover is least and the soil moisture conditions nearly optimum for indicating soil pattern sometime between late April and the end of June. Unfavorable atmospheric conditions may further limit flying time. For economy, scheduling requires close study of regional weather patterns such as the anticipated number of "photographic days" (no more than 10 percent cloud cover) in each month for a survey area. To be completed in a reasonable time under such limitations, a large project requires much equipment and many people and is expensive. For many soil surveys, the added cost can be fully justified.

Many agencies obtain aerial photographs, prepare aerial mosaics and planimetric and topographic maps, and establish ground control. The cartographic staff of the Soil Conservation Service can assist in obtaining cartographic material for each new survey area in the United States and in preparing contracts for new photography. It can also provide complete information on the status of aerial photography, mapping, and ground control activities for any area in the United States.

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Aerial photography

Aerial photographs are widely used as the mapping base in soil surveys [1/] Aerial photographs provide important clues about kinds of soil from such features as the shape and color of the surface and the vegetation. The relationships between patterns of soil and patterns of images on photographs can be learned for an area. These relationships can be used to predict the location of soil boundaries and kinds of soil within them.

Several kinds of aerial photography are available. Conventional panchromatic (black and white) photography is sensitive to approximately the visible portion of the electromagnetic spectrum (wavelengths of 0.38 to 0.78 μm). Color photography covers a similar range. Infrared photography, which covers radiation of somewhat longer wavelengths, is also available. The main kinds of aerial photography are described in the following paragraphs.

Panchromatic photography records all colors in varying shades of gray. Most modern black and white photography is of excellent quality. Because of their quality and economy, photographs made from panchromatic film are the most widely used for soil surveys.

Color photography records features of the surface in colors of the visible spectrum. The colors on the print are about the same as the colors of the features when the photograph was taken, but the colors of the ground features may be different at other times. The color of a kind of soil also may be different at different places, depending on many factors such as sun angle, atmospheric conditions, delays between flights, and moisture state of the surface. The cost for obtaining color photography is about 1 1/2 to 2 times as much as panchromatic photography. Color prints cost 2 1/2 to 4 times as much as black and white prints. Excellent black and white prints can be made directly from color negatives at the same cost as prints from panchromatic film.

Infrared photography records a portion of the spectrum that is not visible to the human eye. Infrared film is also sensitive to part of the visible spectrum, but true infrared photography is exposed through a deep red filter so that only the infrared radiation is recorded. Prints from infrared film have distorted shades of gray in comparison to prints from panchromatic film. Bodies of water and areas in shadow appear black. Broad-leaved trees appear very light, as though covered with frost. Foliage of coniferous trees appears distinctly darker. Roads are dark, instead of very light as on panchromatic prints. These characteristics are useful for detecting patterns of soil moisture states, identifying forest types, and detecting vegetation under stress from disease or other causes. Infrared aerial photography is especially valuable in areas having atmospheric haze because the film is not sensitive to the blue portion of the spectrum that is normally associated with haze. Infrared photography costs about 10 percent more than panchromatic photography.

Modified infrared photography is a compromise between true infrared photography and panchromatic photography. The images have some of the characteristics of each. At first glance, a modified infrared photograph looks very much like a photograph made from panchromatic film. It shows more contrast between some kinds of vegetation and records differences in soil wetness in more distinctive patterns than panchromatic photographs. Modified infrared photography costs about 10 percent more than panchromatic photography. Prints from these negatives cost the same as prints from panchromatic film.

Color infrared photography is sensitive to the green, red, and infrared portions of the electromagnetic spectrum. It produces false colors for most objects. The prints are spectacular; the colors are often brilliant and contrasting. This type of photography is especially useful for the study of vegetation. Vigorously growing vegetation appears brilliant red and less vigorous vegetation appears duller. Color infrared photography costs about the same as conventional color photography.

Remote sensing

Remote sensing refers to the full range of activities that collect information from a distance. It includes photography, which has been the most widely used remote sensing technique for many years. However, the range of the electromagnetic spectrum that can be sensed from a distance is much greater than that covered by conventional photography, and other techniques have been devised to use part of this range. [27] Nonphotographic sensors can perceive the parts of the electromagnetic spectrum from ultraviolet (wavelengths less than 0.38 μm) through microwave to the upper wavelength of 100 cm.

The extent to which some of the newer remote sensing techniques can be used in soil surveys has not been fully explored. Fieldwork cannot be eliminated, but how much it can be reduced is not clear. Soils must be examined to a depth of about 2 m or to solid rock--far beyond the present reach of any remote sensor or combination of sensors. Yet at least some clues to many soil properties are provided by surface features. It is these clues, many of them quite subtle and obscure, that are sought and used in drawing soil boundaries. It is these clues that permit the making of accurate soil maps without excessive digging or probing. And it is by revealing these clues that remote sensing can contribute most to soil surveys. The imagery is a tool for extending to new areas hard data about soils and about factors responsible for their formation.

The prospect of using more than one set of imagery is important. Such a set might be made up of two or more kinds of photography made at the same time--multiband photography--or two sets of one kind of photography made at different times of the year, or some combination of these. Several sets of photographs and other imagery are likely to yield more clues about soils than one set; whether the additional clues are enough to justify the extra cost probably depends on the nature of the survey area.

Photographlike images can be made by nonphotographic sensors of any part of the electromagnetic spectrum. Hence, outputs from the sensors can be viewed and treated like photographs. An example is side-looking radar, which can penetrate clouds and can be used at night as well as in the daytime. The radar can produce prints that resemble photographs, although the images are not as clear as panchromatic photographs. Side-looking radar is useful where continuing cloud cover prevents conventional photography. For use with computers, impulses from side-looking radar and other nonphotographic sensors can go directly into automatic data processing systems for storage or analysis.

Space exploration has added a new dimension to remote sensing. Earth-orbiting satellites can be equipped with several kinds of sensors, including cameras. Imaging from space has the same problems as imaging from aircraft and the additional problem of transmitting the data to earth. Imaging from space also has two important advantages. First, large areas--thousands of square kilometers--can be examined from a single point in orbit. Second, any area can be repeatedly examined on a regular schedule.

Kinds of mapping base

More than one kind of cartographic material suitable as a mapping base may be available for an area. The choice of base material depends on the relative advantages of available material for all aspects of the job, including map compilation and reproduction as well as fieldwork. The base material selected must be adequate for the whole job, not for just one activity. The choice can make the difference between an excellent soil survey and a poor one.

A soil survey is expensive; proper selection of the base material can have considerable influence on efficiency. Where existing aerial photographs are available, their cost rarely exceeds 1 or 2 percent of the total survey cost. Original aerial photography seldom costs more than 5 percent. The cost of base material is weighed against its use in all operations--field mapping, map preparation, and publication.

If possible, the same scale is used throughout an area. If base material of varying scales is used, the soil mapping is likely to vary in detail, giving a distorted picture of the soil patterns in different parts of the area. Cartographic base material can be readily reproduced at the desired scale for field use.

A description of the characteristics, advantages, and disadvantages of the principal kinds of mapping bases used in soil surveys follows:

Single-lens aerial photographs.--The two basic types of aerial photographs are vertical and oblique. Single-lens vertical photographs are the best for soil mapping, although oblique or multiple-lens photographs can be used when rectified. USDA specifications for single-lens aerial photography require an overlap in line of flight of about 60 percent; the sidelap between adjacent flight lines averages about 30 percent. With this overlap, all ground images appear on two or more photographs exposed from different air positions, providing stereoscopic coverage. Two consecutive photographs within a line of flight are called a stereoscopic pair.

If every other photograph in a continuous line of flight is removed, the remaining photographs provide alternate coverage. Adjoining photographs of alternate coverage in the same line of flight are called alternate pairs. Alternate pairs overlap about 20 percent--too little to permit stereoscopic study of the entire area. Using alternate coverage instead of full stereoscopic coverage for mapping leads to problems with relief displacement during map compilation. Alternate coverage is inadequate for constructing maps by photogrammetric methods based on complete stereoscopic coverage.

Photographs are exposed on film at a predetermined scale and fixed negative size. The scale depends on their purpose. Until recently most of the aerial photographs for the United States Department of Agriculture were taken with a 210 mm lens at an altitude of about 4,200 m above the mean land surface. The resulting scale is approximately 1:20,000. Such negatives can be satisfactorily enlarged to a scale of 1:3,960. Now most USDA aerial photographs are taken with a 153 mm lens and scale ranges from 1:38,000 to 1:80,000. Satisfactory enlargements up to 1:7,920 can be made from 1:40,000 negatives. Most aerial cameras currently in use expose an image of about 23 by 23 cm.

Photographs made directly from the original negatives at the same scale are called contact prints. In contact printing, errors cannot be rectified and the scale cannot be changed. Contact prints are economical to make and have better resolution than enlargements.

Photographs can be readily enlarged or reduced; this is one of their advantages. The process is slower and more expensive than contact printing. Some detail is lost in the preparation of enlargements, but the loss is small when skilled operators use modern processing equipment and the original negatives.

Enlarging has certain advantages. All prints for an area can be brought to a nearly uniform scale. Tilt, which causes displacement of objects and scale distortion, can be rectified. Such operations require more time than simple enlarging, but later savings may more than offset the cost of bringing photographs to a common scale. If the photograph is enlarged more than 5 times, prints are usually unsatisfactory. Of course, enlargement increases the size of the photograph as well as the scale. The size of sheet varies with the enlargement. If the contact print at a scale of 1:20,000 is 23 cm square, an enlargement to 1:15,840 will be 29 cm square and an enlargement to 1:7,920 will be 58 cm square.

Photo indexes are inexpensive and should be obtained when available. They are useful for determining the number and location of individual photographs within an area. They are also useful for schematic mapping and for preliminary studies.

The greatest advantage of aerial photography in soil surveying is the wealth of ground detail shown. Field boundaries, isolated trees, small clumps of bushes, rock outcrops, buildings, and plants are visible and assist in orienting the mapper and in plotting the soil boundaries and other features. Both the speed and accuracy of the work are increased by using photographs. Base maps for publication can be constructed from aerial photographs economically and in a reasonable time. A stereoscopic series provides a relief model of the area, showing all of the intricate cultural and physical details.

Aerial photographs also have some disadvantages and limitations in soil surveying. Elevations are not shown. Scale is not precisely uniform. More sheets are required than when using larger maps, resulting in more matching, joining, and filing. Differences of scale between adjoining photographs create some minor difficulties in matching and transferring soil boundaries. Distances and directions cannot be measured as accurately as on topographic maps or some other kinds of photographs because of distortions caused by tilt, image displacement, and other inherent errors. Finally, although far more detail is shown on aerial photographs than on most maps, the detail is not always as legible and more skill is required to interpret the photograph. Nevertheless, the advantages of aerial photographs usually greatly outweigh the limitations.

Photographic indexes are available for most of the photography available from Federal agencies. Indexes are prepared by fastening together the individual prints of an area. The images are matched, and the photographs are overlapped so that all marginal data are visible. The assembly is then photographed at a smaller scale. Most indexes prepared by the United States Department of Agriculture have a scale of 1:63,360 or 1:126,720.

Once a survey area has been scheduled, photographs should be ordered as soon as possible. The order gives the exact boundaries of the survey area, the scale of photography needed, desired coverage (stereoscopic or alternate), and the date that

fieldwork is to begin. Any special requirements, such as weight or finish of paper, are stated. Low-shrink paper is recommended for most field mapping.

High-altitude photographs for soil mapping.--High-altitude photography is used for field mapping wherever local relief is 300 feet or less within a radius of 2 miles. Most of the United States east of the 105th meridian except the Ozark and Appalachian Mountains is suited to such photography. Figure 3-10 shows approximately the parts of the 48 conterminous states suited to high-altitude photography. Such photography is made at scales ranging from 1:38,000 to 1:75,000, depending on anticipated publication scale. From these negatives, rectified enlargements for standard atlas-size sheets about 25 by 38 cm are prepared to give complete coverage of the area (table 3-1).

With high-altitude photography, fewer photographs are required to cover an area. Contact prints of the original negatives can be used for stereographic coverage. Enlarged stereographic coverage can be prepared from selected stereographic pairs. Special stereoscopes are helpful when viewing the larger prints in field offices.

For some soil surveys, photobase maps are printed from high-altitude photography on low-shrink paper. In other surveys, the photobase maps are printed on transparent film with a matte surface. Normally, field mapping on outdated photographs is transferred to film prints, and paper prints are used for new field mapping. 37

Obtaining high-altitude photography and preparing photobase maps nearly always costs less than constructing photobase maps from a controlled aerial mosaic. High-altitude photographs have better image quality than controlled mosaics.

Aerial mosaics.--Aerial mosaics are made by matching and assembling individual photographs to form a continuous image of an area. Several methods of assembly are used, and the resulting mosaics vary widely in accuracy and usefulness.

The two general types of aerial mosaics are uncontrolled and controlled. An uncontrolled mosaic is made by simply matching like images on adjoining photographs without geographic control of the positions of the features. For a controlled mosaic, the photographs are brought very close to uniform scale and rectified to reduce tilt and displacement. The positions of selected features are adjusted to ground control. These features on the mosaic are close to their correct positions on the map grid. The accuracy of a controlled mosaic approaches that of a good planimetric map.

Between the uncontrolled mosaic and the controlled mosaic are a wide variety of semicontrolled mosaics for which different degrees of ground control are used. Thus, mosaics vary greatly in accuracy and must be carefully checked before being used in soil mapping.

Since an aerial mosaic covers a larger area than a single photograph, fewer photobase sheets need be matched. A mosaic can be made to cover a specific area, such as a township or a drainage basin. They are more accurate than individual photographs.

A major disadvantage is that mosaics cannot be used for stereoscopic study of the area. Prints of the original photographs can be obtained.

Mosaics are not used unless they expedite fieldwork and map publication. A controlled aerial mosaic costs more than the individual photographs but less than an accurate planimetric map. If controlled mosaics are to be used for a soil survey, arrangements for ordering them should be made well in advance.

Orthophotographs.-- An orthophotograph is an aerial photograph with nearly all the image displacement and scale errors removed. Aerial photographs are converted to orthophotographs by simple rectification for low-relief terrain or by differential rectification for high-relief terrain. Orthophotography is prepared by methods designed to meet National Map Accuracy Standards. Various accuracy tests are performed to verify that 90% of the well-defined points tested are within 12.19 meters of true horizontal position - the horizontal accuracy standards for 1:24,000 scale topographic maps. An orthophotoquad is an orthophotograph formatted to the same size and scale as a USGS 7½-minute topographic quadrangle.

Orthophotographs portray an abundance of detail and have correct scale and positional accuracy not found in conventional aerial photography. Production costs of orthophotographs compare favorably with controlled mosaic production costs. Orthophotographs of varying scales are used as base maps for soil surveys, land use planning, resource studies, topographic maps and other purposes. Orthophotography can be enhanced with cartographic features such as contours, elevations, political boundaries, highways, principal places, etc. to provide maps designed to meet the general need of most users.

Topographic maps.--Unlike the other kinds of mapping bases, topographic maps are not photographs. A topographic map represents both horizontal and vertical positions of physical features by using standard symbols. Published maps usually show such cultural features as roads, railroads, and buildings in black; drainage features in blue; and contour lines in brown. Some also show additional features, such as vegetation, in overprints of green or other colors.

Most topographic maps published by the U.S. Geological Survey and other Federal agencies comply with national standards of map accuracy. The standards for horizontal accuracy require that not more than 10 percent of the tested points be in error by more than a specified distance on the map. This distance is 0.85 mm for maps published at scales larger than 1:20,000 and 0.50 mm for maps published at 1:20,000 or smaller. These limits apply to positions of well-defined points, such as roads, monuments, large structures, and railroads, which are readily visible and can be plotted on the map within 0.25 mm of their true positions. Standards for vertical accuracy require that not more than 10 percent of the tested elevations be in error by more than one-half of the contour interval.

Because of the prescribed standards of accuracy, topographic maps published by different agencies differ little. Some variations may be noted in format, scales, sheet boundaries, and classification and selection of planimetric detail--variations due primarily to the need to meet specific requirements.

Standard topographic maps are published in quadrangles bounded by lines of latitude and longitude. Generally, topographic quadrangles cover 30 minutes, 15 minutes, 7 1/2 minutes, or 3 3/4 minutes of latitude and longitude. Scale varies with topography and contour interval. The most common publication scales are 1:24,000 (the largest generally available), 1:25,000, 1:31,680, 1:48,000, 1:62,500, and 1:63,360. Coverage at 1:250,000 compiled from larger scale maps is distributed by the Geological Survey for the entire country, and a new series of maps at scales of 1:50,000 and 1:100,000 is available for certain areas. The smaller scale maps

are useful as bases for general soil maps, for reference, and for schematic soil maps. Topographic maps can be used as the base for detailed mapping if recent large-scale maps are available for the whole survey area.

The accuracy of standard topographic maps gives them definite advantages in measuring distances and directions. The topographic pattern is helpful in understanding soil and studying drainage, irrigation, hydrology, and the like. The detail on the maps relieves soil scientists of part of the task of recording the location of ground features while mapping.

As a base for soil mapping, topographic quadrangles lack the details--field boundaries, isolated trees and bushes, fences, and similar features--that are shown on photographs. The small scale of many topographic maps and the lack of up-to-date coverage for some areas are further disadvantages. Some old topographic maps are not accurate; some need too many revisions to be useful. The topographic maps of recent years made from aerial photographs by photogrammetric methods are much more accurate.

In the United States, most standard topographic maps are published by the U.S. Geological Survey. The cartographic staffs of the Soil Conservation Service receive new lists and new quadrangles as they are published and can supply information about work in progress, expected dates of completion, and the topographic mapping program. Topographic maps needed for a soil survey can be ordered directly from the Geological Survey. Preliminary proofs or copies of manuscript material frequently can be obtained in advance of publication if the need is urgent.

Topographic maps of standard accuracy are expensive to construct and publish, but the published maps can be purchased for a small price per sheet. Besides serving as the mapping base in some areas, they are useful references.

Maps and data base requirements

The demand for natural resource data in SCS and the Federal sector has increased. In the past these data were displayed on various base maps that generally did not meet National Map Accuracy. SCS could not feasibly digitize the resource data since its use in the SCS and by other agencies was limited by the inaccurate bases being used. Using accurate uniform scale orthophotographs and planimetric base maps, resource data will be digitized and available for automated mapping procedures and repeated manipulation in providing various inventories and interpretive maps at great cost reduction. Repeatability of use of digitized data by the SCS and other agencies including exchanging of digitized resource data by agencies precludes a duplication of effort in the Federal sector and results in savings in Federal mapping programs.

Selecting Mapping Scale

The best map scale for a survey is determined by many factors. The purposes of the map are the main consideration. Soil maps in areas of intensive land uses are designed for predictions about soil use, management, and behavior in relatively small areas. The scale must be large enough to permit delineation of most areas significant for such predictions. The scale does not have to be large enough for all property lines, cultural features, works, and structures significant for detailed plans to be plotted directly. A large scale increases the number of map sheets, the amount of joining of sheets, and the costs of compilation, reproduction, publication, and storage.

Most soil surveys are made at a scale of 1:24,000, 1:20,000, or 1:15,840. Scales of 1:24,000 and 1:31,680 commonly are used for surveys in areas of less intensive land use. Scales larger than 1:15,840 are needed for highly detailed surveys.

Generally, the scale of mapping depends on the intricacy of the soil pattern in relation to the expected intensity of soil use. The patterns of soils are very complex in many areas where potentials do not justify a mapping scale large enough to show the patterns in detail. Where the purposes of the survey do require that small areas be delineated, the scale must be large enough to permit delineating and labeling the areas. Part of a survey area may have high value or intensive land use that justifies a scale larger than that of the rest of the area. Two publication scales can be used in such an area if the needs justify the extra costs.

Legibility of the maps is very important. Many potential users will not use maps that they can not read easily. Figure 3-11 illustrates differing legibility of the same map at different scales. Map C is clearly illegible. Map B can be read with difficulty. Map A is reasonably legible. If the map is to be published at scale B, detail that is legible only at scale A should not be delineated.

The following list gives a general idea of the smallest areas that can be shown legibly at different scales. These sizes are for isolated areas within much larger delineations. If numerous intermingled areas of the smallest size are delineated, the map will be difficult to use.

Map scale	Minimum size of delineation
	ha
1:2,000	0.16
1:7,920	0.25
1:12,000	0.57
1:15,840	1.0
1:20,000	1.6
1:24,000	2.3
1:31,680	4.1
1:63,360	15.8
1:125,000	63.0
1:300,000	363.0
1:1,000,000	4,000.0

The "minimum size delineation" is a roughly square or circular area approximately 6 mm across. This is about the smallest area in which a symbol can be lettered readily. Smaller areas can be delineated and the symbol lined in from the outside, but such small delineations reduce legibility of maps. On maps of the smaller scales, delineations are commonly 1 1/2 to 2 times the size of the minimum area that can be shown.

If the field sheets are made at the planned publication scale, the amount of detail that can be drawn in the field is limited to that judged adequate for the purposes of the published survey. Using the publication scale also eliminates the necessity of transferring the field mapping to a different scale. If mapping scale is larger than publication scale, the surveyor should try to visualize what the map will look like at publication scale. A reducing lens can be used.

Reference Maps

Many types of maps are published by public and private agencies. They range from small-scale road maps distributed by oil companies and county highway maps prepared by State highway departments to large-scale detailed maps used in city planning.

Most reference maps are designed, constructed, and reproduced to meet a special purpose. Certain details are emphasized and others are subordinated. On small-scale road maps, for example, highways, highway numbers, towns and cities, points of interest, and mileages are prominently shown; drainage, railroads, pipelines, powerlines, and public land lines are omitted or subordinated.

Aeronautical charts are designed and constructed specifically for air navigation. The scale is small so that large areas can be shown on a single sheet. Ground features prominent from the air are emphasized in bold and simple symbols. Other features of equal importance on the ground but less noticeable from the air are subdued or omitted entirely. Elevation is shown by gradient tints. Navigational data are shown by bright overprinting.

Plats prepared from public land surveys are designed to present land survey data. They usually cover a survey unit, such as a township. The scale is large. Courses and distances, subdivisions of sections, acreage figures, and other data from the survey are shown. Cultural and drainage features are reduced to a minimum and are accurate only on the survey lines.

Special-purpose maps have little value as bases for detailed soil surveys. Such maps are very useful for reference, however, and they may be the best base maps available for surveys of remote areas. Aeronautical charts, for example, are useful for rapid small-scale surveys of large areas.

Many other kinds of special maps are available for some areas. These include maps of published soil surveys, maps of geology, maps of forest or other vegetative cover, coast and harbor charts, census maps, Postal Service maps, and highway maps. County highway planning maps are available for many areas and are good references. Some State highway or transportation departments make good small- to medium-scale highway planning maps for internal use that can be reproduced with special permission. Maps protected by copyright cannot be reproduced without permission.

Index maps for field sheets.--An index map is prepared to show approximately the location of each field sheet. A useful scale is about 1:125,000. Many States have county highway maps at about this scale, and many of these are good bases for preparing the index.

The mapping limits of each field sheet are drawn on the index map, and the field sheet number is written in each area. The map is labeled "Index to Field Sheets," preferably at the top center. The index accompanies the completed survey when it is submitted for map assembly.

Premapping Activities

The soil survey party leader should be located in the area before soil mapping begins and usually before the other party members arrive. This allows the party leader time to become familiar with the area, review preliminary data, investigate

the major soils and their pattern of occurrence, review the stated purposes of the survey, check the adequacy of the base map material, and prepare a preliminary mapping legend. During the general premapping appraisal of the survey area, the party leader also assembles the information needed to schedule survey operations.

A well established principle of research is first to assemble the existing information about the subject. A soil survey is no exception. Time and effort are saved and costly errors are avoided if what is already known is used. The time required to find and appraise existing information is usually small relative to the time required to compensate for failure to use the information. Even for areas about which little is thought to be known, a diligent search usually uncovers useful information. Information about adjacent areas can often be applied to the survey area.

If an older soil survey has been made, it is generally the most important reference available. Soil surveys made in the United States before 1920 emphasized the character of the parent material. The maps commonly provide some of the best information available for dividing the survey area into sections within which parent material is reasonably uniform. Many soil surveys made after about 1920 to 1930 provide most of the information needed to broadly characterize the area and its soils. Those made after about 1930 to 1940 provide a very important part of the information needed for identifying map units. The earlier surveys are also useful for identifying map units but must be used in conjunction with a systematic preliminary field study. Mapping and examples of established soil series can be examined in nearby areas that have been recently surveyed.

Unpublished soil surveys of scattered farms are another source of information about the area. The value of this information depends on the quality of the legend and consistency of mapping over long periods. Regardless of the quality of the legend, the scattered farm mapping must not be made a part of the modern soil survey without careful field checking.

A soil survey is a study of the geography of soil. Maps present geographic information and are basic tools of soil survey. Aerial photographs, topographic maps, and other maps are useful references whether or not they are used as the mapping base. Each kind shows features that the others do not.

Topographic maps are the best references for appraising relief for most areas. Maps and texts on geology for many areas have been published by the U.S. Geological Survey and by comparable State agencies. The publications are on various subjects, such as bedrock geology, surficial deposits, water resources, or mineral resources. The maps were made at various scales and degrees of detail. Almost all contain important information about the parent material of soils and related factors. Vegetation maps have been published for many areas, though the coverage is less than for geology. The U.S. Forest Service and State agencies are likely sources. Climatic maps are available for many areas. They are commonly at small scale and general in nature. The cartographic staff of the Soil Conservation Service, local libraries, and university libraries are good sources of information about what has been published and where it can be obtained.

Local sources such as libraries of local schools, universities, municipalities, and historical societies, as well as State agencies, are sources of published material on soils, agriculture, geology, geomorphology, hydrology, climate, engineering, biology, history, and related subjects bearing specifically

on the survey area. If a university is located within reasonable distance of the area, the theses it has produced may include significant material. Local weather stations can provide data on temperature, precipitation, and other weather events. Reports of the Bureau of the Census and of the Economics, Statistics, and Cooperatives Service are authoritative references on land use and crop production. Computerized bibliographic search services such as the one provided by the soils staff of the Soil Conservation Service are invaluable as sources of references for publications about the survey area.

Knowledgeable people are also important sources of information. Faculty members of universities often have information that is not available in published form or know of published information that the party leader has not found. The local representatives of the Cooperative Extension Service, area and district conservationists of SCS, and vocational agriculture teachers may also be sources of knowledge that is not generally available. Representatives of planning boards, sanitation departments, highway departments, and the like are knowledgeable about matters that are important for interpreting soils and designing map units. Strong working relationships with the office of the State geologist and with geologists working in the survey area are very important. They can provide much information that is helpful in understanding soil-rock relationships.

Some information not directly related to soils is also helpful in planning, organizing, and conducting a soil survey. Questions that should be answered include:

1. What is the present land use pattern? Is it relatively uniform or a mixture of conflicting uses and intensities? Are there political or economic problems associated with present land uses?

2. Is there a land use policy or plan for the area? Is it active and effective? What changes in land use does it outline?

3. What is the general ownership pattern? Is it expected to change?

4. Are mineral rights important in the area? Who owns them?

5. Are water rights, either ground or surface, controlled? Does water supply limit land use and continued growth and development? What is the quality of the water?

6. What cultural, social, or economic factors influence or control land use?

7. What qualities (climate, soils, mineral, etc.) of the area are unique, valuable, or limiting for some uses?

Not all of these questions are universally important, nor is the list complete. However, information about these subjects can be important in satisfying the needs for the soil survey.

Only some of the more promising sources of reference material have been mentioned. The amount and significance of existing information varies widely, but in most parts of the United States it is substantial. Preliminary research can provide much, if not most, of the information about the area and its soils needed to start preliminary field studies. It can provide some of the information about the soils of the area and their geography needed to prepare a preliminary mapping

legend. It can guide field studies and can suggest the best procedures for mapping. It can contribute directly to the information on the maps. And it can provide basic data for interpreting the soils.

Preliminary field studies

Preliminary field studies are made to supplement and verify the information assembled from existing sources. Field studies help in developing a perspective of the broad patterns of soils; of the relationships of soil to landscape, parent material, and the like; and of general relationships between soils and land use.

The party leader first scouts the survey area to learn its general characteristics. Local landforms and the manner in which they are associated are noted. Roadcuts and other excavations are studied. Vegetation and land use, parent material, and other factors related to soil properties are recorded. The soils are examined at selected places in relation to these factors. When the entire area has been scouted, a first draft of a small-scale general soil map is prepared. This map delineates large areas having distinctive physiography, vegetation, parent material, and other factors related to soil properties.

If the information about soils, geology, vegetation, and current land use is abundant and accurate, the party leader need only scout the area in enough detail to understand the relationships of features already known. But in some areas of the United States and many areas abroad, little is known about the soils. In these areas, the general nature of the most important sets of soil properties must be established, the soils must be classified, and the taxa must be related to the factors of soil formation.

Where little is known about the soils, preliminary studies are organized to relate soil properties to landscapes. In an unfamiliar environment there may be no standards for comparison. If even one unique set of soil properties can be consistently associated with an identifiable set of soil-forming factors, that relationship can lead to understanding other relationships.

After the first broad studies, a few places are chosen that are similar in relief, physiographic position, vegetation, and parent material. The party leader can predict that the soils at these places are in the same class. If study reveals that the prediction holds, the soil is described and identified as a taxon of the lowest category that is feasible--commonly series or family.

Having identified a unique kind of soil in this manner, the party leader continues to look for it in characteristic places. If this taxon is indeed found to be representative of distinctive parts of the area, a relationship that reveals order for at least one soil has been established. This soil and its relationships to soil-forming factors have become familiar. This soil can be used as a standard for comparison with soils on other landscapes. Other soils of the area are identified in the same manner, producing an increasing number of comparisons.

If possible, a soil identified as a standard for comparison is one in which the effects of the active factors of soil formation--climate and vegetation--are well expressed. The effects of climate and vegetation on soil properties are expressed regionally and can be seen in most soils; in fact, these effects may be so commonplace that they are overlooked when attention is attracted by local differences caused by variations in relief, parent material, and time. If the strongly expressed marks of climate and vegetation can be established, the local

variations related to relief, parent material, and time can be studied in orderly perspective.

Generally, the party leader looks first for natural landscapes that have (1) parent materials without extremes of either physical or chemical composition that might inhibit soil-forming processes, (2) relief that disposes of excess water without losing normal precipitation (so that the effects of climate have not been modified by extreme wetness or dryness), and (3) a surface that has been stable long enough for the soil to have undergone the full effects of climate and vegetation.

All of these features cannot be found in combination in every soil survey area; indeed, none can be found in some areas. The party leader attempts to locate landscapes that approach the ideal. He uses the best available set. It may be worth the extra time and effort to go outside the survey area to find a suitable standard of comparison if none exists within it. In many areas, soils that characterize the regional effects of climate and vegetation are already known.

After characteristic soils have been identified, small areas within each of the tentatively identified general soil areas are selected for intensive examination. Within each area, sets of orderly relationships among a small number of related soils can generally be determined. Studying each general area individually limits the number of different kinds of soil that must be dealt with at one time.

Generally, areas are selected that appear to have readily understandable soil-landscape relationships. Figure 3-12 illustrates a landscape that might serve as a study area. The soils all formed under the same general climate and vegetation and share some properties that are the marks of those factors. But the soils on this landscape undoubtedly differ in important ways related to landform and physiographic position. The soils at the highest positions (A) are developing in one kind of geologic deposit; those on the lower parts of the slope (B) may be developing in another deposit exposed during the current geomorphic cycle; the soils in the lowest positions (C and D) are undoubtedly developing at least partly in sediment washed from the surrounding areas. The soils in the higher positions lose runoff water to the lower soils. The lower soils are wet for longer periods, and their vegetation differs in kind and vigor from that on the higher soils. The different areas will have soils of different taxa. The soils undoubtedly behave differently for some, and perhaps most, uses.

Investigation proceeds from one distinctive area to another. Relationships within the different areas are established. With each study an increasing number of comparisons can be made. Soils in comparable physiographic positions in different areas are compared. They may, for example, have differences related to parent material but have many similarities imposed by physiography. As work progresses the ranges in all properties are noted.

Almost always during the course of the work, some landscapes in which the soils do not fit neatly into a known pattern are encountered. Some relationships are very complex and require a thorough understanding of the geology and geomorphic processes of the area. Some areas are so complex that even with a thorough understanding of the local stratigraphy and geomorphology, accurate predictions about the occurrence of specific soils are difficult or impossible. An example is a thick fluvial deposit that has been thoroughly dissected. Many fluvial deposits have abrupt changes in sediment grain size. Clayey backswamp deposits may overlie

point bar deposits of coarse sand and gravel that overlie silty sediments. When dissected, all of the different kinds of sediments may be exposed to soil formation. The soils in these deposits can differ greatly in texture, horizon thickness, and other features within short distances. The soil-landscape relationships may be further complicated by locally derived deposits of variable thickness on linear and concave side slopes. Regardless of the complexity of the soil pattern, intensive study of small areas reveals relationships that are extremely helpful in mapping.

Information obtained during early studies is recorded. At no time is keeping complete and accurate notes more important than during early assembly of data and preliminary studies.

The number of pedons that can be described in detail during preliminary studies is limited because of the large amount of time and effort required. Consequently, most of sites are examined using probes, augers, or the like. Though incomplete in detail, the data from such examinations can provide information on critical properties for a large number of kinds of soil. Detailed studies of internal soil properties necessary to characterize soil taxa are made at a few places, usually after the general character of taxonomic units have been tentatively established. The locations of these sites are important because the number that can be investigated is small and the cost is high.

Table 3-1. --High-altitude photographs: scales, sizes, and area covered

Negative scale	Publication scale	Size of base sheet	Area covered
		cm	km^2
1:75,000	1:31,680	25.4 x 38.1	97.2
1:58,000	1:24,000	23.4 x 36.8	50.0
1:48,000	1:20,000	24.1 x 36.3	34.9
1:38,000	1:15,840	25.4 x 35.6	22.8

Illustration legends

Figure 3-1.--Pickup truck with a power probe and a tool compartment mounted on the back. Two sizes of probes and an extension rod are shown.

Figure 3-2.--One type of light tracked vehicle used for soil survey operations in areas inaccessible to wheeled vehicles.

Figure 3-3.--Tools for digging: A, square-pointed spade; B, side view and C, front view of post-hole spade; D, screw soil auger and extension.

Figure 3-4.--Soil augers and probes: A, screw auger; B, barrel auger, C, sampling probe; D, Dutch mud auger; E, peat sampler.

Figure 3-5.--Backhoe mounted on a small tractor.

Figure 3-6.--Power auger mounted on a pickup truck.

Figure 3-7.--Hydraulically operated sampling tube mounted on a pickup truck. The open-faced tube is in place. Hydraulic controls are at the right.

Figure 3-8.--Hand-held map board with aerial photograph in place.

Figure 3-9.--Abney hand level with case.

Figure 3-10.--Shaded area is suitable for high-altitude photography for soil mapping.

Figure 3-11.--Reproductions of the same map at four different scales.

Figure 3-12.--The several kinds of soils in this photograph are closely related to topographic position.

Footnotes

1/ Details on procedures and techniques in the use of aerial photographs in soil surveys is provided in Agriculture Handbook 294, "Aerial-Photo Interpretations in Classifying and Mapping Soils." Soil Conservation Service, USDA, 1966.

2/ See Remote Sensing: With Special Reference to Agriculture and Forestry. Committee on Remote Sensing for Agricultural Purposes, Agricultural Board, National Research Council. Washington, D. C.: National Academy of Sciences, 1970.

3/ More detailed information about cartographic techniques and requirements for photobase maps are given in the "Guide for Soil Map Compilation on Photobase Map Sheets." Cartographic Division, Soil Conservation Service, USDA, 1970 (Processed). Photobase maps can also be prepared in a similar form from controlled mosaics or other suitable photography.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-310-944/SCS-47

Chapter 4

Examination and Description of Soils in the Field

Complete descriptions of the soils are essential in any soil survey. The descriptions serve as a basis for soil identification, classification, correlation, mapping, and interpretation. A complete description also documents the conditions at the site of any soil-related research.

Soil descriptions must be objective, complete, and clear. The descriptions are used by different people for different purposes. This chapter provides standards and guidelines for describing most soil properties and for describing related facts that are necessary parts of a complete soil description. Precisely defined standard terms are needed if different people are to record their observations so that others can understand. Standard terms are brief yet meaningful.

Devising standard terminology is not practical for some properties. For some soils, standard terms are not adequate and must be supplemented by a narrative to insure the accuracy of the description. The field scientist must always evaluate the adequacy of standard terms and add needed information. Otherwise, much information will be lost.

The standards discussed in this chapter have been tested in many parts of the world. The class limits for some properties are necessarily arbitrary. Some descriptions will certainly require refinement and elaboration of some terms. If class limits are modified the new limits must be given.

Some things, such as the length of time that cracks remain open, patterns of soil temperature and moisture, and variations in size, shape, and hardness of clods in the surface layer, must be observed over periods of time and summarized. A complete description of a kind of soil is more inclusive than any single description taken at one particular time. A complete description tells the reader what the soil is like throughout the year.

Each investigation of the internal properties of a soil is made on a soil body of some dimensions, which may be larger than a pedon or represent a small sample of a pedon. During field operations of a soil survey, the size of a sampling tube usually determines the dimensions of some of the sampling units. Many soils are studied in profiles exposed on the side of a pit. Many soils are investigated by examining the soil material removed by an auger. For rapid investigations of thin soils, a small pit can be dug and a section of soil removed with a spade. The section may be only 10 or 15 cm across and can be laid almost intact on the ground for study. All of these soil volumes are samples of pedons, and knowledge of the internal properties of a soil is derived mainly from studies of such samples. They can be studied more rapidly than entire pedons; consequently, a much larger number can be studied in many more places.

For many soils, the information obtained from such a sample describes the pedon from which it is taken with few omissions. For other soils, however, important properties of a pedon are not seen in the smaller sample. For most soils, detailed studies of some entire pedons are needed. The smaller samples are used to determine how soil properties vary from place to place. Complete study of an entire pedon requires the exposure of a vertical section and the removal of

horizontal sections layer by layer. Horizons are studied in both horizontal and vertical dimensions.

For some soils it is not practical to dig deep enough to reveal all of the relationships between soils and plants. For example, roots of plants may derive much of their moisture from fractured bedrock close to the surface. Descriptions indicate the nature of the soil-rock contact and as much as can be determined about the upper part of the underlying rock.

The format of the description and the order in which individual properties are described are less important than the content of the description, but following a standard format has distinct advantages. If soil properties are consistently described in a given order, the reader is helped in finding information and the writer is less likely to omit important features. A standard format makes easier the coding of data for automatic processing in an orderly and systematic manner. However, the limitations of standard forms must be understood. To depend entirely on such forms would imply that all of the soil characteristics that need to be recorded are known and can be described in standard terms. Some soils must be described at least partially in narrative form because they have unique characteristics not provided for in the standard form. Formats for recording and retrieving information about pedons will be discussed in more detail in Chapter 9.

Studying Pedons

The description of a body of soil in the field, whether an entire pedon or a sample within it, records the kinds of layers, their depth and thickness, and the properties of each layer. These properties include color, texture, structure, properties of failure and disruption, roots and animals and their traces, reaction, salts, and boundaries between layers. Some properties that apply to the entire sampling unit are also measured and recorded. Generally, external features are observed throughout the extent of the polypedon; internal features are observed from study of a pedon or a part of a pedon that is judged to be representative of the polypedon.

For a soil description to be of greatest value the part of the landscape that the pedon represents should be known and recorded. Descriptions of pedons that represent an extensive mappable area are generally more useful than pedons that represent the border of an area or a small inclusion. Consideration is given to external and internal features of the soil, related features such as vegetation and climate 1/ and the setting--the position of the particular soil in relation to other soils and to the landscape as a whole.

Pedons for detailed study of a soil are selected tentatively at first. Areas that previous studies have shown to contain the kind of soil to be described and sampled are most commonly chosen. The pedon is usually selected on the basis of external evidence. Depending on the purposes of the study, the selected pedon may be one that has properties either near the middle of the range of the taxon or near the limits of the range. Having tentatively located a sample site, it is probed with an auger, spade, or sampling tube to verify that the soil does have the diagnostic features of the soil and that its properties represent the desired segment of its range.

A pit exposing a vertical face approximately 1 *m* across to an appropriate depth is convenient for studying most soils in detail. 2/ Horizontal variations in the pedon can be observed, as well as features too large or too widely spaced to be seen otherwise. The sides of the pit are cleaned of all loose material disturbed by digging. The exposed vertical faces are then examined, usually starting at the top and working downward, to identify significant differences in any property that would distinguish between adjacent layers. Boundaries between layers are marked on the face of the pit, and the layers are identified and described.

Photographs can be taken after the layers have been identified but before the vertical section has been disturbed for description. Preparation of a profile for photography will be described in Chapter 9. If point counts are to be made for estimation of the volume of stones or other features (Chapter 8), the grid is applied and the counts are made before the layers are disturbed. If samples are to be taken to the laboratory for analyses or other studies, they are collected after the soil has been described.

Horizontal relationships between soil features can be observed in a cross section of each layer exposed by removing the soil above it. Each horizontal section needs to be large enough to expose any structural units. A great deal more about a layer is apparent when also viewing it from above in horizontal section than when only studying a vertical section. Structural units that are otherwise not obvious, as well as the third dimension of many other features, can be seen and recorded. Patterns of color within structural units, variations of particle size from the outside to the inside of structural units, the pattern in which roots penetrate structural units, and similar features are often seen in horizontal section more clearly than in a vertical exposure.

Excavations associated with roads, railways, gravel pits, and other soil disturbances provide easy access for studying soils. Variations in layer thickness and other properties can be readily observed. However, old exposures in particular have been repeatedly subjected to different conditions than exist in fresh pits. The soils dry out or freeze and thaw from both the surface and the sides. Frequently, the soil structure is more pronounced than is typical; salts may accumulate near the edges of exposures or be removed by seepage; and other changes may have taken place. Detailed soil descriptions must be made and laboratory samples obtained far enough away from excavations to assure that the soil has not been affected by unusual conditions.

Many of the properties discussed in this chapter need not be described for every soil body investigated. Some need to be described for only a small fraction of the sampling units studied. All of the properties are needed in descriptions of some soils. For some soils, properties other than those discussed in this chapter need to be described. Good judgment will decide what properties merit attention in detail for any given sampling unit: observations must not be limited by preconceived ideas about what is important.

Some General Terms Used in Describing Soils

Several of the general terms for internal elements of the soil are described here; other more specific terms are described or defined in following sections.

A soil profile is a vertical section through the soil. It is commonly conceived as a plane at right angles to the surface. In practice, a description of a soil profile includes some soil properties that can be determined only by inspecting volumes of soil. A description of a pedon is commonly based on examination of a profile, and the properties of the pedon are projected from the properties of the profile. The width of a profile varies from a few decimeters to several meters or more, but is enough to include the largest structural units.

A soil horizon is a layer, approximately parallel to the surface of the soil, distinguishable from adjacent layers by a distinctive set of properties produced by soil forming processes. The term layer rather than horizon is used if all of the properties are inherited from the parent material or no judgment is made as to whether the layer is genetic.

A sequum (plural sequa) is a B horizon together with any overlying eluvial horizons. A single sequum is the product of a specific combination of soil-forming processes.

Most soils have a single sequum, but some have two or more. A Spodosol, for example, can form in the upper part of an Alfisol, producing an eluviated zone and a spodic horizon underlain by another eluviated zone overlying an argillic horizon. Such a soil has two sequa. Soils in which two sequa have formed, one above the other in the same deposit, are said to a have a bisequum.

If two sequa formed in different deposits at different times, the soil is not bisequal. For example, a soil having an A-E-B horizon sequence may form in material that was deposited over another soil that already had an A-E-B horizon sequence. Each set of A-E-B horizons is a sequum but the combination is not a bisequum. The lower set is a buried soil. If the horizons of the upper sequum extend into the underlying sequum, the affected layer is considered part of the upper sequum. For example, the A horizon of the lower soil may retain some of its original characteristics and also have some characteristics of the overlying soil. Here, too, the soils are not considered bisequal; the upper part of the lower soil is the parent material of the lower part of the currently forming soil. In many soils the distinction cannot be made with certainty. Nevertheless, the distinction is useful when it can be made. Where some of the C material of the upper sequum remains, the distinction is clear.

The solum (plural sola) of a soil consists of a set of related horizons. The solum of a soil presently at the surface, for example, includes all horizons now forming. It includes a bisequum but not a buried soil or a layer that has not acquired some of its properties by currently active soil-forming processes. A buried soil has another solum because it was formed by past processes. The solum of a soil is not necessarily confined to the zone of major biological activity. Its genetic horizons may be expressed faintly or prominently. A solum does not have a maximum or a minimum thickness.

In terms of soil horizons described in this chapter, a solum consists of A, E, and B horizons and their transitional horizons [redacted] and are judged to be at least partly produced in the same period of soil formation.

Solum and soil are not synonymous. Some soils include layers that are not affected by soil formation. These layers are not part of the solum. The number of

genetic horizons ranges from one to several. An A horizon 5 cm thick overlying bedrock is by itself the solum. A soil that consists only of recently deposited alluvium or recently exposed soft sediment does not have a solum.

Although the term "solum" is commonly used in soil science, its application is not simple. 3/ In some soils, the actual solum is not easily determined; and in some soils the lower limit of the solum can be set only arbitrarily and needs to be defined in relation to the particular soil. For example, horizons of carbonate accumulation are easily visualized as part of the solum in many soils in arid and semiarid environments. To conceive of hardened carbonate accumulations extending for 5 meters or more below the B horizon as part of the solum is more difficult. Gleyed soil material begins in some soils a few centimeters below the surface and continues practically unchanged to a depth of many meters. Gleying immediately below the A horizon is likely to be related to processes of soil formation in the modern soil. At great depth, it is likely to be relict. Much the same kind of problem exists in some deeply weathered soils in which the deepest material penetrated by roots is very similar to the weathered material at much greater depth.

Features of the Landscape and the Soil Surface

The setting of a soil--its position in the landscape--and the surface features of the soil itself deserve emphasis, not only in mapping soils but also in describing them. Landscape features strongly influence the distribution of soils. From the landscape, the properties and extent of the soil and the location of soil boundaries can be deduced. Features of the soil surface, when considered along with internal properties of the soil, are important in making predictions about soil use, management, and behavior. The kind of landform or the part of it that a particular soil occupies should be described so that the reader will know how that soil fits into the landscape.

Surface features other than rock fragments are discussed in this section. Rock fragments, both on top of the soil and within it, are covered in the section "Soil texture and rock fragments."

To list all of the terms used to characterize landforms is beyond the scope of this manual. The literature of geology and geomorphology guides the choice and definition of terms.

Relief refers to the elevations or differences in elevation, considered collectively, of a land surface on a broad scale.

Microrelief refers to differences in relief measured over distances of centimeters or meters. In areas of similar relief, the surface may be nearly uniform or it may be interrupted by mounds, swales, or pits that contrast sharply with the broad pattern of relief. Examples include the microrelief created when trees are blown over--cradle-knoll microrelief--consisting of the knoll left by the earth that clung to the roots of the tree when it was uprooted and the depression from which it came. Coppice dunes form where windblown soil material accumulates around widely spaced plants in arid regions. Gilgai produced by expansion and contraction of soils is a form of microrelief. Mima mounds and biscuit-scabland are other examples of microrelief, though in places individual mounds cover 100 square meters or more.

Descriptions of microrelief should indicate whether the mounds or depressions are closed, form a network, or are in a linear pattern. If mounds rest on a smooth surface, their size and spacing should be described. At a specific site within an area having microrelief, it is important to note whether a described pedon is at a high point, on a slope, in a depression, or at some combination of these places. Internal soil properties in mounds may be different from the properties in depressions.

To some, the term "topography" means the same thing as "relief," but is commonly used for features disclosed on a contour map. It should be avoided in describing soils, and the more specific terms--relief, landform, or slope--used instead.

Elevation above mean sea level should be recorded with every pedon description. In many soil surveys the difference in elevation within the area is small, but in some surveys the range is great. Elevation can be determined from topographic maps or by using a properly calibrated altimeter.

Soil Slope

The slope of the soil surface has several distinct properties: gradient, complexity, configuration, length, and aspect. In soil science, slope is considered a property of the soil, not a landform like a ridge or a valley side.

Slope influences the retention and movement of water, transfer of heat, movement of soil material, rate and amount of runoff, potential for soil slippage and accelerated erosion, ease with which machinery can be used, soil-water state, and perhaps other factors. None of these, however, is a function of slope alone. Evaluation of the significance of the slope of a soil must be made in relation to the other properties of the soil and to the environment.

Slope gradient is the inclination of the surface of the soil from the horizontal. It is generally measured with a hand level. The difference in elevation between two points is expressed as a percentage of the distance between those points. If the difference in elevation is 1 m over a horizontal distance of 100 m, slope is 1 percent. A slope of 45° is a slope of 100 percent, since on a 45° slope the difference in elevation between two points 100 m apart horizontally is 100 m. The following list shows approximate equivalences between percentage gradient and degree of slope angle:

Percentage	Angle	Angle	Percentage
0	0°00'	0°	0
5	2°52'	2°	3.5
10	5°43'	4°	7.0
15	8°32'	6°	10.5
20	11°19'	8°	14.0
25	14°02'	10°	17.6
30	16°42'	12°	21.2
35	19°17'	15°	26.8
40	21°48'	20°	36.4
50	26°34'	25°	46.6
60	30°58'	30°	57.7

Percentage	Angle	Angle	Percentage
70	34°59'	35°	70.0
80	38°39'	40°	83.9
90	41°59'	45°	100.0
100	45°00'	50°	119.2

A guide to terminology for various slope classes defined in terms of gradient and complexity is given in table 4-1. The terms are used in discussing soil slope, and they can also be used in naming slope phases, as discussed in the next chapter.

The significance of slope gradient varies so much in relation to other soil properties, slope patterns, and the purposes of soil surveys that conventions are provided in table 4-1 to adjust the slope limits of the various classes. Gently sloping or undulating soils, for example, can be defined to range as broadly as 1 to 8 percent or as narrowly as 3 to 5 percent. Also, some classes may exceed even the broadest range indicated in table 4-1 by a percentage point or two where the range is narrow and by as much as 5 percent or more where the range is broad.

Terms are provided for both simple and complex slopes in some classes. Complex slopes are actually a complex of slopes--groups of slopes that have definite breaks in several different directions and in most cases markedly different slope gradients within the areas delineated.

No hard and fast rules for terminology of slope gradient are possible or even desirable; nevertheless, terms used to describe various gradients should have about the same meaning wherever they are used. The terms in table 4-1 are sufficient to cover slope classes used in most soil surveys. In some surveys, the number of slope classes needed for various interpretations exceeds the number of groups in the table. If the detail of mapping requires slope classes that are more detailed than those in table 4-1, some of the classes can be divided as follows:

Nearly level: Level, Nearly level
Gently sloping: Very gently sloping, Gently sloping
Strongly sloping: Sloping, Strongly sloping
Undulating: Gently undulating, Undulating
Rolling: Rolling, Strongly rolling

For example, if in a highly detailed survey slope classes of 0 to 1 percent and 1 to 3 percent are used, these would be named "level" and "nearly level."

Only in a very general way can special significance be attached to specific slope classes across the entire range of soil conditions. In designing mapping units, slope classes must fit the natural landscape and also meet the objectives of the survey.

In many places internal soil properties are more closely related to the configuration of the soil surface than to the gradient. Shape of the surface has an important influence on the amount and rate of runoff and on sedimentation associated with runoff.

Surface configuration has two components. One is in a direction roughly parallel to the contours of the landform; that is, the shape seen by looking at the landform (or the contour lines on a map) from directly overhead. The other component of configuration is in a direction perpendicular to the contours; that is, the shape of the slope as seen from the side. These characteristics of slope are illustrated in figure 4-1. The shape parallel to the contours is less commonly consistent for a soil than is the shape perpendicular to the contours.

The shape parallel to the contours (across the slope) can be described by the shape of the contours. The shape is linear if contours are substantially a straight line, as on the side of a moraine. An alluvial fan has a convex contour, as does a spur of the upland projecting into a valley. A cove on a hillside and a cirque in a glaciated landscape have concave contours. In figure 4-1, the two upper blocks have concave contours and the two lower blocks have convex contours. Where the contour is convex, runoff water tends to spread laterally as it moves down the slope. Where the contour is concave, runoff water tends to be concentrated toward the middle of the landform.

The shape of the surface at right angles to the contours (up and down the slope) may also be described as linear, convex, or concave. Shape in this dimension is usually identified simply as slope shape in contrast to slope contour in the other dimension. The surface of a linear slope is substantially a straight line when seen in profile at right angles to the contours. The gradient neither increases nor decreases significantly with distance. An example is the dip slope of a cuesta. On a concave slope (Figure 4-1, right), gradient decreases down the slope, as on foot slopes. Runoff water tends to decelerate as it moves down the slope, and if it is loaded with sediment, the water tends to deposit the sediment on the lower parts of the slope. The soil on the lower part of the slope also tends to dispose of water less rapidly than the soil above it. On a convex slope (Figure 4-1, left), such as the shoulder of a ridge, gradient increases down the slope and runoff tends to accelerate as it flows down the slope. Soil on the lower part of the slope tends to dispose of water by runoff more rapidly than the soil above it. The soil on the lower part of a convex slope also is subject to greater erosion than the higher-lying soil.

The configuration of the surface of a soil may be described in terms of both the shape of the contour and the shape of the slope. For example, a surface can be described as having a convex contour and a convex slope (an alluvial fan) or a linear contour and a concave slope (the base of a moraine).

Slope length has an important bearing on the behavior of water and on the potential for erosion. Runoff and potential soil losses are proportional to slope length, but the relationship is not the same for all soils nor for all conditions at any place. Terms such as "long" or "short" can be used to describe slope lengths that are typical of certain kinds of soils. These terms are usually relative within a physiographic region. A "long" slope in one place might be "short" in another. If such terms are used, they are defined locally. When a soil is described, the length of the slope that contributes water to the site sampled is estimated in addition to the total length of the slope.

Slope aspect is the direction toward which the surface of the soil faces. The direction is expressed as an angle between 0° and 360° measured clockwise from true north or as a compass point such as east or north-northwest. When soils are described in the field, the direction that the slope faces is recorded.

Where direction of slope is the principal variable, soils on north-facing slopes in the northern hemisphere are cooler and have lower evapotranspiration than soils on south-facing slopes because the north-facing soils receive less sunlight. In some critical areas this may favor trees on north-facing slopes and grass on south-facing slopes. Slope aspect is more critical at high latitudes than lower latitudes because the angle of the sun from the earth is lower at high latitudes.

Slope aspect is also important in areas of strong winds. Usually in these areas the winds blow from one general direction at least seasonally. Evapotranspiration is higher in areas facing the prevailing winds. Strong winds favor low-growing vegetation, such as grasses or shrubs, over trees. Also, soil temperature may be altered, depending on whether the winds are hot or cool.

In mountainous areas slope characteristics, exposure to wind, and elevation vary within short distances. All of these must be known to predict soil-plant relationships.

Rock Outcrop

Rock outcrops are exposures of bedrock. Most outcrops are too hard to be broken and mixed by tillage. The exposures are presumed to be a part of a large body of underground bedrock; rock fragments are discrete pieces of rock and are not attached to the bedrock.

In some places, bodies of rock 100 m or more in diameter are detached from any extensive continuum of bedrock and may have been displaced; however, whether or not such bodies are detached or displaced is not readily observable and for most purposes is not important. Bodies of rock this large are treated as bedrock. For bodies about the size of a pedon, a distinction between detached fragments and exposed rock outcrop is more meaningful. Generally, bodies of rock that have few cracks in which plants can grow and that appear to be displaced little are treated as rock outcrop if they are as large as a pedon. However, bodies up to 10 meters or more across that are clearly detached and displaced, such as large glacial erratics, are described as boulders (see "Rock fragments," p. 4-58).

The effects of rock outcrop on land use depend on the part of an area occupied by outcrops, the size and spacing of the outcrops, the manner in which the outcrops protrude above the surface of the surrounding soil, the kind of land use, the technology employed in using the land, and the properties of the soil between the outcrops. The area occupied by outcrops, by itself, is not the most useful criterion of the significance of rock outcrop. The spacing of outcrops determines how often operation of equipment across an area is interrupted, the efficiency of operations, probability of equipment breakage, and the like. The manner in which outcrops protrude above the surrounding soil surface affects the kinds of equipment that can be used and the routes of movement. These properties, as well as the properties of the surrounding soil, are described when a site is surveyed.

Classes of area of rock outcrop, including soil supporting little or no vegetation, are as follows:

Class 1:	Less than 0.1 percent of the surface is exposed bedrock.
Class 2:	0.1 to 2 percent of the surface is exposed bedrock.
Class 3:	2 to 10 percent of the surface is exposed bedrock.
Class 4:	10 to 25 percent of the surface is exposed bedrock.
Class 5:	25 to 50 percent of the surface is exposed bedrock.
Class 6:	50 to 90 percent of the surface is exposed bedrock.
Class 7:	More than 90 percent of the surface is exposed bedrock.

Vegetation

Correlations between vegetation and soils are made for three main purposes: (1) understanding soil genesis, (2) recognizing soil boundaries, and (3) making predictions from soil maps about the kind and amount of vegetation produced.

Where possible, the kinds and amounts of plants in the potential natural vegetation on a soil should be estimated. This vegetation is most closely related to the soil and its genesis. Where vegetation has been altered, as in abandoned fields, cut-over woodland, or heavily grazed range, the present vegetation is listed. Records are maintained of the common cultivated crops.

Most areas of the United States and many other countries have publications that describe in detail the common plants. Some give important relationships between the plants and their environments. Literature of this kind is assembled and becomes part of the working documents of the soil survey.

For some areas, most of the information about soil use and crops grown on different soils is already known from special studies. Even in these areas, complete notes may reveal soil-plant relationships not previously recognized. Care is taken to make regular observations. Notes taken by a sampling plan and by methods designed to avoid bias are the most reliable. Casual notes taken without a plan are likely to record mainly the unusual uses and unusual kinds of plants that catch the eye.

Where soils are examined, the principal kinds of plants are listed in the approximate order of their abundance. In forested areas, separate treatment is often necessary for (1) the forest trees, (2) the understory of small trees and shrubs, and (3) the ground cover of low growing shrubs, herbaceous plants, mosses, and the like. Many soils of rangeland have an overstory of shrubs or low trees, which are listed separately from the grasses, forbs, and other ground cover. An idea of the density of stand or plant cover, such as average canopy cover of trees or shrubs, can be given. For trees, the range in size of dominant species can be given as "diameter breast high" if desired. Estimated percentage of the ground covered by grasses and forbs should be included.

Common names of the plants may be used if such names are clear and specific. Many common names vary from place to place for the same species, and some names are used for different species in the same region. In areas where the plants are important for the use and interpretation of the soil map, the soil survey record should include both common and scientific names of plants. The plant

identification should be checked by plant taxonomists, either in the field or from collected specimens, but the soil survey party members also need to learn both the common and scientific names of the principal plants and be able to identify them.

At any one site, only the present vegetation and current management can be described. In many areas of the United States, almost all of the land is under cultivation. Weeds in unused areas are as unlike the original plant community as crop plants are. Nevertheless, the crop plants or the principal weeds in uncropped areas are listed for the site where a pedon is studied. Both are included in the descriptions of mapping units and kinds of soil. If the original vegetation can be determined, it is described as well.

By studying many sites of the same kind of soil under differing plant covers, the potential plant community and principles of plant succession for that kind of soil can be ascertained. Such studies permit some measure of the rate and direction of change. Important principles can be developed by learning the land-use history of the sites examined. For example, the order of plant succession that follows fires or harvesting of forests is important. Similar principles are important in grazing areas, where different species succeed one another when different grazing practices are followed. Forest and range specialists can help greatly in such studies.

The separate descriptions of vegetation at individual sites are later summarized for kinds of soil or map units in the soil survey area. The designation of the appropriate range site or woodland suitability group is included. If soil associations or complexes are mapped, appropriate and useful descriptions of vegetation are prepared for each soil.

Vegetation, observed in the field and on aerial photographs, can be of great help in classifying and mapping soils. But the use of either vegetation or patterns on aerial photographs without complete soil examinations to the full depth of the soil is certain to lead to a soil map with limited predictive value.

Observations of the growth of both native vegetation and cultivated crops aid in recognizing soil boundaries and provide direct information about the behavior of specific plants on different kinds of soil. Generally, close relationships exist between native vegetation and kinds of soil; yet there are important exceptions. A reliable soil map cannot be made by studying vegetation alone; but with careful observations of both soils and vegetation, excellent correlations can be established.

Over an extended period of cultivation, farmers learn which crops do well and which do poorly on different kinds of soil and adjust their cropping patterns to varying degrees accordingly. If the differences are large--as between crop failure and reasonable performance--the near absence of a given crop on a specific kind of soil may reflect experience with the suitability of that kind of soil for the crop. If the differences are small, many nonsoil factors can determine the farmer's choice of fields for a given crop. Relationships observed must be interpreted with caution because of economic factors, management systems, and farmer preference. But within fields of a single crop, differences of vigor, stand, or color of the crop or of weeds commonly mark soil differences and are valuable clues to the location of soil boundaries.

In the soil survey record, the characteristics of growth and the use of important plants are described in relation to the individual soils and their

management. The seasonal growth and palatability of the various kinds of plants eaten by different kinds of grazing animals are important. The results from research plots and the experience of ranchers are helpful in making estimates for map units or groups of map units. The kinds and amounts of poisonous and other undesirable plants may need special emphasis. Current or potential invasions of weedy plants on soil used for grazing are described or predicted.

Care is needed in relating the kind and vigor of plant cover to expected performance of other plants in a cultural environment on a given soil. Different cultivated and native plants have different requirements. Some differences in soil properties that are important if a soil is irrigated may have little effect on the original semiarid grassland. Classification of a soil and predictions about a map unit must take full account of the influence of soil properties on management as well as on natural vegetation.

By the time the fieldwork is completed, enough data will have been assembled from the survey or from other sources to describe the approximate proportions of each map unit in the major land use classes (cropland, pasture, orchard, forest, idle land, etc.), as well as the principal crops, pasture or range plants, trees, and weeds of the various soils. The uses of the soils, the crops grown, the common weeds, and the management systems used are recorded in relation to map units. Departures from the general patterns of the areas are noted, but care is exercised to record the common as well as the unusual uses, plants, and practices.

Parent Material

Parent material refers to that great variety of unconsolidated organic and mineral materials in which soils form. Fresh peat and unconsolidated mineral matter are parent material by this concept, but consolidated bedrock is not.

Much of the mineral matter in which soils form derives in one way or another from hard rocks, such as granite. Glaciers may grind the granite into rock fragments and earthy material and deposit a mixture of granite particles as glacial till; such material is identified as "glacial till derived from granite." In contrast, granite may be weathered with great chemical and physical changes but not moved from its place of origin; this altered material is called "residuum from granite."

The parent material of a genetic horizon cannot be observed in its original state; it must be inferred from the properties the horizon has inherited and from other evidence. In some soils, the parent material has changed little, and what it was like can be deduced with confidence. In others, such as some very old soils of the tropics and many organic soils, the specific kind of parent material or its mode of origin is speculative.

In some cases, little is gained from attempting to differentiate between geologic weathering and soil formation because both are weathering processes. It may be possible to infer that a material was weathered prior to soil formation. In the weathering process some constituents have been lost, some have been transformed, and others have been concentrated.

The parent material of a modern mineral soil is not necessarily residuum from the bedrock that is directly below. Movement of soil material downslope is an important process and can be appreciable even on gentle slopes, especially on very old landscapes. Also, soils form in different layers of sedimentary rocks. The material that developed into a modern soil may be unrelated to the underlying bedrock.

Seldom is there certainty that a highly weathered material weathered in place. The term "residuum" is used when the properties of the soil indicate that it has been derived from rock like that which underlies it and when evidence is lacking that it has been modified by movement. In sloping soils a rock fragment distribution that decreases in amount with increasing depth, especially over saprolite, indicates that soil material probably has been transported downslope. Stone lines, especially if the stones have a different lithology than the underlying bedrock, provide evidence that the soil did not form entirely in residuum. In some soils, transported material overlies residuum and illuvial organic matter and clay films are superimposed across the discontinuity between the contrasting materials. A certain degree of landscape stability is inferred for residual soils, and a lesser degree is inferred for soils that developed in transported material.

Both consolidated and unconsolidated material beneath the solum that influence the genesis and behavior of the soil are described in standard terms. Besides the observations themselves, the scientist records his judgment about the origin of the parent material from which the solum developed; but observations must be separated clearly from inferences.

The hardness, lithologic composition, and hydraulic conductivity of the material directly beneath the solum are important. Evidence of stratification of the material--textural differences, stone lines, and the like--need to be noted. Many soils obviously developed from stratified parent material; others seem to have developed from uniform material like that directly beneath the solum, although this conclusion is rarely certain without chemical, physical, and mineralogical or stratigraphic data.

Commonly, the upper layers of outwash deposits settled out of more slowly moving water and are finer in texture than the lower layers. Windblown fines and volcanic ash are laid down at different rates in blankets of varying thickness. Examples of such complications are nearly endless.

Where alluvium, loess, or ash are quickly dropped on old soils, buried soils may be well preserved. Elsewhere the accumulation of mineral material on the top of the soil is so slow that the solum thickens only gradually. In such places the material beneath the solum was once near the surface but may now be buried below the zone of active weathering.

Where hard rocks or other strongly contrasting materials lie near enough to the surface to affect the behavior of the soil, their depths need to be measured accurately. The depth of soil over such nonconforming materials is an important criterion for distinguishing different kinds of soil.

The classification and nomenclature of rocks and of geological formations fall in the field of geology and are not dealt with in this manual. Geological materials need to be defined in accordance with the accepted standards and nomenclature of geology. The best textbooks, handbooks, and monographs on geology

that apply to the area are used as references.. The accepted authoritative names of the geological formations are recorded in soil descriptions where these can be identified with reasonable accuracy. As soil research progresses, an increasing number of correlations are being found between particular geological formations and the mineral and nutrient content of parent materials and soils. For example, certain terrace materials and deposits of volcanic ash that are different in age or source, but otherwise indistinguishable, vary widely in the content of cobalt. Wide variations in the phosphorus content of two otherwise similar soils may reflect differences in the phosphorus content of two similar limestones that can be distinguished in the field only by specific fossils.

In relation to soil formation, lithologic composition often is more important than mode of formation of the rock. Soils derived from basalt and soils derived from limestone are likely to be more alike than soils derived from basalt and those derived from quartz diorite.

The principal broad subdivisions of parent material are discussed in the following paragraphs.

Material Produced by Weathering of Rock in Place

The kinds of material produced by weathering of rock in place are related to the nature of the original rock. The soil forms in the weathered material itself, which may have undergone various changes from the original rock, including changes in volume and loss of minerals such as plagioclase feldspar and other easily weathered minerals. Under some conditions rocks may lose minerals without any change in volume or in the original rock structure. The point where rock weathering ends and soil formation begins is not always clear. The processes may be consecutive and even overlapping. Saprolite, like loess and glacial till, essentially is parent material. Quite different soils may form from similar or even identical rocks under different weathering conditions. Texture, color, consistence, and other characteristics of the material are described as well as important features such as quartz dikes. As much useful information as can be obtained about the mineralogical composition, hardness, and structure of the parent rock itself should be added to help in understanding the changes from parent rock to weathered material.

Igneous rocks formed by the solidification of molten materials that originated within the earth. Examples of igneous rocks that weather to important soil material are granite, syenite, basalt, andesite, diabase, and rhyolite.

Sedimentary rocks formed from sediments laid down in previous geologic ages. The principal broad groups of sedimentary rocks are limestone, sandstone, shale, and conglomerate, all of which have varying degrees of hardness. There are many varieties of these broad classes of sedimentary rocks and many types intermediate between them, such as calcareous sandstone and arenaceous limestone. Chalk and marl are soft varieties of limestone. Also included are deposits of diatomaceous earth, which formed from the siliceous remains of primitive plants called diatoms.

Metamorphic rocks resulted from profound alteration of igneous and sedimentary rocks by heat and pressure. General classes of metamorphic rocks important as sources of weathered parent material of soils are gneiss, schist, slate, marble, quartzite, and phyllite.

About three-quarters of the land area of the world is underlain by sedimentary rocks and one-quarter by igneous and metamorphic rocks.

Transported Material

The most extensive group of parent materials in the world is the very broad group of materials that have been moved from the place of their origin and deposited elsewhere. The principal groups of transported materials are usually named according to the main force responsible for their transport and deposition. In most places sufficient evidence is available to make a clear determination; elsewhere the precise origin is uncertain.

In soil morphology and classification, it is exceedingly important that the characteristics of the material itself be observed and described. It is not enough simply to identify the parent material as alluvium, loess, or glacial till. Such names supplement the descriptions of the material, and any doubt of the correctness of the identification is mentioned. For example, it is often impossible to be sure whether certain silty deposits are alluvium, loess, or residuum. Certain mud flows are indistinguishable from glacial till. Some sandy glacial till is nearly identical to sandy outwash. However, such hard-to-make distinctions are not very significant.

Material moved and deposited by water

Alluvium.--Alluvium consists of sediment deposited by streams and rivers. It may occur on terraces well above present streams or in the normally flooded bottom land of existing streams. Remnants of very old stream terraces may be found in dissected country far from any present stream. Along many old established streams lie a whole series of alluvial deposits in terraces--young deposits in the immediate flood plain, up step by step to the very old deposits on the highest terraces. In some places recent alluvium covers older terraces.

Lacustrine deposits.--These deposits consist of material that has settled out of the still water of lakes. Deposits laid down in fresh-water lakes associated with glaciers are commonly included as a kind of glacial drift. Besides these are other lake deposits, including some of Pleistocene age, not associated with the continental glaciers. Some old lake basins in the western United States are commonly called playas; the soils in these basins may be more or less salty, depending on climate and drainage.

Marine sediments.--These sediments settled out of the sea and were reworked by currents and tides. Later they were exposed either naturally or following the construction of dikes and drainage canals. They vary widely in composition. Some resemble lacustrine deposits.

Beach deposits.--Beach deposits mark the present or former shorelines of the sea or lakes. These deposits are low ridges of sorted material and are commonly sandy, gravelly, cobbly, or stony. Deposits on the beaches of former glacial lakes are usually included with glacial drift.

Material moved and deposited by wind

Windblown material can be divided into groups based on particle size or on origin. Volcanic ash and cinders are examples of materials classed by both particle size and origin. Other windblown material that is mainly silty is called loess, and that which is primarily sand is called eolian sand. Eolian sand is commonly but not always in dunes. Nearly all textures intermediate between silty loess and sandy dune material can be found.

Volcanic ash and cinders are sometimes regarded as unconsolidated igneous rock, but they have been moved from their place of origin and most have been reworked by wind and in places by water. Ash is volcanic ejecta smaller than 2 mm. Ash smaller than 0.05 mm may be called "fine ash." Cinders are volcanic ejecta 2 mm or larger. (Most geologists use different size limits for ash and cinders.)

Loess deposits typically are very silty but may contain significant amounts of clay and very fine sand. The material is generally calcareous. Most loess deposits are pale brown to brown, although gray and red colors are common. The thick deposits are generally massive and have some gross vertical cracking. The walls of road cuts in thick loess stand nearly vertical for years. Other silty deposits that formed in other ways, however, have some or all of these characteristics. Some windblown silt has been leached and strongly weathered so that it is acid and rich in clay. On the other hand, some young deposits of windblown material, called loess, are mainly silt and very fine sand and are exceedingly low in clay.

Sand dunes, especially in humid regions, characteristically consist of sand, especially fine or medium sand, that is very rich in quartz and low in clay-forming materials. Especially in deserts and semideserts, the sand dunes may contain large amounts of calcium carbonate. Some dunes consist almost wholly of sand composed of calcium carbonate or gypsum.

During periods of drought and in deserts, local wind movements may mix and pile up soil material of different textures or even material that is very rich in clay. Piles of such material have been called "soil dunes" or "clay dunes." It is better, however, to use an expression such as "wind-deposited material" for local accumulations of mixed material moved by the wind than to identify them as "loess" or "dunes."

Also important but not generally recognized as a distinctive deposit is dust, which is carried for long distances and deposited in small increments on a large part of the world. Dust can circle the earth in the upper atmosphere. The accumulated deposits are large in some places. An immense amount of dust has been distributed widely throughout the ages, and dust is an important factor affecting soils in some places. Dust is the source of the unexpected fertility of some old, highly leached soils in the path of wind that blows from extensive deserts some hundreds of kilometers distant. It explains unexpected micronutrient distribution in some places. Dust particles are mostly clay and very fine silt.

The most likely sources of dust at present are the drier regions of the world, where the soils are generally rich in bases and other constituents. Large amounts of dust may have been distributed worldwide during and immediately following the glacial periods. Besides dust, fixed nitrogen, sulfur, sodium, potassium, and other elements from the atmosphere are deposited on the soil in varying amounts.

(430-V-SSM, May 1981)

Material moved and deposited by glacial processes

Several kinds of material were moved and deposited by glacial processes. Glacial drift consists of all of the material picked up, mixed, disintegrated, transported, and deposited by glacial ice or by water from melting glaciers. In many places glacial drift is covered by a mantle of loess. Deep mantles of loess are usually easily recognized, but very thin mantles may be so altered by soil-building forces that they can scarcely be differentiated from the underlying modified drift.

Glacial till.--Till is that part of the glacial drift deposited directly by the ice with little or no transportation by water. It is generally an unstratified, unconsolidated, heterogeneous mixture of clay, silt, sand, gravel, and sometimes boulders. Some settled out as the ice melted with very little washing by water, and some was overridden by the glacier and is compacted and unsorted. Till may be found in ground moraines, terminal moraines, medial moraines, and lateral moraines. In many places it is important to differentiate between the tills of the several glaciations. Commonly, the tills underlie one another and may be separated by other deposits or old weathered surfaces. Many deposits of glacial till were later washed by lakes, but without important additions. The upper part of such wave-cut till is rich in coarse fragments as a result of the wave action in glacial lakes. Drumlins are long, low, cigar-shaped hills of glacial till with a smooth skyline; the long axis lies parallel to the direction of movement of the ice.

Till varies widely in texture, chemical composition, and the degree of weathering following its deposition. Most till is calcareous, but an important part is noncalcareous because no calcite- or dolomite-bearing rocks contributed to the material or because subsequent leaching and chemical weathering have removed the carbonates.

Glaciofluvial deposits.--These deposits are material produced by glaciers and carried, sorted, and deposited by water that originated mainly from melting glacial ice.

The most important kind of glaciofluvial deposit is glacial outwash. This broad term includes all of the material swept out, sorted, and deposited beyond the glacial ice front by streams of melt water. Commonly, this outwash is in the form of plains, valley trains, or deltas in old glacial lakes. The valley trains of outwash may extend far beyond the farthest advance of the ice.

Especially near moraines, poorly sorted glaciofluvial material may form kames, eskers, and crevasse fills.

Glacial beach deposits.--These consist of gravel and sand and mark the beach lines of former glacial lakes. Depending on the character of the original drift, beach deposits may be sandy, gravelly, cobbly, or stony.

Glaciolacustrine deposits.--These deposits range from fine clay to sand. They are derived from glaciers but were reworked and laid down in glacial lakes. Many of them are stratified or laminated. Alternating strata exposed in a section of glaciolacustrine clay, each related to one year's deposition and one season's glacial ice melt, are called varves.

Good examples of all of the glacial materials and forms described in the preceding paragraphs can be found. In many places, however, it is not easy to distinguish definitely among the kinds of drift on the basis of mode of origin and landform. For example, pitted outwash plains can scarcely be distinguished from sandy till in terminal moraines. Distinguishing between wave-cut till and lacustrine material is often difficult. The names themselves connote only a little about the actual characteristics of the parent material. Certainly mode of origin of the parent material is not a sufficient basis, by itself, for distinguishing soils because similar parent materials may have different origins.

Material moved and deposited by gravity

Colluvium is an incoherent mass of soil material or rock fragments at the base of slopes. It is largely material that has rolled, slid, or fallen down the slope under the influence of gravity. An accumulation of rock fragments is called talus. The rock fragments in colluvium are usually angular, in contrast to the rounded, water-worn cobbles and stones in alluvium and glacial outwash. "Colluvium" is used generally for that part of the poorly sorted debris that has accumulated at the base of slopes, in depressions, or along tiny streams through gravity, soil creep, and local wash.

Organic Material

Organic material accumulates in wet places where it is deposited more rapidly than it decomposes. These deposits are called peat. This peat in turn may become parent material for soils. The principal general kinds of peat, according to origin, are:

Sedimentary peat: the remains mostly of floating aquatic plants, such as algae, and the remains and fecal material of aquatic animals, including coprogenous earth.

Moss peat: the remains of mosses, including Sphagnum.

Herbaceous peat: the remains of sedges, reeds, cattails, and other herbaceous plants.

Woody peat: the remains of trees, shrubs, and other woody plants.

Many deposits of organic material are mixtures of these kinds of peat. Some organic soils formed in alternating layers of different kinds of peat. In places peat is mixed with varying amounts of mineral material, such as alluvium and volcanic ash. Some organic soils have layers that are largely or entirely mineral material.

In describing organic soils, the material is called peat if virtually all of the organic remains are sufficiently fresh and intact to permit identification of plant forms. It is called muck if virtually all of the material has undergone sufficient decomposition that the plant parts cannot be recognized. It is called mucky peat if a significant part of the material can be recognized and a significant part cannot.

Descriptions of organic material should include the origin and the botanical composition of the material to the extent that these can be reasonably inferred.

Contrasting Materials

Contrasting layers of geologic material affect soils and soil patterns in several ways. The stratigraphy of rock is commonly reflected in soil patterns where the various strata are exposed at the surface. In the folded Appalachians of the eastern United States, for example, belts of contrasting soils are related to belts of contrasting rocks exposed on the ridges and in the valleys. Some areas in the north-central United States have soil patterns that are related to the distribution of loess and till and to zones of weathering in them where they are exposed in valleys. At a smaller scale, contrasting layers within a soil are reflected in differences in the properties of horizons.

Contrasting layers of unconsolidated material may differ in pore-size distribution, particle-size distribution, mineralogy, bulk density, color, or other properties. Some of the differences may not be obvious. The ratio of two or more resistant heavy minerals, used as an index of the uniformity of some deposits, frequently varies erractically within pedons that appear homogeneous. Some deposits are clearly stratified, such as some lake sediments and glacial outwash, and the discontinuities may be sharply defined. The master soil horizons and layers may have developed in contrasting deposits that are not coextensive.

The effects of some contrasting materials can be confused with the effects of soil formation, making identification of the materials uncertain. In some areas, for example, silt content decreases regularly with depth in soils presumed to have formed in glacial till. In some of these soils, small amounts of eolian material may have been deposited on the surface over the centuries and mixed by insects and rodents with the underlying glacial till. In others, the silt distribution reflects water sorting. Thus, the higher silt content in the upper part of these soils can be explained by factors other than soil formation.

Inferences about contrasting properties inherited from differing layers of geologic material are noted when the soil is described. Generally, each identifiable layer that is genetically influenced and differs clearly in inherited properties from adjacent layers is recognized as a subhorizon. Whether it is marked in soil descriptions as a lithologic discontinuity or not depends on the degree of contrast with overlying and underlying layers and the thickness. For many soils the properties inherited from even sharply contrasting layers are not consistent from place to place and are described in general terms. The C layer of a soil in stratified lake sediments, for example, might be described as follows: "consists of layers of silt or clay 1 to 20 cm thick; the aggregate thickness of layers of silt and that of the layers of clay are in a ratio of about 4 to 1; material is about 80 percent silt."

Erosion

In its broad sense, erosion means the wearing away of the earth's surface by the forces of ice, water, and wind. The sculpturing of mountains, the abrasion of rock surface on plains, and the obliteration of ancient soils and weathered zones

by continental glaciers are examples of erosion on a grand scale by ice. The Dakota Badlands and the Grand Canyon of the Colorado River are examples of spectacular erosion by water. The shifting of sands to form the dunes of the Nubian Desert is erosion by wind. More subtle are the detachment and transport of particles from fields or from the bare surface of a new building site by water and the blowing of soils from fallow fields or unvegetated playgrounds.

The inevitable wearing down of high places and filling of low places of the earth's surface continues with or without assistance from man. To distinguish erosion characteristic of the natural environment from the more rapid erosion that results from activities of man, the concepts of "natural" and "accelerated" erosion are applied. The two are not everywhere distinguishable.

Natural Erosion

Natural erosion is the detachment and movement of material under conditions unaffected by the activities of man. Natural erosion may be very slow or very rapid, and it may fluctuate considerably depending on local conditions. The formation of the Channel Scablands in the state of Washington is an example of extremely rapid natural, or geologic, erosion. The broad, nearly level interstream divides on the Coastal Plain of the southeastern United States are examples of areas with very slow or no natural erosion.

Natural erosion has left its mark on soils. It has sculptured landforms on the uplands and built landforms on the lowlands. Its rate and distribution in time controls the age of land surfaces and many of the internal properties of soils on the surfaces. The results of natural erosion are used to identify soils and predict soil properties. The marks of past natural erosion on the landscape must be recognized and their significance in the local environment understood. All of the available information on the geomorphic history of the area should be used during a soil survey, and the assistance of geomorphologists should be sought in its interpretation.

Landscapes and their soils are evaluated from the perspective of their natural erosional history. Attention is needed to the smoothing of the land's surface in old and young landscapes--the movement of soil material down slopes and the filling of lowland depressions. Buried soils, stone lines, deposits of wind-blown material, and other evidence that material has been moved and redeposited is helpful in understanding soil genesis. In the process of erosion, thick weathered zones that developed under earlier climatic conditions may be exposed and are the material in which new soils form. On the young landscapes of the most recently glaciated areas, the consequences of natural erosion, or lack of it, are less obvious than where the surface and the landscape are of early Pleistocene or even Tertiary age. Even on the landscapes of most recent glaciation, however, the impact of postglacial natural erosion may be significant in the redistribution of materials on the local landscape.

The rate of erosion can be increased by activities other than those of man. Fire that destroys vegetation and triggers erosion has the same effect whether set by lightning or by man, whether set by primitive people as a "natural" element of the ecological system or by civilized man as an "unnatural" element. The spectacular episodes of erosion, such as the soil blowing on the Great Plains of the central United States in the 1930's, have not all been man-made. Frequent dust storms were recorded on the Great Plains long before the region became a

grain-producing area. "Natural" erosion is not easily distinguished from "accelerated" erosion on every soil, nor is acceleration by man easily distinguished from erosion produced by accidents of nature. But to attempt a distinction is useful on many soils, and in places the distinction is clear. However, the distinction must be made primarily by studying and understanding the sequence of sediments and surfaces on the local landscape, not by studying soil properties alone.

Accelerated Erosion

Accelerated erosion and natural erosion are so intimately interrelated in some cultural landscapes that distinguishing them is difficult. Natural erosion is an important process that affects soil formation, and like man-induced erosion may remove all or part of soils formed in the natural landscape.

Kinds of accelerated erosion

The processes of erosion influenced by man can be divided into two classes, water erosion and wind erosion, 4/ according to the moving agent. Erosion by glacial ice is mainly a process of natural erosion.

Wind erosion is important primarily, but not exclusively, in subhumid, semiarid, and desert regions. Water erosion is important in humid regions, but water is also a major eroding agent in arid regions.

Water erosion.--Water erosion results from disturbance of the soil surface by flowing water and the material it carries. A part of the process is the detachment of soil particles by the impact of raindrops. The particles are suspended in runoff water and carried away. Three kinds of accelerated water erosion are commonly recognized: sheet, rill, and gully. These are distinguished by the relative depth and stability of the channels cut by running water.

Sheet erosion is the more or less uniform removal of soil from an area without the development of conspicuous water channels. The channels are tiny or tortuous, exceedingly numerous, and unstable; they enlarge and straighten as the volume of runoff increases. Sheet erosion is less apparent, particularly in its early stages, than other types of erosion. It can be serious on some soils having a slope gradient of only 1 or 2 percent. It is generally more serious as slope gradient increases.

Rill erosion is the removal of soil through the cutting of many small but conspicuous channels where runoff concentrates. Rill erosion is intermediate between sheet and gully erosion. The channels are shallow enough that they are easily obliterated by tillage; thus, after an eroded field has been cultivated, determining whether the soil losses resulted from sheet or rill erosion is generally impossible.

Gully erosion is conspicuous. Gullies form where water concentrates and flows as a stream, cutting down into the soil along the line of flow. Gullies form in exposed natural drainageways, in plow furrows, in animal trails, in vehicle ruts, between rows of crop plants, and below broken man-made terraces. In contrast to rills, they cannot be obliterated by ordinary tillage. Deep gullies cannot be crossed with common types of farm equipment.

Gullies and gully patterns vary widely in different kinds of soil and on different landforms. In some places, a single gully forms in a field; in other places, gullies are closely spaced leaving little or no unaffected surface between them. V-shaped gullies (Figure 4-2) cutting into the soil more or less uniformly throughout their courses are most common. These form in material that is equally or increasingly resistant to erosion with depth. U-shaped gullies (Figure 4-3) form in material that is equally resistant or decreases in resistance to erosion with depth, as where the water cuts through coherent upper material into a loose, incoherent substratum. As the substratum is washed away, the overlying material loses its support and falls into the gully to be washed away. Most U-shaped gullies become modified toward a V shape once the channel stabilizes and the banks start to spall and slump.

The maximum depth to which gullies cut is governed by resistant layers in the soil, by bedrock, or by the local base level of the lowland into which the water runs. Many gullies develop headward; that is, they extend up the slope as the gully deepens in the lower part. Some extend headward as a single channel. Others form branches where depressions of the surface intersect the main gully. If gullying is not controlled, the lower part of the landform may be reduced to a smooth eroded area at a new level separated from an ungullied upper part by a strip of gullied soil. Many gullies are too small to be delineated as areas on the soil map and are shown by special symbols. Other gullied areas are large enough to be mapped. The areas are classified as soil if unconsolidated material that will support plants remains.

Deposition of sediment carried by water is likely anywhere that the velocity of running water is reduced--at the mouth of gullies, at the base of slopes, along stream banks, on alluvial plains, in reservoirs, and at the mouth of streams. Rapidly moving water, when slowed, drops stones, then cobbles, pebbles, sand, and finally silt and clay. Fine clay settles out of still water. Deposits of rock fragments or sand on productive lower-lying soils are harmful. Deposits of fine earth may be beneficial. Some deposits of fine earth help to maintain the fertility of the soils on which they are deposited; some clayey deposits and some sandy deposits create poor physical soil conditions. The character of such deposits is noted in examining the soils, and mapping units are designed to accommodate them in the mapping legend if the area is significant.

Water erosion is at a maximum in areas that receive about 300 mm annual rainfall and decreases with either increasing or decreasing annual rainfall. Vegetation generally does not form a continuous cover in such dry areas, and some rains are very intense. Intensive water erosion and deposition of sediment can take place during a single storm, but storms are infrequent and total erosion is low. The effects of this kind of storm can be greatly increased by land use that reduces the amount of vegetation, especially in areas of higher rainfall.

Wind erosion.--Wind is not generally an important cause of erosion in humid areas except on unprotected sandy soils and on tracts of drained and cultivated organic soils. In regions of low rainfall, wind erosion can be widespread, especially during periods of drought. Unlike water erosion, wind erosion is generally not related to slope gradient. The hazard of wind erosion is increased by removing or reducing the vegetation.

When winds are strong, the finer particles are swept into the air and may be carried for great distances. Some circle the globe at very high elevations. Coarser particles are rolled or swept along on or near the soil surface, kicking

finer particles into the air, and are deposited in places sheltered from the wind. When wind erosion is severe the sand particles may drift back and forth locally with changes in wind direction while the silt and clay are carried away. Blowouts, spots from which the surface layer has blown away, may be associated with spots of deposition in such an intricate pattern that the two cannot be identified separately on soil maps.

Eroded condition of soils

The degree to which accelerated erosion has modified the soil is estimated during soil examinations. Mapping units are designed to record the condition of the remaining soil if it differs significantly in use, suitability, or management requirements from the uneroded soil. The definition of the soil in the mapping unit and interpretations for mapped areas must focus on the properties of the soil that remains; properties of the material that has been lost can only be inferred and are not used to define or classify soils.

Estimating the degree of erosion.--To estimate the degree of accelerated erosion of a specific soil, the properties of the uneroded soil in a site and state of use comparable to those of the eroded soil are determined first, if possible. Then the properties of the eroded soil are determined. By comparing the two sets of properties, the degree to which erosion has modified the soil can be estimated. Parts of horizons or entire horizons and the thickness of surface layers that have been lost, the variations within mappable areas, and similar features can be estimated by comparing properties.

In the natural environment, the individual horizons and the solum of each soil have characteristic ranges in thickness and other properties. These properties are determined as accurately as possible as standards for comparison. If these standards are to be useful and reliable guides to erosion losses, several precautions must be taken.

First, cultivation causes differences in the thickness of horizons of many soils where no erosion has taken place. The upper parts of many forested soils contain roots in as much as one-half of the soil volume. When these decay, the soil settles. The upper horizons of some undisturbed soils have low bulk density, and bulk density may be increased by tillage. The depth to reference layers is measured from the top of the mineral soil in setting standards because organic horizons at the surface of mineral soils are destroyed by cultivation. Removal of stones can also lower the surface. Depths in plowed soils are measured after the plowed layer has settled.

The thickness of a plowed layer of a specific soil cannot be used as a standard for either losses or additions of material, because as a soil erodes the plow cuts progressively deeper. Nor can the thickness of the uncultivated A horizon be used as a standard for all cultivated soils unless the A horizon is much thicker than the plow layer. If the horizon immediately below the plowed layer of an uneroded soil is distinctly higher in clay than the A horizon, the plow layer becomes progressively more clayey under continued cultivation as erosion progresses; the texture of the plow layer is a criterion of erosion.

Comparisons also must be made on comparable slopes. Near the upper limit of the range of slope gradient for a soil, horizons may normally be thinner than near the lower limit of the range for the same soil. Thus, the standards for horizon

thickness within the range of the soil may differ according to slope. Naming that part of a soil having slopes of 20 percent as an eroded phase is an error if the observed difference in thickness between strongly sloping and gently sloping sites is characteristic for the soil.

Roadsides, cemeteries, fence rows, and similar small, uncultivated areas are not suitable for setting standards. If they are so used, the standards for surface-layer thickness are generally set too high. In naturally treeless areas, or in areas cleared of trees, dust collects in fence rows, along roadsides, and on other small uncultivated areas that are covered with grass or other stabilizing plants. In a short time the surface horizon may become thickened by several centimeters.

For soils having clearly defined horizons, differences due to erosion can be accurately determined by reference to the undisturbed or uncultivated norm. The distinctive horizons and their depths or thicknesses are reliable guides within the limits of their variation from place to place. Guides for soils having a thin A horizon and little or no other horizon expression are more difficult to set and harder to follow in the field. After the thin surface layer is gone or has been mixed with underlying horizons, little remains to furnish a clue for estimating the degree of erosion. The physical condition of the material in the plowed layer, the appearance and amount of rock fragments on the surface, the number and shape of gullies, and similar evidence are relied on.

For many soils having almost no horizon expression, attempting to estimate the degree of erosion serves little useful purpose. Estimates on such soils are unreliable for evaluating the effects of past use and management, and predictions of future soil behavior are determined by the properties of the soil that remains regardless of past erosion.

Estimates of erosion losses should not be confused with susceptibility to erosion. Kinds of soil may be grouped according to their susceptibility to erosion, but this is a different matter.

The amount of soil lost at a particular point within an area is rarely a useful measure of the significance of the loss to use and management. The pattern of soil erosion in areas of mappable size is normally complex. The pattern is nearly as important as the amount of soil lost. All map units are areas, not points, and the area as a whole is described and mapped.

Classes of water and wind erosion based on estimated soil losses are useful for some purposes, such as evaluating the amount of degradation on the soil resource that has occurred or characterizing soil areas in terms of effects of erosion on soil morphology. Field notes record whether erosion was caused by water or wind.

Classes of erosion by water.--Definitions of classes of erosion by water are as follows:

Class 1: This class consists of soils that have lost some of the original A horizon but on the average less than 25 percent of the original A horizon or of the uppermost 20 cm if the original A horizon was less than 20 cm thick. Throughout most of the area the thickness of the surface layer is within the normal range of variability of the uneroded soil. Scattered spots amounting to less than 20 percent of the area may be modified appreciably.

Evidence for class 1 erosion includes (1) a few rills, (2) accumulation of sediment at the base of slopes or in depressions, (3) scattered spots where the plow layer contains material from below the original plow layer, and (4) evidence of formation of widely spaced deep rills or shallow gullies without consistently measurable reduction in thickness or other change in properties between the rills or gullies.

Class 2: This class consists of soils that have lost on the average 25 to 75 percent of the original A horizon or of the uppermost 20 cm if the original A horizon was less than 20 cm thick. Throughout most cultivated areas of class 2 erosion the surface layer consists of a mixture of the original A horizon and material from below. Some areas may have intricate patterns ranging from uneroded spots to spots where all of the original A horizon has been removed. Where the original A horizon was very thick, little or no mixing of underlying material with the original A horizon may have taken place.

Class 3: This class consists of soils that have lost on the average 75 percent or more of the original A horizon or of the uppermost 20 cm if the original A horizon was less than 20 cm thick. In most areas of class 3 erosion, material below the original A horizon is exposed at the surface in cultivated areas. The plow layer consists entirely or largely of material that was below the original A horizon. Even where the original A horizon was very thick, at least some mixing of underlying material with the original A horizon has generally taken place.

Class 4: This class consists of soils that have lost all of the A horizon or the uppermost 20 cm if the original A horizon was less than 20 cm thick plus some or all of the deeper horizons throughout most of the area. The original soil can be identified only in spots. Some areas may be smooth, but most have an intricate pattern of gullies.

Classes of erosion by wind.--Definitions of classes of erosion by wind are as follows:

Class 1: This class consists of soils that have lost some of the original A horizon but on the average less than 25 percent of the original A horizon or of the uppermost 20 cm if the original A horizon was less than 20 cm thick. Throughout most of the area the thickness of the surface layer is within the normal range of variability of the uneroded soil. Scattered spots, amounting to less than 20 percent of the area, may be modified appreciably.

Evidence for class 1 wind erosion includes (1) a surface layer coarser in texture than in the uneroded areas nearby, (2) low mounds of sand and perhaps coarser particles, and (3) low depressions, or swales, from which soil material has been blown.

Class 2: This class consists of soils that have lost on the average 25 to 75 percent of the original A horizon or of the uppermost 20 cm if the original A horizon was less than 20 cm thick. Throughout most cultivated areas of class 2 wind erosion the surface layer consists of a mixture of the original A horizon and material from below. Most class 2 areas consist of an intricate pattern of eroded and uneroded spots and some spots of deposition.

Class 3: This class consists of soils that have lost on the average 75 percent or more of the original A horizon or of the uppermost 20 cm if the

original A horizon was less than 20 cm thick. In most areas of class 3 wind erosion, horizons originally below the surface layer are exposed at the surface; in places enough of the original surface layer remains that it can be identified. The removal of material is generally not uniform. A few blow-out areas may be included.

Class 4: This class consists of soils that have lost all the A horizon or the uppermost 20 cm if the original A horizon was less than 20 cm thick plus some or all of the deeper horizons throughout most of the area. The original soil can be identified only in spots. Depressions where all of the material has been blown out are common. Areas between blowouts may be buried by soil from the blowouts.

Erosion hazard

Erosion hazard, or the susceptibility of a soil to erosion, is the potential inherent in the soil itself to erode if the forces that cause erosion are applied to an area that is not adequately protected. Erosion hazard does not describe past erosion; it describes the possibility of future erosion. Principal internal soil features affecting hazard of erosion by water are texture (particularly the proportion of silt and very fine sand), organic matter content, structure, and hydraulic conductivity. The main soil features affecting hazard of erosion by wind are texture, organic matter content, and structure.

During the course of a soil survey the different kinds of soil are evaluated in terms of their erodibility. Division into slope phases is based in large part on susceptibility of specific soils to erosion by water. Tentative estimates of the erodibility of different soils are made while the mapping legend is being prepared. The estimates serve as useful guides for defining map units. Soils that are extremely erodible by water generally require more narrowly defined slope phases than those that are not. As the soil survey progresses the estimates are refined.

All available information about erosion of the soils in the area, about erosion of similar soils in other areas, and about the relationships between the properties of the soils and their susceptibility to erosion must be assembled. For most areas in the United States, information of these kinds is available. Empirical soil-loss equations for which numerical values have been assigned to each of the principal factors that affect erosion are available and are widely used to predict erosion from specific areas. For the universal soil loss equation, the principal factors are rainfall and runoff, soil erodibility, soil length, slope steepness, cover and management, and support practices.

Usually the soils of a survey area can be ranked according to their relative susceptibility to erosion and placed into a small number of groups that differ significantly in susceptibility. Three or five classes can be used, depending on the information available and the detail that is significant. The definitions are in terms of estimated annual soil loss in metric tons per hectare. The five classes are:

1. None ----------0 t/ha
2. Slight ----------Less than 2.5 t/ha
3. Moderate ----------2.5-10 t/ha
4. Severe ----------10-25 t/ha
5. Very severe ----------More than 25 t/ha

If three classes are used, they are 1. none to slight (less than 2.5 t/ha), 2. moderate (2.5 to 10 t/ha), and 3. severe to very severe (more than 10 t/ha). Estimates of erosion hazard are meaningful only if the condition of the surface and of the plant cover are given (as "bare surface," "badly overgrazed") or the sets of management practices are clearly defined.

Depth to Restricting and Contrasting Layers

Depth to restricting or contrasting layers is important to water- and nutrient-supplying capacity, downward movement of water, root penetration, and the like. Depth to and kind of material can have an important effect on how a soil behaves when used for various purposes and on how it responds to management. The range of depth is defined for each soil. The limits that are significant differ depending on the other soil characteristics.

In descriptions of depth, the nature of the restricting or contrasting layer is specified. If the nature of the contrasting layer is not given, it is understood to be consolidated bedrock.

Depth to a restricting or contrasting layer is measured from the soil surface. For soils with an O horizon that has never been saturated for prolonged periods, the soil surface is the top of the part of the O horizon that has decomposed so much that most of the original material cannot be recognized with the naked eye. If the uppermost horizon is an O horizon that is or has been saturated for prolonged periods, the soil surface is the top of that horizon. Otherwise, the soil surface is the top of the mineral soil.

So that the terms used to indicate depth will have approximately the same meaning everywhere, the following classes are suggested:

Very shallow	Less than 25 cm
Shallow	25 to 50 cm
Moderately deep (moderately shallow)	50 to 100 cm
Deep	100 to 150 cm
Very deep	More than 150 cm

The terms "very shallow," "shallow," etc. as used in conversation and in writing about soil depth do not necessarily carry these definitions. The upper and lower limits given are guidelines. Any of the terms may be used to name ranges in depth that differ somewhat from the limits shown, but unless different ranges are specified these approximate depths are understood.

Soil-Water Relations

Soil-water relations are important in evaluating plant response and engineering behavior and in understanding soil development. Because of precipitation, plant rooting habits, temperature gradients, and evaporation and transpiration, the soil water conditions are constantly changing. They may change significantly in a few hours or days or only over a season or a year or longer. They may change so slowly that they appear to be constant.

Soil-Water States

Soil-water state describes the moisture condition of a layer of soil. Three soil-water states--dry, moist, and wet--can be estimated in the field.

When a soil is described, the soil-water states throughout the soil are recorded in order to relate them to soil properties. Ideally, the soil-water states should be observed for each soil periodically to determine the annual pattern. However, a soil scientist generally makes observations only when traversing the landscape; hence the moisture pattern is usually estimated by relating it to available climatic data and landscape position.

Soil is dry when the water is held at a tension of 1,500 kPa (15 bars) 5/ or more. Most mesophytic plants cannot extract enough water at these high tensions to stay alive. The term "air-dry" means that the soil is in equilibrium with the air. The amount of water in the soil when air dry varies with the humidity of the air. When soil is air-dry, the water is held at tension much greater than 1,500 kPa.

Soil is moist when the water is held at a tension between 1 kPa and 1,500 kPa. The use of 1 kPa tension to separate the moist and wet states is arbitrary, but at tensions less than 1 kPa all or almost all of the total pore space in most soils is completely filled with water. Soil properties change appreciably with change in water content within the moist state. For some purposes it may be useful to divide the moist class into slightly moist and very moist using 33 kPa as the division point. Tension of 33 kPa approximates "field capacity," and water content has been measured at 33 kPa on a great number of soils.

Soil is wet when it contains water, including free water, at a tension of 1 kPa or less. Free water is at a tension of 0 kPa or less. Depth to free water is defined as the depth to water standing in a freshly dug uncased borehole after adequate time has elapsed (about 1 day) for the water level to adjust to the surrounding soil. 6/ The lower boundary of a zone of free water is established by sinking two or more boreholes cased to different depths. In practice, the depth to and thickness of zones of free water are estimated during mapping, and boreholes are generally not used.

Zones of free water range greatly in thickness and continuity. Free water may be restricted to a single thin zone near the surface. In soils having a fragipan, free water is often above the fragipan but not immediately below it. Two or more layers containing free water may be separated by a zone without free water, as in soils that formed in stratified alluvium that is mostly clayey but contains loamy and sandy bands. In many soils, free water is continuous from its highest level to below the depth normally observed during a soil survey.

Several kinds of field clues can be used to determine soil-water state. In wet soil, water films on sand grains and peds are visible without magnification. Excavation through a wet layer causes water to flow down the exposed face, though flow may be very slow and confined to large pores and cracks. Free water may not be evident where there are no large pores that hold water at very low tension and the hydraulic head on the free water is slight. Many layers of high bulk density contain very little pore space that drain under 1 kPa suction and therefore, although wet, do not contain evident free water.

Most soils become perceptibly darker on being moistened within the range of slightly moist. The change of color within the range of very moist is usually less and is negligible in some soils. A ball of moist soil can be formed at progressively lower moisture content as the proportion of silt increases relative to sand and as the proportion of clay increases. Many clayey soils, especially those high in 2:1 lattice clays, can be formed into balls when they are slightly moist. If, after the structure of clayey soil is thoroughly destroyed, a thread 3 mm in diameter can be formed by rolling the soil between the palms and the thread does not crumble when handled, then the soil is moist or wet.

Soil-water state is not evaluated in soil material that is frozen.

Annual pattern of soil-water states

The annual pattern of soil-water states provides a continuous record of the moisture conditions in the soil. Water state is reported by layers. An annual pattern of soil-water states for a hypothetical soil is shown in table 4-2. This approach can be elaborated by dividing the moist state into slightly moist and very moist and by indicating the presence of free water.

Soil Wetness

Knowledge of the times and depths at which a soil is wet is important in using the soil and in studying the soil. Free water exerts a strong influence on biological and chemical processes.

Soil wetness is influenced by climate, slope, and landscape position as well as by characteristics of the soil. Precipitation, runoff, amount of moisture entering the soil, and rate of water movement through the soil affect the degree and duration of wetness. Different areas of the same soil may differ in wetness because of landscape position. A soil in a higher position may be deeper to the water table or have a shorter duration of wetness than the same soil downslope.

Although the depth to free water changes greatly during a year and between years, most soils have typical times and depths of saturation. During a soil survey, the depth to freewater is recorded systematically at selected sites with piezometers and other devices. Data must be obtained through the year to show seasonal fluctuations of zones of wetness and over a period of several years to determine year-to-year variations. Instructions for conducting wetness studies are given in Chapter 8.

Soil morphology (mainly the color pattern) is used to infer moisture conditions in a soil. In many soils, depth and duration of saturation can be related to the quantity, nature, and pattern of mottles and to soil structure. Correlations between soil color and wetness are supported by observations of soil wetness and its fluctuations; data from test holes; evaluation of amount, distribution, and intensity of rainfall, runoff, and evaporation; and position on the landscape. However, morphological features cannot be correlated over wide areas to determine soil wetness. After sufficient data have been gathered locally for the proper wetness characterization of a soil, morphological features can be used in identifying soils with similar wetness characteristics.

Most soils that have repeated or extended periods of wetness are mottled or dull colored in all or part of the profile. Soil mottles are gray, bluish to reddish spots produced by oxidation-reduction processes. These spots are caused principally by migration, depletion, or concentration of iron within peds. When soil is saturated with water in the presence of organic matter, strong reducing conditions can exist. Iron reduction produces bluish colors, and migration of reduced iron leaves gray zones. After reduced iron reaches a zone having higher oxygen content, such as along root channels or other large pores connected with an aerated layer, the iron oxidizes and turns reddish. Red, iron-rich domains may also form in peds as the soil dries.

The proportion of grayness implies the thoroughness with which reduced iron has been removed. In similar materials of similar age that were not originally gray, a gray matrix with reddish or brownish mottles indicates a wetter or more reduced regime than a brown or red matrix with gray mottles. In a layer that is at or near saturation at some time, red or brown mottles may form as the soil slowly dries. If a soil has peds with grayish exteriors and brownish interiors, reducing conditions are apparent in the water that flows past the peds but not within the peds.

Mottles (other than relic mottles) generally indicate the presence of a zone of saturation at some period during the year. However, relationships between mottles and duration of saturation must be developed for each set of similar soils and landscape positions. Inferences about reducing conditions associated with wetness must be related to depth of the wet zone and the degree to which it is enriched with organic matter. If mottling is used to determine the need for water management systems, care must be taken to be sure that the mottled zone is in fact saturated for extended periods. In some cases, the mottling is related to a nearly saturated condition caused by fine pores and medium or coarse peds and does not indicate a water table.

In studying relationships between saturation and soil color patterns, it is best to support morphometric data with wetness studies and perhaps measurements of the degree of reduction. Mottled zones are often relic (formed in an earlier period of wetness), as in basal till or in gray weathering zones in loess. Reddish mottles composed of iron oxides persist as relics after natural drainage improves. An exception is very sandy soils, in which colors may change immediately upon aeration. Bluish gray color of reduced iron tends to change rapidly with aeration. The gray color of iron depleted horizons will persist indefinitely or until iron or organic matter is reintroduced into the horizon. Mottles may be peculiar to a certain weathering sequence such as that in mine spoil.

Not all wet soils have morphological properties reflecting the wetness. Some soils are wet for significant periods, but the water contains sufficient oxygen to maintain bright, unmottled soil colors. Most of these soils, for example many Hapludalfs, are wet only during winter when soil temperatures are so low that organisms have a very slow rate of respiration and chemical reactions virtually stop. These soils are wet only when the processes that would cause mottles and dull colors do not operate.

Two systems are used in this manual to describe soil wetness. Soil wetness characterization is based on systematic measurement of zones of wetness and describes where and when soil layers are wet. It deals only with the wet state in soils. At present there is not sufficient field data to establish meaningful

limits for general classes of soil water states. Soil wetness characterization will permit important statements to be made for crop production, engineering, and other uses that are affected by wetness.

Soil drainage classes are useful locally to summarize soil wetness and other soil water states that are important to major crops and farming systems in a given area.

Soil drainage classes may be correlated for areas the size of states, but to transfer a concept of a drainage class to areas with greatly different climates or crops is seldom successful.

Soil wetness characterization

The following classes describe depth to the wet state and duration of the wet state. Specific classes are not defined for thickness of the wet layer or for the time of year that the soil is wet. These are generally described by stating the average thickness of the wet layer, if the layer is perched, and the months that wetness occurs.

Classes of depth to the wet state: 7/

>40" Class 1: Not wet above a depth of 150 cm
40-60" Class 2: Wet in some part above a depth of 150 cm but not above a depth of 100 cm
20-40 Class 3: Wet in some part above a depth of 100 cm but not above a depth of 50 cm
10-20 Class 4: Wet in some part above a depth of 50 cm but not above a depth of 25 cm
<10" Class 5: Wet above a depth of 25 cm

Classes of duration of the wet state:

Class a: Wet less than one-twelfth of the time
Class b: Wet one-twelfth to one-fourth of the time
Class c: Wet one-fourth to one-half of the time
Class d: Wet more than one-half of the time

Soil wetness characterizations may be written in narrative form or shown graphically. In general, periods of wetness are rounded to the nearest whole month. For example, a soil that has a wet layer 15 cm thick above a fragipan at a depth of 75 cm from about March 1 to June 20 and again from the end of September to the end of October would be described thus: "The soil is wet between 50 cm and 1 m for 5 months, from March through June and in October; wet zone is perched and averages 15 cm in thickness."

The soil shown in table 4-2 could be described as follows: "The soil is wet below a depth of 50 cm January through March, below a depth of 25 cm in April, and below a depth of 100 cm in May. There is a perched wet zone between depths of 25 and 50 cm in December."

Soil drainage classes

Seven drainage classes are recognized. The first two, excessively drained and somewhat excessively drained, describe soils that are dry longer than is typical for the dominant soils of an area. Well drained soils are neither unusually dry nor unusually wet. Increasing degrees of wetness limit use of moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained soils.

The following definitions are purposely vague in order to provide the flexibility that is desirable for assigning drainage classes in a given area. The concept of the drainage class evolved in areas with a humid-temperate climate. The definitions, consequently, reflect a bias for these areas and may have to be modified in other parts of the world.

The seven classes are:

1. Excessively drained: These are soils have very high and high hydraulic conductivity and low water holding capacity. They are not suited for crop production unless irrigated.

2. Somewhat excessively drained: These soils have high hydraulic conductivity and low water holding capacity. Without irrigation only a narrow range of crops can be grown and yields are low.

3. Well drained: These soils have intermediate water holding capacity. They retain optimum amounts of moisture, but they are not wet close enough to the surface or long enough during the growing season to adversely affect yields.

4. Moderately well drained: These soils are wet close enough to the surface for long enough that planting or harvesting operations or yields of some field crops are adversely affected unless artificial drainage is provided. Moderately well drained soils, commonly have a layer with low hydraulic conductivity, wet state relatively high in the profile, additions of water by seepage, or some combination of these conditions.

5. Somewhat poorly drained: These soils are wet close enough to the surface or long enough that planting or harvesting operations or crop growth is markedly restricted unless artificial drainage is provided. Somewhat poorly drained soils commonly have a layer with low hydraulic conductivity, wet state high in the profile, additions of water through seepage, or a combination of these conditions.

6. Poorly drained: These soils commonly are wet at or near the surface during a considerable part of the year, so that field crops cannot be grown under natural conditions. Poorly drained conditions are caused by a saturated zone, a layer with low hydraulic conductivity, seepage, or a combination of these conditions.

7. Very poorly drained: These soils are wet to the surface most of the time. These soils are wet enough to prevent the growth of important crops (except rice) unless artificially drained.

Water Retention Difference

The amount of water that a soil can hold between 33 kPa and 1,500 kPa within the zone accessible to roots is the commonly used measure of water retention difference of the soil, which in the past has been referred to as the available water capacity. Water retention difference can be determined for individual layers or for the whole soil. The water retention difference of the whole soil is calculated by (1) estimating the amount of water each layer can hold, (2) determining which layers or parts of layers are sufficiently accessible to plant roots to be significant sources of water, and (3) summing the water retention differences of the accessible layers. The estimated water retention difference of a soil does not reflect the amount of water that plants can remove from the soil or the water supplying capacity of the soil; that also depends on hydraulic conductivity, stratification, osmotic potential, rainfall, runoff and runon, irrigation, characteristics of the plants, and the like.

Water retention difference is affected by such factors as texture, kind of clay, soil structure, volume of rock fragments, organic matter, and bulk density. Many kinds of material affect water retention difference, including bedrock, rock fragments, cemented layers, and saturated zones. Horizons of high bulk density generally contain little water that is available to plants.

Estimates of water retention difference are based on field measurements and observations, supplemented by available laboratory data. Relationships can be established, such as that between field-estimated clay content, bulk density, structure, and moisture at 1,500 kPa tension. Such relationships apply only within a limited range of soils; nevertheless, useful guidelines can be established within regions.

Water retention difference is commonly expressed in centimeters of water per centimeter of soil. Classes based on the amount of water available in the upper 1.5 m or above a limiting layer are as follows:

Very low	Less than 7.5 cm	= 3"
Low	7.5 to 15.0 cm	= 3 to 6"
Moderate	15.0 to 22.5 cm	= 6 to 9"
High	22.5 to 30 cm	= 9 to 12"
Very high	More than 30 cm	= >12"

Water Movement

The movement of water over, into, and through the soil is controlled by supply, by internal and external soil properties, and by environmental factors. Soil properties influencing water movement include slope, surface roughness, water repellency, cracks, coarse fragments, structure, total porosity, size and continuity of pores, and water content of the soil. Environmental factors include form and intensity of precipitation, nature of the plant cover, and temperature.

Any factor that changes the resistance to water flow changes the amount of water moving over, into, or through the soil and the rate of movement. For example, a rough surface is more resistant to water flow than a smooth surface. Since water moves much more easily through large pores than through small ones, the size and continuity of pores in a soil largely determines the rate of internal water movement. Cracks, structure, coarse fragments, and porosity determine the

cross-sectional area available for water movement through a soil. Decreasing the cross-sectional area available for flow decreases the rate and amount of water movement through the soil. Trapped air decreases flow if the soil has free water or water at very low tension, because the air bubbles act like coarse fragments and block water flow.

Runoff is the movement of water across the surface of the soil. Infiltration is the entry of water into the soil at the surface. Percolation is the downward movement of water within the soil. Hydraulic conductivity is the rate of movement of water within the soil as related to hydraulic gradient. Saturated hydraulic conductivity is the term used if free water is present, and unsaturated hydraulic conductivity is used if the water is under tension; both terms can be applied to vertical or horizontal water movement.

Runoff

Runoff is the water that flows away from the soil over the surface without infiltrating. 8/ The water may come from precipitation or run-on from adjacent areas. The rate and amount of runoff are determined by internal and external characteristics of the soil and by climate and plant cover. Runoff can be significantly different on a soil under natural cover, under cultivation, and under different kinds of management. Differences in runoff can also be caused by differences in topography. Rainfall intensity influences runoff. Soils may have a high rate of runoff when frozen. These conditions should be specified when estimating runoff.

Six classes of rate of runoff are recognized:

Ponded: Little of the precipitation and run-on escapes as runoff, and free water stands on the surface for significant periods. The amount of water that must be removed from ponded areas by movement through the soil, by plants, or by evaporation is usually greater than the total rainfall. Ponding normally occurs on level to nearly level depressional soils, and water depth may fluctuate greatly.

Very slow: Surface water flows away slowly, and free water stands on the surface for long periods or immediately enters the soil. Most of the water passes through the soil, is used by plants, or evaporates. The soils are commonly level or nearly level or are very open and porous.

Slow: Surface water flows away slowly enough that free water stands on the surface for moderate periods or enters the soil rapidly. Most of the water passes through the soil, is used by plants, or evaporates. The soils are nearly level or very gently sloping, or they are steeper but absorb precipitation very rapidly.

Medium: Surface water flows away fast enough that free water stands on the surface for only short periods. Part of the precipitation enters the soil and is used by plants, is lost by evaporation, or moves into underground channels. The soils are nearly level or gently sloping and absorb precipitation at a moderate rate, or they are steeper but absorb water rapidly.

Rapid: Surface water flows away fast enough that the period of concentration is brief and free water does not stand on the surface. Only a small part of the water enters the soil. The soils are mainly moderately steep or steep and have moderate to slow rates of absorption.

Very rapid: Surface water flows away so fast that the period of concentration is very brief and free water does not stand on the surface. Only a small part of the water enters the soil. The soils are mainly steep or very steep and absorb precipitation slowly.

Hydraulic conductivity

Hydraulic conductivity is the rate of water movement within the soil. It is a measure of the ease with which water moves through the soil. The rate of water movement at any time depends on soil properties, which determine the maximum conductivity, and the hydraulic gradient at that time.

A distinction is made between saturated hydraulic conductivity and unsaturated hydraulic conductivity. Saturated flow occurs when soil water pressure is positive (tension of less than 0 kPa). In most soils water pressure is possible when about 95 percent or more of the total pore space is filled with water. If the soil remains saturated for a long time (several months or more) the proportion of total pore space filled with water may approach 100 percent. Saturated hydraulic conductivity is a function of such soil properties as pore size distribution, pore geometry, total porosity (water-filled porosity at saturation), and clay mineralogy. Saturated hydraulic conductivity is the greatest rate at which water can move through the soil.

Water flow is unsaturated when the soil water is under tension (negative pressure). Unsaturated hydraulic conductivity is a function of the same soil properties as saturated hydraulic conductivity and also of the soil water content (water-filled porosity). Unsaturated flow is always slower than saturated flow.

Hydraulic conductivity classes in this manual are defined in terms of vertical saturated hydraulic conductivity. Unsaturated hydraulic conductivity classes cannot be defined at this time.

Hydraulic conductivity is highly variable. Measured values for a particular soil series can vary by 100-fold or more. Values measured on soil samples taken only centimeters apart may vary by 10-fold or more. Furthermore, laboratory-determined values are generally higher than field-measured values, often by as much as 100-fold. Field methods generally are more reliable than laboratory methods. Because of this variability, a single measured value is a poor indicator of a soil's hydraulic conductivity. An average of several values gives a reliable estimate that can be used to place the soil into a particular hydraulic conductivity class.

Hydraulic conductivity can be given for the soil as a whole or for a particular layer or combination of layers. The layer with the lowest value determines the hydraulic conductivity classification of the soil. If an appreciable thickness of soil above or below the least conductive layer has significantly higher hydraulic conductivity, then the estimates of both parts are usually given.

Since measured values of hydraulic conductivity are available on relatively few soils, estimates are based on soil properties and on correlations that have been made between these properties and hydraulic conductivity measurements.

A soil or layer in the high hydraulic conductivity class commonly transmits water downward so readily that the soil or layer remains wet for no more than a few hours after thorough wetting. Soil in this class is largely gravel, sand, or both and has little silt and clay. It has large connected voids. The layer or soil has many continuous conducting pores that are usually medium to coarse. The size and continuity of pores and voids are the critical factors. Many pores and voids are large enough to be distinguished easily; their continuity and persistence when the soil is wet must be determined. Some medium- and fine-textured layers have strong granular structure and large connecting pores. Others have many large voids, pores, or root channels that transmit water rapidly. If the soil cracks when dry, the cracks may not close on wetting. Some artificially drained marine clays have large cracks through which water moves rapidly. Layers that are largely volcanic cinders commonly are placed in the high class. This class can be divided into high and very high. Soils in the very high class are dominated by coarse rock fragments without enough fines to fill the voids between them; have large permanent cracks or many worm holes; or are coarse sand, very coarse sand, or gravelly sand.

A soil or layer in the moderate hydraulic conductivity class commonly transmits water downward readily enough that it remains wet for no more than a few days after thorough wetting. Layers may be massive, granular, blocky, prismatic, or weakly platy if they contain common continuous pores. If the soil cracks when dry, the cracks may not close on wetting. This class includes many soils considered favorable for rooting and for supplying water to plants. The moderate class can be divided into moderate and moderately low.

A soil in the low hydraulic conductivity class commonly transmits water downward so slowly that it remains wet for a week or more after thorough wetting. Soils in the low class are structureless or have only fine and discontinuous pores (as in some clays, fragipans, or cemented layers). Layers may be massive, blocky, or platy. Structural plates or blocks commonly are overlapping. There are few connecting pores that could conduct water when the soil is wet. If the soil cracks when dry, the cracks close completely on wetting. Plant roots are usually few or absent and are localized along the cracks. Slickensides and continuous stress surfaces also indicate low hydraulic conductivity. If desirable, the low class can be divided into low and very low.

The following are definitions of the hydraulic conductivity classes:

Hydraulic conductivity class	Saturated hydraulic conductivity 9/ µm/s
High:	
Very high	>100
High	10-100
Moderate:	
Moderate	1-10
Moderately low	0.1-1

Low:

Low	0.01-0.1
Very low	<0.01

Hydraulic conductivity does not describe the ability of soils in their natural setting to dispose of water internally. A soil may have very high conductivity yet contain free water because there are restricting layers below the soil or because the soil is in a depression where water from surrounding areas accumulates faster than it can pass through the soil. The water may actually move very slowly despire the soil's high conductivity. Actual rate of water movement is a product of the hydraulic conductivity and the hydraulic gradient. Saturated hydraulic conductivity cannot be used to describe water movement under unsaturated conditions.

Soil Temperature

Temperature, like soil-water state, changes with time, and it usually differs from layer to layer at any given time. Because it does change with time, characterizing soil temperature is a different kind of problem than characterizing properties that do not change, or that change little, such as texture, structure, and cation exchange capacity. Values for soil temperature measured over time contribute to the characterization of kinds of soil.

During the course of a soil survey, the temperatures of the soils are described as one of the properties important both in soil genesis and classification and in soil use. Soil temperature exerts a strong influence on biological activities. It also influences the rates of chemical and physical processes within the soil.

Characteristics of Soil Temperature

Heat is both absorbed at and lost from the surface of the soil. Temperature at the surface can change from hour to hour in a daily cycle, though it does not do so everywhere--for example, not under snow. The high and low temperatures that define the limits of the daily cycle also change from season to season in an annual pattern related to net gains and losses of heat. The temperature at the surface of the soil can be described in terms of daily cycles within annual cycles. It can also be characterized as an annual average or as a sequence of seasonal averages.

The soil transmits heat downward when the temperature near the surface is higher than the temperature below. It transmits heat upward when the temperature is warmer within the soil than at the surface. Soil temperatures at various depths within the soil, as well as in the surface horizon, follow cycles that can be described in detail or characterized by annual and seasonal averages. The cycles decrease in amplitude as depth increases; the daily cycles are scarcely measurable below a depth of 50 cm in most soils. Seasonal cycles are evident to much greater depths where seasonal air temperature differences are pronounced, but the temperature at a depth of 10 m is nearly constant in most soils and is about the same as the mean annual temperature of the soil above.

The temperature cycle at depth lags behind that nearer the surface. It takes time for heat to be transmitted within the soil. In some parts of the Northern Great Plains of the United States, for example, if the mean soil temperature at a depth of 50 cm reaches its maximum in the seasonal cycle in early July, soil temperature at a depth of 200 cm may not reach its maximum until mid-August. The summer temperature of a seasonal cycle at a depth of 200 cm may be 10° C less than at a depth of 50 cm in that area. In winter the relationship is reversed: temperature is higher at depth than at the surface. The lag of the annual cycle persists, however.

As a consequence of these depth relationships, soil temperature varies from layer to layer at a given site at a given time. Yet if the average annual temperatures at different depths in the same pedon are compared, they usually do not differ. If the temperatures are different, the difference is related either to a significant source of heat within the soil or to a sink, such as permanent ice, where heat is dissipated. Mean annual temperature is one of several useful values that describe the temperature regime of a soil.

The amplitude of seasonal fluctuation of soil temperature is a second characteristic of a soil. Soil temperature fluctuates little seasonally near the equator; it fluctuates widely as seasons change in the middle and high latitudes. A number of modifying factors can affect the relationship, but differences in seasonal mean temperature within the upper meter of soil is a useful distinction between soils in different parts of the world.

For soils that freeze in winter, soil temperature is influenced by another phenomenon. The conversion of water from the liquid form to the solid form, ice, releases about 80 calories per gram of water. This heat must be dissipated before the water in the soil freezes. As winter progresses, and if moisture is present, the frozen layer becomes thicker. In the northern plains of North America, soils may freeze to depths greater than 2 m and still thaw out in summer. In colder regions frozen layers are continuously present. Frozen soils thaw out slowly in the summer because heat is required to warm the soil and to melt the ice. In areas of heavy snowfall, the snow provides an insulating blanket and soils do not freeze as deeply.

Mean seasonal temperatures, too, can be used to characterize soil temperature. Seasonal temperature differences decrease and the seasonal cycles lag progressively as depth increases.

Soil temperature influences the rate of weathering in soil and the growth of plants and animals. When the soil is frozen, biological activities and chemical processes essentially stop. Some physical processes associated with ice formation are active if unfrozen zones are associated with freezing zones. Below a soil temperature of about 5° C, growth of roots of most plants is negligible. However, in areas where soils have permanently frozen layers near the surface, even large roots of adapted plants are present immediately above the frozen layer late in summer. Most plants grow best within a restricted range of soil and air temperature. Knowledge of soil and air temperature is essential in understanding soil-plant relationships.

Many other factors influence soil temperature. They include amount, intensity, and distribution of precipitation, daily and monthly fluctuations in temperature, and insolation; kinds, amounts, and persistence of vegetation;

duration of moisture states and snow cover; kinds of organic deposits; soil color; aspect and gradient of slope; elevation; and ground water. All of these factors are described where they are significant.

Estimating Soil Temperature

Mean annual soil temperature in temperate humid continental climates can be approximated by adding 1° C to the mean annual air temperature reported by standard meteorological stations at locations representative of the soil to be characterized. The mean annual soil temperature at a given place can be estimated more reliably by a single reading at a depth of 10 meters. If water in wells is at depths between 10 and 20 meters, the temperature of the water usually gives a close estimate of mean annual soil temperature. Mean annual soil temperature can also be estimated closely from the average of four readings at about 50 cm depth equally spaced throughout the year.

The mean soil temperature for summer can be estimated by averaging three measurements taken at a constant depth between 50 cm and 1 m on the 15th of each of the three months of the season. Similar methods may be used to estimate soil temperature for other seasons. These methods give values subject to minor variation caused by differences in vegetation (particularly density of canopy), ground water, snow, aspect, rain, unusual weather conditions, and other factors. Tests for nearly level, freely drained soils, both grass-covered and cultivated, produce comparable values. Over the usual period of a soil survey, systematic studies can be made to establish temperature relationships in the survey area.

Measurement of temperature to characterize a specific kind of soil, such as a soil series, should take into account the geographic variation of soil temperature as well as its variation with time. Soil temperature, like other soil properties, differs among pedons. Differences in the factors mentioned in the preceding paragraph contribute to differences among soils of the same series.

Designations for Horizons and Layers

In making soil examinations, every horizon or layer is described separately, regardless of whether it is genetic or all the properties are inherited from the parent material. The descriptions must be completely objective. Laboratory data on collected samples increase the importance of the descriptions; but without objective descriptions the laboratory data cannot be interpreted safely, if indeed the data are relevant at all.

Soils vary widely in the degree to which horizons are expressed. Relatively fresh geologic formations, such as alluvial fans, sand dunes, or blankets of volcanic ash, may have no recognizable genetic horizons, although they may have distinct layers that reflect different modes of deposition. As soil formation proceeds, horizons may be detected in their early stages only by very careful examination. As age increases, horizons generally are more easily identified in the field, though only one or two different horizons may be readily apparent in some very old, deeply weathered soils in tropical areas where annual precipitation is high.

Layers of different kinds are identified by symbols. Designations are provided for layers that have been changed by soil formation and for those that have not. Each horizon designation indicates that the original material has been changed in certain ways. The designation is assigned after comparison of the observed properties of the layer with properties inferred for the material before it was affected by soil formation. The processes that have caused the change need not be known; properties of soils relative to those of an estimated parent material are the criteria for judgment. The parent material inferred for the horizon in question, not the material below the solum, is used as the basis of comparison. The inferred parent material commonly is very similar to or the same as the unaltered material below.

Layers in soil need not be identified by symbols for a good description of the soil. Yet the usefulness of soil descriptions is greatly enhanced by the proper use of designations. These designations show the investigator's interpretations of genetic relationships among the layers within a soil.

These designations are not substitutes for descriptions. A designation tells little about the properties of the horizon or layer, but if both designations and adequate descriptions of a soil are provided, the reader has the interpretation made by the person who described the soil and also the evidence on which the interpretation was based. Additional studies and investigations may indicate the need for a change in designations.

Genetic horizons are not the equivalent of the diagnostic horizons of Soil Taxonomy. Designations of genetic horizons express a qualitative judgment about the kind of changes that are believed to have taken place. Diagnostic horizons are quantitatively defined features used to differentiate between taxa. The diagnostic horizons may encompass several genetic horizons, and changes implied by genetic horizon designations may not be large enough to justify recognizing different diagnostic criteria.

Three kinds of symbols are used in various combinations to designate horizons and layers. These are capital letters, lower case letters, and Arabic numerals. Capital letters are used to designate the master horizons and layers; lower case letters are used as suffixes to indicate specific characteristics of the master horizon and layer; and Arabic numerals are used both as suffixes to indicate vertical subdivisions within a horizon or layer and as prefixes to indicate discontinuities.

Some of the symbols for designating horizons and layers and conventions for using them are different from those described in the 1962 supplement to the Soil Survey Manual. The old and new symbols and conventions are compared in Attachment I.

Master Horizons and Layers

The capital letters O, A, E, B, C, and R represent the master horizons and layers of soils. The capital letters are the base symbols to which other characters are added to complete the designations. Most horizons and layers are given a single capital letter symbol; some require two.

O horizons or layers: Layers dominated by organic material, except limnic layers 10/ that are organic. Some are saturated with water for long periods or were once saturated but are now artificially drained; others have never been saturated.

Some O layers consist of undecomposed or partially decomposed litter, such as leaves, needles, twigs, moss, and lichens, that has been deposited on the surface; they may be on top of either mineral or organic soils. Other O layers, called peat, muck, or mucky peat, are organic material that was deposited underwater and that has decomposed to varying stages. The mineral fraction of such material is only a small percentage of the volume of the material and generally is much less than half of the weight. Some soils consist entirely of material designated as O horizons or layers.

An O layer may be on the surface of a mineral soil or at any depth beneath the surface if it is buried. A horizon formed by illuviation of organic material into a mineral subsoil is not an O horizon, though some horizons formed in this manner contain much organic matter.

A limnic layer that is organic is designated a C layer.

A horizons: Mineral horizons that formed at the surface or below an O horizon and (1) are characterized by an accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by properties characteristic of E or B horizons (defined below) or (2) have properties resulting from cultivation, pasturing, or similar kinds of disturbance.

If a surface horizon has properties of both A and E horizons but the feature emphasized is an accumulation of humified organic matter, it is designated an A horizon. In some places, as in warm arid climates, the undisturbed surface horizon is less dark than the adjacent underlying horizon and contains only small amounts of organic matter. It has a morphology distinct from the C layer, though the mineral fraction is unaltered or only slightly altered by weathering. Such a horizon is designated A because it is at the surface. However, recent alluvial or eolian deposits that retain fine stratification are not considered to be an A horizon unless cultivated.

E horizons: Mineral horizons in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles of quartz or other resistant minerals.

An E horizon is usually, but not necessarily, lighter in color than an underlying B horizon. In some soils the color is that of the sand and silt particles, but in many soils coats of iron or other compounds mask the color of the primary particles. An E horizon is most commonly differentiated from an overlying A horizon by lighter color and generally has measurably less organic matter than the A horizon. An E horizon is most commonly differentiated from an underlying B horizon in the same sequum by color of higher value or lower chroma, by coarser texture, or by a combination of these properties. An E horizon is commonly near the surface below an O or A horizon and above a B horizon, but the symbol E may be used without regard to position in the profile for any horizon that meets the requirements and that has resulted from soil genesis.

B horizons: Horizons that formed below an A, E, or O horizon and are dominated by obliteration of all or much of the original rock structure 11/ and by (1) illuvial concentration of silicate clay, iron, aluminum, humus, carbonates, gypsum, or

silica, alone or in combination; (2) evidence of removal of carbonates; (3) residual concentration of sesquioxides; (4) coatings of sesquioxides that make the horizon conspicuously lower in value, higher in chroma, or redder in hue than overlying and underlying horizons without apparent illuviation of iron; (5) alteration that forms silicate clay or liberates oxides or both and that forms granular, blocky, or prismatic structure if volume changes accompany changes in moisture content; or (6) any combination of these.

Obviously there are several kinds of B horizon. No common location within the soil characterizes them, but all are subsurface horizons or were originally. Included as B horizons where contiguous to another genetic horizon are layers of illuvial concentration of carbonates, gypsum, or silica that are the result of pedogenic processes (these layers may or may not be cemented) and brittle layers that have other evidence of alteration, such as prismatic structure or illuvial accumulation of clay.

Examples of layers that are not B horizons are layers in which clay films coat rock fragments or are on finely stratified unconsolidated sediments, whether the films were formed in place or by illuviation, and layers into which carbonates have been illuviated unless contiguous to an overlying genetic horizon.

C horizons or layers: Horizons or layers, excluding hard bedrock, that are little affected by pedogenic processes and lack properties of O, A, E, or B horizons. Most are mineral layers, but limnic layers, 10/ whether organic or inorganic, are included. The material of C layers may be either like or unlike that from which the solum presumably formed. A C horizon may have been modified even if there is no evidence of pedogenesis.

Included as C layers are sediments, saprolite, and consolidated bedrock that when moist can be dug with a spade. Some soils form in material that is already highly weathered, and such material that does not meet the requirements of A, E, or B horizons is designated C. Changes not considered pedogenic are those not related to overlying horizons. Layers having accumulations of silica, carbonates, or gypsum or more soluble salts are included in C horizons, even if indurated, unless these layers are contiguous to an overlying genetic horizon; then they are a B horizon.

R Layers: Hard Bedrock.

Granite, basalt, quartzite, and indurated limestone or sandstone are examples of bedrock that are designated R. The bedrock of an R layer is sufficiently coherent when moist to make hand digging with a spade impractical, although it may be chipped or scraped with a spade. Some R layers can be ripped with heavy power equipment. The bedrock may contain cracks, but these are few enough and small enough that few roots can penetrate. The cracks may be coated or filled with clay or other material.

Transitional horizons

There are two kinds of transitional horizon. In one, the properties of an underlying or overlying horizon are superimposed on properties of the other horizon throughout the transition zone. In the other, parts that are characteristic of an overlying or underlying horizon are enclosed by parts that are characteristic of the other horizon. Special conventions are used to designate these kinds of horizons.

Horizons dominated by properties of one master horizon but having subordinate properties of another. Two capital letter symbols are used, as AB, EB, BE, BC. The master horizon symbol that is given first designates the kind of horizon whose properties dominate the transitional horizon. An AB horizon, for example, has characteristics of both an overlying A horizon and an underlying B horizon, but is more like the A than like the B.

In some cases, a horizon can be designated as transitional even if one of the master horizons to which it is apparently transitional is not present. A BE horizon may be recognized in a truncated soil if its properties are similar to those of a BE horizon in a soil in which the overlying E horizon has not been removed by erosion. An AB or a BA horizon may be recognized where bedrock underlies the transitional horizon. A BC horizon may be recognized even if no underlying C horizon is present; it is transitional to assumed parent material.

Horizons in which distinct parts have recognizable properties of the two kinds of master horizons indicated by the capital letters. The two capital letters are separated by a virgule (/), as E/B, B/E, B/C. Most of the individual parts of at least one of the components are surrounded by the other.

The designation may be used even though horizons similar to one or both of the components are not present, if the separate components can be recognized in the transitional horizon. The first symbol is that of the horizon that makes up the greater volume.

Subordinate Distinctions Within Master Horizons and Layers

Lower case letters are used as suffixes to designate specific kinds of master horizons and layers. The symbols and their meanings are as follows:

a Highly decomposed organic material

This symbol is used with "O" to indicate the most highly decomposed of the organic materials. Rubbed fiber content averages less than about 1/6 of the volume.

b Buried genetic horizon

This symbol is used in mineral soils to indicate identifiable buried genetic horizons if the major features of the buried horizon had been established before it was buried. It is not used in organic soils or to separate an organic layer from a mineral layer. Genetic horizons may or may not have formed in the overlying material, which may be either like or unlike the assumed parent material of the buried soil.

c Concretions or hard nonconcretionary nodules

This symbol is used to indicate a significant accumulation of concretions or nonconcretionary nodules cemented by material other than silica. This symbol is not used if concretions or nodules are dolomite or calcite or more soluble salts, but it is used if the nodules or concretions are iron, aluminum, manganese, or titanium. Their consistence is specified in the horizon description.

e Organic material of intermediate decomposition

This symbol is used with "O" to indicate organic materials of intermediate decomposition. Rubbed fiber content is 1/6 to 2/5 of the volume.

f Frozen soil

This symbol is used to indicate that the horizon or layer contains permanent ice. Symbol is not used for seasonally frozen layers or for "dry permafrost" (material that is colder than 0° C but does not contain ice).

g Strong gleying

This symbol is used to indicate either that iron has been reduced and removed during soil formation or that saturation with stagnant water has preserved a reduced state. Most of the affected layers have low chroma and many are mottled. The low chroma can be the color of reduced iron or the color of uncoated sand and silt particles from which iron has been removed. Symbol "g" is not used for soil materials of low chroma, such as some shales or E horizons, unless they have a history of wetness. If "g" is used with "B," pedogenic change in addition to gleying is implied. If no other change has taken place, the horizon is designated Cg.

h Illuvial accumulation of organic matter

This symbol is used with "B" to indicate the accumulation of illuvial, amorphous, dispersible organic matter-sesquioxide complexes if the sesquioxide component is dominated by aluminum but is present only in very small quantities. The organosesquioxide material coats sand and silt particles or may occur as discrete pellets. In some horizons, coatings have coalesced, filled pores, and cemented the horizon. The symbol "h" is also used in combination with "s" as "Bhs" if the amount of sesquioxide component is significant but value and chroma of the horizon are approximately 3 or less.

i Slightly decomposed organic material

This symbol is used with "O" to indicate the least decomposed of the organic materials. Rubbed fiber content is more than about 2/5 of the volume.

k Accumulation of carbonates

This symbol is used to indicate accumulation of alkaline earth carbonates, commonly calcium carbonate.

m Cementation or induration

This symbol is used to indicate continuous or nearly continuous cementation. Symbol is used only for horizons that are more than 90 percent cemented, though they may be fractured. Roots penetrate "m" horizons only through cracks. The cementing material is also

symbolized. If 90 percent or more of the horizon is cemented by carbonates, "km" is used; by silica, "qm"; by iron, "sm"; by gypsum, "ym"; by both lime and silica, "kqm"; by salts more soluble than gypsum, "zm."

n Accumulation of sodium

This symbol is used to indicate accumulation of exchangeable sodium.

o Residual accumulation of sesquioxides

This symbol is used to indicate residual accumulation of sesquioxides.

p Plowing or other disturbance

This symbol is used to indicate disturbance of the surface layer by cultivation, pasturing, or similar uses. A disturbed organic horizon is designated Op. A disturbed mineral horizon, even though clearly once a E, B, or C horizon, is designated Ap.

q Accumulation of silica

This symbol is used to indicate accumulation of secondary silica. If silica cements the layer and cementation is continuous or nearly continuous, "qm" is used.

r Weathered or soft bedrock

This symbol is used with "C" to indicate layers of soft bedrock or saprolite, such as weathered igneous rock; partly consolidated soft sandstone, siltstone, or shale; or dense till that roots cannot enter except along fracture planes. The material can be dug with a spade.

s Illuvial accumulation of sesquioxides and organic matter

This symbol is used with "B" to indicate the accumulation of illuvial, amorphous, dispersable organic matter-sequioxide complexes if both the organic matter and sesquioxide components are significant and the value and chroma of the horizon is more than 3. The symbol is also used in combination with "h" as "Bhs" if both the organic matter and sesquioxide components are significant and the value and chroma are approximately 3 or less.

t Accumulation of silicate clay

This symbol is used to indicate an accumulation of silicate clay that either has formed in the horizon or has been moved into it by illuviation. The clay can be in the form of coatings on ped surfaces or in pores, lamellae, or bridges between mineral grains.

v Plinthite

This symbol is used to indicate the presence of iron-rich, humus-poor, reddish material that is firm or very firm when moist and that hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying. These properties are characteristic of plinthite.

w Development of color or structure

This symbol is used with "B" to indicate development of color or structure, or both, with little or no apparent illuvial accumulation of material.

x Fragipan character

This symbol is used to indicate genetically developed firmness, brittleness, or high bulk density. These features are characteristic of fragipans, but some horizons designated "x" do not have all properties of a fragipan.

y Accumulation of gypsum

This symbol is used to indicate accumulation of gypsum.

z Accumulation of salts more soluble than gypsum

This symbol is used to indicate accumulation of salts more soluble than gypsum.

Conventions for using letter suffixes.--Many master horizons and layers that are symbolized by a single capital letter will have one or more lower case letter suffixes. Common exceptions are an undisturbed A horizon and many, if not most, E and C horizons and layers. Seldom are more than three suffixes needed.

When letter suffixes are used, they immediately follow the capital letter. If a surface horizon is disturbed, only "p" is used.

[redacted] the following letters, if used, are written first: a, e, i, h, r, s, t, u, and w. Except for Bhs or Crt 12/ horizons, none of these letters are used in combination in a single horizon.

A horizon is never designated Bth, Bts, or Btw, though a Bw, Bs, or Bh horizon may be above or below a Bt horizon. A B horizon that has a significant accumulation of clay and also shows evidence of development of color or structure, or both, is designated Bt, ("t" has precedence over "w," "s," and "h"). A B horizon that is gleyed or that has accumulatons of carbonates, silica, gypsum, salts more soluble than gypsum, or residual accumulation of sesquioxides carries the appropriate symbol--g, k, q, y, z, or o. If illuvial clay is also present, "t" precedes the other symbol: Bto. Suffixes "h", "s", and "w" are not used with g, k, q, y, z, or o.

If a horizon is buried, the suffix "b" is written last. Suffix "b" is used only for buried mineral soils. If more than one suffix is needed and the horizon is not buried, these symbols, if used, are written last: c, f, g, m, and x. Some examples: Btc, Ckm, and Bsv.

Lower case letter suffixes are not used with transitional horizons unless needed for explanatory purposes; for example, use of "k" is appropriate in the sequence A-ACk1-ACk2-AC-C to indicate an accumulation of carbonates in the upper parts of the AC horizon.

Vertical subdivision.--Commonly a horizon or layer designated by a single combination of letters needs to be subdivided. The Arabic numerals used for this purpose always follow all letters. Within a C, for example, successive layers could be C1, C2, C3, etc.; or if the lower part is gleyed and the upper part is not, the designations could be C1-C2-Cg1-Cg2 or C-Cg1-Cg2-R.

These conventions apply whatever the purpose of subdivision. In many soils, horizons that would be identified by one unique set of letters are subdivided on the basis of evident morphological features, such as structure, color, or texture. These divisions are numbered consecutively. The numbering starts with 1 at whatever level in the profile any element of the letter symbol changes. Thus Bt1-Bt2-Btk1-Btk2 is used, not Bt1-Bt2-Btk3-Btk4. The numbering of vertical subdivisions within a horizon is not interrupted at a discontinuity (indicated by a numerical prefix) if the same letter combination is used in both materials: Bs1-Bs2-2Bs3-2Bs4 is used, not Bs1-Bs2-2Bs1-2Bs2.

Sometimes, thick layers are subdivided during sampling for laboratory analyses even though differences in morphology are not evident in the field. These layers need to be identified, and this is done simply by numbering each subdivision consecutively within a layer having a unique symbol, starting at the top. For example, four layers of a Bt horizon sampled by 10-cm increments would be designated Bt1, Bt2, Bt3, and Bt4.

Discontinuities.--In mineral soils [redacted] numerals are used as prefixes to indicate discontinuities. Wherever needed, they are used preceding A, E, B, C, and R. These prefixes are distinct from Arabic numerals used as suffixes to denote vertical subdivisions.

A discontinuity is a significant change in particle-size distribution or mineralogy that indicates a difference in the material from which the horizons formed or, [redacted] a significant difference in age. Symbols to identify discontinuities are used only when they will contribute substantially to the reader's understanding of relationships among horizons. The significance of a given kind of discontinuity may be large in one soil and small in another, or even large in one horizon and small in another of the same profile. Stratification common to soils formed in alluvium is not designated as discontinuities even if particle size distribution differs markedly from layer to layer unless genetic horizons have formed in the contrasting layers.

Where a soil has formed entirely in one kind of material, a prefix is omitted from the symbol; the whole profile is material 1. Similarly, the uppermost material in a profile having two or more contrasting materials is understood to be material 1, but the number is omitted. Numbering starts with the second layer of contrasting material, which is designated "2." Underlying contrasting layers are numbered consecutively. Even though a layer below material 2 is similar to material 1, it is designated "3" in the sequence. The numbers indicate a change in the material, not the type of material. Where two or more consecutive horizons formed in one kind of material, the same prefix number is applied to all of the horizon designations in that material: Ap-E-Bt1-2Bt2-2Bt3-2BC. The number suffixes designating subdivisions of the Bt horizon continue in consecutive order across the discontinuity.

If an R layer is below a soil that formed in residuum and the material of the R layer is presumed to be like that from which the material of the soil weathered, the Arabic number prefix is not used. If the R layer would not produce material like that in the solum, the number prefix is used, as in A-Bt-C-2R or A-Bt-2R. If part of the solum formed in residuum, "R" is given the appropriate prefix: Ap-Bt1-2Bt2-2Bt3-2C1-2C2-2R.

Buried horizons (designated "b") are special problems. A buried horizon is obviously not in the same deposit as horizons in the overlying deposit. Some buried horizons, however, formed in material lithologically like that of the overlying deposit. A prefix is not used to distinguish material of such buried horizons. If the material in which a horizon of a buried soil formed is lithologically unlike that of the overlying material, the discontinuity is designated by number prefixes and the symbol for a buried horizon is used as well: Ap-Bt1-Bt2-BC-C-2Ab-2Btb1-2Btb2-2C.

In organic soils, discontinuities between different kinds of layers are not identified. In most cases the differences are shown by the letter suffix designations, if the different layers are organic, or by the master symbol if the different layers are mineral.

Use of the prime.--Identical designations may be appropriate for two or more horizons or layers separated by at least one horizon or layer of a different kind in the same pedon. The sequence A-E-Bt-E-Btx-C is an example: the soil has two E horizons. To make communication easier, the prime is used with the master horizon symbol of the lower of two horizons having identical letter designations: A-E-Bt-E'-Btx-C. The prime is applied to the capital letter designation, and any lower case symbols follow it: B't. The prime is not used unless all letters of the designations of two different layers are identical. Rarely, three layers have identical letter symbols; a double prime can be used: E"

The same principle applies in designating layers of organic soils. The prime is used only to distinguish two or more horizons that have identical symbols: Oi-C-O'i-C' or Oi-C-Oe-C'. The prime is added to the lower C layer to differentiate it from the upper.

Sample Horizon Sequences

The following examples illustrate some common horizon and layer sequences of important kinds of soil and the use of conventions for designations. The examples were selected from soil descriptions on file and modified to reflect present conventions.

Mineral soils:

Typic Hapludoll: A1-A2-Bw-BC-C
Typic Haploboroll: Ap-A-Bw-Bk-Bky1-Bky2-C
Pachic Haploboroll: Ap-A-Bw1-Bw2-BC-Ab-Bwb1-Bwb2-2C
Typic Argialboll: Ap-A-E-Bt1-Bt2-BC-Ck
Typic Argiaquoll: A-AB-BA-Btg-BCg-Cg
Entic Haplorthod: O1-O2-Bs1-Bs2-BC-C
Typic Haplorthod: Ap-E-Bhs-Bs-BC-C1-C2
Typic Fragiudalf: O-A-E-BE-Bt1-Bt2-B/E-B't1-B't2-Btx1-Btx2-C

Typic Haploxeralf: A1-A2-A3-2Bt1-2Bt2-2Bt3-2BC-2C
Glossoboric Hapludalf: Ap-E-B/E-Bt1-Bt2-C
Typic Hapludult: O-A1-A2-BA-Bt1-Bt2-BC-C
Arenic Plinthic Paleudult: Ap-E-Bt-Btc-Btv1-Btv2-BC-C
Typic Haplargid: A-Bt-Bk1-Bk2-C
Entic Durorthid: A-Bw-Bq-Bqm-2Ab-2Btkb-3Byb-3Bqmb-3Bqkb
Typic Dystrochrept: Ap-Bw1-Bw2-C-R
Typic Fragiochrept: Ap-Bw-E-Bx1-Bx2-C
Typic Haplaquept: Ap-AB-Bg1-Bg2-BCg-Cg
Typic Udifluvent: Ap-C-Ab-C'
Typic Pellustert: Ap-A-AC-C1-C2

Organic soils:

Typic Medisaprist: Op-Oa1-Oa2-Oa3-C
Typic Sphagnofibrist: Oi1-Oi2-Oi3-Oe
Limnic Borofibrist: Oi-C-Oi1-Oi2-C'-Oe-C"
Lithic Cryofolist: O1-O2-R

Single sets of designators do not cover all situations, and some improvising has to be done. For example, Alfic Udipsamments have lamellae that are separated from each other by eluvial layers. Since it is generally not practical to describe each lamella and eluvial layer as a separate horizon, they are combined but the components are described separately. One horizon would then contain several lamellae and eluvial layers and might be designated an E and Bt horizon. The complete horizon sequence for this soil could be: Ap-Bw-E and Bt1-E and Bt2-C.

Cyclic and Intermittent Horizons and Layers

A few soils have cyclic horizons or layers, a few others have intermittent horizons or layers.

A profile of a soil having cyclic horizons exposes layers whose boundaries are near the surface at one point and extend deep into the soil at another. At one place the aggregate horizon thickness may be only 50 cm; two meters away, the same horizons may be more than 125 cm thick. The cycle is repeated, commonly with considerable variation in both depth and horizontal interval, but still with some degree of regularity. If the soil is visualized in three dimensions instead of two, some cyclic horizons extend downward in inverted cones. The cone of the lower horizon fits around the cone of the horizon above. Other cyclic horizons appear wedge shaped.

A profile of a soil having an intermittent horizon shows that the horizon extends horizontally for some distance, ends, and reappears again some distance away. A B horizon interrupted at intervals by upward extensions of bedrock into the A horizon is an example. The distance between places where the horizon is absent is commonly variable yet has some degree of regularity. The distances range from less than one meter to several meters.

Obviously, a soil profile at one place could be unlike a profile only a few meters away for soils with cyclic or intermittent horizons or layers. The orderly variations of these soils are given in soil descriptions.

Descriptions of orderly horizontal variation within a pedon include the kind of variation, the spacing of cycles or interruptions, and the amplitude of depth variation of cyclic horizons.

Depth and Thickness or Horizons and Layers

A description of a pedon includes the thickness and the depth limits of each layer. Depths are measured from the soil surface. For soils with an O horizon that has never been saturated for prolonged periods, the soil surface is the top of the part of the O horizon that has decomposed so much that most of the original material cannot be recognized with the naked eye. If the uppermost layer is an O horizon that is or has been saturated for prolonged periods, the soil surface is at the top of that horizon. Otherwise the soil surface is the top of the mineral soil.

The depth limits of the deepest horizon or layer described include only that part actually seen. For example, the depth limits of a sequence 01-02-A-E-Bs-C, if the 01 and 02 horizons are not decomposed, are written: 01--20 to 10 cm; 02--10 to 0 cm; A--0 to 5 cm; E--5 to 25 cm; Bs--25 to 60 cm; C--60 to 100 cm. If the 02 horizon is decomposed, the depth limits are 01--10 to 0 cm; 02--0 to 10 cm; A--10 to 15 cm; E--15 to 35 cm; Bs--35 to 70 cm; C--70 to 110 cm.

The depth to a horizon or layer boundary commonly differs within short distances, even within a pedon. The part of the pedon that is typical or most common is described. In the soil description, the horizon or layer designation is listed and is followed by the values representing the depths to the upper and lower boundaries, in that order. The depth to the lower boundary of a horizon or layer is the depth to the upper boundary of the horizon or layer beneath it. The variation in the depths of the boundaries is recorded in the description of the horizon or layer.

In some soils the variations in depths to boundaries are so complex that usual terms for description of topography of the boundary are inadequate. These variations are described separately. An example is "depth to the lower boundary is mainly 30 to 40 cm, but tongues extend to depths of 60 to 80 cm." The irregularity of the lower boundary is described; this is the same as the irregularity of the upper boundary of the horizon or layer below.

The thickness of each horizon or layer is recorded separately. The thickness is the vertical distance between the upper and lower boundaries. Thickness, too, varies within pedons, and the variation is shown in the description. Thickness also varies among pedons, and this variation is described for the series.

Thickness is measured directly; it cannot be determined by comparing the ranges of depth to the upper and lower boundaries. The actual range in thickness cannot be determined unless it has been measured directly, because the extremes of depth limits of upper and lower boundaries are commonly in different places. The upper boundary of a horizon, for example, may range in depth from 25 to 45 cm and the lower boundary from 50 to 75 cm. Taking the extremes of these two ranges, the conclusion could be that the horizon ranges in thickness from as little as 5 cm to as much as 50 cm within the series.

Boundaries of Horizons and Layers

A boundary is a surface or transitional layer between two adjoining horizons or layers. It is roughly parallel to the soil surface. Most boundaries are zones of transition rather than sharp lines of division. Boundaries are determined in the field.

Boundaries vary in distinctness and in topography. Distinctness refers to the ease of determining the zone within which the boundary can be located at any level with equal confidence. Topography refers to the irregularities of the surface that divides the horizons.

Distinctness.--The distinctness of a boundary depends partly on the degree of contrast between the adjacent layers and partly on the thickness of the transition zone between them. Distinctness is defined in terms of thickness of the transition zone:

Abrupt: Less than 2 cm thick
Clear: 2 to 5 cm thick
Gradual: 5 to 15 cm thick
Diffuse: More than 15 cm thick

Abrupt soil boundaries, such as those between the E and Bt horizons in many soils, are easily determined. Some boundaries are not readily seen but can be located by testing the soil above and below the boundary. Diffuse boundaries, such as those in many old soils in tropical areas, are most difficult to locate and require time-consuming comparisons of small specimens of soil from various parts of the profile until the midpoint of the transition zone is determined. For soils that have nearly uniform properties or that change very gradually as depth increases, horizon designations are imposed more or less arbitrarily without clear evidence of differences.

Topography.--Even though soil layers are commonly seen in vertical section, they are three-dimensional. Topography of boundaries describes irregularities measured in centimeters or decimeters. Topography of boundaries is described with the following terms:

Smooth: The boundary is a plane with few or no irregularities.
Wavy: The boundary has undulations in which depressions are wider than they are deep.
Irregular: The boundary has pockets that are deeper than they are wide.
Broken: At least one of the horizons or layers separated by the boundary is discontinuous and the boundary is interrupted.

Soil Texture and Rock Fragments

This section discusses the sizes of mineral particles in soils and conventions for expressing combinations of particles of the various sizes. The finer sizes are called fine earth as distinct from rock fragments (pebbles, cobbles, stones, and boulders). The fine earth fraction is, specifically, that part of the mineral material composed of particles smaller than 2 mm in diameter.

It is necessary to treat soil material smaller than 2 mm separately from rock fragments. Particle-size distribution of material smaller than 2 mm is determined in the field mainly by feel. The content of particles much coarser than 2 mm cannot be determined by manipulating a sample of soil in the hand; therefore, the composition of the fine earth is determined by feel and the content of coarser particles is determined by estimating the proportion of the soil volume that they occupy.

Soil separates

Soil separates are the individual size groups of mineral particles. Different disciplines and different groups of workers within some disciplines use different size limits for separating particles into classes. The choice of limits is arbitrary within some range around various points on the scale, but relationships between a number of properties and particle size do suggest some critical limits. Much depends on the purposes for which the data are to be used and the other properties of the soil.

Most arguments for one set of limits as opposed to another focus on relationships of particle size to water-holding or -transmitting properties, mineralogy, susceptibility to being transported, and chemical properties such as cation exchange. Many workers agree on critical limits between 0.05 and 0.1 mm and between 0.001 and 0.002 mm. From the standpoint of sampling and field estimates of texture, a class limit near 1.0 to 2.0 mm is also critical.

The United States Department of Agriculture and the National Cooperative Soil Survey use the following classes of soil separates for fine earth:

Very coarse sand	2.0-1.0 mm
Coarse sand	1.0-0.5 mm
Medium sand	0.5-0.25 mm
Fine sand	0.25-0.10 mm
Very fine sand	0.10-0.05 mm
Silt	0.05-0.002 mm
Clay	Smaller than 0.002 mm

Figure 4-4 compares the USDA system used by the National Cooperative Soil Survey, the system of the International Society of Soil Science, the Unified system used by many engineers, and the system used by the American Association of State Highway and Transportation Officials (AASHTO). The terminology for the various size classes is not the same in all of the systems. Misunderstanding can result if users of one system are not aware of the others. Also shown are U.S. standard sieve sizes.

Figure 4-5 illustrates the sizes of particles of separates larger than silt.

Soil Texture

Soil texture refers to the physical composition of soil defined in terms of the relative proportions, by weight, of each separate finer. The texture classes are defined in terms of particle-size distribution of the material finer than 2 mm as determined in the laboratory, but are based on the distribution determined for a large number of soil samples that many soil scientists had placed in the texture classes on the basis of field techniques.

Properties related to consistence are the main criteria for estimating particle-size distribution in the field. No single set of characteristics detectable by handling soil material can be used to judge particle-size distribution of all soils.

Field criteria for estimating soil texture must be chosen to fit the soils in the individual area. Sand particles can be seen individually with the naked eye and have a gritty feel to the fingers. Many sand soils are loose, but some are not. Silt particles cannot be seen individually without magnification; they have a smooth feel to the fingers when dry or wet. In some places clay soils are sticky; in others they are not. Soils dominated by montmorillonitic clays, for example, feel perceptibly different from soils that contain similar amounts of micaceous or kaolinitic clay. Even locally, the relationships that are useful for judging texture of one kind of soil may not apply as well to another kind.

The late Professor C. F. Shaw worked out the following definitions of the basic soil textural classes in terms of field experience and feel. They are included here as an example of the kind of field criteria that can be used locally:

Sand: Sand is loose and single grained. The individual grains can readily be seen or felt. Squeezed in the hand when dry it will fall apart when the pressure is released. Squeezed when moist, it will form a cast, but will crumble when touched.

Sandy loam: A sandy loam is a soil containing much sand but which has enough silt and clay to make it somewhat coherent. The individual sand grains can readily be seen and felt. Squeezed when dry, it will form a cast which will readily fall apart, but if squeezed when moist a cast can be formed that will bear careful handling without breaking.

Loam: A loam is a soil having a relatively even mixture of different grades of sand and of silt and clay. It is mellow with a somewhat gritty feel, yet fairly smooth and slightly plastic. Squeezed when dry, it will form a cast that will bear careful handling, while the cast formed by squeezing the moist soil can be handled quite freely without breaking.

Silt loam: A silt loam is a soil having a moderate amount of the fine grades of sand and only a small amount of clay, over half of the particles being of the size called "silt." When dry it may appear cloddy but the lumps can be readily broken, and when pulverized it feels soft and floury. When wet the soil readily runs together and puddles. Either dry or moist it will form casts that can be freely handled without breaking, but when moistened and squeezed between thumb and finger it will not "ribbon" but will give a broken appearance.

Clay loam: A clay loam is a fine textured soil which usually breaks into clods or lumps that are hard when dry. When the moist soil is pinched between the thumb and finger it will form a thin "ribbon" which will break readily, barely sustaining its own weight. The moist soil is plastic and will form a cast that will bear much handling. When kneaded in the hand it does not crumble readily but tends to work into a heavy compact mass.

Clay: A clay is a fine textured soil that usually forms very hard lumps or clods when dry and is quite plastic and usually sticky when wet. When the moist soil is pinched out between the thumb and fingers it will form a long, flexible "ribbon."

Field estimates are subject to error. They need to be checked against laboratory determinations of particle-size distribution, and the field criteria should be adjusted as necessary. The soil scientist should not attempt to estimate texture with greater precision than is justified by the reliability of field estimates. For most soils, for example, attempting to distinguish loam from silt loam is futile if the textures of the samples are near the boundary between the classes.

Some soils are not dispersed completely by standard particle-size analysis. These soils generally contain amorphous material, but some are strongly weathered and contain large amounts of hydrated oxides. Degree of dispersion can be determined in the laboratory by either optical methods or surface area measurement as determined by 1,500-kPa water content. The actual texture of these soils is not relevant, but apparent field texture is important locally for distinguishing between soils. If apparent field texture is used, the standards against which it is compared are recorded.

Texture, by itself without qualification in terms of other soil properties, has limited value for predicting the behavior of the soil. The standard of field texture was once mainly properties of physical behavior, and particle-size analyses were performed to determine what particle sizes were associated with given physical properties. Now particle-size distribution is the standard against which field estimates are measured. This means that a clay-textured horizon of a soil in the humid tropics and a clay-textured horizon of a soil in temperate regions have similar particle-size distribution; but the one may be slightly plastic and rapidly permeable and the other very plastic and slowly permeable. As the coarse extreme of the particle-size distribution range is approached, texture assumes predictive value for other physical properties. Near the fine extreme, the kind of clay is more important than the amount of clay as such. Within an area where the range in kind of clay is small, texture is very useful for characterizing soils. Texture changes little with time and is valuable for predicting the related physical properties of associated soils.

Few, if any, soils consist wholly of particles of one size class. The basic textures in order of generally increasing proportions of finer particles are sand, loamy sand, sandy loam, loam, 13/ silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The classes of sand are coarse sand, sand, fine sand, and very fine sand; no modifier is used for medium sand. Classes of loamy sands and sandy loams are named similarly, loamy sand and sandy loam being the equivalents of loamy medium sand and medium sandy loam.

Definitions of the basic classes are set forth in graphic form in figure 4-6 in terms of the USDA particle-size classes. This triangle is useful for those who frequently translate laboratory data into soil texture.

Definitions of the soil texture classes according to distribution of size classes of mineral particles less than 2 mm in diameter are as follows:

Sands: 85 percent or more sand and the percentage of silt plus 1½ times the percentage of clay is 15 or less.

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Coarse sand: 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sand: 25 percent or more very coarse, coarse, and medium sand (but less than 25 percent very coarse and coarse sand) and less than 50 percent either fine sand or very fine sand.

Fine sand: 50 percent or more fine sand; or less than 25 percent very coarse, coarse, and medium sand and less than 50 percent very fine sand.

Very fine sand: 50 percent or more very fine sand.

Loamy sands: At the upper limit 85 to 90 percent sand and the percentage of silt plus 1½ times the percentage of clay is 15 or more; at the lower limit 70 to 85 percent sand and the percentage of silt plus twice the percentage of clay is 30 or less.

Loamy coarse sand: 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Loamy sand: 25 percent or more very coarse, coarse, and medium sand (but less than 25 percent very coarse and coarse sand) and less than 50 percent either fine sand or very fine sand.

Loamy fine sand: 50 percent or more fine sand; or less than 50 percent very fine sand and less than 25 percent very coarse, coarse, and medium sand.

Loamy very fine sand: 50 percent or more very fine sand.

Sandy loams: 20 percent or less clay and 52 percent or more sand and the percentage of silt plus twice the percentage of clay exceeds 30; or less than 7 percent clay, less than 50 percent silt, and between 43 and 52 percent sand.

Coarse sandy loam: 25 percent or more very coarse and coarse sand and less than 50 percent any other single grade of sand.

Sandy loam: 30 percent or more very coarse, coarse, and medium sand (but less than 25 percent very coarse and coarse sand) and less than 30 percent either fine sand or very fine sand.

Fine sandy loam: 30 percent or more fine sand and less than 30 percent very fine sand; or between 15 and 30 percent very coarse, coarse, and medium sand; or more than 40 percent fine and very fine sand, at least half of which is fine sand, and less than 15 percent very coarse, coarse, and medium sand.

Very fine sandy loam: 30 percent or more very fine sand; or more than 40 percent fine and very fine sand, at least half of which is very fine sand, and less than 15 percent very coarse, coarse, and medium sand.

Loam: 7 to 27 percent clay, 28 to 50 percent silt, and less than 52 percent sand.

Silt loam: 50 percent or more silt and 12 to 27 percent clay; or 50 to 80 percent silt and less than 12 percent clay.

Silt: 80 percent or more silt and less than 12 percent clay.

Sandy clay loam: 20 to 35 percent clay, less than 28 percent silt, and 45 percent or more sand.

Clay loam: 27 to 40 percent clay and 20 to 45 percent sand.

Silty clay loam: 27 to 40 percent clay and less than 20 percent sand.

Sandy clay: 35 percent or more clay and 45 percent or more sand.

Silty clay: 40 percent or more clay and 40 percent or more silt.

Clay: 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Necessarily these verbal definitions are somewhat complicated. The texture triangle is used to resolve problems related to word definitions. The eight distinctions in the sand and loamy sand groups provide refinement greater than can be consistently determined by field techniques. Only those distinctions that are significant to use and management and can be consistently made in the field should be applied.

Groupings of soil texture classes. The need for fine distinctions in the texture of the soil layers results in a large number of classes of soil texture. Often it is convenient to speak generally of broad groups or classes of texture. An outline of soil texture groups, in three classes and in five, follows. In some areas where soils are high in silt, a fourth general class, silty soils, may be used for silt and silt loam.

General terms 14/	Texture classes
Sandy soils:	
Coarse textured	Sands (coarse sand, sand, fine sand, very fine sand), loamy sands (loamy coarse sand, loamy sand, loamy fine sand, loamy very fine sand)
Loamy soils:	
Moderately coarse textured	Coarse sandy loam, sandy loam, fine sandy loam
Medium textured	Very fine sandy loam, loam, silt loam, silt
Moderately fine textured	Clay loam, sandy clay loam, silty clay loam

Clayey soils:

Fine textured.....Sandy clay, silty clay, clay

Organic Soils

The terms peat, muck, and mucky peat are used for organic materials in a manner similar to the way in which mineral textural terms are used. Muck is well-decomposed organic soil material. Peat is raw undecomposed organic material in which the original fibers constitute almost all of the material. Mucky peat is material intermediate between muck and peat.

Mucky is used to modify mineral soil texture. The term implies the presence of enough organic matter that the material has some properties of organic soil combined with the properties of the mineral material. The material does not, however, have enough organic matter to be "muck." Mucky material is usually dark, friable, and retentive of moisture, but it is mineral in basic composition. The organic matter content is commonly more than 10 percent.

Although nearly pure organic and mineral materials are sharply contrasting, a range of mixtures of the two is found in nature. Layers that are never saturated with water for more than a few days at a time are organic if they have 20 percent or more organic carbon. Layers that are saturated for longer periods, or were before being drained, are organic if they have 12 percent or more organic carbon and no clay or a proportional amount of organic carbon between 12 and 18 percent if the clay content is between 0 and 60 percent.

The kind and amount of clay in the mineral fraction, the kind of organism from which the organic material was derived, and the amount and state of decomposition affect the properties of the soil material.

Descriptions of organic layers include the kinds of organic material and their proportions. Special effort is made to identify and estimate the volume occupied by Sphagnum fibers, which have extraordinary water retention characteristics. When squeezed firmly in the hand to remove as much water as possible, Sphagnum fibers are lighter in color than fibers of Hypnum and most other mosses.

In addition, descriptions include the percentage of undecomposed fibers and the solubility in sodium pyrophosphate of the humified material (Chapter 8).

Fragments of wood more than 2 cm across and so undecomposed that they cannot be crushed by the fingers when moist or wet are called "wood fragments." They are comparable to rock fragments in mineral soils and are described in a comparable manner.

Rock Fragments

Rock fragments are unattached pieces of rock 2 mm in diameter or larger. Rock fragments influence moisture storage, infiltration, runoff, and land use. They protect fine particles from washing and blowing. They dilute the volume of soil material that roots can penetrate and that provides nutrients to plants.

Rock fragments do not break down after overnight shaking in a weak solution of sodium hexametaphosphate.

Rock fragments are described in terms that characterize their size and shape and, for some, the kind of rock. There are several classes: pebbles, cobbles, channers, flagstones, stones, and boulders. The terms are defined in table 4-3 according to their shape and size limits. If a size or range of sizes predominates, it is stated: "fine pebbles," "cobbles 10 to 15 cm in diameter," "channers 25 to 50 mm long." Boulders are more than 60 cm and mostly less than 3 m in diameter but include large glacial erratics 10 m or more long.

Gravel is a collection of pebbles, as in "outwash gravel." A single piece is a pebble. The terms "pebble" and "cobble" are usually restricted to rounded or subrounded fragments but can be used to describe angular fragments if they are not flat.

Words like chert, slate, and shale refer to a kind of rock, not a piece of rock. If significant to classification or interpretation, the composition of the fragments can be given: "chert pebbles," "limestone channers."

Most of the size limits of the various classes conform to established conventions. The 2-mm lower limit of rock fragments is the upper limit of sand. The 76-mm upper limit of gravel is about the size of the 3-inch sieve (7.6 cm) used by many engineers as the upper limit of the base on which percentages of particles of different sizes (grain-size distribution) are based. The 5-mm and 20-mm divisions separating fine, medium, and coarse gravel are about the sizes of openings in the "number 4" screen (4.76 mm) and the "3/4 inch" screen (19.05 mm) used in engineering to separate fractions of rock fragments. The 250-mm limit corresponds approximately to the 10-inch limit that has been used conventionally to separate cobbles from stones. The limits for flat fragments, 150 mm and 380 mm, follow conventions used for many years to adjust for the relationships of thin, flat shape to volume, compared to roughly spherical fragments, and the differences of limitation for use imposed by different shapes of fragments.

Rock fragments in the soil

The volume of rock fragments is estimated in the field. The adjective form of a class name of rock fragments (Table 4-3) is used as a modifier of the textural class name: "gravelly loam," "stony loam." The following classes are used:

Less than 15 percent by volume: No special term is used; or "nongravelly" and "nonstony" are used in writing for contrast with soils having more than 15 percent pebbles, cobbles, stones, or boulders.

15 to 35 percent by volume: The adjective term of the dominant kind of rock fragment is used as a modifier of the textural term: "gravelly loam," "stony loam," "bouldery loam."

35 to 60 percent by volume: The adjective term of the dominant kind of rock fragment is used with the word "very" as a modifier of the textural term: "very gravelly loam," "very bouldery loam."

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More than 60 percent by volume: If enough fine earth is present to determine the texture class (approximately 5 percent or more by volume) the adjective term of the dominant kind of rock fragment is used with the word "extremely" as a modifier of the textural term: "extremely gravelly loam," "extremely bouldery loam." If there is too little fine earth to determine the texture class (less than about 5 percent by volume) the terms "gravel," "cobbles," "stones," and "boulders" are used in the place of fine earth texture.

The class limits apply to the volume of the layer occupied by all pieces of rock larger than 2 mm. Total volume of rock fragments in each layer is estimated, and the size class that makes up the greatest volume is used as the modifier. Usually the soil also contains fragments smaller or larger than those identified in the term. For example, a stony loam usually contains pebbles, but "gravelly" is not mentioned in the name. Use of a term for larger pieces of rock, such as boulders, does not imply that the pieces are entirely within a given soil layer. A single boulder may extend through several layers.

More precise estimates of the amounts of rock fragments than are provided by the defined classes are needed for some purposes. If the more precise information is needed, estimates of percentages of each size class or a combination of size classes are included in the description: "very cobbly loam; 5 percent stones, 30 percent cobbles, and 15 percent gravel" or "silt loam; about 10 percent gravel."

If loose pieces of rock are significant in use and management of a soil, they are bases of phase distinctions among map units (Chapter 5). Exposed bedrock (p.4-9) is not soil and is separately identified in mapping.

The volume occupied by individual pieces of rock can be seen and their aggregate volume percentage can be calculated. For some purposes, volume percentage must be converted to weight percentage; procedures are given in Chapter 8.

Rock fragments on the surface

Rock fragments on the surface of a soil, including both those that lie on the surface and those that are partly within the soil but protrude above ground, 15/ have important effects on soil use and management. The limitations they impose are related to their number, size, and spacing at the surface.

The class limits that follow are given in terms of the approximate amount of stones and boulders at the surface.

Class 1: Any stones or boulders cover less than 0.01 percent of the surface. Stones of the smallest sizes are at least 25 m apart; boulders of the smallest sizes are at least 60 m apart.

Class 2: Stones or boulders cover about 0.01 to 0.1 percent of the surface. Stones of the smallest sizes are no less than 8 m apart; boulders of the smallest sizes are no less than 20 m apart (Figure 4-7).

Class 3: Stones or boulders cover about 0.1 to 3 percent of the surface. Stones of the smallest sizes are no less than 1 m apart (Figure 4-8); boulders of the smallest size are no less than 3 m apart (Figure 4-9).

Class 4: Stones or boulders cover about 3 to 15 percent of the surface. Stones of the smallest size are as little as 0.5 m apart; boulders of the smallest size are as little as 1 m apart.

Class 5: Stones or boulders cover about 15 to 50 percent of the surface and are so closely spaced that in most places it is possible to step from stone to stone or jump from boulder to boulder without touching the soil (Figure 4-10). Stones of the smallest size are as little as 0.1 m apart; boulders of the smallest size are as little as 0.2 m apart.

Class 6: Stones or boulders appear to be nearly continuous and cover more than 50 percent of the surface. The distances between fragments are measured in centimeters or decimeters in most places. Classifiable soil is among the rubble, and plants can grow if moisture and nutrients are available.

Class 7: Stones or boulders cover more than 50 percent of the surface, and so little earthy material is between the stones or boulders that few plants other than lichens can grow even though other factors are favorable. The deposits are not classifiable as soil and are mapped as "rubble land."

These limits are intended only as guides to amounts that may mark critical limitations for major kinds of land use. The classes are used in writing about soils and in conversation to convey concepts of the surface condition of areas of soil. Table 4-4 is a summary of the classes and a guide to the amount of stones and boulders in each.

Soil Color

Color is the most obvious of soil properties, and it is easily determined. Except for the effect of color on absorption of heat at the surface, it has little known direct influence on the functioning of the soil. Still, color is one of the most useful properties for soil identification and appraisal, mainly because other, more important characteristics that are not so easily and accurately observed can be inferred from it.

Significance of Color

Within a limited area, color can be reliably associated with important soil properties. Color of the surface layer, for example, may be used to judge the content of organic matter. Color is a clue to wetness or droughtiness in some areas. It may be a mark of the effects of past vegetation or of man's use or misuse of the soil. Some soils exhibit color directly inherited from the parent rock. These and other relationships are clues for identifying soils and appraising their properties. Yet, when attempts are made to relate soil color to specific properties, any relationship considered universal has so many exceptions and such complicated qualifications that the generalization itself becomes obscure. Many local relationships are known only empirically.

The importance of soil color is greatest within a local set of microenvironments. Some common relationships of color to other soil properties can serve as a basis for interpreting color. Relationships of color that are observed repeatedly are noted. The exceptions to common relationships are learned for the local area. The reasons for relationships of soil color to other properties, or for the exceptions, may or may not be known, but they are associated with specific materials or specific environments. In this perspective, soil color is important. When applying local relationships, the fact that the same color means different things in different places outside the area is not of special concern. But the possibility of potential exceptions should be kept in mind.

Commonly, dark colors suggest more organic matter than light colors. The relationships may be quite good locally, but exceptions must be understood. Humified organic material is commonly dark; however, raw organic material such as peat is not necessarily dark. Where mean annual temperature is high, soils that are high in organic matter are commonly less dark than soils in cool regions having similar amounts of organic matter. Yet in places in warm regions, black or nearly black clayey soils have less than 2 percent organic matter, and these may be next to much lighter colored soils that have two or three times as much organic matter. Some soils are nearly black because of organic coatings on peds, and when the soil is crushed it appears significantly lighter. In other soils, the organic matter is disseminated throughout the peds. In some soils organic material moved by illuviation is light colored.

Light gray or grayish colors in soils commonly indicate reducing conditions, either now or in the past. They may be evidence of reduced iron, or they may be the colors of primary mineral grains stripped of iron at some past time when the iron was in the reduced state. Gray or grayish colors indicate gleying, but not without qualifications. Some materials, particularly carbonatic material, are gray or grayish and remain so even under oxidizing conditions.

In some environments yellowish or reddish mottles indicate alternating oxidizing and reducing conditions. Yellowish and reddish mottles are concentrations of material of which iron is one of the most important components. Segregations of iron are not necessarily the result of reduction and oxidation in association with a fluctuating water table. Mixed soil colors can result from differential weathering of the parent material instead of impeded drainage; such soils are usually described as "variegated."

Reddish and yellowish colors can be attributed to iron in its various forms. The relationship between color and iron compounds in soil is complex. Color depends on the thickness of the coatings, crystallinity, age, and other factors. No generalization relating color to specific compounds of iron applies everywhere, but within a local area, reddish and yellowish colors can be related to different parent materials, different positions in the landscape, and other factors; and the differently colored soils may behave differently in use.

Color is one of the most useful criteria for recognizing coatings, or the lack of them, on peds. If clay coats differ in color from interiors of peds, they are easily recognized, though proof that the coatings are clay depends on other properties. Most E horizons lack coatings and therefore have the light color of the residual minerals, such as quartz. Some E horizons are difficult to detect because they are not light colored.

Many bodies of segregated material have colors that make them easy to see. Bodies in which iron is segregated commonly are brown, reddish, or yellowish, but some are nearly black. Manganese segregations are nearly black in most soils. Coatings of compounds of iron and manganese on peds are dark and can be mistaken for organic matter. Segregated materials such as carbonates or more soluble salts may be obvious because of their light color.

Color is related to reaction in some soils, but the relationship is to other properties rather than direct. Under highly alkaline conditions, for example, the dark fraction of organic matter goes into solution and dark coatings cover mineral grains below the common depth of organic matter distribution.

The number of soil properties that are indicated by color or that are easily distinguished because of color differences within the soil is large. Many of the relationships are based on empirical correlations, most of which are most useful when applied within the perspective of soils and environments in a small area, such as a county or part of a county.

Determining Soil Color

Soil color is measured by comparison with a standard color chart. The most commonly used chart is taken from the Munsell color system and includes only that part needed for soil colors, about one fifth of the entire range of hue. 16/ The standard Munsell chart for soil color consists of about 175 different colored papers, or chips, systematically arranged according to their Munsell notations, on seven cards that are assembled in a loose-leaf notebook. Three additional cards, two for the reddest hues of soils and one for the blueish and greenish hues of gleyed soils, are also available. Figure 4-11 illustrates the arrangement of color chips on a Munsell color card.

Munsell color standards.--The Munsell color system uses three elements of color--hue, value, and chroma--to make up a specific color notation. The notation is recorded in the form: hue, value/chroma--for example, 5Y 6/3. The three attributes of color are arranged in the system in orderly scales of equal visual steps, which are used to measure and describe color accurately under standard conditions of illumination.

Hue identifies the quality of color registered by the eye as related to the wavelength of the light that reaches the eye. The Munsell system is based on five principal hues: red (R), yellow (Y), green (G), blue (B), and purple (P). Five intermediate hues representing midpoints between each pair of principal hues complete the 10 major hue names used to describe the notation. The intermediate hues are yellow-red (YR), green-yellow (GY), blue-green (BG), purple-blue (PB), and red-purple (RP). The relationships among these 10 hues are shown diagramatically in figure 4-12. For use, each of the 10 major hues is divided into four segments of equal visual steps, 17/ which are designated by numerical values applied as prefixes to the symbol for hue name. In figure 4-12, for example, 10R marks a limit of red hue. Four equally spaced steps of the adjacent yellow-red (YR) hue are identified as 2.5YR, 5YR, 7.5YR, and 10YR respectively. Each of these classes of hue has a narrow range of the wavelength of light. The standard chart for soil has cards from 10R through 5Y hue, a total of seven cards.

Value indicates the degree of lightness or darkness of a color in relation to a neutral gray scale. On a neutral gray (achromatic) scale, value extends from pure black (0/) to pure white (10/). Hue is a measure of the chromatic

composition of light that reaches the eye, and the value notation is a measure of the amount of light that reaches the eye under standard lighting conditions. Gray is perceived as about halfway between black and white, and has a value notation of 5/. (The actual amount of light that reaches the eye is related logarithmically to color value.) Lighter colors are indicated by numbers between 5/ and 10/; darker colors are indicated by numbers from 5/ to 0/. These values may be designated for either achromatic or chromatic conditions. Thus, a card of the color chart for soil has a series of chips arranged vertically to show equal steps from the lightest to the darkest shades of that hue. Figure 4-11 shows this arrangement vertically on the card for the hue of 10YR.

Chroma is the relative purity or strength of the spectral color. Chroma indicates the degree of dilution of a color by neutral gray of the same value. The scales of chroma for soils extend from /0 for neutral colors to a chroma of /8 as the strongest expression of color used for soils. For other purposes chroma as high as /14 or more may be used. Figure 4-11 illustrates that color chips are arranged horizontally by increasing chroma from left to right on the color card.

The complete color notation can be visualized from figure 4-11. Pale brown, for example, is designated 10YR 6/3. Very dark brown is designated 10YR 2/2. All of the colors on the chart have hue of 10YR. The darkest shades of that hue are at the bottom of the card and the lightest shades are at the top. The weakest expression of chroma (the grayest color) is at the left; the strongest expression of chroma is at the right.

At the extreme left of the card are symbols such as N 6/. These are colors of zero chroma which are totally achromatic--neutral color. They have no hue and no chroma but range in value from pure black (N 0/) to pure white (N 10/). The color chips for neutral colors are the same on the cards of every hue; they have no hue. An example of a notation for a neutral (achromatic) color is N 5/, called gray. The color 10YR 5/1 is also called "gray," for the hue is hardly perceptible at such low chroma.

Conditions for measuring color.--The quality and intensity of the light falling on a sample of soil affect the amount and quality of the light reflected from the sample to the eye. The moisture content of the sample and the roughness or smoothness of its surface also affect the amount and quality of the light reflected. The visual impression of color from the standard color chips is accurate only under standard conditions of light intensity and quality. As the color standards are used in the field, therefore, it is important that the light be white enough that the sample reflects its true color and that the amount of light be adequate for visual distinction between chips.

Color determination may be inaccurate early in the morning or late in the evening. When the sun is low in the sky or the atmosphere is smoky, the light reaching the sample is somewhat red and the light reflected from the sample is redder than at midday. Even though the same kind of light reaches the color standard and the sample, the reading of the sample color at these times is commonly one or more intervals of hue redder than at midday. Colors also appear different in the subdued light of a cloudy day than in bright sunlight. If artificial light is used, as for color determinations in an office, the light source used must be as near the white light of midday as possible. With practice, compensation can be made for the differences unless the light is so subdued that the distinctions between color chips are not apparent. Intensity of the incident light is especially critical when matching soil to chips of low chroma and low value.

The color value of most soils becomes lower as the soil is moistened. Consequently, moisture state of the sample is given for each color determination. The "dry" state for determinations of soil color is air-dry. This state can be attained in the field or in the office; further drying causes no further change in color value. Most soils are perceptibly darker when slightly moist. The change of color value within the range of very moist is less and is negligible for many soils. Consequently, the color when moist is determined from very moist soil. Color determinations of wet soil may be in error because of the effect of light reflected from water films. Commonly, both moist and dry colors are recorded.

If there are differences in color between the soil material in place and the crushed or rubbed mass or between ped faces and interiors, these differences are recorded in the description of a soil layer. The first color given is the undisturbed apparent color, generally that of the major mass of the specimen. Color after the mass is crushed or color of ped surfaces as contrasted to color of ped interiors is recorded next (see p.4 68).

Roughness of the soil sample affects the amount of reflected light, especially if the incident light falls on the surface of the sample at an acute angle. Even small irregularities cast shadows that make the surface appear darker. Roughness of the soil in its undisturbed or broken state is accepted as it is found, but care is exercised that the incident light is as nearly as possible at right angles to the face of the sample. To determine the color of crushed samples, the surface of the sample is smoothed with a knife or spatula before measuring color and the state is recorded as "dry and smoothed."

Reliability of color measurements.--Under field conditions, measurements of color are reproducible by different individuals within 2.5 units of hue (one page) and 1 unit of value and chroma. Notations are made to the nearest whole unit of value and chroma.

The cards for hues of 2.5YR, 7.5YR, and 2.5Y do not include chips for colors having chroma of 3. These colors are encountered frequently in some soils and can be estimated reliably by interpolation between adjacent chips of the same hue. Chips for chromas of 5 and 7 are not provided on any of the standard color cards. Determinations are usually not precise enough to justify interpolation between chromas of 4 and 6 or of 6 and 8. Color should never be extrapolated beyond the highest chip.

For many purposes, the differences between colors of some adjacent color chips have little significance. For such purposes color notations have been grouped, and the groups have been named. Figure 4-11 illustrates the range of such groups within a single hue.

On some of the color cards, certain chips fall on the boundary between two color names. The name that better describes the color is assigned. Expressions such as "brown to dark brown" are not used. Most soil colors do not precisely match a color chip.

Color Patterns

The color of each layer is recorded in soil descriptions. The aggregate of descriptions of each individual layer describes the color pattern of the whole soil.

The single layer may be uniform in color, or it may be streaked, spotted, variegated, or otherwise heterogeneous in color. Accumulations of carbonates, organic matter, iron, manganese, and other substances commonly differ in color from the surrounding soil. Soils that have impeded drainage commonly are marked by a mixture of gray colors and brown, yellow, or red colors. In some soils, coatings are present on primary particles or peds in one part of a layer but not in another, creating a mixture of colors. These kinds of color patterns within layers are recorded and are part of the color pattern of the whole soil.

Some soil color patterns are patches of one color within another. Others are colors intermingled in such a way that no one color is clearly continuous throughout the layer. In the first kind, the continuous color can occupy a small part of the total surface observed, as in layers that have a network of thin bands of one color along parting planes between peds. This threadlike network encloses another color within the peds. In another soil, the continuous color can occupy almost all of the observed surface, as where a few small spots of color are found in an otherwise uniformly colored layer. In patterns of intermingled colors, one color can be most abundant, though not necessarily continuous. Some layers have intermingled colors in which no single color is most abundant.

Color patterns within soil layers are discussed under three headings: (1) dominant color, (2) mottling, and (3) color patterns related to physical organization. These are elements of the internal color pattern of a layer, which is seen when the soil is broken, revealing the natural physical organization of the soil in section. A broken section passes through peds and other unit bodies if they can be broken with the soil as a whole. A broken section commonly exposes only the faces of strong granules, fine blocks, and plates, but these should not be accepted in determining color; the colors of the interior of peds are also recorded. Some small peds must be crushed in order to reveal the interior color.

Dominant color

The dominant color is the color that occupies the greatest volume of the layer. It is judged on the basis of colors of broken sections that sample the volume. For only two colors, the dominant color occupies more than 50 percent of the volume. For three or more colors, the dominant color occupies more of the volume of the layer than any other color, but it may occupy less than 50 percent. In some layers, no single color is dominant. Dominant color (or colors) is always given first among those of a multicolored layer. The expression "brown with yellowish brown and grayish brown" signifies that brown is the dominant color. It may or may not occupy more than 50 percent of the layer. The expression "brown and yellowish brown with grayish brown" indicates that brown and yellowish brown are about equal and are codominant. If the colors are described as "brown, yellowish brown, and grayish brown," the three colors occupy nearly equal parts of the layer.

If the description makes it obvious that some colors occupy a small percentage, in the aggregate, the percentage of the dominant color need not be given, though recording the proportion helps to avoid mistakes. By conventions given below, the word "few" signifies less than 2 percent of the layer. If yellowish brown and strong brown mottles in a grayish brown layer were each "few," the approximate percentage of grayish brown is obvious. Of course, if the percentage is used, there can be no question about the writer's meaning.

Mottling

The word "mottled" means marked with spots of different colors, but the application of the term to soils is not as simple as the dictionary definition. An example will illustrate some of the complications:

A section of soil broken through the peds, which may be strong very coarse prisms parting to weak medium blocks, might include the following distinctive colors: (1) a dominant color inside the blocky peds, (2) spots of different color within the peds and not associated with any discrete structural unit or body, (3) spots of still different color marking exposed surfaces of nodules within the peds, (4) a thin band, perhaps 1 mm wide, of yet another color in a discontinuous network marking interrupted boundaries between the weak blocks, (5) a thicker continuous band of color, perhaps 2 mm wide, marking the outer rim of the very coarse prisms, and (6) spots of still different color on the surfaces of pebbles. These are all "spots of color" and a soil description distinguishes them, but not all of them are called "mottles."

The dominant color (or colors) is given first. Mottles are then described as details of the color pattern. Some of the associated colors may be related to specific locations or discrete bodies, and that kind of relationship is recorded. The colors of concretions, nodules, coats of peds, fillings in burrows of animals, and the like are commonly described as properties of identifiable bodies or surfaces and are usually not called "mottles" in the description.

Mottles are described in terms of quantity, size, contrast, and color, in that order. Other properties, including shape, location, and character of boundaries of mottles, are recorded as needed. Color of mottles is recorded according to the conventions described in the preceding section. Quantity, size, and contrast of mottles are described using the conventions that follow.

Quantity can be indicated by one of three general classes based on the percentage of the observed surface that is occupied by mottles of a given kind:

Few	Less than 2 percent
Common	2 to 20 percent
Many	More than 20 percent

The conventions for quantity are used to describe mottling on surfaces, such as faces of peds, as well as within the body of the soil. A card having sections showing spots of different sizes in different proportions provides standards for visual impressions of quantity.

The words used to name quantity classes may imply to some that the mottles are spots on a background of another color. This is not always true. If the mottling is a continuous network of different color, the term threadlike may be added: "few threadlike...mottles." Estimated percentages may be used instead of class terms: "one percent threadlike...mottles."

When describing multicolored materials, the notations must clearly indicate to which colors the terms for quantity apply. For example, "common grayish brown and yellowish brown mottles" could mean that each occupies 2 to 20 percent of the horizon. By convention, the example is interpreted to mean that the quantity of the two colors together is between 2 and 20 percent. If each color occupies between 2 and 20 percent, the description should read "common grayish brown and common yellowish brown mottles."

Size refers to the approximate dimensions of the mottles as seen on a plane surface. If the length of a mottle is not more than two or three times the width, the dimension recorded is the greater of the two. If the mottle is long and narrow, as a band of color at the periphery of a ped, the dimension recorded is the smaller of the two and the shape and location are also described. Three size classes are used:

Fine	Smaller than 5 mm
Medium	5 to 15 mm
Coarse	Larger than 15 mm

Size of mottles, like quantity, must be carefully identified in terms of the kinds of mottles to which the terms apply. A card having spots of various shapes in sizes that correspond to size classes is helpful for field use.

Contrast refers to the degree of visual distinction that is evident between associated colors. Contrast may be described as faint, distinct, or prominent:

Faint: Evident only on close examination. Faint mottles commonly have the same hue as the color to which they are compared and differ by no more than 1 unit of chroma or 2 units of value. Some faint mottles of similar but low chroma and value differ by 2.5 units (one page) of hue.

Distinct: Readily seen but contrast only moderately with the color to which they are compared. Distinct mottles commonly have the same hue as the color to which they are compared but differ by 2 to 4 units of chroma or 3 to 4 units of value; or differ from the color to which they are compared by 2.5 units (one page) of hue but by no more than 1 unit of chroma or 2 units of value.

Prominent: Contrast strongly with the color to which they are compared. Prominent mottles are commonly the most obvious color feature of the section described. Prominent mottles that have medium chroma and value commonly differ from the color to which they are compared by at least 5 units (two pages) of hue if chroma and value are the same; at least 4 units of value or chroma if the hue is the same; or at least 1 unit of chroma or 2 units of value if hue differs by 2.5 units (one page).

If colors of mottles and of the background are recorded by Munsell notations, the degree of contrast is evident from the notations. For readers who do not use the Munsell color system regularly, however, the notations do not create a clear impression of color or contrast. The connotative terms for contrast are usually used, even though color notations are given. A judgment of degree of contrast at the time the soil is described is useful, since the contrast is often not a simple comparison of one color with another but is a visual impression of the prominence of one color against a background commonly involving several colors. The guides provided in the definitions of contrast classes, therefore, are used with appropriate judgment of the visual impression of the layer. The description shows whether the contrast term compares only two colors or is a visual impression of contrast of color against a multicolored background.

Shape of some mottles is significant and is often described by common words like streaks, bands, tongues, tubes, and spots. Commonly, the location and shape of mottles is related to structure of the soil. Such relationships are described. The nature of boundaries of mottles is important in some soils and can be

described as sharp (like a knife edge), clear (color grades over less than 2 mm), or diffuse (color grades over more than 2 mm). These and other attributes of mottling are described as necessary to record features that may be significant for understanding the properties of the soil and how it formed. No special conventions are provided for these attributes because of their diversity. Generally, more useful records are obtained by tailoring the description to the special features observed rather than by depending on conventions that are likely to be inadequate.

The elements of mottling are conventionally described after the dominant color in the order (1) quantity, (2) size, (3) contrast, (4) color, (5) other attributes: "few, medium, distinct, yellowish brown (10YR 5/4), diffuse, streaklike mottles, brown (10YR 5/3) moist." Color is recorded by Munsell notation in detailed field descriptions. In nontechnical descriptions the color group name may be used alone, but if the description is for technical use as well, the Munsell notation is given in parentheses.

Color patterns related to physical organization

Color, including mottling, is described separately for any structure that merits separate description as a unique part of the soil. The colors, including internal color patterns, are described for such bodies as peds, concretions, nodules, cemented bodies, filled animal burrows, and the like. (See "Physical organization in soil," p. 4-70.)

Colors are given for coatings on faces of peds as well as for faces of peds that do not have identifiable coatings. Extensions of material from another soil layer are usually described as unique attributes of the soil, and the descriptions of them include color. The conventions for describing the color of the soil are used for descriptions of unique bodies and surfaces.

Commonly, the colors of unique bodies and surfaces have significant relationships to location on or in the element described. Some are products of boundary features between the interior and exterior of a discrete body. The fine tubular color patterns that extend vertically below the A horizon of some wet soils, for example, reflect chemical phenomena adjacent to roots that once occupied the tubules. The rim of bright color within an outer layer of light color at the surface of some peds reflects important boundary features that affect water movement into and out of the peds and oxidation-reduction relationships at the surface of the peds. Color patterns that are consistently associated with specific locations are described in relation to location. If color differences are related to differences in other properties, such as texture, that relationship is noted.

In general, any color pattern that exhibits order requires explanation because order implies a cause and effect relationship. Much of the understanding of soil originated from such clues. Commonly, not all of the reasons for observed relationships are understood, but the observed order is recorded as data for developing understanding.

Recording Color

The many colors and color combinations in soils defy design of a set of conventions that are equally convenient and logical for all who write soil

descriptions, for the varied color patterns observed in soils, and for those who use soil descriptions. Nevertheless, some order in the manner in which color is recorded is helpful. These guidelines are not intended to be followed blindly. They are intended to suggest the kinds of information to be recorded and formats that are useful for most descriptions.

Elements of color descriptions include (1) the color name, (2) the Munsell notation in parentheses, (3) the moisture state, and (4) the physical state: "brown (10YR 5/3), dry, crushed and smoothed." In field notebooks the color name is usually omitted, but it is supplied when the description is prepared for general use.

Moisture state is recorded for all color determinations. To avoid unnecessary repetition, a standard moisture state of the whole soil, or of a given part of it, can be recorded in an introductory remark stating that, unless specified otherwise, all colors are for that moisture state. If this convention is used, each color recorded for a different moisture state must have its moisture specified. This applies to dominant colors, mottles, and bodies and surfaces.

Descriptions of soil series within a region can consistently report either dry or moist color as the standard state for the area or region. Usually in a humid region the moist state is taken as standard, and in an arid region the dry state.

In detailed descriptions, colors of both dry and moist soil are recorded if feasible. The color for the moisture state at the time the soil is examined in the field is usually described first. Recording color for both dry and moist states is not always practical, for in moist weather drying a moist soil in the field may not be feasible in reasonable time. A dry soil can be moistened and a moist soil can be brought into a room to dry.

Physical state of the sample is recorded as broken, rubbed, crushed, or crushed and smoothed. The term "crushed" usually applies to dry samples and "rubbed" to moist samples. A standard physical state for which color is described can be specified in an introductory statement; other physical states for which color is recorded must then be specified. For soil descriptions that lack a statement about the physical state, the usual understanding is that the color is recorded as seen on the surface of broken soil.

In mottled soils especially, the color and color patterns of faces of peds and those of a surface broken through the peds can be markedly different. The color of the soil is recorded for a surface broken through a ped if a ped can be broken as a unit rather than crushed or rubbed. Coherent bodies such as concretions or nodules are usually described as special features, not as mottles; however, if such bodies break with the soil, the colors exposed are sometimes described as mottles, depending on the distinctness of the body within the soil.

Mottling is described following the dominant color. The quantity, size, and contrast of mottles and the name and Munsell notation of the color are recorded. Moisture state and physical state of the dominant color are presumed to apply to the mottles unless the description states otherwise. An example, for which a standard moist broken state of the sample has been specified, might read "dark brown (10YR 4/3), brown (10YR 5/3) dry; many medium distinct yellowish brown (10YR 5/6) mottles, brownish yellow (10YR 6/6) dry." Such a description implies no special relationship of mottling to structure. Alternatively, the colors in the

standard moisture state may be given together, followed by the colors at other moisture states. The color of mottles commonly is given only for the standard state unless special significance can be attached to color of mottles at another state.

If no color dominates the layer, a nearly equal mixture of two colors for a moist broken standard state can be written "intermingled dark brown (10YR 4/3) and yellowish brown (10YR 5/6) in a medium distinct pattern, brown (10YR 5/3) and brownish yellow (10YR 6/6) dry." If a third color is present, "common medium faint dark grayish brown (10YR 4/2) mottles, grayish brown (10YR 5/2) dry" can be added. If the mottles are fine and faint so that they cannot be compared easily with the color standards, the Munsell notation should be omitted. Other abbreviated descriptions are used for specific circumstances.

Contrasting colors associated with special soil features, such as nodules and tongues, are also part of the color pattern of the layer but are described with the other properties of the features. If, for example, the layer contains nodules that remain intact and has penetrations of E material, colors of those structures can be included to complete the visual impression of the broken moist surface: "dark brown (10YR 4/3), brown (10YR 5/3) dry; many medium distinct yellowish brown (10YR 5/6) mottles in peds, brownish yellow (10YR 6/6) dry; few medium prominent yellowish red (5YR 5/6) nodules, reddish yellow (5YR 6/6) dry; common distinct light brownish gray (10YR 6/2) material between peds, light gray (10YR 7/2) dry." Colors that have been recorded for the broken section are commonly described most effectively as part of a single description of the feature: "strong very coarse prisms 15 to 25 cm across having grayish brown (2.5Y 5/2) interiors and common medium faint light olive brown (2.5Y 5/3) mottles, a strong brown (7.5YR 5/6) outer rim 5 mm thick, and gray (2.5Y 5/1) exterior surfaces." The reader can relate the color pattern to the structure.

Physical Organization in Soil

Soils differ in the organization of the individual soil particles and in the numbers, sizes, and kinds of soil pores. Although some soils have little organization, in most soils the particles are organized in varying degrees into units of various sizes, shapes, and compositions. These units and their special arrangements are described in this section. The units themselves are named according to kind, such as "peds," "nodules," "clay coats."

Peds make up the structural framework of most soils. In addition, many soils have other organized morphological elements. Some are associated with ped surfaces. Others are discrete bodies within peds or in structureless soils. Elements on ped faces, pore walls, and other surfaces are described as "Surface features" (p. 4-74). They include coatings of clay, silt, sand, organic material, sesquioxides, carbonates, and the like. Discrete bodies, such as nodules and concretions, are described as "Concentrations within the soil" (p. 4-76). Pores are voids within and between structural units and are consequences of organization. They are described in the section "Pores" (p. 4-84).

Soil Structure

Soil structure refers to the natural organization of soil particles into units. These units are separated by surfaces of weakness. The surfaces persist through more than one cycle of wetting and drying in place. An individual natural unit is called a ped. Most peds described in soils are large enough to be seen without magnification.

Peds are distinguished from (1) clods, which are caused by disturbances, such as plowing, that mold the soil into transient bodies, (2) soil fragments, which form when the soil cracks or is broken and which are bounded by ephemeral planes that do not reappear in the same place on drying, and (3) concretions or nodules, which are local concentrations of substances binding grains of soil together into discrete units within the soil. These kinds of bodies are described in other parts of this section.

The persistent surfaces of peds can often be distinguished from the fracture surfaces of soil fragments by smoothness, coatings, relationship of mineral grains to the surface, and the absence of shapes and grooving characteristic of slickensides. Identification of some peds requires careful examination of sections through the soil for clearly defined parting planes repeated over reasonably consistent distances and careful examination of the surfaces of units when they are removed.

Some soils lack structure. Some have simple structure, each ped being an entity without component smaller peds that persist through successive wetting and drying cycles. Others have compound structure, in which large peds are composed of smaller peds separated by persistent planes of weakness.

Layers that lack structure are structureless. In structureless soils, no peds are observable in place or after the soil has been gently disturbed, as by tapping a spade containing a slice of soil against a hard surface, dropping a large fragment on the ground, or tossing a fragment up in the air and catching it. When structureless soils are disturbed, soil fragments and single mineral grains can be identified. The soil fragments may be strongly coherent or they may be easily broken or crushed.

In soils that have structure, the shape, size, and grade (distinctness) of the peds are described. Field terminology for soil structure consists of separate sets of terms designating each of the three properties, which by combination form the names for structure.

Shape.--Several basic shapes of peds are recognized in soils. Supplemental statements about the variations in shape of individual peds are needed in detailed descriptions of some soils. The following terms describe the basic shapes and related arrangement of peds:

> Platy: The peds are flat and platelike. They are generally oriented horizontally and are usually overlapping. Platy structure is illustrated in figure 4-13. A special form, lenticular platy structure, is recognized for plates that are thickest in the middle and thin toward the edges.
>
> Prismatic: The individual peds are bounded by flat or slightly rounded vertical faces. Peds are distinctly longer vertically, and the faces

are typically casts or molds of adjoining peds. Vertices are angular or subrounded; the tops of the prisms are somewhat indistinct and normally flat. Prismatic structure is illustrated in figure 4-14.

Columnar: The peds are similar to prisms and are bounded by flat or slightly rounded vertical faces. However, the tops of columns, in contrast to those of prisms, are very distinct and normally rounded, as illustrated in figure 4-15.

Blocky: The peds are blocklike or polyhedral. The peds are bounded by flat or slightly rounded surfaces that are casts of the faces of surrounding peds. Blocky peds are nearly equidimensional but grade to prisms, which are longer vertically, and to plates, which are longer horizontally. The structure is described as angular blocky if the faces intersect at relatively sharp angles and as subangular blocky if the faces are a mixture of rounded and plane faces and the angles are mostly rounded. Figure 4-16 illustrates angular blocky peds.

Granular: The peds are approximately spherical or polyhedral and are bounded by curved or very irregular faces that are not casts of adjoining peds. Granular peds are illustrated in figure 4-17.

Size.--Five classes describe the size of peds: very fine, fine, medium, coarse, very coarse. The size limits of the classes differ according to the shape of the peds. The classes of size for the various ped shapes are given in table 4-5. The size limits refer to measurements in the smallest dimension of plates, prisms, and columns and to the largest of the nearly equal dimensions of blocks and granules.

In some horizons the peds are very much larger than the minimum size given for the very coarse class. If the peds are more than twice the minimum size of "very coarse," the actual size is given: "prisms 30 to 40 cm across."

Grade.--Grade describes the distinctness of peds and the relationship of cohesion within peds and adhesion between peds. The determination of grade of structure in the field depends on the ease with which the soil separates into discrete peds and also on the proportion of peds that hold together when the soil is handled. Three classes are used:

Weak: The peds are barely observable in place. When gently disturbed, the soil material parts into a mixture of entire and broken peds and much material that exhibits no ped faces. Ped faces that indicate persistence through at least one wetting and drying cycle are evident if the soil is handled carefully. Distinguishing structurelessness from weak structure is sometimes difficult. In virtually all material that has structure, the surface of individual peds will differ in some way from the interiors of the peds.

Moderate: The peds are well formed and evident in undisturbed soil. When disturbed, the soil material parts into a mixture of many entire peds, some broken peds, and little material that is not in peds. The peds part from adjoining peds to reveal nearly entire faces that have properties distinct from those of fracture surfaces.

Strong: The peds are distinct in undisturbed soil. They separate cleanly when the soil is disturbed. When removed, the soil material separates mainly into entire peds. Generally, faces of peds have distinctive properties that distinguish them from fracture surfaces.

Grade of structure changes with the soil-water state. When soils are described in the field, soil structure of necessity is described for the existing soil-water state. That state is specified, either for the soil as a whole at the beginning of the description or for the individual horizons. When descriptions of a map unit or a taxonomic unit are prepared, structure is described for the soil-water state most common for the soil, and that state is specified. Changes in grade of structure as soil-water state changes are also described.

Structure may be altered in soil sections such as road cuts exposed to variations of temperature and moisture. Soil sections that have been exposed for a long time are not suitable places to determine the grade of structure.

The distinctness of individual peds and the relationship of cohesion within peds to adhesion between peds determine grade of structure. The relationship of adhesion to cohesion is relative to the specific horizon being evaluated: individual peds in a sandy loam A horizon may have strong structure yet be less durable than individual peds in a silty clay loam B horizon of weak structure. The degree of disturbance required to determine structure grade depends largely on moisture content and percentage and kind of clay. Only slight disturbance may be necessary to separate peds of a moist sandy loam having strong granular structure, while considerable disturbance may be required to separate peds of a moist clay loam having strong blocky structure.

The three terms for soil structure are combined in the order (1) grade, (2) size, (3) shape: "strong fine granular structure" is used to describe a soil that separates almost entirely into discrete units that are loosely packed, roughly spherical, and mostly between 1 and 2 mm in diameter.

The designation of structure by grade, size, and shape can be modified with other appropriate terms when necessary to describe other characteristics of the peds. Surface characteristics of peds are described separately. Special structural units such as the wedge-shaped aggregates of Vertisols are described in appropriate terms.

Compound structure

In many soil horizons one or more sets of small peds are held together to form discrete bodies recognizable as larger peds. Both orders of peds, as well as the relationship of one to the other, are described. Grade, size, and shape are given for both. The relationship of one set of structural units to the other is important and is shown: "strong medium blocks within moderate coarse prisms," or "moderate coarse prismatic structure parting to strong medium blocky." The word "parting," not "breaking," is used. The term "breaking" is applied when the soil is fractured along planes other than natural planes of weakness.

A description of peds within peds implies primary and secondary parting planes and voids associated with them. It commonly also suggests differing degrees of continuity of the parting planes and associated voids.

Clods and Soil Fragments

If enough force is used, any body of soil material can be broken into smaller pieces. The pieces are peds if their form and size are related to persistent planes of weakness. Aggregations of soil grains that do not have orderly shape and size or surfaces that indicate persistence are not peds.

Clods are bodies of soil material that form when the soil is subjected to shearing, as during plowing or digging. There is some rearrangement of primary particles, at least next to the surfaces formed. On slaking, some clods leave peds; others slake to structureless material. The shape, grade, and size of clods should be described.

Soil fragments include (1) units of undisturbed soil that are separated by planes of weakness or planar voids at the time they are observed but that do not persist through cycles of wetting and drying and (2) pieces formed independently of planes of weakness by outside pressures, as when massive material or a ped is broken during examination of the soil. The soil fragments formed when a soil contracts upon drying are examples of the first kind (Figure 4-18). They form without manipulation and have size, shape, and arrangement governed by forces within the soil; but the same fracture planes might not form during another wetting and drying cycle. The sizes and shapes of pieces of soil material formed by outside pressures during manipulation depend on the pressure applied. The term "soil fragments" is used to avoid confusion with rock fragments.

Surface Features

Surface features include (1) coats of a variety of substances unlike the adjacent soil material and covering part or all of surfaces, (2) material concentrated on surfaces by the removal of other material, and (3) stress formations in which thin layers at the surfaces have undergone reorientation or packing. All differ from the adjacent material in composition, orientation, or packing.

Descriptions of surface features may include kind, location, amount, continuity, distinctness, and thickness of the features. In addition, color, texture, and other characteristics that apply may be described, especially if they contrast with the characteristics of the adjacent material.

Kinds.--Surface features are distinguished by differences in texture, color, packing, orientation of particles, or reaction to various tests. If a feature is distinctly different from the adjacent material but kind cannot be determined, it is described.

Clay skins (synonymous with clay films) are thin layers of oriented translocated clay.

Clay bridges link together adjacent mineral grains at contact points.

Sand or silt coats are sand or silt grains adhering to a surface. Some sand and silt coats are concentrations of the sand and silt originally in the horizon from which finer particles have been removed. Some are material that has been moved from horizons above and deposited on surfaces. In some coats the grains are

almost free of finer material; in others, the grains themselves are coated. If known, the origin of the coat is noted. Sand or silt coats are commonly high in quartz but may consist of other materials.

Other coats are described by properties that can be observed in the field. The coats may be composed of iron, aluminum or manganese oxides, organic matter, salts, or carbonates. Laboratory analyses may be needed for positive identification.

Stress surfaces are smoothed surfaces that have greater density than the adjacent soil. They are caused by pressure and may persist through successive drying and wetting cycles.

Slickensides (Figure 4-19) are stress surfaces that are polished and striated. They are produced by one volume of soil sliding over another and are common in swelling clays in which there are marked changes in moisture content.

Location.--The various features may be on some or all surfaces of peds, channels, pores, primary particles or grains, soil fragments, rock fragments, nodules, or concretions. The kind of surface on which coats are observed is always given. For example, if clay skins are on vertical but not horizontal faces of peds, this fact should be recorded.

Amount.--The area occupied by a particular surface feature over the extent of the horizon is described. Amount can be characterized by a fraction or percentage or by the following classes:

VI Very few: Occupies less than 5 percent of the total area of the kind of surface described

1 Few: Occupies 5 to 25 percent of the total area of the kind of surface described

2 Common: Occupies 25 to 50 percent of the total area of the kind of surface described

3 Many: Occupies more than 50 percent of the total area of the kind of surface described

The same classes are used to describe the amount of "bridges" connecting particles of structureless soil bodies. The amount is judged on the basis of the percentage of particles of the size designated that are joined to adjacent particles of similar size by bridges at contact points.

Distinctness.--Distinctness refers to the ease and degree of certainty with which a surface feature can be identified. Distinctness is related to thickness, color contrast with the adjacent material, and other properties but is not itself a measure of any one of them. Some thick coats, for example, are faint, whereas some thin ones are prominent. The distinctness of some surface features changes markedly as amount of moisture changes; therefore, the soil-water state is specified. Three distinctness classes are used.

Faint: Evident only on close examination with 10X magnification and cannot be identified positively in all places without greater magnification. The contrast with the adjacent material in color, texture, and other properties is small.

Distinct: Can be detected without magnification, although magnification or tests may be needed for positive identification. The feature contrasts enough with the adjacent material that a difference in color, texture, or other properties is evident.

Prominent: Conspicuous without magnification when compared with a surface broken through the soil. Color, texture, or some other property or combination of properties contrasts sharply with properties of the adjacent material, or the feature is thick enough to be conspicuous.

The order in which properties of a surface feature are described is usually (1) amount, (2) distinctness, (3) color, (4) texture, (5) kind, (6) location. These elements are used to characterize surface features, though not all of them are needed for all descriptions. The elements that provide significant information are described, but insignificant or repetitious detail is avoided. If coats on peds are black and the adjacent material is light gray, there is no need to specify that the coats are "prominent." If texture of the surface feature is obvious, as in most stress surfaces, repeating texture adds nothing. Some of the properties are not relevant to some surface features, or cannot be determined, and are therefore omitted. Kind and location are essential if the feature is mentioned at all. The conventions do not characterize the volume occupied by surface features except in broad and overlapping terms. If volume is important, it is estimated separately. Two examples: "few distinct grayish brown (10YR 5/2) clay skins on vertical faces of peds"; "continuous distinct brown clay bridges between mineral grains."

Concentrations Within the Soil

The features discussed here are identifiable bodies embedded in the soil. Some of these bodies are thin and sheetlike; some are nearly equidimensional; others have irregular shapes. They may contrast sharply with the surrounding material in strength, composition, or internal organization.

Nodules and concretions are discrete bodies strong enough and distinct enough to be removed from the soil intact. They are commonly cemented, but include uncemented but coherent units that separate from the surrounding soil along clearly defined boundaries. They range in composition from material dominantly like that of the soil to concentrations of nearly pure chemical compounds. They differ from crystals and clusters of crystals in that their form is not governed by the forms of crystals of relatively pure substances. Some nodules and concretions are crystalline or have crystalline components, but the crystal structure is not apparent at a magnification of 10X.

Nodules are distinguished from concretions on the basis of internal organization. Concretions have crude internal symmetry organized around a point, a line, or a plane. Nodules lack evident orderly internal organization. A typical example of a concretion organized around a point is illustrated in figure 4-20. The internal structure typically takes the form of concentric layers that are clearly visible to the naked eye. A coat or a very thin outer layer of an otherwise undifferentiated body is not enough to justify use of the term "concretion." Such a coat should, of course, be described. The term concretion is not used unless internal organization is clearly evident. Some nodules are hollow, like the specimen in figure 4-20.

Nodules and concretions are distinct from inherited pieces of rock and other visible bodies of minerals. The distinction becomes obscure in some soils that contain nodules inherited from an ancient soil on another landscape, perhaps at some distance from where they are now found. It is impossible to be sure that some nodules and concretions formed where they are observed, so they are described as they exist when the soil is described. Evidence that the material has been transported is given separately. For example, a pebble band composed of concretions at a lithologic discontinuity is evidence of a buried erosional surface.

Crystals, singly or in complex clusters, are identified if they can be distinguished from mineral grains and from crystals that are components of the soil. Crystals of gypsum, calcite, halite, and other pure compounds are common in some soils. These are described as crystals or clusters of crystals, and their composition is given if known.

Soft accumulations contrast with the surrounding soil in color and composition but are not easily separated as discrete bodies, although some have clearly defined boundaries. Most soft accumulations consist of calcium carbonate, fine crystals of gypsum or more soluble salts, or iron and manganese.

Soft rock fragments have rock structure but break down in sodium hexametaphosphate after overnight shaking. Examples are fragments of some shales and sandstones that lack the hardness and durability of rock fragments.

Plinthite consists of reddish, iron-enriched bodies that are low in organic matter and are coherent enough to be separated readily from the surrounding soil. The bodies are commonly about 5 to 20 mm across their smallest dimension. Plinthite bodies are firm or very firm when moist and hard or very hard when dry, but they can be broken by hand. They are roughly spherical, nodular, or platelike; if platelike, the bodies are oriented horizontally. Soils that contain plinthite rarely dry out in the natural setting.

Field-moist and air-dry nodules or pieces of plinthite do not slake when immersed in water for two hours, even with very gentle agitation, but they generally do become less coherent after prolonged soaking. After a field-moist sample is dried, it will disperse during normal procedures for determining particle-size distribution.

Plinthite that is exposed to the atmosphere and repeated wetting and drying hardens irreversibly to ironstone. Iron-enriched mottles that do not harden irreversibly on exposure to the atmosphere are not plinthite. Plinthite is defined by its hardening characteristics, not by its degree of cementation.

Plinthite commonly is associated with reticulately mottled horizons. The nodular form is a discrete body in the soil above the reticulately mottled horizon. The platelike bodies are in the upper part of the reticulately mottled horizon and generally have a uniformly reddish color and sharp boundaries with the surrounding brown or gray material.

Plinthite is more resistant to penetration by a knife point than adjacent brown or gray bodies or than red bodies that will not harden. Plinthite does not stain the fingers when moist or wet. It has a harsh, dry feel when rubbed, even when the horizon is saturated. Horizons containing plinthite are more difficult to penetrate with an auger than adjacent horizons that have the same moisture and clay content but that do not contain plinthite.

In many soils, ironstone nodules are in horizons above a horizon containing plinthite. These ironstone nodules are apparently plinthite that has hardened irreversibly. At the other extreme, in many iron-rich bodies the center will harden upon repeated wetting and drying but the outside half or more will not. These iron-rich bodies may constitute 20 to 30 percent of the horizon volume but the plinthite much less. The part of the iron-rich body that is not plinthite normally stains the fingers when the saturated material is rubbed, but the plinthite center does not.

Describing concentrations within the soil

Any of a large number of attributes of concentrations within the soil may be important, most commonly number or amount, size, shape, consistence, color, composition, kind, and location. Not all of these attributes are necessarily described. This order is convenient for describing them: "many, fine, irregular, hard, light gray, carbonate nodules distributed uniformly through the horizon." The conventions for describing kind have been indicated in this section. The descriptions of consistence and color follow the conventions for describing soil material given in other parts of this chapter.

Amount or quantity of concentrations refers to the relative volume of a horizon or other specified unit occupied by the bodies. The classes used for quantity of mottles (p. 4-66) are also used for these features.

Size may be measured directly or given by the classes listed below. The dimension to which size-class limits apply depends on the shape of the body described. If the body is nearly uniform, size is measured in the shortest dimension, such as the effective diameter of a cylinder or the thickness of a plate. For irregular bodies, size refers to the longest dimension unless that creates an erroneous impression; or measurements can be given if needed. The following size classes are used:

Fine	Smaller than 2 mm
Medium	2 to 5 mm
Coarse	5 to 20 mm
Very coarse	20 to 76 mm
Extremely coarse	Larger than 76 mm

Shape of bodies is variable. For field descriptions and for descriptions to be used by people of many interests, the common terms "rounded," "cylindrical," "platelike," and "irregular" are suggested:

Rounded: Approximately equidimensional, few sharp corners, and at least approximately regular.

Cylindrical: At least crudely cylindrical or tubular; one dimension is much greater than the other two.

Platelike: Shaped crudely like a plate; one dimension is very much smaller than the other two. The term "platelike" is used to avoid confusion with platy structure.

Irregular: Characterized by branches or convoluted or mycelial forms.

The terms listed apply to concretions, nodules, soft bodies, and clusters of crystals. The terms for crystals, which are commonly angular, imply shape. The names of kinds of organized bodies generally do not connote shape. Nodules, for example, may be rounded, cylindrical, platelike, or irregular.

Composition of bodies is described if known and if important for understanding their nature or the nature of the soil in which they are observed. Some of the physical attributes of the interior of a feature are implied by the name. Other features such as enclosed mineral grains, patterns of voids, or even similarity, or lack of it, to the surrounding soil may be important.

A distinction is made between bodies that are composed dominantly of a single substance and those that are composed of earthy material impregnated by various substances. For many bodies the chemical composition cannot be determined with certainty in the field, but the following sets of terms are useful for describing composition if it is known:

If the substance dominates or is conspicuous	If the substance impregnates other material
Carbonate	Calcareous
Clay	Argillaceous
Gypsum	Gypsiferous
Silica	Siliceous
Iron	Ferruginous
Manganese	Manganiferous
Salt	Saline

Carbonates and iron are common substances that dominate or impregnate nodular or concretionary bodies. Discrete nodules of clay are found in some soils; argillaceous impregnations are less common. Materials dominated by manganese are rare, but manganese is conspicuous in some nodules that are high in iron but that are mistakenly called "manganese nodules."

Cementing agents

Horizons that are cemented are often called "pans." The presence of a pan is of great significance to the use of many soils because it prevents or restricts water and root penetration. The possibility of eliminating the adverse influence of a pan on root and water penetration through management practices depends on the characteristics of the cementing agent. Like other prominent horizons, cemented horizons or pans are important indicators of genetic processes. The common cementing agents in soils are iron, organic matter, silica, calcium carbonate, and gypsum.

Massive indurated or cemented horizons are characteristic of many soils. Relict cemented horizons or pans may have no relation to the existing combination of genetic factors.

Iron.--Cementation by iron is characteristic of layers formed by lowering of the water table in some soils. Many of these hardened layers are permeable to water, and roots may grow through cracks and other openings.

Iron and organic matter.--Horizons cemented with iron and organic matter are called "ortstein." (Material in which iron and organic matter have accumulated without cementation are called "orterde.") The formation of these horizons is thought to result from formation of complexes of organic matter and iron. Although ortstein forms within the zone of a fluctuating high water table, it also exists in well drained soils.

Silica.--Large areas exist of soils having horizons that are cemented with silica. These horizons are structureless or platy. In California, silica-cemented horizons are common on gently sloping fans of alluvium derived from acid igneous rocks. These cemented horizons are also present in semiarid parts of the United States, Australia, and other countries, mostly in nearly level areas. Some silica-cemented horizons are in more humid environments. Silica-cemented horizons inhibit water and root penetration unless they are broken or have fracture planes. Iron oxides and calcium carbonate may be accessory cementing agents. Treatment with acid will not destroy silica cementation. Treatment with hot concentrated alkali dissolves the silica cementation very slowly.

Silica and calcium carbonate.--In arid and semiarid regions some soils have horizons that are cemented with a mixture of silica and calcium carbonate. These horizons frequently underlie an alkaline horizon. Extensive and continuous cemented horizons of this sort are important because they must be broken before irrigation can be successful. In arid regions the natural soil may show little evidence of impeded drainage that would become serious with irrigation.

Calcium carbonate.--In regions where the rainfall is too low to remove all of the soluble minerals from the soil, calcium carbonate usually accumulates in the lower part of the soil. In some soils calcium carbonate accumulates as a soft powdery mass, in others it accumulates in concretions, and in some it forms a cemented horizon. The cemented horizon is often present in areas with an intermittent high water table, although it may persist indefinitely after the water table is lowered. These cemented horizons vary widely in their effects on soil drainage. Some of these horizons that are fractured or that contain solution cavities seem not to cause much reduction in water movement; others do. The indurated accumulations of calcium carbonate are known as croûte calcaire or, more commonly in the Americas, as hardened caliche or simply caliche. Where the accumulations are prominent and thick and are not hardened they are known as soft caliche or carbonate horizons. Calichelike layers are present in some deposits of glacial gravel in regions as humid as Illinois and Indiana. Where the caliche is extensive and continuous it may inhibit the penetration of water and roots. Layers of caliche in soils of humid regions are not always continuous but may be interrupted at intervals of several inches to a few feet.

Gypsum.--Horizons cemented with gypsum are found only in soils of arid climates that formed in parent materials rich in gypsum. Most horizons in which gypsum has accumulated are not cemented. Gypsum-cemented horizons are rare in the United States but are common in some arid parts of Africa and Asia.

Consistence

Soil consistence describes the cohesion among soil particles and the adhesion of soil to other substances. Consistence may be described in terms of (1) resistance to cracking or breaking when force is applied (strength), (2) force required to deform but not rupture soil material (plasticity), (3) degree to which soil material adheres to other objects (stickiness), and (4) behavior of soil material as it deforms when force is applied (smeariness and fluidity).

The reaction of soil when force is applied is closely related to the soil-water state. A description of consistence has little meaning unless the soil-water state is specified or is implied by the term used. Strength is determined both when the soil is air dry and when it is at field moisture capacity; if the material is cemented, strength is determined after the sample has soaked for one hour. Plasticity is determined at the plastic limit, stickiness at the water content of maximum stickiness, smeariness at field capacity, and fluidity under natural field conditions.

In addition to the terms described here, a number of others can be used, as defined in standard dictionaries, to indicate unusual conditions. These terms include brittle, crumbly, dense, elastic, fluffy, mealy, mellow, rigid, spongy, stiff, tight, and tough. Brittle, for example, is commonly used in describing fragipans or fragipanlike layers. Most dry soil material, if at all coherent, is brittle to some degree; thus only evaluations of brittleness made when the soil is moist are useful. Classes of brittleness are not designated in this manual. If such classes are used, they can be defined locally.

Strength

Soil strength is the degree of resistance to breaking or crushing when force is applied. It is evaluated under three different moisture conditions. The terms used to describe strength are specific to the moisture condition. When uncemented material is air dry, strength is described as loose, soft, slightly hard, hard, very hard, or extremely hard; and when at field moisture capacity as loose, very friable, friable, firm, very firm, or extremely firm. Cemented material is evaluated both dry and after it has soaked for one hour and is described as weakly cemented, strongly cemented, or indurated.

A specimen for testing strength is a cube about 25 mm on each side if such a cube can be removed from the soil. In some places the material is so loose that it will not hold together in a cube. Where structure is moderate or strong and peds are less than 25 mm across, a ped of common size is used.

The cube or ped is squeezed on opposite vertical sides for no longer than 5 seconds. 18/ The force needed to crush or break the specimen is recorded. Table 4-6 defines the strength classes by measured force (in newtons) or energy (in joules) and by the field methods used to evaluate soil strength.

If significantly less force is required to separate adjacent peds than to break a ped, as in soils that have moderate or strong structure, the force required to separate the peds should be reported: "very slight force required to separate peds when dry, slight force when moist."

Material is cemented if an air dry test specimen does not slake after being immersed in water for one hour. If the specimen slakes it is not considered to be cemented.

Cemented soil material has at least a brittle, hard consistence caused by some cementing agent other than clay. Calcium carbonate, silica, or oxides or salts of iron and aluminum are common cementing materials. In many soils strength of cemented material is altered little if any by wetting: the hardness and brittleness persist in the wet soil. Semireversible cements, which generally resist moistening but soften under prolonged wetting, occur in some soils and form layers having cementation that is pronounced when dry but very weak when wet. A simple description of cementation implies that the cementation is altered little by wetting. If the strength is altered significantly by prolonged wetting, cementation classes under both wet and dry conditions are given. Cementation can be either continuous or discontinuous within a given horizon.

Plasticity

Plasticity is the degree to which soil is permanently deformed, without rupturing, by force applied continuously in any direction. Plasticity is determined in the field using material smaller than 2 mm.

A ball of wet soil is rolled between the hands until a thread 3 mm in diameter can be formed. If a thread can be formed, the rolling is continued until the thread begins to break. The thread breaks at approximately the plastic limit. Plasticity terms are based on degree of resistance to deformation at the moisture content just before the 3-mm thread breaks:

Nonplastic: No thread can be formed.
Slightly plastic: Thread can be formed and mass is deformed by very slight force.
Plastic: Thread can be formed and mass is deformed by slight force.
Very plastic: Thread can be formed and mass is deformed by moderate or strong force.

Stickiness

Stickiness refers to the capacity of a soil to adhere to other objects. It is determined in the field at the water content at which the material is most sticky.

Material smaller than 2 mm is evaluated. The sample is crushed in the hand and moisture is applied while manipulating the sample between thumb and forefinger until maximum stickiness is reached. The classes of stickiness follow:

Nonsticky: After release of pressure, practically no soil material adheres to thumb or forefinger.
Slightly sticky: After release of pressure, soil material adheres perceptibly to both thumb and forefinger, but as the fingers are separated, the material tends to come off one or the other rather cleanly. The material does not stretch appreciably when the thumb and forefinger are separated.

Sticky: After release of pressure, soil material adheres to both thumb and forefinger and tends to stretch slightly rather than pull completely free from either finger.
Very sticky: After release of pressure, soil material adheres so strongly to both thumb and forefinger that it stretches decidedly when the fingers are separated, and soil material remains on both fingers.

Smeariness

The extent to which a soil exhibits smeariness determines whether or not it is thixotropic. Thixotropy is the property exhibited by various gels of becoming fluid when disturbed and of setting again to a gel when allowed to stand. Many kinds of thixotropic substances have been identified and studied, including some volcanic ash gels, sesquioxide gels, kaolinite gels, montmorillonite gels, and drilling muds. Thixotropy apparently is the result of structure that, if broken down, can rebuild itself. The breakdown may be caused by any of several actions--agitation, shearing, even ultrasonic waves.

Some soils are composed of a mixture of discrete mineral particles and gels and have thixotropic properties. The gel portion is a colloidal suspension of liquid (water) in a framework of solid material. The material has properties of a solid when undisturbed, but pressure causes the material to smear. Highly thixotropic material is strongly smeary and some dehydrates irreversibly on drying.

In evaluating thixotropic soil material, force is applied to a standard test specimen at field moisture capacity until it smears. Classes are based on the degree of force applied.

Weakly smeary: Under moderately strong force between thumb and forefinger, the soil material changes suddenly to fluid, the fingers skid, and the soil smears. After the soil smears, little or no free water remains on the fingers.
Moderately smeary: Under moderate force between thumb and forefinger, the soil material changes suddenly to fluid, the fingers skid, and the soil smears. After the soil smears, some free water remains on the fingers.
Strongly smeary: Under slight force between thumb and forefinger, the soil material suddenly changes to fluid, the fingers skid, and the soil smears and is very slippery. After the soil smears, free water is easily seen on the fingers.

Fluidity

Soils that are saturated much of the time are likely to have a very low bearing capacity when wet. They behave like liquids and flow under pressure. This kind of yielding is called fluidity. Two classes of fluidity are provided for classifying nonthixotropic soils in the field. The classes are determined at the common natural moisture content. A roughly egg-shaped specimen about 4 cm by 8 cm (a handful) is squeezed. The amount of material that flows through the fingers determines the class:

Slightly fluid: When a specimen is squeezed in the hand, some material tends to flow between the fingers, but after full pressure is applied most of the residue is left in the hand (n = 0.7-1.0). 19/

Very fluid: When a specimen is squeezed in the hand, soil material flows easily between the fingers, and after full pressure is applied little or no residue is left in the hand (n = 1.0 or more). 19/

Pores

The volume of pore space in mineral soils ranges generally from one-third to two-thirds of the total volume; the average is probably about one-half. Pores in soils are caused chiefly by the aggregation of primary particles; by the irregularly rounded and angular shapes of mineral particles; by the action of roots; by the burrowing of insects, worms, and other animals; and by entrapment of gases.

The pore space in soils can be considered as a vast interconnected network of voids extending in all directions. The voids hold liquids and gases and regulate their movement, contain most of the living organisms in the soil, and provide space for roots to develop. When the soil contains free water, the movement of water is very closely related to the continuity of even a few voids larger than 0.1 mm. Much about the general nature of the pores in a horizon can be inferred from descriptions of texture, structure, consistence, root distribution, and perhaps other properties that are routinely described; yet additional direct information about pores can be useful and should be recorded in field descriptions of soils.

No practical field method for describing the intricate network of interconnected voids characteristic of all soils is known. Field descriptions of pores should emphasize the pores that can be seen without magnification--those brought about by the action of roots, animals, and entrapment of air--and any unusual arrangement in the pattern of voids.

Pores are described in terms of (1) quantity, (2) size, and (3) shape, usually in that order. Four size classes of pores are recognized:

Very fine: Less than 0.5 mm in diameter
Fine: 0.5 to 2 mm in diameter
Medium: 2 to 5 mm in diameter
Coarse: more than 5 mm in diameter

Pores smaller than 0.075 mm in diameter are micro pores and may be described separately, though this is rarely practical in fieldwork.

Quantity classes of pores are defined in terms of numbers of each kind and size per unit area--1 cm^2 for very fine and fine pores and 1 dm^2 for medium and coarse pores. All pores smaller than 10 mm in diameter are described in terms of the following quantity classes:

Few: Less than 1 per unit area of the specified size
Common: 1 to 5 per unit area of the specified size
Many: More than 5 per unit area of the specified size

Pores larger than 10 mm in diameter may be described separately. If described separately they are counted, and the number and the proportion of the cross section they occupy is recorded.

Most pores described will be either vesicular (approximately spherical or elliptical), or tubular (approximately cylindrical and elongated). Some are irregularly shaped and can be described simply as "irregular"; or, if significant, the shape can be recorded.

Pores are assumed to be within the ped (if a soil has peds) unless otherwise noted. In some cases it may be appropriate to specify inped pores (within peds) and exped pores (along the interfaces between peds).

If pores are oriented in an unusual direction, if they are concentrated in one part of a layer, if other special conditions prevail (such as tubular pores plugged with clay at both ends), or if there are other features that might help the reader understand the genesis of the soil or predict behavior, these features are added. Some examples of descriptions of pores: "many fine tubular pores," "few fine inped tubular pores and many medium exped tubular pores," "many medium vesicular pores in a horizontal band about 1 cm wide at the bottom of horizon."

Roots and Animals in Soils

The roots of plants and the traces of animals in a soil indicate relationships of soil properties to the habits and adaptations of organisms. Some of the features that organisms leave in the soil are major properties of specific kinds of soil; other features are clues to soil properties that are favorable or unfavorable for living things. The significance of many features is not known.

The absence of evidence of plants or animals may be equally significant and is recorded wherever there is reason to believe that the lack of organisms reflects unfavorable conditions in the soil.

Roots and Root Traces

The quantity, size, and location of roots in each layer are recorded in soil descriptions. The conventions that follow provide the minimum detail to be recorded. The relationships of root distribution to special soil attributes or to structure--as well as features of the roots themselves such as length, flattening, nodulation, and lesions--are important and are recorded as special notes.

Roots are described in terms of a specified size and quantity. The size classes are:

Very fine: Less than 1 mm in diameter
Fine: 1 to 2 mm in diameter
Medium: 2 to 5 mm in diameter
Coarse: 5 mm or larger in diameter

Quantity classes of roots are defined in terms of numbers of each size per unit area--1 square centimeter for very fine and fine roots and 1 square decimeter for medium and coarse roots. All roots smaller than 10 mm in diameter are described in terms of the following quantity classes:

Few: Less than 1 per unit area of the specified size
Common: 1 to 5 per unit area of the specified size
Many: More than 5 per unit area of the specified size

Roots larger than 10 mm in diameter may be described separately. If described separately they are counted and the number per unit cross section is recorded. The size range, actual numbers of roots, and dimensions of the cross section are recorded. If the soil contains many larger roots, the percentage of the cross section that they occupy can be estimated and noted.

The location of roots within a layer is described in relation to other features of the layer. Relationships to layer boundaries, animal traces, pores, and other features are described as appropriate. The description indicates, for example, whether roots are inside peds or only follow parting planes between peds.

Descriptive terms for roots are listed in a consistent order. Quantity, size, location is a convenient order: "Many very fine and common fine roots" (implying that roots are uniformly distributed, since location is not given); "Common very fine and common fine roots concentrated along vertical faces of peds"; "Common very fine roots inside peds, many medium roots between peds."

In addition to describing roots layer by layer, the overall impression of the development of the root system in the pedon is described to give a reliable estimate of the rooting volume of the soil. The pattern of root growth may not correspond to soil horizons; therefore, a summary statement of root development by increments of 15 cm or 30 cm or some other convenient thickness is often helpful in describing the effective depth of root penetration and the extent of their lateral distribution. For annual plants this provides information on the part of the soil used by roots in the current year. For perennial plants a longer period is involved.

In many soils the root distribution for a pedon may be summarized by groups of two or more layerss. Boundaries between groups of layers are chosen to reflect significant changes in root distribution or penetration. For example, in a soil having a strongly developed clayey illuvial horizon and a horizon sequence of Ap-A-E1-E2-Bt1-Bt2, root development might be similar throughout the A horizon, different in the E horizon, and still different in the B horizon but similar throughout the B. Thus, root distribution can be described simply for the A, E, and B horizons.

Root distribution varies with type of plant, with the stage of growth of the plant, and sometimes with plant variety. Thus, the root distribution pattern being described in a soil should be related as far as possible to specific kinds of plants and their stage of growth. Plants have characteristic root systems, but unfortunately the systems of many plants are not well known. For example, a crop

such as corn growing in a deep, unrestrictive soil in an average year in a humid, temperate climate, as in the central Corn Belt, tends to have 65 to about 85 percent of the its roots in the top 30 cm of soil. The amount of roots decreases rapidly with depth, and generally only a few percent of the total root mass is below a depth of 120 cm. The better the characteristic root system of a plant is known, the easier is relating development of a root system in a given soil to the more or less ideal rooting pattern.

In annual crops, such as corn, the effect of the soil on rooting patterns and the effect of the root system on the soil are best evaluated after early maturity, when the root system has reached maximum development. Usually roots do not deteriorate significantly for a few months after a crop reaches maturity or a tree is cut.

The effective depth of root penetration in a soil is difficult to determine because the volume or depth of soil utilized by roots for water and nutrients varies with soil properties such as texture, structure, porosity, and base saturation. In a layer with less than "few" roots, the root system probably would not be very effective in absorbing water and nutrients. In fact in many soils, a system of "few" roots probably is unable to contribute much to the sustenance of plants.

The channels left by roots that have died and the dead roots themselves are sometimes clues to soil properties that change with time. For example, the distribution of roots and channels left by dead roots of red pine in some soils suggests that roots of red pine may grow normally for a few years in these soils, only to be killed when the soils are saturated for a long period. Both root channels and dead roots may be described, but root channels are often described as pores. Some root channels are marked by special morphological features, such as "rhizoconcretions" in some moderately wet soils. Some root traces appear as long tubules of charcoal resulting from forest fires.

Root traces in deep layers (C layers, for example) may persist for years and in many cases may be described as pores. Many of these traces have organic-coatings or linings and are below the normal rooting depth of annual crops, suggesting that they were left by deeper rooting systems of native perennial plants.

Animals and Their Traces

Mixing, changing, and moving of soil material by animals is a major factor affecting properties of some soils. Activities of prairie dogs, moles, mice, gophers, shrews, woodchucks, squirrels, and rabbits are examples. Crayfish are active in some areas. Small burrows of earthworms, beetles, cicada larvae, millipedes, ants, and the like riddle the uppermost horizons of some soils, and some burrows penetrate deeply into the soil. Earthworms and some other soil-dwelling animals pass soil and plant material through their digestive tracts and leave castings of fecal material in their channels or in the soil. The structures left by some animals reflect mainly mixing or transport of material from one part of the soil to another or to the surface. The material of other structures is substantially modified physically or chemically.

Krotovinas are irregular tubular streaks within one layer of material transported from another layer. They are caused by the filling of tunnels made by

burrowing animals in one layer with material from outside the layer. In a profile they appear as rounded or elliptical spots of various sizes. They may have a light color in dark layers or a dark color in light layers, and their other qualities of texture and structure may be unlike those of the soil around them. Animals commonly responsible for the presence of krotovinas are rodents and crayfish. The burrows of rodents are usually found in well-drained soils, and the burrows of crayfish in poorly drained soils. Krotovinas are a common feature of dark-colored soils that developed under grass.

Many animals play an important role in the decomposition of organic material. Earthworms, ants, and termites are among the well known examples. In some soils the surface layer consists mostly of worm casts, and the underlying layers contain many filled worm channels. Distinctive horizons of some tropical soils result from activities of termites and earthworms. Mites, millipedes, springtails, various beetles and flies, slugs and snails, and segmented worms also affect soils. The effects of these animals are less easily observed and evaluated than are the structures formed by burrowing and mixing, though perhaps they are no less important. Generally, only the most obvious marks of these activities, such as the consumption of leaf tissue on the forest floor or the fecal casts left behind, are described. Even for these, special studies are usually necessary to estimate the amount and significance of the activity.

The soil harbors a host of small animals that either prey on other animal life or attack living plants. Ants, centipedes, and spiders are examples of predators that probably affect physical properties of soils. A large number of insects that are parasitic to plants pupate in the soil. Other small parasitic or predatory animals inhabit the soil. Their effects on the soil are virtually unknown. Determination of the impact of most small animals of these kinds on the soil is probably beyond the scope of soil survey operations, but the obvious effects can be noted. A spectacular example is illustrated by figure 4-21.

The activities of animals in relation to the different kinds of soil should be recorded routinely. Soil scientists should learn at least the elementary principles of the ecology of animals in the soil and the principal kinds of animals important in a soil survey area. They can obtain the help of professional zoologists for advice about techniques for the simplest observations needed. In some surveys, they can interest professional zoologists in cooperative studies of problems of common concern.

At present, guidelines for describing the animal populations of soils and their activities are necessarily general. An assessment of the structures that animals produce on the surface is the most obvious and easiest place to start. Termit mounds, ant hills, heaps of excavated earth beside burrows, the openings of burrows themselves, paths, feeding grounds, earthworm or other castings, and other traces on the surface are easily observed and described. Simple measurements and estimates--such as the number of structures per unit area, proportionate area occupied, volume of above-ground structures--give quantitative values that can be used to calculate the extent of activity and even the number of organisms. These kinds of records can easily be kept and classified by map units, and activities of different animals can be related to specific kinds of soil.

The marks and structures of animals below the surface are more difficult to observe and measure. Observations are confined mainly to places where pits are dug to describe pedons or to collect specimens of soil material. The volume of soil that can be studied limits observations of activities of animals within the

soil. Unless the spacing of structures, or of the animals, is less than the horizontal dimensions of a pedon and is reasonably uniform, the size of the sample volume seen is usually too small to support valid conclusions. But for activities of many kinds of animals, the normal sample of pedons for soil characterization provides as valid an estimate of the nature of structures made by animals, the volume of soil affected, and the depth of soil penetrated by animals as it does for the internal properties of the soils. There commonly are enough earthworm burrows, rodent burrows, and insect castings to permit reasonable estimates from the sampling that is feasible.

The structures produced by animals in the soil are described in terms of amount, location, size, shape, and arrangement, and also in terms of the color, texture, composition, and other properties of the component material. The structures produced by animals are so varied that no special conventions are suggested for describing them. To the extent feasible, quantitative estimates of structures produced by animals are given. The descriptions of animal traces are most effective when common words in their standard dictionary meanings are used in conjunction with the special terms for soil properties and morphological features described elsewhere in this manual.

Selected Chemical Properties

This section discusses selected chemical properties that are important for describing and identifying soils and that can be determined in the field or field office.

Reaction

The numerical designation of reaction is expressed as pH. With this notation, pH 7 is neutral. Lower values indicate greater acidity; higher values, greater alkalinity. Soils range in pH from a little less than 2.0 to a little more than 11.0, although when some naturally wet soils that contain sulfides are drained, sulfuric acid forms and pH decreases to below 2.0.

The descriptive terms to use for ranges in pH are as follows:

	pH		pH
Extremely acid	Less than 4.5	Neutral	6.6 - 7.3
Very strongly acid	4.5 - 5.0	Mildly alkaline	7.4 - 7.8
Strongly acid	5.1 - 5.5	Moderately alkaline	7.9 - 8.4
Moderately acid	5.6 - 6.0	Strongly alkaline	8.5 - 9.0
Slightly acid	6.1 - 6.5	Very strongly alkaline	More than 9.0

Within a limited range of soil properties such as is likely to be observed in a single survey, pH is a very useful indicator of base status, degree of weathering, amount of leaching, availability of some plant nutrients, and toxicity to various plants. However, relationships established for one kind of soil cannot be extended to other kinds of soil without verification.

For similar kinds of soil, pH generally reflects the base status. The more acid soils have a lower proportion of exchangeable bases relative to exchangeable hydrogen than less acid (or more alkaline) soils. Base status, considered with the other properties, permits many inferences about weathering, leaching, composition of parent material, the effects of climate and vegetation, and the like. A quantitative method for determining base saturation has been adapted for use in field offices. This method will be described in Chapter 8.

Many, but not all, soil materials having pH between 8.0 and 8.5 contain carbonates of divalent cations. Soils having pH above 8.5 are likely to have significant amounts of exchangeable sodium. Soils having pH less than 5.2 are likely to have large amounts of exchangeable aluminum, and plants growing in them are likely to be affected by aluminum toxicity. Available information about similar relationships are assembled for individual areas, and the significance of soil reaction is evaluated for soils in the area. Chapter 8 will discuss factors that affect measurement of reaction.

Measuring pH in the field

Both colorimetric and electrometric methods are used for measuring pH. Each method has advantages. Because colorimetric methods are simple and inexpensive, they are used most commonly for measuring pH in the field. Reliable portable pH meters are now available, and field use of these instruments has increased greatly. When properly used, they provide data that are comparable in precision to data obtained in the laboratory.

Some colorimetric methods use an indicator solution with a mixture of indicator dyes; others use several indicators individually, each of which covers a narrow range of pH. The mixtures are more convenient; the sets of several indicators are commonly more accurate. For either method, a small amount of soil is placed in a porcelain spot plate and the indicator is added. The resulting color is then compared to a standard printed color chart. The indicator colors are observed against the white background of the spot plate, or the indicator is absorbed in a thin layer of barium sulfate dusted on the surface of the sample.

Errors from several sources can result in inaccurate colorimetric measurements of pH. For accurate results the indicators used in the field must be prepared in the same manner as those that were used in making the color charts. Faded or worn charts must be replaced. Sometimes the indicators deteriorate because the chloroform or alcohol preservative evaporates, permitting bacterial contamination. The salt added to indicators or formed during its preparation may have an appreciable but unpredictable effect on pH measurement. Some soils, especially those high in organic matter, absorb the indicator or disperse in the solution so that a reading is unreliable. A different method should be followed. To ensure that the indicators are accurate, they can be checked using soil samples of known pH recently determined with a pH meter. Colorimetric values are usually within 0.2 to 0.5 pH unit of those obtained with the pH meter. The kind of indicator used is recorded in addition to pH.

Techniques for field pH measurements using an electrometric pH meter are similar to laboratory techniques. The pH meter is especially useful when pH measurements are needed at definite soil-water ratios and for soil-salt solution mixtures using reagents such as 0.01M $CaCl_2$ or 1N KCl.

Buffer solutions are used to check the proper functioning of the pH meter. Buffers at pH 4.0 and pH 7.0 are commonly used for calibration. Extreme care is taken not to contaminate the buffer solutions, and used solutions are discarded. Buffers are checked for any cloudiness, which indicates microbial growth or chemical deterioration.

When a pH meter is used, a volume of soil approximating a specified weight is added to a disposable cup and the appropriate amount of water or salt solution is added. The specimen is stirred and allowed to equilibrate for 10 to 30 minutes. It is then restirred, and the tips of the electrodes are immersed in the partially settled suspension. The cup is rotated around the electrodes to eliminate air pockets, and pH is read. The manufacturer's instructions are followed for using the instrument and for making temperature corrections.

Soil particles and solutions are removed from the electrodes after each determination by spraying the electrodes with distilled water and wiping off the excess water with a soft, clean, absorbent paper. Rugged glass electrodes are available for use in soil suspensions, but care must be exercised to prevent scratching the tip. Such scratching often happens when the sample contains coarse fragments or the electrodes are pushed too deeply into the suspension.

Ordinary electrometric pH measurements are accurate within 0.1 and 0.3 pH units, which is less than the seasonal variation in pH of many soil horizons.

Carbonates of Divalent Cations

Calcium carbonate and calcium-magnesium carbonate (dolomite) are important constituents of many soils. Many soils formed in calcareous material. In humid regions, carbonates are removed by percolating water, but many soils that formed in calcareous material of late Pleistocene age or younger have carbonates in part of the soil or in the substratum. In arid regions, carbonates accumulate in various horizons if there is a source of divalent cations. Carbonates range from clay- and silt-sized particles in some soils to rocklike layers in others.

Dilute hydrochloric acid is used to test for carbonates in the field. Calcium carbonate effervesces when treated with a cold 10-percent (about 1N) solution of hydrochloric acid; dolomite reacts little or not at all and is commonly overlooked if only cold dilute acid is used. Dolomite can be detected by heating the sample, using concentrated acid, or thoroughly powdering the sample; the acid is then allowed to react for a few minutes. The efferverscence of powdered dolomite with cold dilute acid is slow and frothy.

The amount and violence of effervescence are affected by many factors besides the amount of carbonates. Consequently, the violence of effervescence provides a qualitative description rather than a quantitative estimate of the amount of carbonates. Four classes of effervescence are used to describe the results of the test:

Very slightly effervescent: Few bubbles seen.
Slightly effervescent: Bubbles readily seen.
Strongly effervescent: Bubbles form low foam.
Violently effervescent: Thick foam forms quickly.

Quantitative field methods for determining amount of carbonates have been devised. They will be described in Chapter 8.

Salinity and Sodicity

Saline and sodic soils are most common in semiarid and arid areas, but they also are found in some places in humid regions, particularly near coasts. Accurate determination of salinity and sodicity in the field requires special equipment and is not necessarily part of each pedon investigation. Reasonable estimates of salinity and sodicity can be made if field criteria are correlated to more precise laboratory measurements.

Salinity

The electrical conductivity of a saturation extract is the standard measure of salinity. Electrical conductivity is related to the amount of salts more soluble than gypsum in the soil, but it may include a small contribution (up to 0.22 S/m) 20/ from dissolved gypsum.

If it has been measured, the electrical conductivity (in siemens per meter corrected to a temperature of 25° C) is reported in soil descriptions. The following classes of salinity are used if the electrical conductivity has not been determined but salinity is inferred:

Class	Electrical conductivity
1. Very slightly saline	0-0.4 S/m
2. Slightly saline	0.4-0.8 S/m
3. Moderately saline	0.8-1.6 S/m
4. Strongly saline	> 1.6 S/m

Sodicity

The sodium adsorption ratio (SAR) is the standard measure of the sodicity of a soil. The sodium adsorption ratio is calculated from the concentrations (in milliequivalents per liter) of sodium, calcium, and magnesium in the saturation extract:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}}$$

Formerly, the exchangeable sodium percentage, which equals exchangeable sodium (meq/100 g soil) divided by the cation exchange capacity (meq/100 g soil) times 100, was the primary measure of sodicity. The test for exchangeable sodium percentage, however, has proved unreliable in soils containing soluble sodium silicate minerals or large amounts of sodium chloride.

Sodium is toxic to some crops, such as avocados and other fruit trees. More importantly, sodium affects the soil's physical properties, mainly permeability. A sodic condition has little effect on permeability in highly saline soils. A soil that is both saline and sodic may, when artifically drained, drain freely at first; but after some of the salt has been removed, further leaching of salt becomes difficult or impossible. The sodium adsorption ratio usually decreases as a soil is leached, but the amount of change depends in part on the composition of the water used for leaching and therefore cannot be predicted with certainty. If the initial sodium adsorption ratio is greater than 10 and the initial electrical conductivity is more than 2 S/m and information is needed as to whether the soil will be sodic following leaching, the sodium adsorption ratio is determined on another sample following leaching with the intended irrigation water. For the classification of soils with an electrical conductivity of more than 2 S/m the sodium adsorption ratio determined after leaching with distilled water to an electrical conductivity of about 0.4 S/m is used. The amount of amendments such as gypsum needed to reclaim a sodic soil depends in part on the sodium adsorption ratio and in part on the cation exchange capacity of the soil. If the cation exchange capacity is not known, a gypsum requirement test is useful.

Gypsum

Gypsum (calcium sulfate) can be inherited from the parent material, or it can precipitate from supersaturated solutions in the soil or in the substratum. Gypsum can alleviate the effects of sodium, making possible the use of irrigation water having a relatively high amount of sodium. Soils that contain large amounts of gypsum can settle unevenly after irrigation; frequent releveling may be required. Gypsum is soluble in water, but its solubility (30 meq/l) is low enough that in absence of other salts a salinity hazard does not exist except for the most sensitive plants, such as strawberries and some ornamentals. Gypsum and other sulfates may cause damage to concrete.

Much gypsum is tabular or fibrous and tends to accumulate as clusters of crystals or as coats on peds. Some of it is cemented. Gypsum can usually be identified tentatively by its form and lack of effervescence with acid. Gypsum in the parent material may not be readily identifiable. If determined, the amount of gypsum is shown in the description or the amount may be estimated. Semiquantitative field methods for determining amount of gypsum are available. They will be discussed in Chapter 8.

Sodium Sulfate

A few soils contain large amounts of sodium sulfate, which looks like gypsum. At temperatures above 32.4° C it is in the form of thenardite (Na_2SO_4) and at lower temperatures in the form of mirabilite ($Na_2SO_4 \cdot 10H_2O$). The increase in volume and decrease in solubility as thenardite changes to mirabilite can cause spectacular salt heaving. In sodium-affected soils, sodium sulfate is a common water-soluble salt.

Sulfides

Sulfides, mainly iron sulfide, are in some soils of tidal marshes and in some sedimentary rocks. When these materials are exposed, as when marsh soils are

drained or sulfide-bearing rock is excavated, oxidation commonly produces sulfuric acid. Sulfuric acid is toxic to plants and animals in the soil and nearby waters. The solutions produced are extremely acid and are highly corrosive to exposed metal and concrete. Soils and rock suspected of potential sulfur acidity are tested for the presence of sulfide salts.

A few soils with appreciable amounts of sulfides contain enough carbonates to neutralize all or part of the acidity when the sulfides are oxidized. In such soils, the total amounts of both calcium carbonate and sulfides must be known.

No reliable field methods are available for determining the amount of sulfides in tidal marshes. The sulfide odor of marshes is not a reliable indicator of the presence of oxidizable sulfides. Drained or excavated marsh soils that contain large amounts of sulfides commonly have yellow efflorescences of the mineral jarosite on the exteriors of clods.

Two field tests are commonly used to detect excess oxidizable sulfides. In one test, pH is measured before and after the soil is allowed to dry for 18 days. A large drop in pH, or pH of 3.5 or less after drying, indicates excessive amounts of sulfides.

In the other test, the sample is treated with 30 to 36 percent hydrogen peroxide and heated to complete oxidation and drive off the excess peroxide. Then pH is measured. If the decrease in pH is large, sulfides are probably present. A meter is preferred for measuring pH because of the possibility of oxidation of indicator dyes. Special dyes suitable for this test are available.

If the field tests for oxidizable sulfides are positive, laboratory determinations of sulfur content may be required for precise interpretations.

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Table 4-1.--Definitions of slope classes

Classes		Slope gradient limits	
Simple slopes	Complex slopes	Lower	Upper
		Percent	Percent
Nearly level.....	Nearly level.....	0	1-3
Gently sloping.....	Undulating.....	1-3	5-8
Strongly sloping...	Rolling.....	5-8	10-16
Moderately steep...	Hilly.....	10-16	20-30
Steep.....	Steep.....	20-30	45-65
Very steep.....	Very steep.....	45-65	None

Table 4-2.--Annual pattern of soil-water states

Depth	J	F	M	A	M	J	J	A	S	O	N	D
cm												
0-25	f	f	m	m	m	m	d	d	d	m	m	f
25-50	f	f	f	w	m	m	m	d	d	d	m	w
50-100	w	w	w	w	m	m	m	d	d	d	m	m
100-150	w	w	w	w	w	m	m	m	d	d	d	m

f: frozen more than half of the month
w: wet more than half of the month
m: moist more than half of the month
d: dry more than half of the month

Table 4-3.--Terms for rock fragments

Shape 1/ and size	Noun	Adjective
Rounded, subrounded, angular, or irregular:		
2-7.6 cm diameter.....	Gravel 2/.....	Gravelly.
0.2-0.5 cm diameter.....	Fine gravel....	Fine gravelly.
0.5-2 cm diameter.....	Medium gravel..	Medium gravelly.
2-7.6 cm diameter.....	Coarse gravel..	Coarse gravelly.
7.6-25 cm diameter.....	Cobble.....	Cobbly.
25-60 cm diameter.....	Stone.....	Stony.
> 60 cm diameter.....	Boulder.....	Bouldery.
Flat:		
0.2-15 cm long.....	Channer.....	Channery.
15-38 cm long.....	Flagstone.....	Flaggy.
38-60 cm long.....	Stone.....	Stony.
> 60 cm long.....	Boulder.....	Bouldery.

1/ If significant to classification or interpretation, the shape of the fragments is indicated: "angular gravel," "irregular boulders."

2/ A single fragment is called a "pebble."

Table 4-4.--Classes of stoniness and boulderiness in relation to surface coverage and spacing between fragments

Class	Percentage of surface covered	Distance between stones or boulders if their diameter is--		
		25 cm	60 cm	120 cm
		meters	meters	meters
1	< 0.01	> 25	> 60	> 120
ST { 2	0.01-0.1	8-25	20-60	37-120
ST { 3	0.1-3	1-8	3-20	6-37
STV - 4	3-15	0.5-1	1-3	2-6
STX - 5	15-50	0.1-0.5	0.2-1	0.5-2
RUBBLY- 6	> 50	< 0.1	< 0.2	< 0.5

Table 4-5.--Size classes of soil structure

Size classes	Shape of structure			
	Platy 1/	Prismatic and Columnar	Blocky	Granular
	mm	mm	mm	mm
Very fine..	<1	<10	<5	<1
Fine.....	1-2	10-20	5-10	1-2
Medium.....	2-5	20-50	10-20	2-5
Coarse.....	5-10	50-100	20-50	5-10
Very coarse	>10	>100	>50	>10

1/ In describing plates, "thin" is used instead of "fine" and "thick" instead of "coarse."

Table 4-6.--Strength classes of soil

Field method and condition of failure of specimen	Units	Consistence		
		Air-dry	Field capacity	Cemented material
No specimen can be obtained----------	----------	Loose	Loose	
Specimen crushes or breaks when very slight force applied by thumb and forefinger.	<8 N 1/	Soft	Very friable	
Specimen crushes or breaks when slight force applied by thumb and forefinger.	8-20 N	Slightly hard	Friable	
Specimen crushes or breaks when moderate force applied by thumb and forefinger.	20-40 N	Slightly hard	Firm	Weakly cemented 2/
Specimen crushes or breaks when strong force applied by thumb and forefinger.	40-80 N	Hard	Very firm	Weakly cemented 2/
Specimen cannot be crushed or broken by thumb and forefinger but can be by squeezing slowly between hands.	80-160 N	Very hard	Extremely firm	Weakly cemented 2/
Specimen cannot be crushed or broken in hands but can be broken or crushed underfoot by person weighing 80 kg applying weight slowly.	160-800 N	Extremely hard	Extremely hard	Weakly cemented 2/
Specimen cannot be crushed underfoot but can be crushed or broken by blow of 3 J. 3/	800 N = lower limit 3 J = upper limit			Strongly cemented
Specimen cannot be broken or crushed by blow of 3 J. 3/	>3 J			Indurated

1/ One newton (N) = 1 kg-m/s^2

2/ If applicable.

3/ A weight of 1 kg dropped a distance of 10 cm = 1 joule. A geologist's hammer weighing 1.36 kg dropped a distance of 0.22 m exerts an impact energy of 3 J.

Illustration legends

Figure 4-1.--Four combinations of concavity and convexity of landforms. The upper forms have concave contours; the lower forms have convex contours. The forms on the left have convex slope; the forms on the right have concave slope.

Figure 4-2.--V-shaped gullies in a material high in clay.

Figure 4-3.--U-shaped gullies. The underlying material is more erodible than the upper part of the soil.

Figure 4-4.--Relationships among soil separate classes of five different systems. Scale is logarithmic.

Figure 4-5.--Size of particles of indicated diameters (d).

Figure 4-6.--Chart showing the percentages of clay, silt, and sand in the basic textural classes.

Figure 4-7.--Area that is near the margin between class 2 and class 3 boulderiness in the foreground.

Figure 4-8.--Area of class 3 stoniness. Rock fragments 25 to 60 cm across control most uses, though many smaller fragments of rock are present.

Figure 4-9.--Area of class 3 boulderiness.

Figure 4-10.--Area of class 5 stoniness.

Figure 4-11.--The arrangement of color chips according to value and chroma on the soil-color card for hue of 10YR.

Figure 4-12.--Schematic diagram of the relationships among the five principal and five intermediate hues of the Munsell color system and the subdivisions within the part used for most soil colors.

Figure 4-13.--Fine plates.

Figure 4-14.--Medium prisms 35 to 45 mm across.

Figure 4-15.--A cluster of medium, columnar peds. The cluster is about 135 mm across.

Figure 4-16.--Medium and coarse, angular blocky peds.

Figure 4-17.--Fine and medium, granular peds.

Figure 4-18.--Soil fragments formed by cracking of a structureless soil when it contracted upon drying.

Figure 4-19.--Intersecting slickensides in the AC horizon of a clayey soil. The cracking was caused by drying after the soil was exposed.

Figure 4-20.--Nodules and concretions: an unbroken nodule at the left; a broken concretion at the right; a hollow nodule in the middle.

Figure 4-21.--Cicada casts in an indurated horizon about 35 cm thick. Cicada casts in varying degrees of induration are common in some soils of semiarid climates. Casts are 0.4 times actual size.

Footnotes

1/ As a minimum the following information about the climate should be given for each soil: average annual precipitation, seasonal pattern of the precipitation, mean annual temperature, and frost-free season.

2/ For soils having cyclic horizons or layers recurring at intervals between 2 m and 7 m, a pit large enough to study at least one-half of the cycle is necessary.

3/ Because some soils commonly receive thin deposits of material on the surface, as much as 50 cm of recently deposited sediment is disregarded in classifying the underlying set of genetic horizons (See Soil Taxonomy). These thin deposits are not part of the solum but may be otherwise important. By the same convention a soil is not considered to be buried unless there is at least 50 cm of overlying sediment that has no genetic horizons in the lower part.

4/ "Wind erosion" is sometimes used for the sculpture of rocks by wind-blown particles. The term is used in this manual, in soil science generally, and by many geologists for the detachment, transportation, and deposition of soil particles by wind.

5/ 100 kilopascals (kPa) = 1 bar.

6/ The presence of restricting layers in the soil can significantly affect the level of water in an uncased borehole. Perched water may drain and water under artesian pressure may rise to higher levels.

7/ Based on soils that are not irrigated and not frozen in any part.

8/ Sometimes "runoff" is applied to whole watersheds to refer to all of the water entering streams, including subsurface flow. If any possibility of confusion exists, "surface runoff" should be used instead of "runoff" in soil descriptions.

9/ One inch per hour = 7.06 micrometers per second.

10/ Coprogenous earth, diatomaceous earth, marl.

11/ Rock structure includes fine stratification in unconsolidated or weakly consolidated sediment or pseudomorphs of weathered minerals retaining their positions relative to each other and to unweathered minerals in saprolite from consolidated rocks.

12/ Indicating weathered bedrock or saprolite in which clay skins are present.

13/ "Loam" is an old English word formerly applied to crumbly soils rich in humus. It is still used by some in that sense. In soil classification, however, it is used only in naming soil texture classes.

14/ These are sandy, loamy, and clayey texture groups, not the sandy, loamy, and clayey particle-size classes defined in Soil Taxonomy.

15/ These terms are defined in table 4-3.

16/ The appropriate color chips, separate or mounted by hue on special cards for a loose-leaf notebook may be obtained from the Munsell Company.

17/ The notation for hue, and for value and chroma, is decimal and could be refined to any degree. In practice, however, only the divisions used on the color charts are needed or useful.

18/ For many platy bodies, including materials such as shale, applying force at right angles to the plate may give misleading results. The resistance of platy material to rupture when torque is applied may be more meaningful for some interpretations. The following procedure can be used in the field:

A test specimen about 2 to 5 cm across is selected. Thickness of the plate is recorded by size class or by measurement. If the plate is in the thickest class, the maximum thickness is recorded.

The plate is held by pliers near the edge or to one side of the plate. At an established distance from the inside edge of the pliers, force is applied downward until the plate ruptures. Force can be applied with a penetrometer, which will measure force, or with a finger. If a finger is used, the degree of force is estimated. The pliers can be steadied on a surface if necessary.

Torque is calculated by this formula: $t = \frac{F \times D}{100}$, where F is the force (in kilograms) needed to rupture the plate and D is the distance (in centimeters) from the outside of the area on which force is applied to the inside edge of the pliers. The value for torque (t) is in kilogram-meters.

Resistance to rupture increases as the square of thickness of the plate, but increases linearly with width. Therefore, placement of the specimen in the proper thickness class is more important than close control of the width of the specimen. If possible, resistance should be determined on plates of medium thickness (2 to 5 mm); this may require splitting the plate.

19/ The n value expresses the relation between the percentage of water under field conditions and the percentages of inorganic clay and humus. The n value can be calculated for mineral soil materials that are not thixotropic by the formula:

$$n = \frac{A - 0.2R}{L + 3H}$$

where A is the percentage of water, R is the percentage of silt plus sand, L is the percentage of clay, and H is the percentage of organic matter (all calculated on basis of dry soil).

20/ One siemens (S) = one mho.

Attachment I

Horizon Designations

A comparison of the old and new systems

1. The purpose of using horizon designations remains unchanged. They reflect the describer's interpretations of the genetic relationships between the horizons in a soil.

2. Capital letters, lowercase letters, and Arabic numerals are used to form the horizon designators.

   a. Capital letters are used to designate master horizons. This convention is unchanged.

   b. Lowercase letters are used as suffixes to indicate specific characteristics of the master horizon. This convention is unchanged.

   c. Arabic numerals are used as suffixes to indicate vertical subdivisions within a horizon and as prefixes to indicate discontinuities. This is a change. Previously, Arabic numerals were used as suffixes to indicate a kind of O, A, or B horizon and to indicate vertical subdivisions of a horizon, and Roman numerals were used as prefixes to indicate discontinuities.

3. The symbols used for many horizon characteristics have been changed. The comparison of symbols used to designate master horizons and subordinate distinctions within master horizons can be only approximate. Some designations for master horizons in the old system can best be equated with a combination of master horizon symbol and subordinate symbol in the new system.

   a. Master horizons

Old	New
O	O
O1	Oi, Oe
O2	Oa, Oe
A	A
A1	A
A2	E
A3	AB or EB
AB	---

A&B	E/B
AC	AC
B	B
B1	BA or BE
B&A	B/E
B2	B or Bw
B3	BC or CB
C	C
R	R

b. Subordinate distinctions within master horizons

Old	New	
---	a	highly decomposed organic matter
b	b	buried soil horizon
cn	c	concretions or nodules
---	e	intermediately decomposed organic matter
f	f	frozen soil
g	g	strong gleying
h	h	illuvial accumulation of organic matter
---	i	slightly decomposed organic matter
ca	k	accumulation of carbonates
m	m	strong cementation
sa	n	accumulation of sodium
---	o	residual accumulation of sesquioxides
p	p	plowing or other disturbance
si	q	accumulation of silica
r	r	weathered or soft bedrock
ir	s	illuvial accumulation of sesquioxides

t	t	accumulation of clay
---	v	plinthite
---	w	color or structural B
x	x	fragipan character
cs	y	accumulation of gypsum
sa	z	accumulation of salts

4. Primes are used in both the old and new systems, but the conventions for using them are different. In the old system primes were used to identify the lower sequum of a soil having two sequa, although not for a buried soil. In the new system it may be appropriate to give the same designation to two or more horizons in a pedon if the horizons are separated by a horizon of a different kind. The prime is used on the lower of the two horizons having identical letter designations. If three horizons have identical designations a double prime is used on the lowest.

★U.S. GOVERNMENT PRINTING OFFICE: 1981—340-931:144

Addendum to chapter 4

Subordinate Distinctions Within Master Horizons and Layers

Lower case letters are used as suffixes to designate specific kinds of master horizons and layers. The symbols and their meanings and usage are as follows:

a Highly decomposed organic material

This symbol is used with "O" to indicate the most highly decomposed of the organic materials. Rubbed fiber content averages less than about 1/6 of the volume. Occurs in soils saturated for prolonged periods. If more than one suffix letter is used, the letter "a" is listed first.

b Buried genetic horizon

This symbol is used in mineral soils to indicate identifiable buried genetic horizons if the major features of the buried horizon had been established before it was buried. It is not used in organic soils or to separate an organic layer from a mineral layer. Genetic horizons may or may not have formed in the overlying material, which may be either like or unlike the assumed parent material of the buried soil. A buried horizon is not in the same deposit as the overlying horizons. If the lithology of the buried horizon is the same as that of the overlying horizons, a prefix numeral is not used (such as A-Bt-BC-Ab-Btb). If lithologically unlike the overlying material, then a numeral prefix is used (such as A-Bt-BC-2Ab-2Btb). The suffix "b" may be used with any of the master horizon symbols except O and C (C horizons are not considered genetic horizons.) The suffix "b" is written last when used in conjunction with other suffix symbols.

c Concretions or hard nonconcretionary nodules

This symbol is used to indicate a significant accumulation of concretions or nonconcretionary nodules cemented by material other than silica. This symbol is not used if concretions or nodules are dolomite or calcite or more soluble salts, but it is used if the nodules or concretions are iron, aluminum, manganese, or titanium. Their consistence is specified in the horizon description. The "c" suffix symbol is used with another suffix symbol, is always listed last, such as Btc.

e Organic material of intermediate decomposition

This symbol is used with "O" to indicate organic materials of intermediate decomposition. Rubbed fiber content is 1/6 to 2/5 of the volume. Usually occurs in soils saturated for prolonged periods, however can occur in soils not saturated for prolonged periods. If more than one suffix letter is used, the letter "e" is written first.

f Frozen soil

This symbol is used to indicate that the horizon or layer contains permanent ice. Symbol is not used for seasonally frozen layers or for "dry permafrost" (material that is colder than 0°C but does not contain ice). If more than one suffix letter is used, the letter "f" is listed last.

g Strong gleying

This symbol is used to indicate either that iron has been reduced and removed during soil formation or that saturation with stagnant water has preserved a reduced state. Most of the affected layers have low chroma and many are mottled. The low chroma can be the color of reduced iron or the color of uncoated sand and silt particles from which iron has been removed. Symbol "g" is not used for soil materials of low chroma, such as some shales or E horizons, unless they have a history of wetness. If "g" is used with "B," pedogenic change in addition to gleying is implied. If no other change has taken place, the horizon is designated Cg. If more than one suffix letter is used, the letter "g" is listed last. Suffixes "h," "s," and "w" are not used with "g."

h Illuvial accumulation of organic matter

This symbol is used with "B" to indicate the accumulation of illuvial amorphous, dispersible organic matter—sesquioxide complexes if the sesquioxide component is dominated by aluminum but is present only in very small quantities. The organosesquioxide material coats sand and silt particles or may occur as discrete pellets. In some horizons, coatings have coalesced, filled pores, and cemented the horizon. The symbol "h" is also used in combination with "s" as "Bhs" if the amount of sesquioxide component is significant but value and chroma of the horizon are approximately 3 or less. If more than one suffix letter is used, the letter "h" is written first. The suffix "h" is not used with suffixes a, e, g, i, k, m, o, q, r, t, w, y or z.

Bh - Significant O.M. Insignificant SiO_2. Chroma and value 3 or less.

Bhs - Significant O.M. Significant SiO_2. Chroma and value 3 or less.

i Slightly decomposed organic material

This symbol is used with "O" to indicate the least decomposed of the organic materials. Rubbed fiber content is more than about 2/5 of the volume. Usually occurs in soils not saturated for prolonged periods. If more than one suffix letter is used, the letter "i" is written first.

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k Accumulation of carbonates

This symbol is used to indicate accumulation of alkaline earth carbonates, commonly calcium carbonate. If illuvial clay is also present, "t" precedes the symbol "k." Suffixes h, s, and w are not used with "k."

m Cementation or induration

This symbol is used to indicate continuous or nearly continuous cementation. Symbol is used only for horizons that are more than 90 percent cemented, though they may be fractured. Roots penetrate "m" horizons only through cracks. The cementing material is also symbolized. If 90 percent or more of the horizon is cemented by carbonates, "km" is used; by silica, "qm"; by iron, "sm"; by gypsum, "ym"; by both lime and silica, "kqm"; by salts more soluble than gypsum, "xm." If more than one suffix letter is used, the letter "m" is written last.

n Accumulation of sodium

This symbol is used to indicate accumulation of exchangeable sodium. If illuvial clay is also present "t" precedes the symbol "n." Suffixes h, s, and w are not used with "n."

o Residual accumulation of sesquioxides

This symbol is used to indicate residual accumulation of sesquioxides. Differs from the use of symbol "s" which indicates illuvial accumulation of organic matter and sesquioxides complexes. Suffixes h, s, and w are not used with "o." If illuvial clay is also present, "t" precedes the symbol "o."

p Plowing or other disturbance

This symbol is used to indicate disturbance of the surface layer by cultivation, pasturing, or similar uses. A disturbed organic horizon is designated Op. A disturbed mineral horizon, even though clearly once an E, B, or C horizon, is designated Ap. If a surface horizon is disturbed, only symbol "p" is used.

q Accumulation of silica

This symbol is used to indicate accumulation of secondary silica. If silica cements the layer and cementation is continuous or nearly continuous, "qm" is used. The symbol "q" can be used alone or with symbol "m" suffixes h, s, or w are not used with "q."

r Weathered or soft bedrock

This symbol is used with "C" to indicate layers of soft bedrock or saprolite, such as weathered igneous rock; partly consolidated soft

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sandstone, siltstone, or shale; or dense till that roots cannot enter except along fracture planes. The material can be dug with a spade. Symbol "r" can be used with "t" such as Crt to indicate weathered bedrock or saprolite in which clay skins are present. –

s Illuvial accumulation of sesquioxides and organic matter

This symbol is sued with "B" to indicate the accumulation of illuvial amorphous, dispersible organic matter-sesquioxide complexes if both the organic matter and sesquioxide components are significant and the value and chroma of the horizon is more than 3. The symbol is also used in combination with "h" as "Bhs" if both the organic matter and sesquioxide components are significant and the value and chroma are approximately 3 or less. When more than one suffix is used, the letter "s" is written first, except for Bhs. The suffix "s" is not used with suffixes a, e, g, i, k, n, o, q, r, t, w, y or z.

Bs Significant O.M. Significant SiO_2 chroma and value more than 3.

Bhs Significant O.M. Significant SiO_2. Chroma and value 3 or less.

t Accumulation of silicate clay

This symbol is used to indicate an accumulation of silicate clay that either has formed in the horizon or has been moved into it by illuviation. The clay can be in the form of coatings on ped surfaces or in pores, lamellae, or bridges between mineral grains. If more than one suffix letter is used, the symbol "t" is written first. "t" is not used with symbols a, e, h, i, s and w. If used with symbol "r" it is written last as in Crt.

v Plinthite

This symbol is used to indicate the presence of iron-rich, humus-poor, reddish material that is firm or very firm when moist and that hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying. These properties are characteristic of plinthite. If more than one suffix letter is used, the symbol "v" is written last.

w Development of color or structure

This symbol is used with "B" to indicate development of color or structure, or both, with little or no apparent illuvial accumulation of material. Although not synonomous with cambic horizon, in many instances it recognizes the properties of a cambic. If more than one suffix letter is used, the symbol "w" is written first. "w" is not used with symbols a, e, h, i, s and t.

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x Fragipan character

This symbol is used to indicate genetically developed firmness, brittleness, or high bulk density. These features are characteristic of fragipans, but some horizons designated "x" do not have all the properties of a fragipan. If more than one suffix letter is used, the symbol x is written last.

y Accumulation of gypsum

This symbol is used to indicate accumulation of gypsum. If illuvial clay is also present, "t" precedes the symbol "y." Suffixes h, s, and w are not used with "y."

z Accumulation of salts more soluble than gypsum

This symbol is used to indicate accumulation of salts more soluble than gypsum. If illuvial clay is also present, "t" precedes the symbol "z." Suffixes h, s, and w are not used with "z."

B. Horizon Nomenclature

1. Master Horizons

O
A
E
B
C
R

2. Transitional Horizon

AB	A/B
BA	B/A
EB	E/B
BE	B/E
BC	B/C
CB	C/B
AC	

3. Subordinate Distinctions within Master Horizons

New	Old	New	Old
a	02, Aoo	o	-
b	b	p	p

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New	Old	New	Old
c	cn	q	si
e	01, 02, Aoo, Ao	r	r
f	f	s	ir
g	g	t	t
h	h	v	
i	01, Ao	w	
k	ca	x	x
m	m	y	cs
n	sa	z	sa

4. Conventions for Using Letter Suffixes

- ~~undisturbed~~ A horizons - no suffix
- disturbed A horizon - p
- most E horizons no suffix
- ~~most~~ C ~~horizons~~ no suffix

- more than one suffix - if used, a, e, i, h, r, s, t, and w are written first - none of the above suffixes are used together except in Bhs or Crt

- never use Bth, Bts or Btw - "t" has precedence over w, s, and h. (a, Bw, Bh, or Bs horizon can be below or above a Bt). Suffixes h, s, and w are not used with q, k, n, q, y, z or o.

- If horizon is buried, the suffix "b" is written last. (Only buried mineral soils)

- If more than one suffix is used, c, f, g, m, v, and x are written last.

- Suffixes are not used with transitional horizons unless needed for ~~explanatory purposes~~.

5. Vertical Subdivision

Any time you change suffixes or add a suffix, vertical numbering starts over, such asBt1-Bt2-Btx1-Btx2. If suffixes remain, the same or no suffixes are used, numbering is continuous. Vertical subdivisions follow horizons. Letters indicating discontinuities precede horizons letters such as C1-C2-C3, Bt1-Bt2,2Bt3.

6. Discontinuities

- Arabic numberals used as prefixes to indicate discontinuities. Precede A, E, B, C, and R. Discontinuity arabic numberals precede horizon letters. Vertical subdivisions, arabic numberals follow horizon letters.

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- Starts with 2; any discontinuity below the first one is numbered in sequence 3-4, etc.

- Numbers designating subdivisions of a horizon continue in consecutive order across the discontinuity such as Bt1-2Bt2-2Bt3-3Bt4-3Bt5.

- R horizons. If same material as which the soil formed from, do not use arabic numberal prefix such as A-B-C-R. If unlike material from which the soil above formed, use arabic numeral prefix such as A-B-C-2R or A-B-2C-2R.

- Buried horizons - If like material above no prefix number is used, just use suffix "b." If unlike material above, use arabic numeral prefix and suffix "b" such as A, B, C, Bb or A, B, C, 2Bb.

- In organic soils, discontinuities are not identified.

7. Use of Prime Notation

- Identical designations are sometimes needed for soils which have two or more horizons alike, but separated by at least one horizon of a different kind. The prime notation is used on the lower one of the two. The prime is used with the master horizon designation and any lower case suffixes follow. The prime is not used unless all letters of the designations for the two horizons are the same such as A-Bt-C-B't, not in A-Bt-C-Bxt.

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Chapter 5

Map Units

A map unit is a collection of areas defined and named the same in terms of their soil components or miscellaneous areas or both. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. Each individual area on the map is a delineation.

Map units may consist dominantly of one component or of two or more components which are identified in the name of the map unit. Components of minor extent not identified in the name of a map unit are inclusions which are discussed on page 6. All components, whether dominant or inclusions, that are identified as important to the interpretations or understanding of the map unit are described in the map unit description.

An individual component of a map unit represents the collection of polypedons [1/] or parts of polypedons that are members of the taxon or a kind of miscellaneous area. Parts of polypedons are common when phases are used to divide a taxon. Classes of miscellaneous areas are treated the same as soil taxa in soil surveys. A taxonomic unit description describes the ranges in soil properties exhibited in the polypedons for the maps in a survey area that are referenced by that taxonomic unit. The limits of these ranges are set by Soil Taxonomy for the taxonomic class of which a taxonomic unit is a member but generally the full range allowed by the taxonomic class is not exhibited in a small survey area (<200,000 ha).

A delineation of a map unit has the same dominant components as identified and named in the map unit. Also each delineation generally contains a representative of each kind of inclusion. A dominant component is represented in a delineation by a part of a polypedon, a complete polypedon, or several polypedons. A part of a polypedon is represented when the phase criteria, which are discussed on page 10, such as slope, requires that a polypedon be divided. A complete polypedon is represented when there are no phase criteria requiring the subdivision of the polypedon or the range of features exhibited by the individual polypedon do not cross the limits of the phase. Several polypedons of a component may be represented when the map unit consists of two or more dominant components and the pattern is such that at least one component is not continuous but occurs as isolated bodies or polypedons. Similarly, each inclusion in a delineation is represented by a part of a polypedon, a complete polypedon, or several polypedons but their extent is small relative to the extent of the dominant component(s). Soil boundaries can seldom be shown with complete accuracy on soils maps, hence parts and pieces of adjacent polypedons are inadvertently included or excluded from delineations.

The kinds of map units used in a survey depend primarily on the purposes of the survey and the pattern of the soils and miscellaneous areas in the landscape. The pattern in nature is fixed and it is not exactly the same in each delineation of a given map unit. In soil surveys these patterns must be recognized and map units designed to meet the major objectives of the survey.

Designing map units to indicate significant differences in behavior between soils is particularly important to meet the current objectives of a survey. Reflecting differences in genesis and morphology is also important, even if no immediate differences in interpretations are known. Differences in soil properties that do not affect current interpretations may be important in the future. However, having too many delineations seriously reduces the immediate usefulness of a soil map. Any potential benefits must be weighed carefully against the costs incurred in making additional separations. One objective of every soil survey is to accumulate knowledge about soils, but this does not mean that the soil map must show the location of every kind of soil in a survey area or that the publication must record all that could be learned about the soils.

Designing Map Units

While studying the soil patterns in different landscapes, the soil scientist must keep in mind how best to relate the patterns in nature to appropriate map units. The kinds of map units, the level of soil taxa, and the phases needed to satisfy the survey objectives must be determined. This requires many judgments. Every map unit that is tentatively identified is evaluated by two tests: (1) Can it be mapped consistently? (2) Is it needed to meet the objectives of the survey?

Taxonomic classes provide the basic sets of soil properties with which soil map units are defined. They summarize an immense amount of research and experience related to the significance of soil properties and combinations of properties. They provide predefined sets of soil properties that have been tested for genetic relationships and for interpretive value. Taxa provide a firm base for recognizing the components of potential map units in an unfamiliar area. Using established taxa is much easier than independently sorting out sets of properties and determining significant class limits.

The objectives of a survey determine the kind of map units and the taxonomic level used to identify components of map units. For the more detailed surveys (1st and 2nd order surveys), decisions must be made about what criteria to use to recognize phases of soil series, how broadly or narrowly to define the phases, and whether similar phases of different series have such similar interpretations that they can be combined. For the less detailed surveys (3rd, 4th, and 5th order surveys), decisions must be made about how the complexities of soils in large areas can be identified best for purposes of the survey, what associations of soils characterize useful and mappable units, what taxonomic level should be used in naming map units, and which phases contribute to the usefulness of the map units.

The names of soil taxa, along with one or more modifying terms, are used to identify the soils in map units. The name "Tama silt loam, 2 to 5 percent slopes," for example, indicates that soil of the Tama series is dominant in that map unit. The names of taxa of higher categories are also used in map unit names, especially on small scale maps. "Udolls, rolling," for example, identifies a map unit consisting dominantly of soils of the Udoll suborder, which includes Tama and other series. The name of a taxon of the lowest category that accurately identifies the dominant soil is commonly used.

The soil series category is the most homogeneous category in the taxonomy used in the United States. As a class a series is a group of soils that have horizons similar in arrangement and in differentiating characteristics. The soils of a series have a relatively narrow range in sets of properties, although the surface layer and such features as slope, stoniness, degree of erosion, and topographic position may vary unless these features are associated with significant differences in the kind and arrangement of horizons.

Soil series are differentiated on all the differentia of the higher categories plus those additional and significant properties in the series control section. Some of the properties commonly used to differentiate series are the kind, thickness, and arrangement of horizons and their structure, color, texture, reaction, consistence, content of carbonates and other salts, content of humus, content of rock fragments, and mineralogical composition. A significant difference in any one of these properties can be the basis for recognizing a different series. Very rarely, however, do two soil series differ in just one of these characteristics. Most characteristics are genetically related, and usually several change together.

Some land areas have no soil and thus support little or no vegetation without major reclamation. Rock outcrop is an example. Such areas are called miscellaneous areas. The names of the different kinds of miscellaneous areas--such as "Beaches," "Rock outcrop," "Dumps," and "Badland"--are used in the same manner as the names of soil taxa to identify map units.

Within each survey, soil map units can be designed with component taxa of low or high categories that reflect narrowly or broadly defined ranges of soil properties. Also soil map units can be designed with different compositions of soil taxonomic units and mapping inclusions. This flexibility permits the design of map units that will be most useful for the purposes of a specific survey as well as to attain as much uniformity in mapping as possible.

If a property of a taxon has too wide a range for the interpretations needed or if some feature outside the soil itself is significant for use and management, these are bases for defining phases. Phases commonly include only part of the range of features exhibited by a taxon, but phases can be based on attributes such as frost hazard, character of the deeper substratum, or physiographic position that are not characteristics used to identify taxa but that affect use and management. If these vary from place to place within the survey area, phases can be defined to accommodate the differences.

A soil map unit that bears the name of a phase of a taxon consists dominantly of that phase of the taxon, but also includes other soil components. The other components are included because of the limitations imposed by the scale of mapping and the number of points that can be examined. When the limits of soil taxa are superimposed on the pattern of soil in nature, areas of taxonomic classes rarely, if ever, coincide precisely with mappable areas. Some polypedons are too small to

be drawn on the map and are included in delineations named for another soil. The boundaries between polypedons are not everywhere so obvious that they can be plotted precisely on a map, so part of one polypedon is commonly included in the delineation of an adjacent polypedon. Some polypedons are so intimately intermingled that mappable areas are necessarily identified in terms of two of more taxa. Other polypedons are not easily distinguished from similar adjacent ones and are inadvertently or deliberately included in delineations named for other soils because apparent differences in use and management are small.

As methods of measuring soil properties are refined, as experience in the field increases, and as use and management requirements are intensified, progressively narrower ranges in soil properties can be recognized and established. Narrow ranges of properties are not established just because methods permit it. Unnecessary separations are time-consuming to delineate consistently, and they make the survey more difficult to use. However, not separating two significantly different but mappable units makes a survey less useful. The significance of each map unit must be constantly evaluated during the mapping process.

Phase distinctions must be compatible with natural variability. To illustrate, a series may range in depth to bedrock from 1 m to more than 2 m. For some uses a separation at 1.5 m would be significant. Yet, if within a survey area the soils of the series ranges in depth to bedrock from slightly less than 1.5 m to slightly more, designating two depth phases, with the break at 1.5 m, cannot be justified. The mapping is likely to be inconsistent and the difference of a few centimeters in depth is likely to be of minor significance. In this case it is far better to designate only one phase on the basis of depth to bedrock. The description of the map unit should, of course, give the depth range.

Another example: In some areas a slope of 8 percent is about the upper limit for cropping many soils without special practices for erosion control. Yet in some series a large part of the soil has slopes of less than 3 percent, most of the rest has slopes of 6 to 10 percent, and a small acreage has slopes of 3 to 6 percent. Dividing phases of such soils at 8 percent slope would produce a large number of delineations having gradient a little below 8 percent and a large number having gradient a little above 8 percent. The differences in interpretations of the phases thus defined would probably not be consistently significant. For these soils, slope phases could be set at 0 to 3 percent, 3 to 6 percent, and 6 to 10 percent; or, if there is little or no significance of the break at 3 percent, they could be set at 0 to 6 percent and 6 to 10 percent.

Phases must also be compatible with practical objectives. As an illustration that is relevant to farming, in a hypothetical survey area the polypedons of Alpha soils are similar in all properties except stoniness and slope. The areas range from nearly stone-free to very stony and from undulating to steep. The most important single distinction for farming is the distinction between areas that can be cultivated feasibly and areas that cannot. As many as three mappable classes of stoniness could be combined with four mappable classes of slope--a total of 12 potential phases. Four of these twelve phases might be used to distinguish combinations of degrees of slope and degrees of stoniness within the limits that permit cultivation. Using the remaining eight to subdivide the nonarable areas would confuse the user with unnecessary detail more than it would help. Perhaps two, and probably no more than three, phases are adequate for all significant

distinctions among nonarable areas if the survey area is to be used primarily for farming. A list of potentially useful phases is as follows:

A. Arable areas:

1. An undulating, nonstony phase
2. An undulating, moderately stony phase
3. A rolling, nonstony phase
4. A rolling, moderately stony phase

B. Nonarable areas:

1. An undulating and rolling, very stony phase
2. A hilly phase (ranging from nonstony to very stony)
3. A steep phase (ranging from nonstony to very stony)

If the soil map is to be used for planning operations related to forestry or other non-farming activities, other distinctions may be needed.

Improper use of phases to designate map units and misinterpretation of soil survey procedures can result in unreasonably detailed soil maps delineating unnecessary map units or in less detail than is needed to accomplish the objectives of the survey. Using preestablished classes of selected soil properties--such as surface texture, depth, slope, accelerated erosion, and stoniness--as phase criteria, and then using all combinations of these in defining phases, is easy, but creates problems. A large number of meaningless map units causes errors and high costs all through a soil survey.

Classes of soil properties are not necessarily used directly as phases. Defined class limits of properties are designed for convenient description of soil, and they can also be used to define phases of soil where appropriate. But they are not useful for all soils. Distinctions significant for one kind of soil are not significant for every other kind. Any single property is significant only through its interactions with other properties. The usefulness of each phase must be repeatedly tested and verified during a survey. Separate phases of a taxon must differ significantly in behavior. Similar phases of different taxa may be combined, and the combination described, if no useful purpose will be served by separating them in mapping. The interpretations prepared during the course of a survey provide evidence of similarities and differences between map units.

The justification for most phases rests on behavior of soils under use. At least one statement about soil behavior must be unique to each phase of a taxon, and the differences of soil properties must exceed normal errors of observation.

The object of soil survey is not simply gathering facts: the object is gathering relevant facts, presenting them on maps, and interpreting these facts. Field records and observations together with other relevant information must be coordinated in defining phases and map units that meet the objectives of a soil survey.

New series, variants, and taxadjuncts

Some soils are outside the limits of any recognized soil series and have unique sets of properties. These are potential new series. When such a soil is first recognized, it is described and identified as a taxon of the lowest category in which it can be classified. A phase of that taxon can be used to identify a map unit. In some surveys, including virtually all 1st and 2nd order surveys, greater refinement of definition is needed. For these, the soil is proposed as a new series, but the new series remains tentative until its properties can be described in detail, its extent determined, and any conflicts with established series resolved. If the soil proves to be unique and significant in extent, it is established as a new series.

Some unique kinds of soils do not occupy a large enough total area to warrant the establishment of a new series. These are called variants of soil series. Variants differ enough in one or more properties from the series for which they are named that major interpretations for comparable phases are different. They are named by adding the word "Variant" to the name of a closely related series, preferably one within the survey area: Gale Variant.

A kind of soil is commonly identified as a variant if its total known area is less than about 800 ha. Variants are potential soil series, and if a significant area of a variant is eventually recognized, the soil is established as a new series. Some soils that contrast strongly with all established series may be named and defined as series even though the total known extent is less than 800 ha, but this is rarely done.

Taxadjuncts are polypedons that have properties outside the range of any recognized series. However, taxadjuncts differ from a recognized series in so few properties and to so small a degree that major interpretations are not affected. A taxadjunct is given the name of an established series that is most similar in characteristics. It is an adjunct to, but not part of, the named series. It is treated as if it were a member of the named series, and its interpretations are similar to those for comparable phases of the series for which it is named. The difference from the established series is described. Example: A potential series is in a fine-silty family particle size class, marginal to fine-loamy; however, it differs from an established fine-loamy series in only particle size and no appropriate fine-silty series has been identified. The potential series is given the name of the established series, and a new series is not proposed. If pedons sampled to represent a specific series are taxadjuncts to that series the polypedons so represented are referenced as taxadjuncts.

Inclusions within map units

In all soil surveys, virtually every delineation of a map unit includes areas of soil components or miscellaneous areas that are not identified in the name of the map unit. Many areas of these components are too small to be delineated separately. The location of some components cannot be identified by practical field methods. Some mapping inclusions are deliberately placed in delineations identified as another taxon to avoid excessive detail of the map or the legend.

Inclusions reduce the homogeneity of map units and may affect interpretations. The objective is to define map units that will contain as few inclusions as practical of components that behave differently from the named taxa. Also, map units must be so defined that they can be recognized and delineated consistently in the field.

The amount of inclusions measures the taxonomic purity of map units. The amount and degree of contrast of inclusions with the reference taxa can be used to estimate the interpretive purity of map units. Purity of map units is, in part, the result of a conscious decision based on the intended uses of a soil survey. The actual amount of inclusions is estimated from observations made during the survey and adjustments in mapping made if appropriate.

When map units are defined, judgment must be exercised about the effects of inclusions on management and about how much effort is justified to keep the amount of inclusions small. In exercising these judgments, visualizing two kinds of differences between components is useful. If differences are small, the components are compared as similar. If differences are large, the components are contrasted as dissimilar.

Similar components occur together in landscapes, are alike or much alike in most properties, and share limits of those diagnostic properties in which they differ. Differences are beyond the limits of the reference taxon or phase class but generally are within or slightly beyond normal errors of observation. Because only a few limits are shared or the range is small, interpretations for most common uses are alike or reasonably similar and the interpretive purity of a map unit is not affected.

Dissimilar components on the other hand, differ appreciably in one or more properties, and the differences generally are great enough to affect major interpretations. Some dissimilar component are limiting, and others are nonlimiting relative to the interpretations being considered.

If an inclusion does not restrict the use of entire areas or impose limitations on the feasibility of management practices, its impact on predictions for the map unit is small. Inclusions of soil components having less severe restrictions on use than the dominant soil of a map unit do not adversely affect predictions about the unit as a whole and they may even be beneficial. Such inclusions are nonlimiting and the interpretive purity of a map unit for most interpretations is not altered.

For example, the inclusion of many small areas having slopes of 4 to 8 percent in an area having slopes mainly of 15 to 25 percent has no adverse effect on use of the area for most purposes. Similarly, the inclusion of small areas of Aquic Hapludalfs in areas dominated by Typic Ochraqualfs having properties similar except for those related to greater wetness is usually nonlimiting for most common uses. Spots of the drier soil in the generally wet area may affect some uses for which homogeneity is important, but they do not place general restrictions on most uses of the area.

If an inclusion has significantly lower potential for use than the dominant component in the map unit or affects the feasibility of meeting management needs, a small amount in a map unit can affect predictions greatly. These are the most critical inclusions because they decrease the interpretive purity of map units. Even a small area having slopes of 15 to 25 percent in a map unit dominated by slopes of 4 to 8 percent can seriously affect the use of the area for many purposes.

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Small inclusions of Typic Ochraqualfs in areas of Aquic Hapludalfs may be controlling. Even though the areas of the Typic Ochraqualfs are small, they may be limiting.

Soils that cannot be used feasibly for the same purposes as the surrounding soil are especially critical. They are separately delineated if the map scale permits it and if showing them will improve the usefulness of the map for major anticipated uses. Areas too small to delineate may be identified and located on the map by special symbols. If two kinds of soils lie in small areas in a consistent repeating pattern and affect use or management differently, they are mapped together as a complex.

Some inclusions may be limiting for one kind of use and nonlimiting--or even beneficial--for another kind. For example, a soil with a high water table included within a map unit dominated by well drained soil may produce lower yields of most crops or be impractical to cultivate because of wetness but be much better suited for excavated ponds. There commonly are different interpretive purities of a map unit depending on the specific interpretation.

Kinds of Map Units

Soils differ in size and shape of their areas, in degree of contrast with adjacent soils, and in geographic relationships. Four kinds of map units are used in soil surveys to show the relationships. The four kinds of map units are: consociations, complexes, associations, and undifferentiated groups.

Consociations

In a consociation delineated areas are dominated by a single soil taxon (or miscellaneous area) and similar soils. As a rule, at least one-half of the pedons in each delineation of a soil consociation are of the same soil component providing the name for the map unit. 2/ Most of the remainder of the delineation consists of soil components so similar to the named soil that major interpretations are not affected significantly. The total amount of dissimilar inclusions of other components in a map unit generally does not exceed about 15 percent if limiting and 25 percent if nonlimiting, with a single component of dissimilar limiting inclusion generally not exceeding 10 percent if very contrasting. The amount of dissimilar inclusions in an individual delineation of a map unit can be greater than this if no useful purpose would be served by defining a new map unit. The soil in a consociation may be identified at any taxonomic level.

A consociation named for a kind of miscellaneous area is dominated by the kind of area for which it is named to the extent that any inclusions do not significantly affect the use of the map unit. Generally, this means that less than about 15 percent of any delineation is soil or less than about 25 percent is other kinds of miscellaneous areas. Percentages may vary, depending on the kind of miscellaneous area and the kind, size, and pattern of the inclusions.

Some consociations consist of two or more dissimilar phases of a series that occur in such an intricate pattern that they cannot be mapped separately at a scale of about 1:24,000. Each of the phases in question exceed about 15 percent in all delineations. An example of two dissimilar phases is Alpha sand, 0 to 3 percent slopes and Alpha silty clay, 0 to 3 percent slopes. If the consociation consists of such a mixture of dissimilar surfact texture phases of the same series both textural class names separated by a hyphen is used following the series name: Alpha sand-silty clay, 0 to 3 percent slopes.

Consociations are named for the phase of the taxon or miscellaneous area that dominates the map unit if the potential phases are similar: Alderwood gravelly loam, 0 to 3 percent slopes; Antilon gravelly silt loam, deep, 0 to 3 percent slopes; Badland; Houghton muck; Rock outcrop; Typic Fragiochrepts, rolling.

Complexes and associations

Complexes and associations consist of two or more dissimilar taxa components or miscellaneous areas occurring in a regularly repeating pattern. Only the following arbitrary rule related to mapping scale determines whether the name complex or association be used. The major components of a complex cannot be mapped separately at a scale of about 1:24,000. The major components of an association can be separated. In either case, the major taxa components are sufficiently different in morphology or behavior that the map unit cannot be called a consociation. In each delineation of either a complex or an association, all of the major components are normally present, though their proportions may vary appreciably from one delineation to another. The total amount of inclusions that are dissimilar to any of the major components does not exceed about 15 percent if limiting and 25 percent if nonlimiting in a map unit, with a single kind of dissimilar limiting inclusion generally not exceeding 10 percent if very contrasting.

The first part of the name of a soil complex is formed by using names of taxa, usually soil series joined by hyphens. If a miscellaneous area is an extensive component, its name is used as though it were the name of a taxon. The names of two or three taxa, rarely four, may be used to name a complex, followed by the surface texture phase term if the surface texture of all major components is the same, otherwise the taxa are followed by the word "complex." The name of the most extensive component is given first. Examples: Sharkey-Alligator clays; Skaggs-Duncan-Hughesville complex; Travessila-Rock outcrop complex; Gem-Springerville complex, 0 to 5 percent slopes.

Names of associations are similar to those of complexes except that the word "association" always appears in the name. Examples: Cohoe-Kenai association; Cohoe-Kenai association, steep; Ruston-Cuthbert-Shubuta association; Hollis-Rock outcrop association. Associations can also be named for taxa of higher categories: Crete-Butler families association; Typic Fragiochrepts-Aeric Fragiaquepts association; Fragiochrepts-Fragiaquepts association; Ochrepts-Aquepts association; Ochrepts-Aquepts association, very stony.

Undifferentiated groups

Undifferentiated groups consist of two or more taxa components that are not consistently associated geographically but that are included in the same map unit because use and management are the same or very similar for common uses. Generally they are included together because some common feature such as steepness, stoniness, or flooding determines use and management. For example, if two or more very steep soils geographically separated are so similar in their potentials for use and management that mapping them separately would serve no useful purpose they may be placed in the same map unit. Every delineation has at least one of the major components and some may have all of them. The same principles regarding proportion of inclusions apply to undifferentiated groups as to consociations.

The term "undifferentiated group" refers to groups of taxa at the level of classification indicated in the name of the map unit, not to a single taxon made up of taxa at lower levels. Thus, "Haploborolls, rolling," though undifferentiated with respect to all of the subgroups, families, and series within it, is a consociation, not an undifferentiated group of Haploborolls.

The name of an undifferentiated group identifies the principal components, but the map unit is identified by one symbol on the map and by one name: Mardin and Wellsboro channery silt loams, very steep, is an undifferentiated group of very steep soils of two series; Renshaw and Sioux soils, undulating, is an undifferentiated group of soils in two series that have different surface texture phases. The areas of very steep Mardin and Wellsboro soils may be side by side in some places, but either may be by itself in other places. The word "and" connecting the names of the taxa distinguishes undifferentiated groups from complexes, associations, and consociations.

Complexes or associations, not undifferentiated groups, should be used in mapping legends if two or more distinctive kinds of soils or miscellaneous areas are consistently associated in the delineations. The geographic pattern and relative proportions of components of complexes and associations are important in interpreting map units. The name "Cohoe-Kenai association," for example, indicates that both kinds of soil will be in each delineation of that map unit. It also implies that they are associated in characteristic patterns and proportions, which are described. The name "Cohoe and Kenai soils" says that either Cohoe or Kenai soils, or possibly both, may be in any particular delineation.

Phases

Phases are functional groupings created to serve specific purposes in individual soil surveys. A map unit carrying the name of a soil phase is one example of the bridge between taxonomy and mapping. Phases can be defined for any class of any category. Differences in soil or environmental features that are significant to use, management, or behavior are the bases for designating soil phases. To keep map unit names from being too cumbersome, only those phase characteristics that uniquely identify the unit are generally used in its name.

Any property or combination of properties that does not duplicate class limits for a taxon can be used to differentiate phases, and any value of a property can be set to divide phases. The choices of properties and limits are determined by the purposes of the survey and by how consistently the phase criteria can be applied. Because objectives differ from one soil survey to another, limits and ranges of a property or attribute may also differ from one survey to another. In general, phase criteria are given less of a range where soil use is intensive (as for irrigated farming or urban development) and more of a range where use is extensive (as for forestry or grazing).

Following are discussions of the attributes most commonly used in defining phases in soil surveys.

Texture of the surface layer.--Because the surface layer has special significance for use of the soil, its texture is commonly indicated in the names of phases bearing the names of soil series. Exceptions are: complexes and undifferentiated groups in which the component taxa have different surface textures and associations.

These phases generally identify the dominant texture of a mineral layer about equal to that commonly mixed in tillage, but the thickness of this layer varies by region, kind of soil, and use. The texture identified is generally that of a mineral layer mixed to a depth of 12 to 25 cm. If the layer has not been mixed, the texture that would be produced by mixing is estimated. If after mixing the

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layer is organic, terms for organic material are used to name the phase. In some areas such as deserts, where the surface layer is normally thin and cultivation is unlikely, the texture of the A horizon can be used in naming phases even if less than 12 cm thick.

Texture classes or texture groups are used to name texture phases. Basic texture class names (such as "sand," "fine sandy loam," and "silt loam") follow the name of a soil series: Alpha sandy loam. The terms for textural groups (such as "medium textured" and "loamy") are used for names of classes in categories above the series: Alpha family, loamy surface. The term "surface" is added to such names to avoid confusion with phases based on texture of other parts of the soil.

For soils having an organic surface layer conventions for naming are similar to those for soils having a mineral surface layer: "Rifle peat," "Carlisle muck."

The term "mucky" preceding a mineral texture term signifies that the surface layer contains so much organic matter that its physical properties approach those of muck: Livingston mucky silt loam. Such phases are used commonly for wet mineral soils that have a surface horizon rich in organic matter.

Some mineral soils have a thin layer at the surface that contrasts sharply with the next layer. Such soils may be designated as separate phases if they are unlikely to be tilled and if clearly significant to use or management. On rangeland, for example, the texture of the uppermost few centimeters of soil is important. A thin layer of sandy material at the surface may mean the difference between success and failure of seedings on some soils. For some surveys, such layers need to be recognized and their areas delineated. Also, on some soils a few centimeters of recent volcanic ash on the surface or a thin cover of silt or clay is an important distinction. Generally, these phases are named only by the broad textural groups: Alpha clay, sandy surface. These layers are so thin that more refined distinctions are not usually consistent over mappable areas.

Conceivably, other kinds of phases based on texture could be useful in mapping, but they should be used only if the indicated property has a major and lasting effect on interpretations. They are not used to record a soil property that is a normal feature of the kind of soil, such as an O horizon on an undisturbed soil.

Deposits on the surface.--Some soils have received deposits of material thick enough to influence interpretations of the soil but not thick enough to change the classification. Depositional phases of the buried soil may be recognized:

> Overblown: A recent deposit of wind-blown material on the surface of an older soil can be identified consistently throughout the area and is thick enough to influence use, management, or behavior.
>
> Wind hummocky: Recent wind-laid deposits form a fine pattern of hummocks that markedly alter management requirements of the soil. The original soil is identifiable throughout most of the area, though it is covered in spots.
>
> Overwash: Material deposited by water contrasts with the underlying soil and is thick enough to influence management requirements significantly. Ordinarily, overwash phases are not used for very young alluvial soils having weakly expressed genetic horizons.

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Texture terms in map unit names describe the material currently at the surface. Terms designating a depositional phase follow the term for texture class: Alpha loamy sand, overblown, 2 to 8 percent slopes.

Phases may be recognized for soils covered by a thin layer of volcanic ash: Alpha loam, volcanic ash cover. Such phases are generally used only if needed to distinguish the phase from another phase that lacks the ash cover.

Rock fragments.--Rock fragments on the surface and in the surface layer are commonly used as phase distinctions. Kinds of rock fragments are defined by shape and size in Chapter 4. The classes are helpful in describing soil phases, but phase limits are set to make the distinctions that are important for the survey, whether or not the phase limits correspond with standard class limits.

The discussion that follows is applicable to arable soils. For other uses--such as forestry, range, or recreation--the sizes, shapes, amounts, and mixtures of rock fragments have different significance. For example, gravel, cobbles, and stones influence forestry much less than they do cultivation, although they could affect access and reforestation.

The following definitions for phases of the smaller rock fragments accommodate most of the detailed phase distinctions that can ordinarily be made accurately by field methods. The term "gravelly" is used in the examples of names that follow, but the adjectives for each of the other kinds of rock fragments smaller than stones, such as cobbly or channery, are substituted as appropriate. [37] Of course, the effect of 20 percent fine gravel on use of arable soil, for example, is quite different from the effect of 20 percent flagstones; therefore, the phase limits may differ for larger fragments.

Slightly gravelly: The surface layer contains enough pebbles to affect special uses that tolerate few if any rock fragments, but the pebbles do not interfere significantly with tillage of field crops such as corn. The volume is usually less than 15 percent. A slightly gravelly phase can be recognized for soils that are used for special purposes, such as growing turf.

Gravelly: The surface layer contains enough pebbles to interfere with tillage of common field crops, but most tillage is performed in the same manner and with the same equipment as on soil free of fragments. The pebbles are a nuisance. They cause some equipment breakage but few major delays in field operations. Their effects on quality of tillage are small or moderate, depending on the kind of operation. The volume of pebbles is usually between 15 and 35 percent but may be less if the fragments are large or more if they are small.

Very gravelly: The surface layer contains enough pebbles to interfere seriously with tillage of common field crops, to damage equipment, and to decrease the rate of most field operations. The quality of tillage operations is affected. The kinds of crops that can be grown is restricted, the precision of planting and of fertilizer placement is reduced, and young plants are frequently covered during tillage. The volume of pebbles is usually between 35 and 60 percent.

Extremely gravelly: The surface layer contains so many pebbles that tillage of common field crops is often impractical, though not necessarily impossible. Tillage implements must force their way through a mass of pebbles that have fines between them. The volume of pebbles is usually more than 60 percent.

The rock fragments in the surface layer commonly span two or more size classes and may include fragments of more than one shape. The name of the kind of fragment that is judged most important in limiting the management of the soil is used in the phase designation. Usually, the largest fragments that are present in significant amounts are most important. A soil having enough cobbles in or on the surface layer to impose important restrictions on soil use, for example, is named "cobbly" even though the soil also contains as much or more gravel. Both terms are not used. Terms for the three size classes of gravel (fine, medium, and coarse) are not used in phase names unless the pebbles are well sorted into one of the narrowly defined size fractions. The term "gravelly" is commonly used as a general term even though one size may be dominant. Some soils do have pebbles almost entirely within the 2-to-5-mm size class. The uniformly fine size of the pebbles may be important enough for some purposes to identify in the name.

Classes of stoniness and boulderiness (Chapter 4) are also used to define phases. The following phases of the larger rock fragments represent about the maximum detail that can be mapped consistently in most soil surveys. "Bouldery" is substituted for "stony" as appropriate.

Stony: The areas have enough stones at or near the surface to be a continuing nuisance during operations that mix the surface layer, but they do not make most operations of these kinds impractical. Conventional wheeled vehicles can move with reasonable freedom over the area. Stones might damage equipment that mixes the soil and vehicles that move on the surface. Usually these areas have class 2 or 3 stoniness. If necessary in a highly detailed survey, class 2 may be designated as "slightly stony" and class 3 as "moderately stony."

Very stony: The areas have so many stones at or near the surface that operations which mix the surface layer either require heavy equipment or use of implements that can operate between the larger stones. Tillage with conventional powered farm equipment is impractical. Wheeled tractors and vehicles with high clearance can operate on carefully chosen routes over and around the stones. Usually these areas have class 4 stoniness.

Extremely stony: The areas have so many stones at or near the surface that wheeled powered equipment, other than some special types, can operate only along selected routes. Tracked vehicles may be used in most places, though some routes have to be cleared. Usually these areas have class 5 stoniness.

Rubbly: The areas have so many stones at or near the surface that tracked vehicles cannot be used in most places. Usually these areas have class 6 stoniness.

If used, the terms for stony and bouldery phases modify terms for surface texture in the name of the phase: Gloucester stony loam. If a term for surface texture is not used, stony or bouldery phase designations are separated from the taxonomic name by a comma: Gloucester family, bouldery. If the soil has stones, boulders, and smaller fragments, the name includes the kind of rock fragment that is most important in limiting use or management of the soil. This is not necessarily the kind that is most abundant or the kind that is used to modify texture class of horizons in the profile description.

Rockiness.--Where rock outcrops cover 10 percent or less of the delineations (classes 1, 2, and 3 of area of rock outcrop, Chapter 4) a "rocky" phase may be needed. Where the area is more than 10 percent Rock outcrop, the map units are named as complexes or associations of soil and Rock outcrop.

In recognizing phases, area is only one consideration. If only one phase is needed, it is designated "rocky": Alpha loam, rocky. If size, spacing, and other features of the rock-soil relationship are significant to use or management of the map unit, phases designated as "slightly rocky," "rocky," and "very rocky" can be used.

Slope.--The slope range of some soil taxa is narrow; in others it is wide enough to include differences that are important for soil use and management. Slope phases are used to divide soil series or other taxa as may be needed for the purposes of the survey.

Slope gradient, complexity, shape, length, and aspect are all potential bases for phase distinctions. By far the most commonly used is gradient. Complexity is also used in many surveys. Slope length can often be appraised directly from delineations on the map, and in many cases the significance to use and management of slope length depends on the kind of landscape in which the soil occurs. Shape is seldom used as a phase distinction; differences in shape are commonly related to differences in internal properties that distinguish taxa. Slope aspect is used mainly in high latitudes. If aspect is used as a phase criterion, its name follows any other slope terms that may be used: 25 to 40 percent north slopes (or north-facing slopes).

Phases defined on the basis of [redacted]. They should be so distinct that they can be identified and mapped consistently. They should not add complexity to the map without improving its usefulness. And most importantly, they should separate areas that have significant differences in suitability or management needs.

A uniform system of slope classes should not be used indiscriminately as the basis for differentiating phases. Slope phases that have narrow ranges in gradient may be needed for soils that can be used intensively. For other soils having additional limitations, such as stoniness, such narrow ranges may be useless. The specific limits between phases may be one set of values for one kind of soil and another set for another kind of soil.

In each survey, the limits of slope phases are based on data or experience indicating that this set of limits makes the most useful distinctions for each kind of soil. Range in the slope of a phase of one series may encompass the ranges of two or more phases of another series. A single set of slope classes that would serve as phase distinctions for all soils is impractical because of the varied relationship of slope to mappable landscapes and the many and varied relationships of slope to the use and management of different kinds of soils.

Table 4-1 (Chapter 4) defines slope classes in terms of flexible limits for both simple and complex slopes. The flexible limits permit use of terms to identify most distinctions of slope that may be needed.

Slope phases can be named either by numerical slope gradient limits, with or without designations of complexity, or by descriptive terms. Slope terms for map units for taxa above the series are generally given in descriptive terms. The word "slopes" is used if gradient is specified as a percentage but is omitted if descriptive terms are used. [redacted] Beta gravelly loam, 8 to 16 percent slopes; Beta gravelly loam, strongly sloping; Beta gravelly loam, thick solum, 8 to 16 percent slopes; Beta soils, rolling; Gamma family, hilly.

Depth.--Soil depth phases are used where variations in depth to a contrasting layer are significant to soil use, management, or behavior. Terms for depth classes in Chapter 4 are generally used in naming phases, but modifications are needed in some areas. For instance, the class "moderately deep," ranging from 50 to 100 cm, may be too broad to satisfy the objectives of some surveys. This range can be divided, with perhaps one class ranging in depth from 50 to 75 cm and the other from 75 to 100 cm, if the more narrowly defined phases occur in a consistent pattern within the survey area and can be mapped. Generally the phase that covers more acreage is not given a depth designation. If that is the deeper phase, "moderately shallow" is used to designate the phase that has a depth range of 50 to 75 cm. If the shallower phase is more extensive, "moderately deep" is used to designate the 75-to-100-cm phase.

In some surveys, using the standard class terms may be misleading. For example, if a series that is normally more than 150 cm deep to bedrock has a phase that is 100 to 150 cm deep, calling the less extensive phase "deep" could be construed to mean that the phase is deeper than normal. In such cases, depth limits can be specified in the phase name--Alpha loam, 100 to 150 cm deep--or substratum phase terminology can be used instead.

Substratum.--Where underlying material contrasts sharply with the material above and interpretations are affected, substratum phases are used. The kind of contrasting material is indicated in the name of the map unit. The terms that follow have been used to identify substratum phases: calcareous substratum, chalk substratum, clay substratum, gravelly substratum, gypsiferous substratum, lacustrine substratum, marly substratum, sandy substratum, silty substratum, shale substratum, till substratum. These terms are descriptive, not mutually exclusive. Other terms can be used as appropriate. The identifying term follows the name of the taxon and any designation for surface texture and precedes any term for slope or erosion in the phase name: Plano silt loam, gravelly substratum, 6 to 20 percent slopes.

Where there is a choice between using a depth phase or a substratum phase to identify a map unit, a depth phase is generally used if the contrasting layer is bedrock.

Soil-water.--Phases are used to distinguish differences in soil-water state, water table level, drainage, and the like where the series' range in one or more of these properties need to be divided for purposes of the survey. Significant differences in these factors are commonly reflected in differences in soil morphology and are distinguished at the series level. In some soils, however, evidence of wetness, such as gray color or mottling, does not fully reflect the natural drainage or wetness of the soil. Such soils may not be differentiated at the series level with the refinement needed for the purposes of the survey.

Phases commonly used include high water table, moderately deep water table, poorly drained, slightly wet, moderately wet, wet, ponded, and drained. Some soils have properties that reflect former wetness but have been drained artificially; "drained" phases can be used to separate drained areas from undrained. In other soils a water table fluctuates below the depth where properties are criteria for defining series; "water table" phases can be used to identify such soils.

Salinity.--Saline phases are used to distinguish between degrees of salinity that are important for soil use or management. Electrical conductivity values and observations of plant growth are guides for recognizing phases.

Designation of salinity phases depends on the various uses likely to be made of the soils and the effect of excessive amounts of salt on those uses. In farming areas the crops most likely to be grown must be considered. Management induced salinity that fluctuates widely with management practices generally would not be a basis for phase distinctions.

Vegetation, especially the native cover, often shows the location of saline soils and their boundaries. Using vegetation along with landform and other features as guides and correlating these field observations with laboratory or field analyses of soil samples, the surveyor can usually draw boundaries with reasonable accuracy. However, plants vary in their tolerance of salt by species, variety, and age, and perhaps other factors. Some plants are not good indicators of salinity because they grow well whether salts are present in excessive amounts or not.

Other problems must also be considered in designating salinity phases. Different kinds of salts and combinations of salts have varied effects on soil behavior. In many soils salts are transitory; in others they are permanent. Excessive sodium may or may not be associated with excess salinity.

The following classes of salinity, which are a general guide to naming phases, refer to the presence of salts anywhere in the soil. Salinity classes are defined in Chapter 4.

Nonsaline: Effects of salinity on plant growth are negligible. Salinity is mainly class 1. "Nonsaline" is omitted from the names of mapping units unless the soil taxon is typically saline. A very slightly saline phase may be useful in some surveys where crops extremely sensitive to salts are grown or are likely to be grown.

Slightly saline: Growth of many plants is affected. Yields of such plants as bromes, sunflower, corn, and peas are reduced seriously. Western wheatgrass, kale, and barley are affected little. Salinity is mainly class 2.

Moderately saline: Only plants tolerant of salinity, such as western wheatgrass, beets, and barley, grow well, and yields of these are commonly reduced. Salinity is mainly class 3.

Strongly saline: Only the most tolerant halophytic plants, such as saltgrass, grow well. Salinity is mainly class 4.

Terms for saline phases follow terms for surface texture in phase names: Alpha silt loam, strongly saline.

Sodicity.--For some soils, recognizing a "sodic" phase is useful. The term "sodic" is used as a phase designation, if needed, generally without terms for degrees of sodicity: Alpha loam, sodic, 0 to 3 percent slopes.

Physiography.--Landform or physiographic position may be used as a phase criterion to distinguish phases of a single taxon. A soil in a deposit of loess 3 meters thick on a terrace, for example, may be so much like a soil in a similar deposit on a till plain that the two are members of the same series. For some uses, however, the two soils need to be distinguished on the map. A physiographic phase can be used to identify the less extensive soil.

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The following terms are examples that have been used to designate physiographic phases: bench, depressional, fan, karst, ridge, and terrace. The terms are usually used to identify phases that differ in position from that typical for the soil. The typical physiography is not given in a phase name. [redacted] gravelly loam, fan, 0 to 8 percent slopes.

Erosion.--Significant differences in a soil's potential for use, its management needs, or its performance may be brought about by accelerated erosion. Such differences are a basis for recognizing phases provided the taxonomic unit has not changed due to the accelerated erosion. Phases of eroded soil are identified on the basis of the properties of the soil that remains, although the amount of soil lost is estimated and noted.

Properties related to natural erosion are a part of the definition of a taxon, not bases for erosion phases. Erodibility, too, is an inherent quality of a soil and not itself a criterion for erosion phases.

Eroded phases are defined so the boundaries on the soil maps separate soil areas of unlike suitabilities and soil areas of unlike management needs and responses. If a tentative phase turns out to have nearly the same limitations, management needs, and responses to management as another phase of the same soil, the two are combined. The term designating the eroded soil phase is the last term in the phase name: Alpha loam, 8 to 15 percent slopes, eroded

Guidelines for naming phases of soil eroded by water are as follows. Erosion classes are defined in Chapter 4.

Slightly eroded: Erosion has changed the soil enough to require only slight modification of management from that of the uneroded soil; potential use and management remain generally the same. Most slightly eroded soils have class 1 erosion. Slightly eroded areas are not distinguished from uneroded areas in most surveys.

Moderately eroded: Erosion has changed the soil to such an extent that required management or the response to management differs in major respects from that of the uneroded soil. Suitabilities for major uses--such as field and horticultural crops, pasture, forestry, and major engineering uses--are the same. The distinction is made by comparing management and suitability of the eroded soil with those of the uneroded soil. In most moderately eroded soils ordinary tillage implements reach through the remaining A horizon, or well below the depth of the original plowed layer if the A horizon was originally less than 20 cm thick (class 2 erosion). Generally the plow layer consists of a mixture of the original A horizon and the underlying horizons. Most mapped areas of moderately eroded soils have patches in which the plow layer consists wholly of the original A horizon and others in which it consists wholly of underlying horizons. Shallow gullies may be present. The word "moderately" is omitted from the name unless it is needed to differentiate between this phase and other eroded phases of the same soil.

Severely eroded: Erosion has changed the soil so much that (1) the eroded soil is suited only to uses significantly less intensive than the uneroded soil, such as use for pasture instead of crops, (2) the eroded soil needs intensive management immediately or over a long period to be

suitable for the same uses as the uneroded soil, (3) productivity is reduced significantly, or (4) limitations for some major engineering interpretations are greater than on the uneroded soil. Severely eroded phases commonly have been eroded to the extent that the plow layer consists essentially of material from underlying horizons (class 3 erosion), though patches in which the plow layer is a mixture of the original A horizon and underlying horizons may be present within delineations. Shallow gullies, or a few deep ones, are common in some places.

If a soil has been so eroded that diagnostic soil horizons have been removed throughout most of the area (class 4 erosion), it is not recognized as an eroded phase of the taxon of the original soil. The original soil is no longer identifiable except in isolated spots; the current soil is placed in a taxonomic class based on the horizons and properties that remain. The unit is not designated as a phase of eroded soil either of the new taxon or of any taxon presumed to represent the soil before erosion. The soil is classified at the lowest level in which it can be placed in the taxonomic system. Similarly, if a soil has been eroded enough to change its classification, say from a Mollisol to an Alfisol, or an Inceptisol even if erosion is only within the range of class 1, it is given the name of a new taxon and is not an eroded phase.

A "gullied" phase can be recognized if a distinction between gullied areas and ungullied areas of the same soil is needed. Gullied phases are used for areas having gullies so deep that intensive measures, including reshaping, are required to reclaim the soil.

Guidelines for designating phases of soil eroded by wind are as follows. Erosion classes are defined in Chapter 4.

Eroded (blown): Wind has removed so much soil that required management differs significantly from that of the uneroded soil, but suitabilities for use remain the same. The term "moderately" is understood. Most moderately wind eroded soils have class 1 wind erosion.

Severely eroded (severely blown): Wind has removed so much material or has shifted it from place to place within the area to such an extent that either the suitability for use is different from that of the uneroded soil or the soil of the area must be extensively reworked and management unlike that of the uneroded soil must be used for the soil to be suitable for the same uses. Most severely wind eroded soils have class 2 or 3 wind erosion.

Many areas identified as moderately and severely wind eroded are, in fact, mixtures of small areas of uneroded soil and soil eroded to various degrees. The amount of erosion throughout a delineation can be described only in general terms.

If a soil has been so eroded by wind that genetic soil horizons have been removed throughout most of the area (class 4 wind erosion) it is not identified as a phase of eroded soil; rather it is classified in another taxon.

Thickness.--The solum and the various horizons in soil have characteristic ranges in thickness for each taxon. Thickness phases are used to divide the range of thickness of the solum or of the upper horizons if mappable areas of one such phase differ consistently from areas of the other phase and require different interpretations for the purposes of the survey. Phases are not used to

differentiate thickness of the subsoil or the substratum. Four thickness phases are used:

Thick surface: The thickness of the A horizon or of the A and E horizons combined is within the thickest half of the range for the taxon.

Thin surface: The thickness of the A horizon or of the A and E horizons combined is within the thinnest half of the range for the taxon.

Thick solum: The thickness of the solum is within the thickest half of the range for the taxon.

Thin solum: The thickness of the solum is within the thinnest half of the range for the taxon.

A term is used for the less extensive of two thickness phases. For example, most delineations of a given soil may have an A horizon that is mainly between 25 and 35 cm thick (though the A horizon of some pedons in these delineations is 40 cm thick). If the A horizon is mainly 35 to 40 cm thick in other delineations of the same soil and the difference is significant for purposes of the survey, a thick-surface phase can be recognized. The phase in which the A horizon is dominantly 25 to 35 cm thick is the norm; thickness of the A horizon is described for this phase but is not identified in the name.

The thickness term follows any terms for surface texture and precedes any terms for slope or erosion: Brownfield fine sand, thick surface, 0 to 3 percent slopes.

Climate.--In some places, especially in mountainous or hilly areas, precipitation or air temperature can differ greatly within short distances, yet these differences may not be reflected in internal properties of the soil. Air drainage can differ enough from one location to another to produce a difference in the dates of the last killing frost in the spring or the first in the fall, or one area may be frost free. Where differences of this kind are significant for the purposes of the survey and can be identified and mapped consistently, climatic phases are used.

Only two climatic conditions are recognized for a given taxon: (1) the common climate, the climate that influences the greatest extent of the taxon, from which the climate designation is omitted, and (2) a departure from the common climate, for which a climatic designation is used. The departure may be in either of two directions from the norm: warm or cool; high precipitation or low precipitation. Each of the terms is connotative only in reference to the common climate of the taxon and must be described specifically for each phase to which it is applied. The appropriate term follows texture: Alpha sandy loam, cool.

In many places, especially on plains, precipitation or temperature changes gradually over distance. A soil in a single survey area commonly includes only part of the range for the series. Climatic phases generally are not used if only part of the range is within a soil survey area. Climatic phases are local distinctions. They are used where temperature or precipitation differs markedly between parts of a survey area.

Other.--A great variety of phase distinctions can be made. In addition to those already described, others may be needed to provide suitable map units; for example: frequently flooded, occasionally flooded, burned, calcareous,

leached surface, dark surface. "Burned," for example, might be used for organic soils that have lost enough of their organic material by fire that their potential for use or their management requirements have been altered.

The phases designated by special terms are defined to fit special kinds of soils. Such phases are defined in reference to the common properties of the taxon of which they are members. Thus, the terms usually have different specific meanings when used for different taxa and in different survey areas.

Miscellaneous Areas

Miscellaneous areas have essentially no soil and support little or no vegetation, without major reclamation, because of active erosion, washing by water, unfavorable soil conditions, or man's activities. Some miscellaneous areas can be made productive but only after major reclamation efforts. Map units are designed to accommodate miscellaneous areas, and most map units named for miscellaneous areas have inclusions of soil. If the amount of soil exceeds the standards for inclusions defined in this chapter, the map unit is named as a complex or association of miscellaneous area and soil.

Following are discussions of recognized kinds of miscellaneous areas.

Badland is moderately steep to very steep barren land dissected by many intermittent drainage channels. The areas are ordinarily not stony. Badland is most common in semiarid and arid regions where streams cut into soft geologic material. Local relief generally ranges between 10 and 200 meters. Potential runoff is very high, and erosion is active. Small inclusions of identifiable soils may support vegetation of very limited value for grazing.

Beaches are sandy, gravelly, or cobbly shores washed and rewashed by waves. The areas may be partly covered with water during high tides or storms.

Blown-out land consists of areas from which all or most of the soil material has been removed by extreme wind erosion. The land is essentially barren. The areas are generally shallow depressions that have flat or irregular floors. In some places the floor is a layer of material that is more resistant to wind than the removed material or is a layer of pebbles or cobbles; or the floor may have been formed by exposure of the water table. Areas covered by water most of the year are mapped as Water. Some areas have a few hummocks or small dunes. Few areas of blown-out land are large enough to be delineated; small areas can be shown by spot symbols.

Cinder land is composed of loose cinders and other scoriaceous magmatic ejecta. Water-holding capacity is very low, and trafficability is poor.

Dumps are areas of smoothed or uneven accumulations or piles of waste rock and general refuse. Dumps, mine, consists of areas of waste rock from mines, quarries, and smelters. Some dumps with closely associated pits are mapped as Dumps - Pits complex.

Dune land consists of sand in ridges and intervening troughs that shift with the wind. Sand dunes that have been stabilized by vegetation are named as a kind of soil rather than as Dune land.

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Glaciers are large masses of ice formed, at least in part, on land by the compaction and recrystallization of snow, moving slowly by creep down slope or outward in all directions due to the stress of its own weight, and surviving from year to year. A little earthy material may be on or in the ice.

Gullied land consists of areas where erosion has cut a network of V-shaped or U-shaped channels. The areas resemble miniature badlands. Small areas can be shown by spot symbols. Phases indicating the kind of material remaining may be useful in some places.

Gypsum land consists of exposures of nearly pure soft gypsum. The surface is generally very unstable and erodes easily. Trafficability is very poor. Areas of hard gypsum are mapped as Rock outcrop.

Lava flows are areas covered with lava. In most humid regions, the flows are of Holocene age, but in arid and very cold regions they may be older. Most flows have sharp, jagged surfaces, crevices, and angular blocks characteristic of lava. Others are relatively smooth and have a ropy glazed surface. A little earthy material may be in a few cracks and sheltered pockets, but the flows are virtually devoid of plants other than lichens. 47

Oil-waste land consists of areas where liquid oily wastes, principally saltwater and oil, have accumulated. It includes slush pits and adjacent areas affected by the liquid wastes. The land is barren, although some of it can be reclaimed at high cost.

Pits are open excavations from which soil and commonly underlying material have been removed, exposing either rock or other material. Kinds include Pits, mine; Pits, gravel; and Pits, quarry. Pits are commonly closely associated with Dumps.

Playas are barren flats in closed basins in arid regions. Many areas are subject to wind erosion and many are saline, sodic, or both. The water table may be near the surface at times.

Quarries (see Pits)

Riverwash is unstabilized sandy, silty, clayey, or gravelly sediment that is flooded and washed and reworked frequently by rivers.

Rock outcrop consists of exposures of bare bedrock other than lava flows and rock-lined pits. If needed, map units can be named according to the kind of rock: Rock outcrop, chalk; Rock outcrop, limestone; Rock outcrop, gypsum. Many rock outcrops are too small to be delineated as areas on soil maps but can be shown by spot symbols. Some areas are large, broken by only small spots of soil. Most rock outcrops are hard rock, but some are soft.

Rubble land consists of areas of stones and boulders. Rubble land is commonly at the base of mountains but some areas are deposits of cobbles, stones, and boulders left on mountainsides by glaciation or by periglacial processes.

Salt flats are undrained flats that have surface deposits of crystalline salt overlying stratified very strongly saline sediment. These areas are closed basins in arid regions. The water table may be near the surface at times.

Scoria land consists of areas of slaglike clinkers, burned shale, and fine-grained sandstone remaining after coal beds burn out. (Scoria land should not be confused with volcanic slag.)

Slickens are accumulations of fine-textured material, such as that separated in placer-mine and ore-mill operations. Slickens from ore mills consist largely of freshly ground rock that commonly has undergone chemical treatment during the milling process. Slickens are usually confined in specially constructed basins.

Slickspots are areas having a puddled or crusted, very smooth, nearly impervious surface. The underlying material is dense and massive. The material ranges from extremely acid to very strongly alkaline and from sand to clay.

Urban land is land mostly covered by streets, parking lots, buildings, and other structures of urban areas.

Water includes streams, lakes, ponds, and estuaries that in most years are covered with water at least during the period warm enough for plants to grow; many areas are covered throughout the year. Pits; blowouts, and playas that contain water most of the time are mapped as Water.

Naming Map Units

All map units in a soil survey are named. Different conventions are used for each of the four kinds of map units so that the kind of unit can be determined at a glance. In general, names are as short as practical; the name of a map unit is generally no longer than necessary to distinguish it from all others in the survey. At times an extra term, not needed to distinguish a phase from all others in the survey, is used so that comparable phases in other areas have the same name.

Although the conventions for naming map units are discussed throughout this chapter, a complete summary is provided here for convenience. Soil names indicate the categorical level used for identification, but soil taxonomic names are never used alone.

Consociations

The name of the reference taxon is given first, followed by appropriate phase terms:

> If a series is the reference taxon and the consociation is not a mixture of dissimilar phases, the series name is followed by the dominant texture (basic texture class) of the surface layer if the surface layer is mineral or by an organic term if the surface layer is organic: Alpha loam; Omega muck. A texture modifier is placed between the series name and the texture class: Alpha gravelly loam.
>
> If the consociation is a mixture of dissimilar surface texture phases both textural class names separated by a hyphen follows the series name: Alpha sand-silty clay.
>
> The term for slope gradient follows texture class: Alpha gravelly loam, 2 to 5 percent slopes. [redacted] A descriptive term for slope can be used rather than percent gradient: Alpha loam, undulating.

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A term for erosion, if used, is the last part of the name: Alpha loam, 2 to 5 percent slopes, eroded. Generally, moderately eroded soil is designated simply as "eroded."

Other modifying terms are placed immediately after texture class: Alpha warm loamy sand, overblown; Alpha gravelly loam, moderately deep, 2 to 5 percent slopes.

If the dominant component of a consociation is a taxadjunct, the name of the series to which it is adjunct is used without qualification. If the dominant component is a variant the word "Variant" follows the name of the most closely related series, usually a series in the survey area. The name of an established series from outside the area is used only if all the series in the survey area contrast sharply with the variant.

A class above the series level can be the reference taxon. Except for families, names of classes above the series level are written as in Soil Taxonomy and are followed by one or more descriptive terms: Udolls, shallow. Generally the short name for a family is used: Gamma family, rolling. [redacted] instead of the short name. Conventions for modifying terms used in consociations named for classes above the series are similar to those used for consociations named for series except for texture and slope. Texture, if part of a name, is separated from the name of the taxon with a comma and is given in general terms (sandy, loamy, clayey), and slope is generally given in descriptive terms (level, steep, etc.): Xerolls, loamy surface; Mollisols, hilly; Hapludolls, shallow, steep; Lithic Hapludolls, stony; Alpha family, undulating; Alpha family, steep.

Miscellaneous areas that occur as consociations are named in the same manner as soil taxa. Generally the name of the miscellaneous area stands alone: Beaches; Rock outcrop. If a modifying term is needed, it follows the name of the miscellaneous area: Rock outcrop, basalt; Rubble land, steep.

Complexes and associations

Names of two or three, rarely four, taxa are used as reference terms in naming complexes and associations. The names are joined by a hyphen. If a miscellaneous area is a major component, its name is used as if it were the name of a taxon. The second part of the name is generally the word "association" or "complex," followed by one or more modifying terms if needed.

If the basic texture class of the surface layer of the major components of a complex is the same, the texture term can be used in the name instead of "complex" and is written in plural form: Alpha-Beta sandy loams. If a modifier for rock fragments or other modifier of texture is needed it precedes the term for basic texture class: Alpha-Beta gravelly sandy loams. If slope is needed in the name either descriptive terms or ranges in percent can be used in names of complexes and associations.

Examples: Alpha-Beta association; Alpha-Beta association, rolling; Alpha-Gamma association, stony, rolling; Alpha-Beta complex; Alpha-Beta complex, 12 to 20 percent slopes; Alpha-Gamma complex, stony, 12 to 20 percent slopes; Alpha-Rock outcrop complex; Alpha-Badlands association; Hapludults-Inceptisols association, steep.

Other terms are arranged as in names for consociations.

Undifferentiated groups

Names of two or three taxa are used as reference terms in naming undifferentiated groups. Generally they are followed by the word "soils." A term for basic texture class can be used instead of "soils" if the surface layer texture of the dominant components is the same. If two names are used, they are connected with "and." If three names are used, they are separated with commas, "and" being used between the last two names. Additional modifying terms are added as for associations.

Examples: Alpha and Beta soils, steep; Alpha and Gamma loams, extremely stony; Alpha, Beta, and Gamma soils, stony, steep.

Footnotes

1/ A polypedon consists of contiguous similar pedons and represents "a soil." It is bounded on all sides by "not-soil" or by pedons or unlike character. The limits of a polypedon are also the conceptual limits between soil series but a series normally has a wider range in its characteristics than a single polypedon.

2/ Some soil consociations may be less than one-half the named soil if most of the remainder of the map unit consists of two or more soils that are similar to the named soil. The unit is named for the dominant soil.

3/ Modifiers such as "cindery" or "very cindery" may be used where necessary.

4/ Lava flows in very wet climates that support a nearly continuous plant cover, even though the amount of fine earth is small, are classified as soil and not as Lava flows. Some soils of this kind have been in place for less than 100 years.

*U.S. GOVERNMENT PRINTING OFFICE: 1980-O-340-931/SCS-232

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Chapter 6

The Mapping Legend

Preparing the mapping legend is the principal duty of the party leader after preliminary field studies have been completed. The purposes of the survey have been stated in the memorandum of understanding; the party leader, in consultation with other specialists, determines what kinds of soil areas are significant for these purposes and can be consistently identified and mapped. He then describes the soils and the map units and proposes names and symbols for them.

The mapping legend is composed of two parts: (1) the descriptive legend, which contains description and classification of the soils, the identification legend, and the legend of conventional and special symbols and (2) mapping aids such as a genetic key, table of soil characteristics, and notes about individual soils or map units. The mapping legend contains the primary references and the principal guides for each survey party member when mapping soils. It is designed to serve the purposes of the soil survey and is unique to each area.

Preliminary studies are made in a survey area to identify sets of soil properties that are repeated in characteristic landscapes and are mappable. Not all of the soil map units needed for the complete survey can be anticipated at the start. An initial mapping legend is prepared after preliminary investigations and test mapping. The initial mapping legend should include only the descriptive legend and mapping aids for those soils, map units, and other features that have been definitely identified as needed. The number of map units in the initial legend depends on the scope of the initial studies, complexity of the area, and intensity of the survey. Map units must be defined and described carefully. These descriptions are the guidelines for mapping soils and the standards against which possible additional map units are evaluated as the survey progresses. The mapping legend should be made available to each member of the party before mapping begins. It is revised as needed during the soil survey.

As the survey progresses other material is added to the mapping legend, making a soil handbook for the survey area. The soil handbook contains all of the information and other related facts about the genesis, morphology, classification, and interpretation of the soils of the survey area. By the time mapping is completed the soil handbook should contain all of the material needed for the published soil survey.

Descriptive Legend

The descriptive legend is the basic document of a soil survey and is composed of three parts: (1) description and classification of the soils, (2) identification legend, and (3) legend of conventional and special symbols.

Description and classification of the soils

The descriptive legend includes descriptions of the taxa as they occur in the survey area and descriptions of map units delineated on field sheets. These descriptions form the primary reference document for identifying kinds of soils and miscellaneous areas. These descriptions provide the information needed for proper classification, correlation, and interpretation. They also provide the information needed to recognize the map units in the survey area. Descriptions of the taxa,

including the ranges in characteristics within the survey area, assure that all members of the field party classify the soils consistently. Creating a clear, concise, accurate, and complete set of descriptions of the soils is one of the most difficult and important jobs in conducting a soil survey.

An up-to-date record of what has been learned about the soils is especially important when members of the survey party change. An adequate set of descriptions shows scientists new to the survey area how the soils have been classified and mapped. If the party leader leaves, an up-to-date descriptive legend assures continuity in the survey operations.

The party leader prepares the descriptions of the soils by organizing the information that has been gathered about the soils in the area. While preparing the descriptions, the party leader may discover matters that need clarification or supporting field data. Field studies can then be planned to clarify concepts and improve knowledge of the soils.

Guidelines for describing soils in Chapter 4 emphasize individual pedons and polypedons. The soil descriptions in the mapping legend give the properties of pedons and polypedons plus the extent of the components in each map unit, the variations in properties and in extent of components from one delineation to another throughout the survey area, [redacted] within each map unit and of map units to each other. The descriptions are made from detailed descriptions of pedons and polypedons, brief notes about internal properties and surface features, and summaries of transects.

As the descriptions of the soils are prepared, every map unit description is compared with the standard definition of the soil for which it is named and with the descriptions of closely related soils. The classification of the soils must be consistent with the descriptions of the soils in the map units and also with the standard definition of series or other taxa.

A table of classification is included in the mapping legend and shows how soils in the survey area fit in the national system of soil classification. Where soil series are used in naming map units, the series can be listed alphabetically followed by the classification, or they can be arranged under the appropriate families, subgroups, etc.

The nature, kind, position, and amount of inclusions are also described for every map unit. The extent, position, and significant differentiating characteristics of [redacted]. The extent and nature of inclusions that are similar to the major components should also be determined.

The descriptions of the soils are references for the ongoing soil survey. The properties of a soil commonly vary from one part of a survey to another, and the central concept for a soil may be changed as a result of increased experience in the area. These changes may be overlooked if written records of the original concepts are not kept.

The soil descriptions are continually revised and updated as mapping progresses. During mapping new map units and taxonomic units are commonly added and a few units are found to be of limited extent and discontinued.

As mapping progresses, kinds of soil are often discovered that do not fit any map units in the legend. If the kind of soil is extensive and uniquely different

from the soils in other map units, it is added to the legend after it has been defined by a party member and approved by supervisory soil scientists of the cooperating agencies. Some new kinds of soil can be accommodated best by redefining existing map units, and others can be accommodated as inclusions. New approved map units must be listed in the legend promptly and so defined that all members of the party will use them correctly.

Some soils are so limited in extent that they should be included in other map units. Two or more soils that have similar use and management may be best combined in one map unit. Soils that are so closely intermingled that they cannot be delineated separately must be mapped as complexes or as associations depending on the detail of the survey. Deletions and other changes are not made formally until the supervisory soil scientists have reviewed the proposed legend changes and found them acceptable. If proposed changes are not acceptable, the agency representatives and the party leader resolve any differences they may have. A complete record is kept concerning changes in map units and the disposition of any discontinued map unit. Any changes made between field reviews are recorded in the report of the next field review.

Distinctions [redacted] are not [redacted]. The soil descriptions must be tested to ensure that the map units are recognized and delineated consistently.

Progressive mapping by the field party is a continuing test of the legend. Preparing and using interpretations of the soils also tests the utility of the legend. Inadequacies are evaluated, and any necessary changes are made in the legend. Changes are recorded on all copies of the legend, and each scientist must clearly understand the new concepts.

Field notes are summarized periodically and the summary is recorded in the revisions of the soil descriptive legend. If observations are not summarized and recorded promptly, they may be lost or not used by other members of the survey party.

Field reviews, other than the final review, also test the legend and its use in mapping to determine whether survey objectives and requirements are being met (Chapter 10). Such reviews usually involve supervisory soil scientists.

The final test of a descriptive legend comes during the formal steps in soil correlation. Correlation is a continuing process from the initial descriptions before mapping starts to the final correlation. A map unit can be tentatively correlated as soon as it has been accurately described and mapped. Few changes are needed in final correlation if the descriptions are adequately tested and revised as the survey progresses.

The quality of the soil survey is determined in large part by the quality of the soil descriptions. It is impossible to overemphasize the importance of these descriptions. Above all, a good set of descriptions is needed for consistent, uniform, and accurate mapping. The descriptions also provide the basic information needed for complete and accurate interpretation. Working from the soil descriptions, supervisory soil scientists can give maximum help to the survey party. The descriptions and their revisions provide the basis for many conferences of the field party.

Soil surveys of lesser detail, made with more widely spaced field observations, resemble the preliminary surveys made to prepare the initial set of soil descriptions for detailed mapping. For these surveys also, map unit descriptions are modified as more is learned about the soils. Map units are added only after they have been defined and approved by the representatives of the cooperating agencies.

Identification legend

A symbol is placed in each delineation on the map to identify it. The identification legend is a list of these symbols and the names of the map units they represent. In some legends the names of the map units are listed alphabetically, followed by their symbols. This list of names is used by soil scientists as they map. In other legends the symbols are listed in order, followed by their names. This list is used by everyone who reads the maps. Usually both lists are prepared. If the symbols are not listed in order, as is common when new map units are added to the legend, associating a symbol on the map with the map unit it represents can be difficult.

The identification legend keys names of map units to delineations on the soil maps through the map unit symbols. Many conventions and systems are used for selecting symbols. The choice of symbols is unimportant provided the symbols are short, each symbol is unique, and the map unit that each symbol represents is named and described.

All symbols must be legible on photographic reproductions of the maps. Long symbols are difficult to place on the map without being made too small to be legible. Long symbols often must be placed outside small delineations and arrowed into them. This increases the chances of error. Experience and tests have shown that map users have great difficulty in reading field sheets that have many symbols placed outside the areas to which they apply. If the symbol is arrowed from a large delineation to a small one, many users assume that it represents the large delineation.

The map symbols serve primarily to identify map units uniquely; any connotations of soil properties are incidental. Efforts to go beyond identification and devise connotative symbols usually leads to a legend that fails to achieve its primary purpose. The connotative value of symbols may be offset by decreased legibility of the map. Map users must not assume that connotative symbols or even the map unit names describe all of the important soil properties. The set of soil descriptions (map unit and taxon descriptions) is essential to the purpose of the soil survey and should be used by mappers and by those who need the information while the survey is in progress.

Using the same or similar symbols during the mapping process and on published maps accelerates map compilation because compilers are not required to spend much time converting one set of symbols to another. Errors are reduced. Such symbols have the greatest advantage in areas where soils are well known. Where soils are not well known at the start of the survey, changes during mapping and correlation may reduce the advantages.

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Following are parts of two identification legends.

Map symbol	Map unit name
AdA	Allendale loamy fine sand, 0 to 3 percent slopes
Ax	Angelica silt loam
Ba	Bach silt loam
Bn	Bonduel loam
Bo	Borosaprists
BrB	Boyer loamy sand, 1 to 6 percent slopes
BrC	Boyer loamy sand, 6 to 12 percent slopes
BrE	Boyer loamy sand, 20 to 35 percent slopes
Ca	Carbondale muck
CbA	Casco sandy loam, 0 to 2 percent slopes
CbB	Casco sandy loam, 2 to 6 percent slopes
CbC2	Casco sandy loam, 6 to 12 percent slopes, eroded
CdB	Casco-Rodman complex, 2 to 6 percent slopes

1	Almota silt loam, 7 to 25 percent slopes
2	Almota silt loam, 25 to 65 percent slopes
3	Alpowa cobbly silt loam, 30 to 65 percent slopes
4	Anders silt loam, 3 to 15 percent slopes
5	Anders-Kuhl complex, 3 to 15 percent slopes
6	Asotin silt loam, 7 to 25 percent slopes
7	Asotin silt loam, 25 to 65 percent slopes
8	Athena silt loam, 3 to 7 percent slopes
9	Athena silt loam, 7 to 25 percent slopes
10	Athena silt loam, 7 to 25 percent slopes, eroded
11	Athena silt loam, 25 to 40 percent slopes
12	Athena silt loam, 25 to 40 percent slopes, eroded
13	Athena silt loam, 40 to 55 percent slopes
14	Bakeoven-Tucannon complex, 0 to 30 percent

Conventional and special symbols legend

Conventional symbols on soil maps show many natural and cultural features other than map units and their boundaries. They help users locate delineations. Special symbols identify some areas of soils or miscellaneous areas that are too small to be delineated at the scale of mapping. [redacted] Definitions of special symbols specify the [redacted] of area that each represents.

The various mapping agencies of the United States Government have agreed on standard symbols for most cultural and natural ground features that are commonly identified on maps. Most of the symbols used on soil maps follow these standards. Some soil maps show special features that are not included in the standard list. The symbols for these must be compatible with symbols used by other mapping agencies. Different symbols are not used for the same feature, nor is the same symbol used for different features. Conventional and special map symbols must be functional and readily identifiable on the map.

Conventional signs and symbols used in soil mapping are shown on plate 6-1. Some of these are described in the paragraphs that follow.

Boundaries of cultural features are shown on soil maps by standard conventional symbols. These include the boundaries of nations, states, counties or parishes, minor civil divisions, reservations (including Federal or State parks and forests), land grants, parks, and cemeteries.

U.S. Geological Survey (USGS) maps are the primary source of cultural boundaries. Where USGS maps are not available or must be supplemented, local sources are used. County or state assessors, planning and zoning officials, and reservation superintendents are authoritative sources. Boundary monuments are located in the field and boundaries are plotted during soil mapping only where boundary location cannot be plotted accurately from references. Boundaries are verified as a precaution against errors.

Where cultural boundaries of different classes coincide, the symbol of the major subdivision is used, for example, where a state boundary coincides with a county boundary the state boundary has priority. Where a boundary obviously follows a stream or road for a short distance, the boundary symbol may be omitted. In some places, the road or stream may be labeled for clarity: "Road is county boundary"; "State boundary is center line of stream."

Township and range numbers are shown along the margins of field sheets for all lands that have been sectionized. Section lines are not shown. In some surveys all section corners are shown; in others, only those that have been located are shown. In the published soil survey, section numbers are printed in the approximate center of each section. Published topographic quadrangle maps show the land grid, though some old ones may need correction. Soil scientists working in an area should be familiar with the local land survey system and its intricacies.

Cemeteries are outlined to scale on field sheets using dashed lines. The name is usually placed within the outline of a large cemetery and outside a smaller one, although the smallest cemeteries are usually indicated by a cross and not named. A feature such as a road or stream may serve as a boundary for a cemetery.

The identification of airports and landing fields is optional on field sheets. Boundaries of large municipal, commercial, and military airports and landing fields are shown by the symbol for a reservation. The runway pattern is not delineated if it is apparent on the aerial photograph. Small airfields can be shown by a dashed line symbol similar to that used for a cemetery, or the symbol for a "located object" can be used and labeled. Each airfield that is identified is labeled by its proper name or as "airfield" if the name is not known.

Roads are identified on soil survey field sheets by symbol or name. In towns and cities only major roads are identified. Standard emblems are used to designate Interstate, Federal, State, and other roads, and route numbers are placed in the emblems. If roads are shown, a simple and explicit classification is used.

The mapping of trails depends on their importance for proper map orientation and the help they will provide in locating specific areas on the map. In sparsely settled areas having few readily observable landmarks, important trails are shown and named. In more densely populated areas where roads are common, trails generally are not shown.

Railroads are shown on field sheets by conventional symbols. They may be labeled as "railroad" or by the name of the line. Electric trolley lines both in urban areas and beyond city limits are shown by the standard railroad symbol and designated by operating name and type. In large railroad yards with parallel spur tracks and switches and sidings alongside single tracks, only the main track is shown.

Pipelines are shown on soil maps if they might be important as landmarks. A pipeline crossing a remote section of a survey area may be important. A similar pipeline in a populated area may be difficult to locate accurately and may have little value as a landmark. If shown, a pipeline must be accurately located.

Trunk power-transmission lines are normally not shown on field sheets unless they have value as landmarks. They must be individually evaluated. Lateral distribution systems are not shown. The symbol for power-transmission lines, if used, begins and terminates at towns, power stations, and survey area boundaries.

Levees are indicated by short ticks. If a road or railroad is on the levee, the ticks extend from both sides of the road or railroad symbol.

Large permanent dams are shown to scale on field sheets. Thin lines are used to delineate the base of the dam. Smaller dams are indicated by single heavy lines. A road following the top of a dam is shown in its correct place, and the road line on the upstream side is thickened to represent the dam. A dam symbol is inked to its scaled length. Important dams are named.

Permanent buildings such as rural dwellings, public buildings, and farm homes are shown on most published soil maps but are optional. In some areas, buildings are constructed so rapidly that the map is out of date before it can be published. In such areas, omitting symbols for all buildings other than churches and schools is best. In most soil surveys churches and schools are shown on the published map and may be named.

Symbols for individual houses are commonly not shown in urban areas. Prominent landmark buildings, such as large schools and large churches, may be shown, but they are not drawn to scale. Schools and churches, if shown, are identified by the conventional symbols.

The cross or pennant of a church or school symbol is oriented at right angles to a nearby roadway. A building used as both a school and a church is marked by the school symbol. If churches or schools are omitted from large urban areas but mapped in rural areas, the notation "omitted in urban areas" is made on the legend of conventional symbols.

Open pits, mines, and quarries smaller than the minimum area for delineation are shown only by conventional symbols. Larger areas are delineated, classified, and correlated as kinds of soil or miscellaneous areas.

Producing oil and gas wells may be shown. Where the number of wells is so large that the symbols are closely spaced on the map, the approximate outline of the field may be shown by dashed lines and the delineated area identified as "Oil field" or "Gas field" without the conventional symbol.

Water features

Streams and rivers are shown on the field sheets, and perennial and intermittent streams are clearly differentiated. The pattern of drainage and the classification must be complete. If the main drainage courses are identified by stereoscopic study of aerial photographs, the lines must be confirmed and the drainage classified in the field. Most distinct drainage courses more than 1 cm long on the field sheets are shown. Drainage courses are mapped to scale if wide enough to be shown legibly; they are shown by single lines if narrow.

A perennial stream is one in which water flows constantly except during periods of unusual drought. That a stream is perennial must be verified, especially in semiarid and arid regions where the water in streams and waterholes is vitally important.

Mapping large rivers that change course and width from time to time is difficult. The shorelines shown on a soil map generally mark the areas covered with water for so long that little or no vegetation grows during low water and unvegetated riverwash persists from year to year. Areas that are covered by flood water for only short periods are excluded. Areas that are uncovered only during very low water stages are included.

The level of river stages varies widely, depending on characteristics of the river in relation to the climate of its watershed and other factors. Where the flow of rivers, though active for brief periods, dwindles or ceases altogether for many months, the normal stage is very low. Thus rivers such as the Platte and much of the Rio Grande are normally braided, and the boundaries of the river are usually placed at the outer limits of the area of braided channels. Unstabilized sediment that is washed and rewashed and supports little or no vegetation but persists from year to year may be identified as riverwash. Areas within a flood plain that can support vegetation are shown as soil.

Some streams, especially in areas underlain by limestone, enter abruptly into caverns and may flow for long distances through subterranean channels. The points where the streams enter and emerge are located accurately, but only the surface drainage is shown.

An intermittent stream is dry each year for extended periods, usually for more than three months. In arid and semiarid regions especially, intermittent streams are distinguished from perennial streams because they are not reliable sources of water.

Poorly defined watercourses are not shown. Aggraded flats are valley floors without well-defined stream channels or scars. They are shown as soil.

Canals and ditches, whether for navigation, irrigation, or drainage, are plotted to scale if they are wide enough. Otherwise they are shown by the single-line symbol. Arrows indicate the direction of flow. Both the main ditches and important laterals of irrigation systems are usually shown. Large canals and ditches are named on the field sheets if they have names. On the map, canals and ditches must be distinguishable from roads.

Lakes, ponds, and reservoirs are delineated to scale on field sheets. The boundary marks the normal water level, which may not be the shoreline observed and recorded at the time of the survey. Normal water level may be marked by a line of

permanent land vegetation, but many lakes are bounded by wave-washed beaches above the normal water level. Many reservoirs are bounded by areas that are submerged when the water level is high. The shoreline that is evident on aerial photographs may be used to delineate the normal stage of a lake, pond, or reservoir. If a high water level other than wave-washed beaches can be identified, it is shown on the map by the intermittent water symbol and is identified. The area between high water level and normal water level can be defined as a soil map unit if the area is important. In these areas, the intermittent water symbol is not used; the intermittent water cover is described in the map unit description.

Reservoirs surrounded by an impounding structure are outlined. Some reservoirs have flood pool lines. These are determined from available sources, shown on the map by a dashed line, and given an appropriate label, such as "approximate flood pool line."

The shoreline of an island is determined at the same water stage as the adjoining mainland shoreline. Islands exposed at a lower stage are not shown.

Tidal shorelines present special problems. The mean high tide level (determined excluding the semimonthly highest tides) can be used where the land rises to elevations well above high tide within a short distance from the shore. Where broad marshes mark the transition from sea to land, the shoreline is the outer boundary of the area that supports plants and the soil boundaries extend to that line.

The shoreline of a body of water is not broken for wharves, piers, and similar structures that may be built over the water. Seawalls and retaining walls that are part of a shoreline are shown as the shoreline.

Intermittent lakes are shown on the field sheets as kinds of soil or miscellaneous areas. The dashed line symbol shows the area covered by water part of the year.

Marshes and swamps are mapped as soil unless they are too small to be delineated. If too small, they are shown by the conventional marsh or swamp symbol.

Springs are shown on the soil map if they are important in the area. In arid and semiarid regions, springs of all kinds are shown. In humid regions, only large and dependable springs are shown. Some springs have names, which may be printed on the soil map. In arid regions, intermittent springs or springs having salty or otherwise impotable water are so identified by notes on the map. Walled-in springs are shown by circles, like those for wells. A spring that is a source of a stream is shown by a circle where the stream symbol starts.

Artesian wells and wells for irrigation are shown on soil maps where they are important sources of water, as in arid and semiarid regions. Artesian wells are designated by a conventional symbol, whether or not they flow at the surface. In regions of few wells, all are shown; but in thickly settled areas that have many nonflowing artesian wells, they can be explained in the report without being shown on the map.

A wet spot is an area of wet soil too small to delineate. It is usually somewhat poorly drained or wetter and at least one drainage class wetter than the soil around it. Wet spot symbols are not placed within areas mapped as a wet soil.

Special symbols

Special symbols are used to identify small areas of various kinds of soil, miscellaneous areas, and special soil features. These are commonly used for areas that are too small to delineate but large enough to significantly influence use and management. If a specific kind of area is shown by special symbols, all such areas of that land are shown; the symbols are not to be used haphazardly. The symbols must be defined in terms of the kinds and size of areas each symbol represents.

Special symbols show relief features that are too small to show as map units, such as bedrock escarpments, short steep slopes, and gullies. Natural depresssions or sinks, such as those common to limestone areas, may be shown by the depression or sink symbol. Small areas of rock outcrop in an area of otherwise deep soil are obstacles to tillage. Small areas of saline soil, very stony soil, and the like in areas otherwise suitable for crops should be shown. Special symbols are also used for small areas of some kinds of soil that contrast sharply with surrounding soils in their management needs or productivity even though they are suited to the same uses. Small areas of gravelly soil in gravel-free areas, sand spots in areas of finer textured soil, and small areas of severely or moderately eroded soil in areas of noneroded soil are examples.

In some places, the pattern of mappable areas is so complex that soil boundaries with symbols leadered to the area they identify clutter the map. Special symbols used with moderation reduce the congestion of lines and symbols, but many special symbols in a small area also reduce legibility. Many areas of intricately associated kinds of soil may be better mapped as complexes.

Mapping Aids

Mapping aids include those items in the mapping legend that are not part of the descriptive legend but that help mappers identify soils in the field, understand relationships among the soils of the survey area, and remember differentiate between soils. Examples of mapping aids are a genetic key, table of soil characteristics, general soil map, remotely sensed data, display maps, photographs, diagrams, and notes.

A genetic key shows the relationships of the various taxa to factors such as parent material, natural drainage, vegetation, annual precipitation, topographic position, landform, and aspect. An example is given in illustration 6-1. The key should emphasize the factors responsible for important soil characteristics and differences in characteristics within the survey area.

A table of soil characteristics highlights important properties of the soils. Comparisons can be made easily and quickly. Both the genetic key and the table of soil characteristics are particularly helpful in orienting newly assigned field personnel.

The general soil map helps the field party in mapping and in organizing field work. The draft of the general soil map prepared during preliminary field studies is refined as more is learned about the soils. The properties, distribution, and extent of the soils in each general area and their suitabilities, limitations, and potentials are described. Signigicant differences in soil moisture or soil temperature between areas can also be shown on the general soil map.

Remotely sensed imagery is produced from both photographic and nonphotographic sensors. The use of more than one set of imagery for reference is important. Several sets of photographs and other images are likely to yield more clues about soils than one set. The kinds of remote imagery and their advantages and disadvantages in soil mapping are discussed in Chapter 3.

Photographs of soil profiles can be very effective in illustrating some soil features. Photographs or diagrams of landscapes show the relationships of soils to various landscapes. Cross-sectional and three-dimensional diagrams of parts of the survey area are also helpful.

Notes are indispensable parts of the mapping legend. Some notes are used in revising the descriptive legend, which becomes incorporated in the manuscript for the publication. Other notes help in mapping. They may record tonal patterns on aerial photographs that are peculiar to a certain map unit, or the relationship between minor but key indicator plants or surface configurations that have little bearing on use or management but that help the mapper locate significant soil areas, or any other information that can make mapping faster or more accurate. Notes and other information needed in mapping but not intended for publication can be kept on separate sheets after each taxon or map unit description in the descriptive legend.

Soil Handbook

The mapping legend is the main document that governs field operations, but it is only part of the information compiled during a survey. The mapping legend and the other information about the soils in the survey area are organized into a soil handbook. The soil handbook is used by the field party and by engineers, agronomists, planners, and others who need information about the soils of the area before the survey is completed.

The handbook contains everything needed for the published soil survey, plus material that is important mainly to soil scientists making the survey. A detailed outline for the text of the published soil survey should be decided on early in the survey to guide development of the handbook.

Included in a soil handbook, in addition to the mapping legend, are interpretations and general sections covering such topics as climate, physiography, relief, drainage, geology, and vegetation, which relate to the kinds of soil in the area and which improve the understanding of the properties, distribution, use, and management of the soils. In some areas sections on water supply and perhaps other topics are useful.

In addition, a record of the acreage of each map unit is maintained. In some surveys acreage is recorded progressively as the field sheets are completed. In other surveys progressive acreage records of each map unit are kept only until the unit is found to be extensive enough to keep in the legend, and the final tally is made after the survey has been completed.

Some items prepared for the mapping legend or handbook may be incorporated into different sections in the publication. For example, the genetic key and classification table could become part of the sections on how the soils formed and how they are classified. Some of the diagrams could also be used in that section or in the section on the general soil map.

In some surveys the mapping legend or soil handbook follows the same format that will be used in the published soil survey. A soil handbook that is kept up to date as mapping progresses and in publication format is the basis for writing the soil survey manuscript after mapping has been completed.

CONVENTIONAL AND SPECIAL SYMBOLS LEGEND

PLATE - 6-1

DESCRIPTION	SYMBOL

CULTURAL FEATURES

BOUNDARIES

- National, state, or province
- County or parish
- Minor civil division
- Reservation (national forest or park, state forest or park, and large airport)
- Land grant
- Limit of soil survey (label)
- Field sheet matchline & neatline

AD HOC BOUNDARY (label)

- Small airport, airfield, park, airfield, cemetery, or flood pool

STATE COORDINATE TICK

1 890 000 FEET

LAND DIVISION CORNERS (sections and land grants)

ROADS

- Divided (median shown if scale permits)
- Country, farm or ranch
- Trail

ROAD EMBLEMS & DESIGNATIONS

- Interstate
- Federal
- State
- Other

RAILROAD

POWER TRANSMISSION LINE (normally not shown)

PIPE LINE (normally not shown)

FENCE (normally not shown)

LEVEES

- Without road
- With road
- With railroad

DAMS

- Large (to scale)
- Medium or small

PITS

- Gravel pit
- Mine or quarry

CULTURAL FEATURES (cont.)

MISCELLANEOUS CULTURAL FEATURES

- Farmstead, house (omit in urban areas)
- Church
- School
- Indian mound (label)
- Lookout closed (label)
- Tank (label)
- Wells, oil or gas
- Shipwell
- Kitchen midden

WATER FEATURES

DRAINAGE

- Perennial, double line
- Perennial, single line
- Intermittent
- Drainage end
- Canals or ditches
  - Double - line (label) — CANAL
  - Drainage and/or irrigation

LAKES, PONDS AND RESERVOIRS

- Perennial — water
- Intermittent — intermittent

MISCELLANEOUS WATER FEATURES

- Marsh or swamp
- Spring
- Well, artesian
- Well, irrigation
- Wet spot

SPECIAL SYMBOLS FOR SOIL SURVEY

SOIL DELINEATIONS AND SOIL SYMBOLS

ESCARPMENTS — CaA FeB2

- Bedrock (points down slope)
- Other than bedrock (points down slope)

SHORT STEEP SLOPE

GULLY

DEPRESSION OR SINK

SOIL SAMPLE SITE (normally not shown)

MISCELLANEOUS

- Blowout
- Clay spot
- Gravelly spot
- Gumbo, silt or cobbly spot (scale)
- Gumbo and other similar non soil areas
- Prominent hill or peak
- Rock outcrop (includes sandstone and shale)
- Saline spot
- Sandy spot
- Severely eroded spot
- Slide or slip (tips point upslope)
- Stony spot, very stony spot

RECOMMENDED AD HOC SOIL SYMBOLS

(430-V-SSM, May 1981)

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Illustration 6-1.--RELATIONSHIPS OF POSITION, PARENT MATERIAL, AND DRAINAGE OF SOME SOILS OF SCHUYLER COUNTY, NEW YORK

Parent Material	Somewhat excessively drained	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained	Very poorly drained
SOILS ON UPLANDS						
Deep, medium textured, brownish glacial till with 18 to 27 percent clay in the subsoil.		Lansing	Conesus	Appleton		
Deep, medium textured, brownish glacial till with a compact fragipan.		Bath	Mardin	Volusia	Chippewa	Chippewa
Moderately deep, medium textured to moderately fine textured, brownish glacial till over shale.			Aurora	Angola		
Shallow, medium textured, brownish glacial till over sandstone and siltstone.		Arnot	Arnot	Tuller	Tuller	
SOILS ON LACUSTRINE PLAINS AND DELTAS						
Deep, clayey, reddish glaciolacustrine deposits			Schoharie	Schoharie	Odessa	
Deep, clayey, grayish glaciolacustrine deposits				Hudson	Rhinebeck	Madalin
Deep, silty, brownish glaciolacustrine deposits			Dunkirk	Collamer	Canandaigua	Canandaigua
SOILS ON OUTWASH PLAINS, TERRACES, AND ALLUVIAL FANS						
Medium textured to moderately coarse textured, brownish, glaciofluvial material over stratified sand and gravel.		Howard	Howard			
Moderately coarse textured, brownish, fluvial material over stratified sand and gravel.		Chenango	Chenango	Castile	Red Hook	Halsey
SOILS ON FLOOD PLAINS						
Medium textured, brownish, mildly alkaline alluvial sediments.			Teel	Teel	Wayland	Wayland
Medium textured, brownish, acid alluvial sediments			Philo		Atkins	
SOILS IN SWAMPS AND BOGS						
Deep organic material more than 51 inches thick						Carlisle
Moderately deep organic material, 16 to 50 inches thick, over loamy mineral soil.						Palms

(430-V-SSM, May 1981)

★U.S. GOVERNMENT PRINTING OFFICE: 1981—340-831:102

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Soil Survey Manual

Chapter 7

Field Operations

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Chapter 7

Field Operations

Soil mapping is a technical art. It requires sound training in soil science and familiarity with the principles of the earth sciences. A skilled mapper is a perceptive observer and understands the significance of landscape. Subtle differences in slope gradient or configuration, in landform, and in vegetation can be important indicators of soil boundaries. The soil scientist must learn to associate sets of landscape features with sets of internal soil properties to be able to visualize the pattern of the soils. A skilled mapper is able to abstract the essentials of the soil pattern and sketch this pattern on a map.

Above all, a good mapper strives for accuracy and is truthful about the reliability of the maps. The demanding standards for detailed soil mapping must be maintained throughout such a survey regardless of vegetative cover.

Even when the map scale is adequate and the legend is well designed, the legibility and usefulness of the maps still depends on the skill and judgment used in applying the legend. Some soil boundaries are more important than others and require greater accuracy. As much time and effort as necessary is spent to delineate small polypedons that contrast with their neighbors. In mapping consociations, for example, boundaries between highly contrasting soils, such as a wet soil and a dry soil or a clayey soil and a sandy soil, must be located as correctly as possible.

The greatest time and effort is spent to delineate dissimilar soils that are more limiting for use than nearby soils. Less time and effort, but still a significant amount, may be spent to delineate small areas of soils that are less limiting. Small areas of some kinds of soil are deliberately mapped with their more extensive neighbors if the two kinds perform similarly for the purposes of the survey. Useless detail is avoided. Special symbols are used to indicate significant areas too small to be delineated. The skill and judgment required of the mapper are part of the art of separating the landscape into meaningful units of soil and recording them on a map.

Using Aerial Photographs

Aerial photographs are used as the mapping base in most soil survey areas in the United States today. With few exceptions aerial photographs are by far the most practical mapping base for field use by soil scientists. The main kinds of aerial photography and their advantages and disadvantages for use in soil mapping are discussed in Chapter 3. The kinds of photography described are: panchromatic, color, infrared, modified infrared, and color infrared. Other kinds of imagery such as that made from side-looking radar are also discussed.

Light and dark tone on panchromatic photographs and color differences on color photographs, for example, are records of light reflected when the photographs were taken. These records must be interpreted by relating the visual pattern on the photographs to soil characteristics found by inspection on the ground. Using the aerial photographs of an area, a soil scientist learns many relationships between the photographic images and soil and landscape features, but many uncertainties inevitably remain. Awareness of the factors that affect the image is required to interpret the aerial photographs as fully as possible.

The techniques used to predict specific kinds of surface features, landforms, attributes of soils, and soil boundaries from photographs are continually being refined. Published material provides information about the techniques and the kinds of clues used by photo interpreters. Some publications provide helpful illustrations of specific features. Nevertheless, reliable predictions of many features in a particular area require experience in relating the images on the photographs to what is actually on the ground.

Such features as roads, railroads, buildings, lakes, rivers, field boundaries, and many kinds of vegetation can be recognized on aerial photographs.

Relief can be perceived by stereoscopic study. Shadows and differences in tone between slopes that faced the sun and those that did not at the time of photography also help show relief. Relief features help locate many soil boundaries on the map. Relief also identifies many kinds of landforms, which are commonly related to kinds of soil.

Many landforms--such as terraces, flood plains, sand dunes, kames, eskers--can be identified and delineated reliably from their shapes, relative heights, and slopes. Their relation to streams and other landforms provide additional clues. The soil scientist must understand geomorphology to take full advantage of photographic imagery.

Some landforms are less easily identified, but most images contain clues that narrow the choices of the kinds of landforms represented. Experience in interpreting tone patterns, configuration of relief, and patterns of drainageways commonly permits correlation of these patterns with kinds of geologic deposits and geomorphic features in an area. As the survey progresses, experience increases and the reliability of predictions usually improves.

Differences in tone or color may reflect soil differences. Differences caused by man-imposed land use usually can be recognized by the angular shapes and abrupt boundaries of the areas. Other tonal differences may reflect differences in vegetation related to soil or differences in the surface of bare soil. Certain patterns of tone or color may reflect local soil patterns within areas that can be mapped in one day. Different soil associations have distinctive patterns that can be recognized on photographs. These patterns serve as bases for drawing tentative soil boundaries and for predicting kinds of soils. These predictions of soils and boundaries must be verified in the field.

Accurate soil maps cannot be produced solely by interpretation of aerial photographs. The clues on the photographs imply different things in different places and at different times in the same place. Shades of gray commonly reflect soil moisture state when the photograph was taken; but the soil moisture state changes with time. Clues to soil boundaries that are evident on photographs taken at one time are not necessarily evident at another time. The activities of man have changed patterns of vegetation and confounded their relationships to soil patterns. The clues must be correlated with soil attributes for each set of photographs, and predictions of soil properties from such clues must be verified in the field. The accuracy of maps improves as fieldwork and experience increase. [17]

Before an area is surveyed, making a careful stereoscopic study is helpful. The area is scanned with a stereoscope for a general impression of farming, relief, geology, landforms, kinds of soils to be expected, soil moisture states, and so forth. Important features that can be accurately identified are sketched lightly on

the photograph. Some features can be determined with more certainty than others. Images that help identify obscure features can be marked. The following steps are commonly used in preliminary studies.

1. Drainageways, streams, and ponds are tentatively sketched.

2. Roads, buildings, and other location references are identified.

3. If soils have been mapped along the match line with an adjacent photograph, the soil boundaries are transferred to the outside edge of the match line. Some soil boundaries can be tentatively extended onto the unmapped sheet.

4. Additional features can be lightly penciled if they can be identified with confidence: boundaries of flood plains and stream terraces, boundaries of wet areas and water, prominent landforms such as escarpments and areas of rock outcrop, gravel and borrow pits, ridge lines, rock outcrops, sinkholes and wet spots.

Routes of traverse can be planned during these preliminary studies. Obstacles can be identified and plans made to avoid them. Enough field checking is planned to ensure maximum accuracy with a minimum of walking per unit of area mapped.

As experience is gained in an area, many soil boundaries and kinds of soil can be tentatively predicted on the photographs. These predictions must be verified in the field, but preliminary interpretation can increase both quantity and quality of mapping. During such preliminary studies, the map should not be cluttered with conjectures. Only features that can be predicted with confidence are marked.

After fieldwork, mapped sheets are examined again while the landscapes are fresh in the mind and can be related to the stereoscopic images. If considerable time elapses, details may be forgotten. Resolving questions that the review may raise becomes more difficult, and a special trip to the field may be needed. Some drainageways, slope breaks, and soil boundaries observed in the field may have been impossible to place accurately on the photograph because of dense vegetation or other conditions that obscure the image on the photograph. Such features are sketched tentatively in the field, and their locations are later checked by stereoscopic study and revised as necessary. Thorough stereoscopic study of areas that have been mapped commonly reveals places where soil boundaries or stream symbols need to be refined to conform to relief. The traces of roads in heavily forested areas may be obscure on single photographs but evident under the stereoscope. If some boundaries inadvertently were not closed during field mapping, they can often be closed with confidence on the basis of stereoscopic study.

In the field the images of features such as roads, houses, streams, field boundaries, individual trees or bushes, and the like are used to identify locations on the ground with points on the base map. The photograph can be oriented so that the relative position of its images corresponds to the relative position of ground features from the surveyor's vantage point. The photographic images of surface features that mark soil boundaries can be followed in sketching the boundaries. Boundaries that are not evident on the photograph can be sketched in relation to identifiable ground features.

In some areas a stereoscope used in the field with stereoscopic pairs of photographs is helpful. A pocket stereoscope (figure 7-1) can be used on the hood of a vehicle or on a dropleaf shelf. It can be carried while walking. The stereoscope

and pairs of photographs can be used to relate the landscape features to the stereoscopic images. Kinds of soils and the location of boundaries can be predicted from the stereoscopic image. Boring or digging is needed to identify soils positively and to verify predictions, but stereoscopic study commonly reduces the number of borings needed to locate the boundaries of an area.

Mapping Soils in the Field

A soil scientist plans the day's work as a series of trips across the area to be mapped. Proceeding along these routes, the soil scientist predicts boundaries and the kinds of soils within them. These predictions are checked as the areas and boundaries are crossed. Finally, boundaries and kinds of soils are plotted on the map. Thus, fieldwork consists of a sequence of predictions and verifications.

To the extent feasible, mapping is scheduled to proceed systematically across contiguous areas. When mapping is resumed each day, the previous day's mapping provides points of reference. The boundaries that were projected tentatively the day before are predictions to be verified. The soil patterns and the clues for interpreting the landscape are already understood. Mapping systematically across contiguous areas contributes greatly to both efficiency and quality of the work.

Ground traverses are planned to cross as many soil boundaries as possible. Soil areas generally conform to the orientation of features of relief, which are commonly related to drainage courses. Consequently, the most soil boundaries and the most soil areas usually can be crossed by traveling at an angle to the secondary or tertiary drainage courses. The traverses are spaced closely enough that the boundaries identified and projected on one traverse can be identified and continued on the next. Traverse spacing depends on the complexity of the soil pattern, visibility, and amount of detail required by the survey objectives. In fairly detailed surveys, for example, traverses are planned to pass within 200 to 400 meters of every point in the area, thereby permitting detection of small areas of contrasting soils.

Where aerial photographs are used as the mapping base, a predetermined line of traverse need not be followed consistently if there are sufficient reference points for accurate location. A traverse can deviate from a planned route to cross landscape features that may be marks of soil boundaries. However, wandering from place to place at random should be avoided. Aerial photographs assist in avoiding obstacles on the route. If boundaries are observed to run in a different direction than had been anticipated, the plan can be adjusted with little trouble.

From any point of observation, the soil scientist looks along the projected route and predicts the kinds of soils on the landscape ahead. A break in slope gradient, a change from convex to concave slope configuration, a change in the color of the surface of a plowed field, the margin of a swamp or forest, the edge of a stony area, a change in kind or vigor of crops--many observable features of this kind can be related to soil boundaries. If possible, these features are identified on the aerial photograph. Some may already have been marked during the stereoscopic examination. If soil boundaries follow identifiable features, they are lightly traced on the photograph in pencil. Boundaries that are not evident on the photograph are sketched on the map in relation to identifiable features. Most features must be located and sketched by estimating location in relation to the point of observation and other known points. Tentative soil boundaries are sketched for perhaps 100 to 200 meters ahead and on either side of the point of observation. Natural and cultural features, such as a stream or drainageway, that are immediately ahead are also sketched on the aerial photograph.

Some soil boundaries are sharply defined, as illustrated in figure 7-2. Others are plotted as lines midway in zones of gradual transition from one soil to another, as in figure 7-3. A judgment is made about whether a broad transition zone is a discrete mappable soil unit or should be split and its parts included with the soils on either side. Every part of the mapped area must be enclosed in a boundary and assigned a symbol.

After predictions are made and sketched on the map, the soil scientist walks across the predicted boundaries. The course is adjusted as necessary to investigate transitional zones and any unusual features. Slope gradient is estimated or measured with an Abney level or a clinometer. As a predicted soil boundary is approached, especially in a broad transition zone, the soil is examined to locate the significant changes in soil properties.

As a projected delineation is crossed, the distribution of microdepressions, microknolls, tiny areas of different vegetation, convexities and concavities, and other features too small to delineate are observed. The soil is examined at a place where the microfeatures suggest that the predicted dominant soil should be best expressed; and this portion of the delineation is identified positively. The prediction may be confirmed, or a different kind of soil may be found. Where microfeatures suggest important inclusions, additional observations are made to ensure that the evaluation of the whole delineation is good. Sites for examination are not chosen at random if reasons exist for dividing the projected delineation into parts that are the predicted soils and parts that are not.

The number of places at which observations are made depends on the certainty of the predictions and the objectives of the survey. If predictions about the kind of landscape under examination have been valid, many times before, soils need be examined in only a few places or not at all. If the landscape features have not been consistently related to kinds of soils, many places must be examined. The depth of the examinations depends on the depth of differentiating criteria for the map unit and on the confidence in the predictions about the kind and uniformity of soil material at depth. The examination itself is rapid and is mostly a search for a few properties that identify the soil. A small sample of a pedon is observed; seldom is an entire pedon studied.

After a delineation has been identified and crossed, the soil scientist turns and looks back on the landscape from a new vantage point. A final judgment is made on the boundaries and symbols. If mapping is done on an aerial photograph the photographic images are checked against the landscape features before the final boundaries are sketched.

Soil boundaries are projected on either side of the traverse as far as they can be seen and identified with reasonable certainty. The ends of their projections are checked from the next traverse. Many boundaries can be seen throughout their length. Other boundaries can be predicted on the aerial photographs with a high degree of certainty. In forests, for example, visibility may be a few tens of meters or less, but where a slope break that marks a soil boundary can be seen under the stereoscope the boundary can be plotted much more accurately by studying the photographs than by observation on the ground. A soil boundary that is found at one point to correspond to a change in color on the photograph is commonly continued along the change on the photograph even though the boundary itself is not visible on the ground during mapping. In detailed soil mapping many boundaries between traverses are drawn on the basis of variations in the photographic image.

In mapping, a pattern of soils and landscapes is conceived, rather than a group of individual map units. Certain soils are typically found together. The number of soils in any locality is usually small. The soils likely to be found in a landscape are known from experience or are learned.

In most places landscape features mark the kinds of soils. But landscape features do not identify soils everywhere, and by no means can all internal soil properties used to define map units be correlated with external features. Where soil boundaries cannot be predicted with confidence, they may be identified by direct examination of the soil.

In some areas, important attributes of the subsoil or substratum are not related to surface features. Depth to bedrock, layers of contrasting texture, salt in the substratum, and similar attributes may have no visible relationship to the vegetation or other natural features but may be important when the soil is used. When desert is irrigated, when wet soils are drained, or when highways are built, soil differences that are not reflected in landscape variations may become important.

Conditions of this kind occur in most survey areas. If common mapping techniques are used, the predictions frequently turn out to be inaccurate for some areas. Unless the mapper can reappraise the landscape and reliably predict the extent of the soil, the boundaries must be determined by actual examination.

In large areas where landscape has low predictive value, geologic history and geomorphology may provide guides to stratigraphy, depth, and distribution of kinds of rocks, which are related to kinds of soils. The general hydrology of an area may indicate where salt-charged water has moved and where the salt has concentrated. Streams and their traces help in locating areas that have layers that differ in texture. As much preliminary information as possible is assembled to help determine the pattern and scale of soil variability. This information helps in planning the route and spacing of traverses and the spacing of samples within the traverses.

In some surveys, for example, areas to be irrigated land, samples of critical layers may be taken for special field testing or examination to determine boundaries. These samples may be taken at points on a predetermined grid which coincides with lines of traverse.

Where internal properties of soils are used for locating boundaries, a predetermined line of traverse is generally followed. Side trips are made wherever landscape features or experience with the soil pattern indicates that there is probably a significant soil change between traverses. Usually, the soil is examined at some standard interval along the traverse to locate important differences. If properties deep in the soil are important, the plan may require observations at fixed depth-intervals to a certain depth, such as 1 meter, and with layer depth intervals to greater depth.

In most areas, some feature of the landscape or some aspect of the pattern of soils already mapped on an adjacent traverse provides a basis for predicting the location of soil boundaries. As evidence of change is observed, preliminary observations are made. Where the evidence indicates an important soil boundary, the soil is examined in more detail or to a greater depth to verify the prediction.

Where power equipment can be moved freely across the countryside, it can be used to examine the soil to considerable depth at close spacing. Map units based on

properties deep in the soil can be delineated with reasonable accuracy and a reasonable rate of progress if the geographic distribution of those properties is consistent with the scale of mapping.

Neither standard intervals between traverses nor intervals for investigating the soil within traverses can be specified with certainty. The plan is adjusted to the direction and scale of the soil boundaries and the variability of the important properties. This kind of evidence is commonly obtained as the survey progresses, and the mapping plan can be altered to fit the accumulated evidence.

A great deal of skill and judgment is required in areas of low predictability because the mapper must depend on individual sites as samples of the area. Rarely are the soils at two sample sites exactly alike. Study of a single site is not enough to identify a significant area. Map units are defined to include the variability within areas large enough to be meaningful for the objectives of the survey. Using preconceived ideas of significant limits of definitive properties to define map units without regard to their geographic distribution usually results in unmappable units. Meaningless boundaries may result. Delineations should show the pattern and scale of orderly variation of soils. The kinds of variability over short distances should be noted in the descriptions of the map units.

In all soil surveys distinctive landscapes are outlined on the map first. In surveys where most map units are fairly large and contain more than one kind of soil, landscape patterns are identified mainly by interpretation of aerial photographs, by aerial observation, and by study of topographic maps, geologic maps, land use maps, and other available information. The size of the outlined areas depends on the objectives of the survey and the landscape pattern. Preliminary areas are of course no smaller than the smallest delineation that will appear on the soil map. They are often much larger. In 3rd, 4th, and 5th order surveys, however, most map units are made up of more than one kind of soil or miscellaneous area. Map units usually coincide with the landscapes outlined in preliminary work and commonly consist of associations of soil series or other soil taxa.

Traverses of the preliminary delineations may be desirable, depending on the level of generalization required for the survey, and the complexity of the soil patterns. The plan of traverses usually is based on interpretations of photographs, but this plan should be tested in the field.

In areas of low accessibility roads or trails may be traveled; but the mapper must understand the bias associated with them. Roads and trails commonly follow the easiest routes and avoid the steeper slopes, the wetter areas, the other places that are difficult to cross. Such places are integral parts of soil associations and should be observed by the mapper on the ground.

Transects are commonly used to determine the composition of map units. In transecting, a planned line of travel is followed as closely as possible and the soils are observed at predetermined regular intervals.

In transecting, routes of travel are systematically planned to give a valid sample of the area. Taxa phases and other features are identified and recorded. Distances or number of points along the route identified by each taxon provides estimates of the composition of the map units. In surveys without easily predictable patterns, soils are sampled most efficiently if the transect lines are selected at random. Lines oriented to cross the drainage pattern often provide the most information about the pattern of soils.

Sample blocks, instead of transects, are used in some soil surveys to determine the composition of map units. Blocks do not replace traverses, however, they permit one to observe spatial patterns not always evident from transects. Sampling by transects is usually more efficient than block sampling for estimating map unit composition.

Methods for sampling by blocks vary among soil surveys. One method imposes a grid of appropriate divisions on the entire area. Grid segments are numbered, and sample blocks are selected by drawing numbers at random. Each sample block is mapped in detail, and the area of each kind of soil is measured. These data provide estimates of the kinds and proportions of soils in each map unit. The number of blocks and their size is determined by statistical principles with consideration of mapping scale, the limits of confidence required for the survey, the general pattern of soils, and the relative size of soil areas.

For 5th order map units, time, resources, and accessibility drastically limit sampling. At least some transects or blocks are mapped in detail in some part of each map unit. The data from these samples, along with observations from traverses and spot observations, yield estimates of "most common" proportions of taxa in each map unit.

Mapping of organic soils follows the same general principles as mapping of mineral soils. However, organic soils have some special relationships to landscape and vegetation. These relationships affect mapping of organic soils at all levels.

In preparing the mapping legend, systematic investigation of organic soils is required as for other kinds of soil. A thorough knowledge of the genesis of organic soils is required, as well as high-quality imagery and appropriate tools.

The kind of organic soil in many areas is closely related to the kind and pattern of native vegetation. Since many areas of organic soils are comparatively undisturbed, reliable relationships between soils and plant communities can be established. Thus, high-quality imagery from serial photography and other forms of remote sensing can be very useful in preparing legends and in mapping these soils.

Where organic soils have formed directly on a mineral substratum, the environment may be rather uniform over extensive areas. Although the kind of organic material can vary with depth because of changes in climate over the period in which the soils have formed and because of differences in rate of decomposition resulting from the accumulation of the organic material, such variations commonly are uniform over large areas. Therefore, the properties of a large area of organic soils can be accurately estimated from the properties of a small sample.

Organic soils are not uniform in some areas that have microrelief of hummocks and swales. The hummocks commonly contain fibric material, and the swales contain hemic and sapric material. In such landscapes, many more sites must be examined to determine the nature of the soils.

These relationships and processes generally apply where organic soils are formed by lake filling. However, each basin in which organic soils have formed has a unique local environment, and the organic soils in adjacent basins may differ considerably. This is particularly true in irregular glacial moraines. For example, limnic materials may be covered by only a thin mantle of organic material in some basins and by several meters of organic material in others.

Areal relationships must be kept in mind when estimating the extent of the different soil components within basins, particularly small basins. For example, one kind of organic soil occupying a rather narrow fringe of a bog may cover a greater area than the kind in the center.

In northern glaciated areas in particular, organic soils may form around the edges of swamps that have open water in the center while adjacent swamps lack surface water.

In some areas a layer of water can underlie the organic soils at a relatively shallow depth. Such areas may not support much weight and should be investigated with caution.

Organic soils of some coastal wetlands lack distinctive landscape features and, additionally, are poorly accessible. In these areas the soil scientist relies on other features to predict kinds of soils. In many coastal areas patterns and kinds of soils can be related to the position of such natural features as shores, deltas, streams, and adjoining higher land. The soil scientist must acquire a thorough knowledge of the geomorphic history of the area in order to make reasonable predictions related to such features and to determine the places where transects and other field chekcs will best verify the predictions.

Recording Field Data

Keeping complete and accurate notes is an important part of every field worker's duties throughout the progress of the survey. Good notes are relevant, easily understood, and legibly written.

Perhaps the most difficult job for an inexperienced soil scientist is learning to notice and record the commonplace--the common soils, vegetation, crops, farms, farming practices, and behavior of soils. The commonplace is unconsciously accepted as the norm, and only departures from the norm are noted. Such notes are inadequate to define and describe map units or prepare other working documents. Learning to describe the ordinary is of great importance.

Notebooks are an important item in a soil survey. Preferences in size and form of notebooks vary widely. The notebook should be easily carried and used in the field, for that is where the observations are recorded. Standardizing the size and form of notebooks within a soil survey project permits sorting and consolidating the notes of different workers. Looseleaf notebooks are useful for this purpose. Author and date should be identified on each sheet.

Standard forms for describing soil properties are useful for recording information rapidly and consistently. Using such forms ensures that information is not omitted. The National Cooperative Soil Survey has for many years used a standard form for describing pedons. The use of a standard set of abbreviations for soil properties adapted to this form has allowed the size of the form to be small and easily carried in a field notebook and has allowed rapid note-taking. Only a fraction of the pedon data currently available would have been assembled without the form. It is equally true that some things are not known because of it; some observers have recorded only the data for which the form provides specific spaces.

Many important attributes of pedons are unique to certain kinds of soils. Some of these eventually prove to be very important. The interfingering of a strongly eluviated horizon into an underlying illuvial horizon, for example, was not

accommodated by the standard form used for many years for pedon descriptions and was seldom recorded. When this property was found to be useful for classification, the data needed to classify many series were lacking. Narrative descriptions can be written for pedons that have unique attributes or a standard form can be used and supplemented with additional notes. All standard forms provide space for additional information.

The characteristics of landscapes and the relationships among associated landscapes and the soils on them should be noted. Patterns on aerial photographs used to predict similarities and differences among landscapes should be noted. During the intensive study of the area, the observed behavior of soils under different uses should be recorded. Notes about composition, size, shape, and distribution of map units provide a sound basis for preparing map unit descriptions.

Recent advances in the field of automatic data processing have led to the development of "mark-sense" forms to record pedon data. These forms list all of the conventional soil properties used to describe pedons. Designations and limits of these properties are listed in a numbered grid system of boxes, which are marked by the user. These marks are read electronically and entered into a computer. The pedon data can then be stored and retrieved as a complete pedon description. As with other standard forms, the mark-sense forms provide space for additional information.

Forms for describing map units are also used in the National Cooperative Soil Survey. These forms have the same benefits and limitations as the ones used to describe pedons. Because these forms list many of the items of information needed to identify and describe map units, their use ensures that these items become well documented during the course of the survey. But some observers tend to be inhibited by forms and record only the items of information called for on the form. Some of the kinds of information needed to adequately describe map units cannot be described in enough detail on a form unless adequate space is provided for additional information. Such kinds of information as the characteristics of landscapes, the geographic relationships of the components of a map unit, and the behavior of these components under different conditions probably need to be given in narrative statements.

Any observation about any attribute of a map unit made during the course of mapping is worthwhile and should be recorded in sufficient detail so as to fit into a pattern when the notes are assembled. Many field notes are too brief and thus have only limited value. No matter how they are taken, complete and accurate notes provide a sound basis for preparing map unit descriptions. They are useful in preparing and verifying interpretations. And they help to test the validity of map units that will serve the purposes of the survey.

Notes should be assembled in a form that permits effective use. Various methods are used to sort field notes, but first the notes must be recorded in a form that can be sorted. Notes for two taxa, for example, should not be recorded on the same page unless the notes characterize relationships within a complex or association. Separate files can be made for map units and their component soils.

Completing Field Sheets

Most soil survey field sheets are individual photographs or compiled photobase maps. As each field sheet is completed it is joined with adjacent sheets and checked for errors.

Joining field sheets.--Each pair of adjacent field sheets shares a common match line. During mapping, soil boundaries are commonly extended beyond the match line to be transferred to the adjacent sheet; but when the field sheet is completed, soil boundaries and other features may be discontinued at the match line. The mapping on each field sheet should be carefully matched with that on adjacent sheets to check boundaries and delineations. Roads and streams also should be continuous from one sheet to another. Special care is needed at the corners where four field sheets join.

If soil boundaries are sketched on overlays, field sheets are matched before soil lines are transferred to the soils overlay. Matching should be completed while the photographic background is available.

The mapping on one field sheet can be matched with that on an adjacent sheet in several ways. For aerial photographs, the mapped field sheet and an adjoining unmapped field sheet can be placed under the stereoscope and the images meshed. The soil boundaries and other features on both sides of the match line can then be transferred from the completed field sheet to the unmapped sheet.

Another method, that is particularly useful if adjoining field sheets vary in scale, is to transfer boundaries by reference to the photographic images. Along the match line the relationship of the soil boundaries to images of isolated trees, clumps of bushes, field corners and the like are observed. Images of the same features are located along the match line of the adjoining photograph, and the boundaries are transferred or checked in relation to the images.

If adjoining field sheets are the same scale, a strip of transparent paper or plastic can be placed along the match line of a mapped sheet. The mapping at the margin is marked on the transparent strip, which is then placed along the match line of the adjacent sheet for checking or for transferring the mapping.

When the second field sheet is mapped, boundaries of delineations that cross the match line may be altered. Consequently, the boundaries at the match line must be rechecked after both field sheets have been completed. If different individuals map adjacent field sheets independently and the sheets are joined after both have been completed, the matching checks the uniformity of fieldwork.

If there is no systematic method of joining sheets, errors are easily made that may require additional fieldwork before the final map can be compiled. Figure 7-4 illustrates some errors on unmatched field sheets.

Inking field sheets.--After mapping has been completed on each field sheet, it may be inked to provide a permanent record and to provide a map from which copies can be made (plate 7-1). All soil boundaries and symbols and important drainage features should be inked. Cultural features needed on the soil maps are determined before mapping starts and are specified in the legend.

Inks or leads that reproduce photographically and are readable by automatic scanning equipment are preferred. The ink or lead used should be compatible with the base material, and the lines should be opaque. Several kinds of inks and leads are suitable. Pens that store carbon-base ink in a reservoir are commonly used.

Several pens that make uniform lines of different thickness are needed for inking different features and for lettering. Line widths recommended for different features are indicated in the list of conventional symbols in Chapter 6.

Commonly, different groups of features are inked in separate operations. Drainage is inked first and inspected to see that individual streams are properly joined, matched, and classified. Then, culture is inked and the classification of roads and other features is checked at the same time. Then soil boundaries and symbols are inked. Finally, the place names are lettered. In some surveys, however, certain features may not be inked. For example, if the photographic image of all roads is pronounced, they do not need to be inked.

If photobase map sheets are used as field sheets, the inking may be done on transparent overlays. As many as three overlays can be used: one for culture and drainage, one for soil boundaries, and one for symbols. Together these form a composite overlay and can be used in printing the final map. The individual overlays can be used in printing special purpose maps. Adhesive-backed clear stripping film with printed symbols can be applied to the overlay, saving handwork.

In inking soil boundaries, a good procedure is to close each boundary within one section of the field sheet. When the boundary of an area of soil is closed, its symbol is placed as near the center of the area as practical. More than one symbol is placed in areas that extend for long distances and in those that have intricate shapes.

Mapping along the match lines may be left in pencil until the field sheets have been joined.

Soil symbols on all sheets should be positioned to be read horizontally, or as nearly so as possible, when the map is oriented in one direction. Usually, north is toward the top of the map. If an area is too small to contain a symbol the symbol may be placed outside it and a leader used to indicate the area to which the symbol applies. The leader should be so placed that it cannot be confused with a soil boundary.

Place names should be inked last so that they may be placed where they will not obscure soil symbols and other details. Place names should be arranged so that they clearly identify their features. Names of features expressed as lines on the map are oriented parallel to the lines. Names of other features are usually oriented horizontally, with north at the top. Important features that serve as landmarks should be named on each sheet. Names of streams should be so positioned that no confusion arises about which branch is meant. Incorrect and correct placement of names are illustrated in figure 7-5.

Neatness and legibility are important in lettering. Maps with many soil symbols, boundaries, cultural features, and the like become confusing unless the lettering is done with special attention to high standards. Every soil scientist should learn the art of freehand lettering.

A simple style of lettering should be used. Freehand styles that use single strokes are best for inking field sheets. The pen is held as in writing and the strokes are made with an even steady motion. Slant or vertical lines are made with a downward stroke; horizontal lines are made with a stroke from left to right. The slant of the letters is kept uniform.

Checking field sheets.--Each field sheet should be checked for open boundaries, areas without symbols, and other errors. Field workers usually check their own sheets, and another person may check each sheet for completeness and legibility. The party leader should be responsible for checking the mapping of each party member.

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The mapping of beginners generally needs much checking. If different soil scientists map adjacent field sheets, the party leader can compare their mapping in the areas where the sheets join. During field reviews, supervisory soil scientists responsible for technical standards often check boundaries and symbols on samples of each soil scientist's field sheets.

After mapping has been completed, the party leader should check all of the field sheets to see if any corrections and remapping are required. Omissions and inconsistencies increase the cost of map construction and delay publication. The most common mistakes, in order of frequency, are--

1. incorrect joining at the match line,
2. failure to close map unit boundaries,
3. omission of symbols or use of symbols not identified in the legend,
4. incorrect interpretation of cultural and drainage features,
5. use of incorrect place names.

Failure to close soil boundaries is a common error. Figure 7-6 has three open boundaries--between map units 11 and 31, between units 62 and 25, and between units 38 and 62. The person who inked this sheet probably overlooked the lack of closure because of the drainage lines and railroad symbols that cross the area. Whatever the cause, the user cannot tell where one unit ends and the other begins. Someone may have to make a special trip to the field to close these boundaries.

Each area of a kind of map unit must be completely separated from all adjoining areas by a soil boundary or the boundary of a body of water. Neither the single lines representing streams nor the conventional symbols for roads, railroads, and the like can serve as map unit boundaries. Each area also must contain the symbol for only one kind of map unit.

Errors in symbols take various forms. A delineation on a field sheet might be closed without a symbol in it, or a symbol not listed in the legend might be used. Symbols might be illegibly drawn on the field sheet. A carelessly made "91" may be read as "11," "71," or "77." Practice and care in lettering, good judgment in placing symbols, and care in erasing and reinking mistakes ensure legibility.

Various methods are available for checking field sheets. A good method is to color each delineation by hand on photographic copies of the field sheets. A color check reviews each delineation and inspects boundaries throughout their length. In another method, each field sheet is divided into sections of perhaps 50 to 100 square centimeters. The delineations within each section are checked one at a time, special care being taken at the edges of the sections. If the map checkers are not familiar with the legend, they must be especially diligent in checking the symbols against the legend.

Incorrect placement of drainage or cultural features on the map can seriously reduce the accuracy of map unit boundaries. The location of streams, roads, and the like must be correct. Most errors in placement cannot be checked with precision except by stereoscopic study or field investigation. If accurate reference maps are available, locations of features on the field sheets are checked against them. If possible, locations are checked while mapping is in progress. Place names are verified with an authoritative source.

Keeping records of field sheets.--Each field sheet may be identified by a number that locates it on an index map of the area. The index map outlines and identifies

all of the field sheets of the survey. Where single-lens aerial photographs are used, several hundred individual sheets are required and a systematic means of identifying their location in the survey area is needed. Photographic indices are available for most areas where photographs are used. An index map can be made from a small-scale map by plotting the match lines of the field sheets.

Each field sheet should contain the name of the survey area, the State, the date of the survey, and the names of the soil scientists who mapped that sheet. Names of others who inked or checked the sheet and its scale may be given also. Commonly all this information can be put only on the back of the sheet. Where it can be put on the front, it may be placed so that it will appear on photographic copies. A stamp can be used to provide spaces for the information.

The adjacent field sheets are identified on the margins of each sheet. When adjacent field sheets have been joined, the margins of the field sheets may be marked and initialed by the persons responsible. The joined match lines can also be marked on a transparent overlay over the map index.

Measuring the area of map units.--Soil maps show both the location and the extent of map units. Measurements of the area of each map unit are needed. Planners, for example, need to know the extent of areas having certain potentials or problems. Processors of farm products frequently need to locate areas suited to growing a certain crop. The data on area are used to help decide whether certain map units of small extent are important enough to be retained on the published map. Measuring the areas also checks the map for open boundaries, delineations without symbols, and unidentified symbols.

Measurements on field sheets are subject to errors caused by distortion of the photographs. Nevertheless, the errors are small compared to errors due to sampling. If the extent of map units is measured for the entire survey area, the data from field sheets are adequate for most uses.

The area of map units can be measured for the entire survey area; or sample areas can be selected and the extent of map units in them measured and expanded to represent the entire area.

The accuracy of the estimate based on sample areas depends on the size of the sample and where the sample areas are located. If the sample is less than 5 percent of the total area, estimates are subject to relatively large errors. Generally, the sample should be at least 10 percent of the total area. Even with this large a sample, map units of small extent are likely to be either missed entirely or overestimated. The estimates of extensive map units by sampling methods are likely to be reasonably reliable. Estimates based on sample areas can be satisfactory for most uses of data for the major soils in the survey area.

If a sampling procedure is used, dividing the area surveyed into soil associations and sampling each association separately is helpful. The most accurate estimates can be derived from sample strips running all the way across each association and oriented at right angles to the prominent unit boundaries. The strips can be spaced to provide the needed sample size. Square areas and rectangular areas oriented at random yield less accurate estimates, especially if the sample is small.

Several methods can be used for measuring the area of map units. The dot-grid method uses a transparent sheet or card on which dots are evenly spaced vertically

and horizontally. Each dot on the grid represents a small square, which has a unit area. The transparent sheet is placed over the map and the dots in each delineation are counted. Dots that fall on the boundary of a delineation are alternately counted. The dots in each delineation are summed for the map unit. The land area represented by each dot can be calculated on the basis of the map scale and the spacing of the dots. Less extensively used are grids that have a network of small squares instead of dots. The squares that fall within a delineation are easily counted. Squares that fall on a boundary of a delineation are averaged during counting. Such averaging depends on the judgment of the person doing the counting. If it is carefully done, the use of squares can result in somewhat greater accuracy than by the use of dot, but of course it is more time consuming.

The dot-grid method is simple, inexpensive, efficient, and convenient. For these reasons, it is the method most commonly used in field offices. A shortcoming of the dot-grid method is that it is not well adapted where there are long, narrow delineations on the map. However, it is sufficiently accurate for most purposes because the land areas for the map units tend to be averaged if large areas, i.e., entire field sheets and the like, are measured.

The planimeter is an instrument used to measure area by measuring the length of the boundary of the delineation. This is done by following the outline of the delineation with a tracer. The value indicated on the planimeter is converted to land area by using an appropriate conversion factor related to map scale. The use of the planimeter is an accurate method to measure maps but it is very slow and tedious. Accuracy depends on the skill and patience of the operator and on the care taken to convert measured values to land areas. The electronic area calculator is an alternative method to the dot-grid method in that it electronically counts squares on a grid. By using an appropriate grid to fit the desired map scale and a wired pencil assembly to trace the map unit boundary, area can be determined easily from a numerical display. This method compares closely in accuracy to the dot-grid method but is much quicker and more convenient. It is initially much more expensive than the dot-grid method.

Computer based electronic mapping systems, for example, the Automated Mapping System (AMS) used by the Soil Conservation Service, have the capability for measuring the area of map units. Such systems are very accurate. They depend on line maps made from half-tone film positives of the finished soil maps.

Weight apportionment, a method used in the past by the Soil Conservation Service, uses paper that has uniform weight per unit area. The map is reproduced on this paper, the delineations are carefully cut out and sorted by map unit, and the paper for each map unit is weighed accurately on an analytical balance. Each unit of weight of the paper represents a certain area of land. This method is not only very accurate but serves as an excellent final check for errors on field sheets--open boundaries, areas without symbols, and the like. It can replace color checks and other methods of checking field sheets.

Footnotes

1/ See the study by James A. Pomerening and Marlin G. Cline, "The accuracy of soil maps prepared by various methods that use aerial photograph interpretation," Photogrammetric Engineering 19: 809-817, 1953.

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Illustration legends

Figure 7-1.--Using a common pocket stereoscope.

Figure 7-2.--Sharply defined boundary between sandy soils on a high terrace (at right) and loamy soils on a lower terrace.

Figure 7-3.--Broad transition zones between contrasting soils. Dark areas are Brookston soils; light areas are Crosby soils.

Figure 7-4.--Failure to join adjacent field sheets:

A, boundaries do not match where four field sheets join;
B, boundaries match but symbols do not;
C, symbols match but boundaries do not.

Figure 7-5.--Location of place names. Only the uppermost of the three lakes is Lake Lewis, and Rat Creek is the lower of the two branches.

Figure 7-6.--The omission of a map unit boundary is a serious error, as in three places in this example.

*U.S. GOVERNMENT PRINTING OFFICE : 1980 O-310-944/SCS-36

CHAPTER 9
Recording and Storing Data

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CHAPTER 9

Recording and Storing Data

Information gathered during a soil survey of an area is recorded partly on maps and partly as notes. Both kinds of records are essential to a good survey.

Field Notes

Taking field notes is an important part of field work. Notes are the basic information used in developing the descriptive legend, soil interpretations, and the manuscript for publication of individual soil surveys. They are also used for preparing standard definitions and descriptions of soil series and for correlating soils in the national program. Although completed field sheets are conspicuous records of accomplishment, *field notes* are equally important.

The best notes are those written while observations are fresh. For example, the description of a soil profile is recorded as it is examined. Information from a conversation with a farmer is best recorded during the conversation or immediately afterward. Unless notes are recorded promptly, part of the information will almost certainly be lost. All field notes should be clearly identified. The survey area, date, location, and author are necessary on loose-leaf sheets and tape recordings. The date and location are needed for each entry in a notebook. Each note should be related to an identified soil. Source of information obtained other than from direct observations should also be identified.

Because of turnover in survey personnel, field notes need to be useful to others besides their author. Shorthand notes need to be transcribed to be useful to others. Standard terminology should be used, and common words used in their standard dictionary meanings.

The most important notes record the commonplace--extensive kinds of soils and their properties, the common crops, the success of septic systems, etc. The tendency is to record departures from the commonplace. Subsequent efforts to prepare a descriptive legend or make interpretations from such notes are unsuccessful because they lack essential information. Consequently, an individual must first learn to see and record the commonplace; the individual can then record departures from the usual.

Three major kinds of field notes are records of the nature of soils of an area, information on their behavior, and inferences about how they formed.

Field notes are the prime source of basic information for describing soils and map units. Such notes record complete descriptions of pedons at specially selected sites and observations made during mapping. Mapping notes are usually not full descriptions. They may record only

color, texture, and thickness of major horizons as seen in auger cores. Records from spots in many mapped bodies show the range of these properties for a soil. This information is used to supplement detailed examinations in describing the soil as a whole. Notes of this kind are especially important for soils that are not well known and for soils of potential but questionable map units.

Field notes include information about the relationship of map units to one another, to landforms, and to other natural features. The setting of a soil, its position in the landscape, is important. Landscape features strongly influence the distribution of soils. From the landscape, the properties and extent of the soil and the location of soil boundaries can be deduced. The kind of landform or the part of it that a particular soil occupies and how the soil fits into the landscape should be described. Soil patterns and shapes of soil delineations are important in relation to large-scale soil management. Chapters 4 and 5 of the manual contain detailed information on landscape indentification.

The kinds and amounts of inclusions in map units are noted and recorded during fieldwork, but such observations need checking after the units have been delineated. Inclusions are identified by name, or their properties are described. Estimates of the amount of inclusions made while mapping are rarely precise. Nevertheless, they are useful for detecting heterogeneous areas that may necessitate changes in the legend. Accurate estimates of amount usually require special sampling techniques such as line-transect or point-intercept methods. (Chapter 5 contains details of naming, designing, and composition of map units.)

Notes should be made on soil erosion in particular map units. This could include such items as description of eroded area, degrees of erosion within and between phases, differences in variability among soils and landscape positions, extent of redeposition in map units, and effect of erosion on crop yields and management of the soil. (See Chapter 4 for more detail on classes of erosion.)

Soil behavior is the performance of soil when used in any way. Behavior includes agricultural productivity, performance as highway subgrade, support for houses, or waste disposal site. Notes on soil behavior, unlike those on nature and properties, are obtained largely from others, rather than being observed directly by field scientists. Some are records of direct observations. Some are inferences by the field scientist and should be labeled as such.

Notes on behavior focus on current and foreseeable future uses of the important kinds of soil in an area. If the primary use of the survey area is range but some soils are irrigated, information on range production may be needed for all soils of the area, but notes on performance of soils under irrigation would probably be required for only a few. Information on probable forest growth might be pertinent to purposes of the survey even though it comes from the experience of only a few individuals or a few kinds of soils. An area with rapidly expanding population needs data on the engineering performance of soils;

how well the different kinds of soils would support houses, what kinds of subgrades are required for streets and roads, and whether on-site waste disposal systems would function satisfactorily.

While surveying, the soil scientist can see poor crop growth on a wet soil or on an eroded area. Failure of a highway subgrade or a waste disposal system in specific kinds of soil is observed and recorded. On the other hand, data on yields and management practices for specific crops usually come from farm records or experimental fields, however, valuable information can be obtained from observations made in the field about the impact of wetness or erosion on crop yields and range conditions. Similarly, information on forest growth is usually derived from observations made by others, but can be supplemented by information recorded by the soil scientist. Most information on the engineering performance of a soil comes from people who work with structures and soil as a construction material. A special effort should be made to obtain these kinds of information from knowledgeable people during field work.

The source of information about soil behavior is recorded in the field notes. Furthermore, the information should be evaluated, for it is not all equally reliable.

Observations and inferences need to be clearly distinguished. Most notes about how soils formed, for example, are inferences. The condition of growing crops is observable, but statements about soil productivity based on such observations are inferences. That soil material is nearly uniform silt loam and lacks coarse fragements is directly observed; the conclusion that the soil formed from loess is an inference.

Inferences are to be clearly distinguished from observations of soil morphology, vegetation, landform, and the like. Theories that have been formed on the basis of inference should not unduly influence the choice of observation sites or the properties to be observed.

Form and storage of notes

Each field party should devise a simple, easy system for taking and filing field notes. No single way of taking field notes is prescribed because any standard system devised for all parts of the country would be burdensome in many places.

Most field notes are handwritten, many in longhand but a few in shorthand. Time is required to take handwritten notes, but they are immediately available for reference. Such notes can be typed later, though typing is seldom necessary if the notes are neat and systematic.

Portable tape recorders can be used for taking field notes. Notetaking will need to be well organized for this method. The risk of oversight is larger with tape recordings than with handwritten notes because less time is available for reflection when recording the spoken word than

when writing notes. Tapes should be played back after notes are recorded. Recorded notes are usually typed later so they can be filed and retrieved.

Some information can be recorded more quickly and accurately as photographs than as words. Photographs could be used much more in soil surveys than they have been in the past.

Notebooks of various sizes and formats are used in soil surveys, depending on working conditions and personal preferences. Large notebooks with pages of about 21 x 27 cm provide ample space for writing and sketching. Smaller notebooks, 8 to 13 cm wide and 13 to 20 cm long, that can be carried in a pocket have advantages for a person on foot.

Loose-leaf notebooks, springback binders, and clipboards are widely used. They permit easy sorting and arrangement, if notes for only one site or observation are made on a sheet. Completed sheets can be filed at field headquarters every day. For the study of large areas and for reconnaissance trips, small bound notebooks are less bulky and offer less risk of losing individual sheets.

The filing system set up at field headquarters to preserve the information should be as simple as possible and yet allow recovery of the information when it is needed. A system for recording withdrawals of material from the files is needed to avoid loss.

In early stages of a survey, a standard filing cabinet with a folder for each map unit is sufficient. Alternatively, descriptions and notes can be kept in binders arranged by map units and taxonomic units. Map unit descriptions and notes are usually filed under series name plus modifiers, and a separate folder is provided for notes that apply to the series as a whole. The mechanics are not important as long as notes and descriptions are accessible.

As the survey continues, additional folders are usually needed for soil interpretations, various kinds of general information about the area, photographs, and other kinds of notes not directly related to map units. Separate folders are usually made for topics that will be sections in the soil survey manuscript--geology, vegetation, land use, crop yields, soil suitability, soil potential ratings, and others At the beginning of a survey, many of these items can be filed with descriptions of map units. As the survey progresses, having the information on each topic in one place becomes increasingly useful, and the notes are transferred to individual files.

Cross-referencing helps in finding notes that include information on more than one subject. For example, a given note may contain some information on the nature of a map unit and some on the yields of one or more crops. That note can be placed in the folder for the map unit and a reference to the map unit placed in the file on crop yields.

Much of the information in field notes is summarized in the descriptive

legend. Field notes on soil behavior are repeated or summarized in sections of the soil handbook. Information in the soil handbook and descriptive legend is readily accessible, but not all field notes are included. Consequently, the orginal notes are kept on file.

Field notes and information in the soil handbook and descriptive legend are very useful after publication for evaluation of the soil survey. Adequate notes help soil correlation and interpretation specialists to update an old survey and may eliminate the need to completely remap the survey area. This information can be copied on microfilm or microfiche. Microfiche copies are inexpensive and may be very useful to technical staffs. The orginial paper can then be discarded.

Soil Profile Descriptions

Soil profile descriptions are basic data in all soil surveys. They provide a major part of the information required for correlation and classification of the soils of an area. They are essential for interpreting soils and for coordinating interpretations across state and regional boundaries. The soil descriptions and the soil map also are the parts of a published survey having the longest useful life.

Field descriptions of soil profiles range from partial descriptions of material removed by an auger to complete descriptions of pedons seen in three dimensions from intersecting pits as horizontal layers are removed sequentially from the surface downward. Most field descriptions of soil profiles are the former, so care in making them is essential.

Good field descriptions should include:

- Observed external attributes of the polypedon, such as landform and characteristics of slope.

- Inferred attributes of the polypedon, such as origin of soil parent material and the annual sequence of soil-water states.

- Observed internal properties of the pedon, such as horizon thickness, color, and texture.

- Inferred attributes of the pedon, such as horizon designations and parent material.

- The classification of the pedon in the lowest feasible category.

- The location of the site both relative to geographic markers and in terms of landscape position.

- The plant cover or use of the site.

- The date, time of day if relevant, and weather conditions.

- The name of the describer.

The degree of detail in which these are recorded depends on whether the description is intended to provide a standard for comparison of nearly complete sets of properties or to determine the variation of selected properties within a taxon or map unit.

The attributes of pedons and polypedons, procedures for describing their internal properties, and standard terminology are described in Chapter 4. Standard terminology is used so that others can understand the description. When standard terms are not adequate to characterize all properties and attributes of a soil, common descriptive words are used to elaborate.

Standard forms for soil profile descriptions

Standard forms are useful for recording some observations and data required in a soil survey. They permit recording of information in a small space. Examples of standard forms used for soil profile descriptions, along with some additional information, are illustrated in figures 75 and 76. These figures are examples. No standard form is suitable for all descriptions everywhere at any time. Furthermore, forms need to be modified as more is learned about soils and the data are better understood.

Standard pages or forms can be prepared in different sizes to fit various notebooks. Forms printed on blue rather than white paper produce less glare when used outdoors.

A standard form serves as a checklist of characteristics that should be recorded. A checklist is especially valuable for beginners because it reminds them to look for a least the listed properties, but observations should not stop with the listed properties. There is a strong tendency to record the information required by the form and then stop. Thus, a form designed to set a minimum on the amount of information recorded also tends to set a maximum. However, good soil profile descriptions require information beyond that needed to complete the form.

Standard forms are most useful for recording the day-to-day observations made during mapping. Many such notes are not full descriptions of pedons. These short notes can usually be made on a standard form more easily than they can be written in longhand. Abbreviated notes are also useful in recording many observations during field reviews and when transecting. For these and similar purposes, the forms make notetaking easier and lessen the risk of recording an inadequate description. Complete descriptions of pedons, such as those made when soils are sampled for special studies or those of the typical pedons of soil series, are usually written in longhand as block descriptions, using a standard form as a checklist.

Notations on forms.--The small spaces on standard forms require that abbreviations or symbols be used for much of the information. Words can

be used to identify and describe the polypedon; symbols are needed for internal properties. Many different standard notations have been used. The symbols and codes used by each soil scientist should be documented either (1) by defining the individual's own notations or (2) by referencing a standard document such as Chapter 4 of this manual or the pedon coding system used by the National Cooperative Soil Survey. This should become a permanent record of the survey area so that the information can be correctly interpreted by others.

The most serious error in using standard symbols is using a symbol when it is not fully appropriate. Additional notes are needed to supplement symbols that do not convey the facts completely and accurately. Another error is the introduction of individual variations in use of the standard symbols. This complicates use of descriptions by others and can defeat the purpose of standard terminology. Standard notations are used exactly as defined.

Pedon descriptions in abbreviations and symbols can be converted to narrative form at field headquarters. If recording and transcribing facilities are available, the narrative can be dictated from the field notes and typed in block form. Typists can transcribe narrative descriptions directly from standard forms, but the scientist should check the descriptions.

Computer-readable forms--for recording soil descriptions can save time and money. The codes for the forms, adaptated from a notation system such as the pedon coding system, are overprinted on the form so that the user has only to mark the provided space with a soft pencil to record a given feature. After the forms have been completed, they are placed in a reader which automatically transfers the marked data to magnetic tape. The taped data are transferred to computer storage and are converted to the codes and format of the pedon coding system. The computer can print descriptions of pedons in block form from the stored data.

Field use of this technique may be hampered by conditions that affect the quality of the form for automatic reading. However, the technique still has advantages even when the data collected in the field must be transferred to the form in the office.

Block decriptions of pedons

Comparisons among soils and within a pedon are most easily made from columnar descriptions that use similar symbols and abbreviations. The descriptions usually give dominant color, texture, mottling, structure, consistence, roots, pores, additional features, reaction, and horizon boundary. Conventions for describing each of these are given in Chapter 4.

Columns of symbols and abbreviations are useful mainly to soil scientists or researchers. They can also be understood by others familiar with the soils and the system. To understand the soils, however, most people need narrative descriptions of typical pedons, pedons sampled for special

studies, and other pedons that help in defining taxa. Descriptions recorded as abbreviations and symbols will need to be converted to words. A standard format for narrative soil descriptions is the "block description" (see typical pedon of Miami series in Appendix 4).

Maps and references

The selection of a mapping base for a soil survey is discussed in Chapter 3. Some of the kinds of reference maps useful in conducting a soil survey are mentioned also. Much geographic information pertinent to soil survey work is available on maps published by various public and private organizations. Maps dealing with climate have been prepared in the past by the Weather Bureau and more recently by its successor in the National Oceanic and Atmospheric Administration. Maps showing surface geology and bedrock geology are prepared by the U.S. Geological Survey, state geological surveys, and various other state agencies, including some universities. Topographic maps are available for most areas; some have overprints showing patterns of vegetation. For some areas, maps showing vegetation, land use, and long-range zoning or land-use planning are available.

Many reference maps are large and should be filed without folding. A plan file or map file large enough to accommodate them can be purchased or improvised. A simple file made from hardboard or plywood is adaquate. The file should have a systematic index so that maps can be found readily.

The soil survey field sheets can normally be stored in a regular letter file. Atlas-size sheets need legal-size or larger files. Individual aerial photographs can be filed by flights which can be separated by file indexes. The index map to field sheets is a part of this file. Some care is required in filing and handling completed field sheets to avoid cracking the photographic emulsion or abrading the inked boundaries and symbols. The file and the completed field sheets should be protected from fire, loss, and theft. Field sheets can be photographed as soon as they are completed, and the prints or negatives stored where a fire cannot destroy both the reproductions and the originals.

During a soil survey, a substantial number of references are accumulated. One of the first activities of the survey party is assembling a list of the available reference material about the survey area and its soils. This list is updated during the survey. Some of the documents can be housed in the soil survey office; others are available only in libraries.

During the survey, interim documents may be generated; these also become references. The field party members need access to certain general standard texts and reference works. By the time of final preparation of the manuscript for publication, a substantial amount of reference material will have been accumulated and should be readily accessible.

Over 120 literature data bases, covering virtually every field of science and technology, are available through the National Agriculture Library and commerical information systems. Bibliographies can be prepared from the data bases for specific research problems, or general

bibliographies can be prepared for several subjects in a selected geographic area. A data base is searched through an interactive computer terminal connected by telephone to the information system computer. Using selected search terms and codes, the operator examines the entire data base, selecting data sets and narrowing them from general to specific. The retrieved citations can be printed online, which is faster for short lists or offline, which is more economical for long lists.

Photographs

Photographs can illustrate important points about soil in soil survey reports, scientific journals, textbooks, and periodicals. Color transparencies are ideal for slide presentations and color publications. Good photographs provide records and reference sources of basic soils information much as field notes do.

Photographs that include a scale are useful in estimating volume, area, or size distribution. Comparison of coarse fragments in a soil against photographs of known quantities of coarse fragments enables making reliable estimates. Similar photographic standards can be used to estimate volume or size of nodules and concretions, mottles, roots, pores, and rock fragments. In like manner, photographic standards can be used in estimating area or special arrangement of surface features and land use.

Equipment for field use.--Cameras suitable for soil survey documentation include the 35-mm single-lens reflex, the 2-1/4 twin-lens reflex, and the 4x5 "press" camera. Polaroid cameras have proved very useful for recording and documenting information for immediate and future reference.

A tripod is necessary, especially at shutter speeds below 1/50 second. Use of a tripod reduces camera movement and enables the photographer to concentrate on composition and focus.

Certain other items of field equipment are necessary for good pictures of soil profiles. A scale to indicate depth or thickness is important. A scale that does not contrast greatly with the soil, such as an unvarnished and unpainted wood rule or a brown or khaki cloth tape, 5-cm by 1.5 m, can be used effectively. Large black or yellow figures at 50-cm intervals, large ticks at 10-cm intervals, and small ticks at 5-cm intervals complete the scale.

A small spatula, kitchen fork, or narrow-bladed knife is useful for dressing the soil profile. Several paint brushes of various widths and a tire pump aid in cleaning dust from peds. A sprayer can be used to moisten the profile where necessary.

Photographing soil profiles.--Careful planning is essential for obtaining high-quality photographs of soil profiles. A representative site is selected on a road cut or borrow-pit face or in an area where a pit can be dug large enough for adequate lighting of all horizons and for the camera to be 1-1/2 to 2-1/2 m from the profile. The pit or cut face should be oriented so that when the picture is taken the maximum amount of light will strike the prepared face at the proper angle.

The profile will need to be properly dressed to bring out significant contrast in structure and color between the soil horizons. Beginning at the top, fragments of the soil can be broken off with a spatula, kitchen fork, or small knife to eliminate digging marks. Dust and small fragments can be brushed or blown away. Moistening the whole profile or part of it with a hand sprayer is helpful in obtaining uniform moisture content and contrast.

Every profile should be photographed three or four times with different aperture settings, angles of light, or exposure times. Notes should be made immediately after each photograph is taken to record location and date, complete description of the subject, time of day, amount and angle of light, camera setting, method of preparing the profile, and other facts that will not show in the photograph. Besides adding to the way the photograph can be used, good notes provide information for improving technique.

Photographing landscapes.--Landscape photographs illustrate important relationships between soils and geomorphology, vegetation, or management. They should be clear, be in sharp focus, and have good contrast. Photographs that are representative of the area being mapped are the most useful, but they are usually difficult to make interesting.

The most important thing in landscape photography is lighting. The best pictures are made at a time of day and during the time of year when the sun lights the scene from the side. The shadows created by this lighting separate parts of the landscape and give the picture depth. Photographs taken at midday or with direct front lighting lack tonal gradation and, therefore, appear flat. Photographs taken on overcast days are unsatisfactory for the same reason. A small enough aperture should be used to gain maximum depth of focus.

A good photograph has one primary point of interest. Objects that clutter the photograph--utility poles, poorly maintained roads and fences, signs, vehicles, and personal items placed to show scale--detract from the main point. The point of interest should not be in the center of the photograph. The "rule of thirds" for composition is used by looking at the scene through the viewfinder and visualizing the image area divided into thirds both horizontally and vertically. The center of interest is placed at one of the four points where these lines intersect. The image should contain no more than one-third sky, and the camera must be kept level with the horizon.

If all photographs are taken from the eye level of a person standing, the results are boring. A variety of angles--from a kneeling position, on a ladder, atop a car or low building--result in a better selection of photographs.

Close-up photography.--Many soil features can be photographed at close range: peds, pores, roots, rock fragments, krotovinas, mottles,

concretions, organisms. The technique for photographing objects at very close range is called photomicrography.

The minimum focusing distance for most cameras used in the field is such that small features can be photographed. Short distances require a much smaller aperture setting and, consequently, a slower shutter speed to ensure adequate depth of focus.

Microlenses are available for 35-mm cameras. These lenses permit focusing as close as about 4 inches. They usually have a focal length of 50 to 55 mm and can be used for general photography as well. Closeup attachments for conventional lenses are available, but these do not always give professional results.

As with landscape photography, the lighting angle is important in close work. Direct front lighting destroys texture, separation, and contrast in the photograph.

Photographing clay skins and other minute soil features requires special equipment and techniques of photomicrography that are outside the range of this manual.

Filing and care of negatives and prints.--A file system similar to that used for field notes is helpful. Most photographs taken in support of the soil survey can be related to a taxonomic unit or map unit and filed by series. A subject card file with cross-references permits the greatest use of photographs with the least effort. Photographic files should be organized in the same way as files of notes. Negatives can be filed with each print in individual envelopes for protection. Card files of an appropriate size with dividers are satisfactory for storage.

Color 35-mm transparencies can be filed in clear vinyl pages, 22 by 28 cm, with pockets for individual slides. These pages are kept in three-ring binders, appropriately divided. Pages can be held to a light source for a quick search of the file.

All photographs and negatives should be kept in a cool area isolated from chemicals and cleaning materials.

Automatic data processing

A large amount of many kinds of data are collected on a soil survey. How to handle accumulated data to make full use of them always is a problem. A powerful tool for dealing with this problem is automatic data processing (ADP) using computers, minicomputers, microprocessors, and word processing equipment. ADP makes possible timely summaries, comparisons, and analyses that otherwise would be impractical or impossible. It enables frequent and inexpensive updating of long lists, such as lists of soil series for states, regions, or the entire nation, in any order or sequence. Such summaries can provide information to guide important policy decisions. ADP can quickly perform routine, time-consuming computations.

ADP is now widely used in soil surveys and its use is expected to increase greatly. Soil scientists need to know the fundamentals of ADP just as they need to know the fundamentals of chemistry, botany, geology, mathematics, economics, and other subjects that support the work of soil survey. Literature on the fundamentals of ADP is readily available. ADP can be used for many soil survey tasks, but this is not to say that it should be used for all of them. Before any decision is made to use ADP, an objective study--systems analysis--is needed to determine what combination of equipment, personnel, and other factors is most useful and economical. Any new system to be used must take into account the compatibility with systems used by cooperating agencies to handle soil survey data and related physical and environmental data. Many combinations of computers, storage media, input-output devices, communications facilities, and so forth are possible.

Even after an ADP system has been designed and implemented, study continues. ADP technology is changing rapidly, and new equipment and new procedures are appearing constantly. Possibly an existing system can be improved or can be replaced by a better system. As experience is gained, goals may also change to use the data more fully, or they may change for reasons unrelated to ADP.

The use of ADP is likely to be justified if the volume of data to be processed is large or if many operations are needed, regardless of the volume of data. The following classes of data appear to be large enough to warrant the use of ADP:

1. Field descriptions of pedons.

2. Results of laboratory analyses.

3. Geographic data about soils (soil maps).

4. Official descriptions of series.

5. Interpretive data, including the interpretations already made and research results and experience from which new or improved interpretations can be made.

6. Status, type location, acreage mapped, and placement in Soil Taxonomy for each soil series.

7. Administrative data on soil surveys (size, location, population, relevant dates, etc.)

8. Sections of manuscripts.

ADP can manipulate data in many ways. Because most of the data are likely to be needed in different combinations, the fundamental application is likely to be data storage and retrieval. Such a system requires that precisely and consistently defined records be entered into some medium readable by computers and arranged in cataloged files. These files of soil records are a soil survey <u>data bank</u>. Data banks can be kept at

more than one location, depending on needs and facilities. Also, soils data can be entered into the banks at more than one location. A uniform coding system is essential so that the data in the banks will have a consistent format. A uniform coding system permits direct transfer and sharing of data and of the computer programs used to manipulate the data.

After the soils information has been systematically entered into the data bank and the necessary equipment and operating instructions have been organized, the data are available for many kinds or operations. Computer programs (software) must be developed if they do not already exist. Software development is usually the most expensive and time-consuming aspect of data processing. A good data management system can reduce the amount of software needed. Some examples of important applications anticipated for soil surveys follow:

1. Many kinds of questions can be answered: What kinds of soils have certain sets of properties? What kinds of soils are mapped in specified localities? What soils will produce corn yields of more than 100 bushels per acre under management system B?

2. Statistical studies, particularly multiple correlations, can be made for many purposes. Among these are the testing of criteria, such as the numerical limits of values in Soil Taxonomy; determining what soil properties observable in the field correlate well with laboratory results; and determining what observable soil properties reliably indicate soil behavior.

3. Many kinds of summaries can be prepared by ADP, such as summaries of interpretations by soil families, or phases of soil families, subgroups, and so on; summaries of the acreage of kinds of soil in states, drainage basins, or other geographic areas; and summaries of the number and area of soils having selected features, such as a fragipan.

4. Tabular material can be arranged and printed out for soil survey manuscripts and other reports. Text that is repeated in published surveys of a given state or region can be stored in finished form.

5. Lists, such as the classification of soil series, can be stored and easily updated.

6. Interpretive maps can be printed on demand. This is likely to become an increasingly valuable application for soil management and land use planning.

Additional examples could be cited, and as experience with ADP is gained, many additional applications will become apparent. However, ADP cannot improve the quality of the data. High-quality data must be used in the first place. Users of ADP outputs need to be made aware of the reliability and accuracy of the original information.

Making information available

The information assembled in a soil survey is public property. The survey party has an obligation to make the information available as quickly as possible. The published soil survey (described in Chapter 12) is a medium through which this is done. Also information is assimilated and made available during the soil survey. Computer data banks of basic soil survey data are also public property and are available to workers in soil research and land use management.

Demands on the time of the soil survey party are large. Their first obligation is to complete the field investigations and assemble the information for final publication. Over the long run, they will serve more people better by completing that function as quickly as possible. The public, however, sometimes has compelling needs of the moment for the information.

While field work is in progress, the survey party has an obligation to provide information of confirmed reliability to some groups and individuals. The soil survey work plan should provide reasonable time for such special services. The techniques for storing and retrieving information described in this chapter make this function easier.

The descriptive legend and soil handbook, along with the completed field sheets, are the primary reference materials while the survey is in progress. The descriptive legend identifies the symbols that appear on the soil maps and describes the soils they represent. It informs the field party and directs their operations, but it is also the primary reference about the properties of soils in specific places for which the public may need information. The completed field sheets and the descriptive legend together provide a ready reference about the kinds of soil and their basic properties where mapping has been done. As the survey progresses, various kinds of interpretations are made for the soils of the area. These are assembled with the descriptive legend in a more comprehensive document, the soil handbook, which gradually becomes a preliminary draft of the published soil survey. While the survey is in progress, the handbook is available to technicians who apply soil survey information; through them the information is available to the general public. The staffs of all of the cooperating agencies should have access to the soil handbook.

The survey party commonly receives requests to prepare interpretative maps and text for special purposes while the survey is still in progress. For example, a town planning board may ask that its township be completed and a special interpretative report be made for their use. These services are time consuming and costly. If provided, special services should be listed in the soil survey work plan with appropriate allowances of time and arrangements for financing. Properly planned, these special services can be a very important part of the soil survey, though they entail consideration of the problems inherent in disseminating information before soils data are complete.

Even though the published soil survey is the principal medium for disseminating soils information, it cannot include detailed interpretations for all of the various uses of soils. Some special interpretations must be made after the soil survey has been published. The published soil survey is the repository for the basic data on which the various agencies depend in making special interpretations.

The soil survey also produces data that are of interest primarily to the scientific community. Such results are published in a variety of forms, commonly under the authorship of an individual or a group. They appear as general articles, bulletins, and a variety of processed releases. Many are products of special investigations (Chapter 8). Those who work in soil survey are obligated to make such data available to other scientists.

A soil survey commonly draws on the data and experience of experts in other disciplines, including direct collaboration of scientists in other fields. Any release of information should acknowledge the source of supporting data and assistance and cite published material from which interpretations have been drawn. The contibutions of individuals who have collaborated must be acknowledged.

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U.S. GOVERNMENT PRINTING OFFICE: 1982-380-931:SCS-947

Chapter 10

Maintaining Standards in Soil Survey

Individual soil surveys are made to satisfy local objectives. In addition, the information assembled about soils of each area can be extended to similar kinds of soils elsewhere.

The party leader responsible for a survey tends to divide the soil continuum in a way that best reveals relationships from the local perspective. Other divisions that are consistent with work in other areas may both reveal the local relationships and permit better transfer of the information to and from other areas. A soil scientist responsible for soil classification and correlation over large areas, such as a State or a region, divides the continuum in ways that reveal relationships from a broader perspective. Usually, not all local circumstances are known well enough to anticipate local needs. Local soil scientists and those with broader perspective must work together to satisfy local, regional, and national objectives.

Field reviews help party leaders solve problems and produce high quality soil surveys. The process of correlation ensures that kinds of soil and associated map units are defined, classified, named, and interpreted consistently among soil surveys. Records and definitions of soil taxa are kept as nationwide standards for identifying and naming kinds of soils.

Field Reviews

Reviews of soil surveys are made in the field by supervisory soil scientists to help party leaders maintain standards that are both adequate for the objectives of the survey and consistent with those of other surveys. Every science requires that conclusions of one person be confirmed by others. Field reviews perform this function for soil surveys.

In a field review, supervisory soil scientists of one or more of the cooperating agencies go to the survey area and work with the party leader and the staff. They review conclusions that have been reached and decisions that have been made. They work with the party leader to decide on adjustments that may be needed in legends and other technical aspects of the work. They examine samples of the fieldwork of party members for soil identification, placement of boundaries, and map detail in relation to survey objectives; and they advise the party leader and other members of the party on ways to attain mapping of good quality. They help the party leader solve problems. They review the identification legend, descriptive legend, and supporting data to keep classification, nomenclature, and interpretations consistent with surveys of other areas. They also review with the party leader and the local administrators problems related to management and scheduling of the work and advise them about improvements that may be needed.

The report of a field review is a record of the current status of fieldwork, observations, conclusions, and recommended actions. It is a guide to future operations for the field party, and it is a guide to management for local administrators.

Participation in field reviews varies according to the state of progress of the soil survey, the survey objectives, the cooperating agencies, and other factors. A realistic balance is needed between the number of people who can contribute and the number that can work effectively; if the number participating exceeds five or six, the efficiency of the review is usually reduced. The soil survey party leader and a supervisory soil scientist from one of the principal cooperating agencies are essential participants in every field review. A representative from each of the cooperating agencies should participate in at least some of the field reviews. Supervisory soil scientists of the Federal agency and the principal cooperating State agency sometimes divide the workload so that one or the other conducts reviews that do not require the attention of both.

Members of the field party participate in most field reviews. Their experience in the area contributes much, and the discussions during the review are valuable to them in their subsequent fieldwork. Some soil scientists participate in the parts of the review directly related to their work.

In addition to the soil scientists, specialists from other disciplines are needed on some field reviews. In some areas, people skilled in soil management for crops, forest, and range can make useful contributions. Engineers, plant taxonomists, geologists, and geomorphologists can help in many areas. Local farmers and extension specialists can provide useful information on yields and practices for field and horticultural crops. Representatives of State and local agencies that use the soil survey also participate in decisions. Their concern for uses of the survey provides perspective for decisions, and their experience during the reviews contributes to effective use of the information when it becomes available. Finally, a local administrative officer of the Federal cooperator participates to provide administrative support and direction. Some specialists participate most effectively by conference in the office. Others should attend the review in the field.

Every soil survey needs an initial field review at the start of fieldwork and a final field review when fieldwork is completed. One or more progress field reviews are needed for most surveys while the work is underway. Quality control is an objective in all reviews; however, the elements of the survey that need special attention are different at different stages.

Initial field review

The initial field review at the beginning of a soil survey insures that legends and other working documents, supplies, and equipment are adequate and that objectives and concepts are understood by the party leader and the field staff. The initial field review sets the standard for conducting the survey. Representatives of all of the principal cooperating agencies participate.

Before the initial field review, a soil survey work plan defining objectives, the kind of survey, and map scale has been prepared and approved by all cooperating agencies. The party leader has worked in the area long enough to become familiar with it and has assembled and reviewed the existing information about the area and its soils. Preliminary studies have been made that show the relationship of soil properties to landscapes. A tentative identification legend and information for the descriptive legend have been assembled. The mapping legend has been tested by mapping sample areas. Information has been accumulated for making judgments about the ranges of important soil properties within the most important kinds of mappable soil areas and about the kinds and amounts of mapping inclusions. Surface features and kinds of vegetation that provide clues to kinds of soil boundaries have been identified. Needs for equipment, supplies, and base maps have been determined and at least partly satisfied. The staff for the field party has been assigned, and some members may have started work.

The initial field review appraises these preparations. A time limit is set for having a draft of the descriptive legend available to all members of the field party, if one has not already been prepared. The review team insures that the latest descriptions and interpretations for established soil series in the area are available to the field party and that descriptions and interpretations of tentative series have been prepared. All of these matters are important, but none is more important than the adequacy of the identification and descriptive legends. A major part of the initial field review is normally spent on these legends, for the quality and usefulness of the survey depend on them.

The review team goes into the field and tests the tentative mapping legend against mappable landscape units. If the soils of the area are like those mapped previously in other areas, testing of the legend may require relatively little time, but it still must be done. In areas having soils unlike those mapped elsewhere, the initial field review requires more careful field investigations.

Before the review, the party leader locates places for test mapping. Much of the review team's time can be saved if profiles of soils for which the classification is in doubt have been exposed in advance. The review team depends on the party leader to identify the most serious problems with the mapping legend and to provide evidence to support judgments about all map units, even those not considered problems.

After all available evidence has been assembled, including that prepared in advance and that studied in the field during the review, the team examines the naming of the various units. The classification of identified soils, the list of ad hoc symbols and their definitions, and the list of conventional symbols and rules for their use are also reviewed. Needed adjustments in the legend are made when the initial review has been completed. The revised legend becomes a part of the field review report and is used by the field party in mapping. This review also starts the process of formal correlation, which continues until the survey is completed.

The review team provides the party leader with instructions for any special studies that may be needed to answer any remaining questions. Such studies may include laboratory analyses, special field investigations, and examination of literature not seen previously. The review team also provides instructions about matters that require special attention, such as adequacy of base maps and equipment, cartographic techniques, mapping procedures, and recording of field notes. These instructions become part of the field review report and guide the work of the field party.

Finally, the review team assists the party leader and administrators in preparing a flow chart showing when and by whom various tasks will be done.

Progress field reviews

Progress field reviews are made during fieldwork to test classification, mapping, nomenclature, and interpretations and to review and confirm findings of the field party. Inspection of fieldwork is one element of the review. Solving problems and assisting the field party is another.

Usually, several reviews are needed during a soil survey. How many are needed depends on the skill and experience of the party leader and the length of time required to complete the survey. Progress reviews that cover all elements of the survey are generally needed at least once a year for those surveys staffed with two or three full-time soil scientists. They are scheduled well in advance and are held at a time agreeable to all participants. The party leader requests field visits by one or more supervisory soil scientists whenever there are unresolved problems that affect the quality of mapping in a significant part of the area. Field visits can be scheduled on short notice.

In contrast to initial field reviews, which concentrate on preparations for fieldwork, progress reviews focus on application in the field. By the time the first progress field review is made, enough mapping has been done to test the legend.

Before the progress field review, the party leader has prepared a list of unsolved problems and a tentative schedule of activities for the review team. The schedule should include time for study of special problems, review of mapping, and appraisal of the soil handbook and other working documents. Up-to-date working documents, such as the mapping legend and interpretations, should be provided. Places are located where mapping or classification problems can be investigated. Exposures and detailed descriptions of soil profiles for the review team to study are prepared. Sites that illustrate the most important problems of interpretation are selected. The record of mapping progress showing the soil scientists responsible for each completed sheet is up to date, and the field sheets and notes of each scientist are available. The party leader should be prepared to describe the progress of all tasks listed for action at earlier reviews.

The mapping of sample areas is examined for soil identification, placement of boundaries, legibility of the maps, kinds and amounts of inclusions, and appropriateness of map units for the objectives. This examination evaluates the fieldwork of individual soil scientists and tests the legend itself and the base maps. Normally, a large part of the time of progress field reviews is spent in the field, though legends, drafts of manuscripts, and interpretations can be reviewed in the office. Problems of soil identification and mapping studied in the field are discussed at the field sites. Sometimes special studies are needed.

The review team revises the identification legend as necessary. It reviews the quality and status of the descriptive legend, interpretations, and classification and nomenclature of the soils. If adjustments or special actions are needed, the team decides what should be done. The supervisory scientists appraise the rate of progress and the mapping and field notes of individuals and make recommendations to correct deficiencies. Progress is compared to the flow chart and is discussed with the party leader and local administrator. Any necessary remapping or revision of mapping is specified. Soils to be sampled for laboratory studies are identified.

All changes of symbols or names of map units--including any that are discontinued--are recorded. The modified identification legend and a list of recommendations for actions are parts of the report of the progress field review and working documents for subsequent activities of the survey. The modified legend serves as a correlation for the parts of the area where mapping has been completed.

About one year before completion of field mapping a <u>comprehensive progress field review</u> is made. This review accomplishes many of the objectives of a final field review while time remains to correct any deficiencies. All survey operations are evaluated. Items such as photographs, block diagrams, and other material for publication are checked. Progress is compared to the flow chart to insure that all aspects of the survey will be completed on time. The field review report describes the progress of all aspects of the survey and includes a plan for completing the remaining work.

Sometimes problems need to be solved and guidelines established when a complete progress field review cannot be justified. The party leader can request <u>field visits</u> from supervisory soil scientists specifically to help solve special problems. A visit by a supervisory soil scientist for a day can often prevent errors that would be costly to correct.

A written record of the decisions reached during field visits is provided to the cooperating agencies and is made part of the survey records. Changes in the identification legend or mapping procedures are promptly given to all members of the field party. Decisions that affect the legend, classification of soils, or interpretations are reviewed at the next progress review and are included in the review report.

Final field review

The final field review is held when the fieldwork is complete or nearly so. It provides a last opportunity to review and confirm conclusions in the field. Initial and progress field reviews focus on matters that affect future mapping. The final field review concentrates on making the most use of the information that has been gathered and on correcting any deficiencies that remain.

As for other field reviews, the party leader provides up-to-date copies of all legends, maps, and interpretive material. Any remaining problems are listed, and a tentative schedule of activities is prepared.

At the time of the final field review the mapping legend includes all symbols that appear on the maps and names for the soils and special features that they represent. Major sections of the soil survey manuscript have been prepared. The field maps are complete or nearing completion, including inking, joining, and checking. The general soil map and the accompanying narrative are in nearly final form. Laboratory data and other data from special studies have been assembled. Photographs and drafts of illustrations for the published soil survey are available.

A final field review must resolve all remaining problems of classification and interpretation. Adjustments to the mapping legend have been made during progress reviews, but some problems may have appeared since the last review. Most field checking of mapping has been done during progress reviews, but the party leader may have some questions about mapping that require field study. The final field review resolves any problems that remain and recommends any corrections that are still needed.

The final field review appraises the material available for the published soil survey and determines whether all field sheets are legible, complete, and suitable for compilation at the publication scale. Information assembled for the manuscript is checked against an outline for the publication.

The mapping legend and supporting information, the validity of map units, their names, and the classification and interpretations of soils are checked. This review is the final appraisal of the legend in preparation for field and final correlations. The field correlation can usually be conducted during the final field review. If they are not conducted together, the final field review report provides recommendations for naming and correlating each map unit.

Field review reports

Reports of field reviews record decisions that were made at various times during the survey. For example, knowing that a given map unit was incorrectly mapped at one time and when the error was found is important. Recording the date permits identifying the field maps on which symbols may need to be changed. Field review reports are a history of the decisions made during the progress of a soil survey.

All field review reports include (1) the name of the area, (2) its location, (3) its size, (4) the dates of the review, (5) the total area mapped to the time of the review, (6) the names of the party leader and members of the field party, (7) the names of others who participated in the review, (8) an appraisal of the adequacy of

equipment and base maps, (9) a list of any deficiencies in the conduct of the survey and agreements for remedying them, (10) commendable items recognizing good performance, and (11) other pertinent general facts.

The initial field review report includes copies of the first identification legend and the first draft of the descriptive legend. Drafts of descriptions and interpretations of new soil series proposed at the initial review are included, or instructions for submitting them at a later date are provided. Recommendations and instructions for the conduct of the survey are included. Notes of observations made during the review about soils or related matters are commonly included as part of the record. A schedule should be developed to show when and by whom various tasks will be done. Recommendations for special laboratory or field studies are recorded, and if possible schedules for sampling and other work are listed.

Reports of progress field reviews must include a complete revised identification legend. Descriptions of new soil series proposed since the last field review are attached or instructions for providing them are included. The report includes a record of deficiencies in the mapping, in the descriptive legend, and in interpretations of soils, and a statement of recommended actions, including any administrative actions. Special problems that were investigated and proposed solutions are recorded. Changes in the legend, mapping procedures, base maps, and soil survey interpretations made by the field party between reviews are also recorded. The dates of such changes are given to show that they predate the review. Map units and symbols that were used but later dropped must be recorded and identified, and the disposition of such symbols on the field sheets must be described.

After a field visit, a written report is submitted, usually to the supervisors of the reviewer and the party leader. Copies are sent to the cooperating agencies. This report is not a formal document of the survey. The recommended actions are listed in the report of the next progress field review and properly documented. Field review reports record the complete history of a survey.

The final field review report includes the same kinds of information as progress field review reports. The status of maps and information for publication of the survey are emphasized. Special attention is given to the status of laboratory data from samples collected for characterization, correlation, and interpretation of the soils. A list of recommended names of map units is included for consideration during the field correlation. If the field correlation is held concurrently with the final field review, the two reports can be combined.

Soil Correlation

Soil correlation is the process of maintaining consistency in naming, classifying, and interpreting kinds of soils and of the units delineated on maps. In the correlation process, field and laboratory data are examined for similarities and differences between soils at different places. Correlation requires consistent methods of observation and measurement and consistent conventions and terminology. Thus, soil correlation involves more than defining, naming, and classifying soils. It requires an evaluation of methods, terminology, and conventions used for describing and defining soils.[1/] It also includes an evaluation of conventions used to name and identify map units and the usefulness of map units for soil interpretation.

The correlation process continues from the beginning to the end of each survey. It includes quality control and mapping decisions carried out by the party leader and other party members during fieldwork. It also includes the formal aspects of field review, field correlation, and final correlation. Formal correlation is normally done in two steps. The field correlation is a reappraisal of the map units and the

information assembled about them. It is commonly conducted in the field where specific sites can be studied to resolve questions. The final correlation is a review of the field correlation by supervisory soil scientists who are responsible for a much larger region than the survey area. The final correlation is the basis for publication of the soil survey.

Correlation during fieldwork

The process of soil correlation starts with preparation of the first draft of the identification legend. Soils are described at different places during preliminary studies of an area. These descriptions are used to compare soils at different places, and to construct the working models that reveal the soil-landscape relationships. If the soils at two different places in the survey area are the same kind, they are identified by the same name. If a soil is the same as one identified and named in another survey, that name is used. The first identification legend is a product of these tentative correlations.

The process of correlation continues as fieldwork progresses. At the initial field review, supervisory soil scientists examine the evidence and the tentative correlations represented by map units in the legend. They test the classification of soils and the usefulness of the map units. As the survey progresses, the correlations represented by defined map units are continually tested against observations by the field staff. The staff accumulates soil descriptions, records of observed soil performance under different uses, and other field data. Each interpretation tests the validity and usefulness of the map units. Soils are sampled and are analyzed in the laboratory. As evidence accumulates from all of these sources, definitions and names of some map units usually are adjusted, some new units are named and defined, and others are combined or dropped. Each such action is a refinement of the correlation. Each successive field review produces a more refined correlation of the soils of the area.

Field correlation

The field correlation is conducted when fieldwork is nearly complete. At least one supervisory soil scientist, the party leader, and others participate. The supervisory soil scientist should be familiar with the soils of the State or region where the area is located. Other members of the field party usually take part, and a representative of each of the principal cooperating agencies participates. Specialists such as foresters, range specialists, extension specialists, or engineers may assist. Soil scientists responsible for surveys of adjacent States participate if they can make useful contributions. The field correlation and final field review are usually conducted concurrently, for their functions are complementary.

The party leader provides a legend that lists all symbols that have been used on the field sheets, complete descriptions of all map units, descriptions of taxa defining their properties as observed in the area, copies of laboratory data, drafts of interpretations of soils and interpretive groupings, and measurements or reliable estimates of the extent of map units. Supporting field notes and data are also available. Field maps of the area and copies of official descriptions of soil series and interpretations are needed. By this stage, all this information has been assembled in the soil handbook for the area.

As much as possible of the field correlation is completed in the survey area. For some surveys, all recommendations can be prepared in the area; for others, information not available in the field office must be consulted before final decisions can be made on some matters.

All map units used during the survey must be checked during field correlation. Some map units may not be clearly distinguishable from others and can be combined with similar units under one name; others may not be needed for the purposes of the survey and can also be combined. Combinations must be recorded so those who compile the map for publication can identify the areas by the proper symbol. Accurate descriptions of

The validity of phases is checked with special care. The justification for most phases rests on behavior of soils when used. Each such phase should differ from other phases of the taxon in at least one statement about soil behavior.

During field correlation names for map units are recommended. The descriptions of soil series are checked against standard descriptions. Many of the kinds of soil may have been identified as established series, but the identifications must be checked. Descriptions of proposed series are compared with standard descriptions of similar series within the same and closely related families. Each proposed series is either recognized as a new series or correlated with an established series. Suggestions for modification of established series to accommodate soils of the area are reviewed. The definitions of all series used in the area are checked against the limits of diagnostic criteria, and all series should be classified.

The field correlation memorandum is a record of the recommended correlations and is approved by representatives of the principal cooperating agencies. This memorandum includes as a minimum--

1. A complete identification legend, giving--
   a. the soil name and symbol used in the field to identify each map unit, and
   b. the recommended name and symbol for each correlated unit.

2. Notes explaining all recommended correlations for which justification is not obvious from the evidence submitted with the memorandum.

3. A complete list of conventional and special symbols, along with their definitions or reference to a published source of definitions.

4. Sections classifying all recommended series and all pedons that were analyzed in the laboratory, including those tested for engineering properties.

5. A statement evaluating the current draft of the soil survey manuscript.

6. Lists of series recommended--
   a. to be established,
   b. to be dropped, and
   c. to be made inactive.

Final correlation

The final correlation is a critical review of the recommendations of the field correlation. It is conducted by a supervisory soil scientist experienced in soil correlation and classification in a region large enough to include most of the soils in the survey area. A soil scientist who is familiar with the soils of the Northern Great Plains, for example, conducts the final correlation of a survey in that region.

Assisting are the party leader and a supervisory soil scientist and representatives of the principal cooperating agencies. They may participate in person or may sometimes be able to make their contributions by correspondence.

The field correlation memorandum and its supporting evidence provide the basic information needed for final correlation. Additional evidence is drawn from descriptions of soils related to those of the survey area, from soil correlation samples collected in the area, from other soil surveys in comparable areas, from interpretations and laboratory data for similar soils in other areas, and from personal knowledge of those participating, especially the party leader.

In the final correlation, special attention is given to classification and interpretation of the soils. The content and adequacy of descriptions and interpretations are appraised. Descriptions of any proposed series are carefully examined. They are studied for possible conflicts with other series. The recommended classification of each series and its ranges of soil properties are reviewed for conformity with diagnostic criteria.

The correlation is reviewed to insure that similarities warrant any proposed combinations of soils and that differences between the units are large enough to justify retaining them. Nomenclature is checked to see that it conforms to established conventions. Definitions and interpretations are checked to insure that they conform to established standards. Questions that cannot be answered by the evidence at hand are referred to soil scientists in the State for additional information. Some problems may require additional field investigation or laboratory studies.

If enough documentation and other evidence is available to make final decisions, the final correlation can be completed in conjunction with the final field review and the field correlation.

The final correlation memorandum is a record of decisions that are reached. Its essential elements are the same as for the field correlation memorandum.

Sometimes review of the final correlation by individuals who did not participate, or new evidence that becomes available after the correlation, reveals a need for some changes. Such changes are recorded as amendments to the final correlation memorandum and become part of the official record.

The final correlation memorandum identifies the map units to be shown on the published map and to be described and interpreted in the text. The memorandum records correlation decisions and certifies that interpretations have been coordinated, that the maps and manuscript are complete, and that all remaining operations have been properly scheduled. It can answer questions that may arise in the future, and it establishes new soil series in the national system of soil classification.

Reference samples for soil correlation

Data from analyses of soil samples are used in the correlation process. Usually, samples representing each series are collected. The initial and progress field review reports define the plans for sample collection and list the soils to be sampled for correlation. In approving the review reports, the representatives of the cooperating agencies approve the sampling program.

Sampling needs vary from area to area. Correlation samples may be collected from each pedon that is sampled for laboratory analysis or engineering tests. They are commonly collected for each series whose type location is in the survey area. They are also collected from any soil for which classification is questionable. Other soils in the survey area are sampled as necessary for other purposes.

After correlation is completed, samples not required as part of a permanent reference collection may be discarded. As greater emphasis has been placed on accuracy and completeness of soil descriptions and on laboratory analysis of soils, the use of samples in correlation has decreased.

The procedures for collecting, shipping, and labeling samples change as needs and methods change.

Records and Definitions of Soil Taxa

Keeping definitions and names of soil taxa up to date is essential for identification of map units, for correlation of soils nationwide, and for transfer of information about soils at one place to similar kinds of soil elsewhere.

Definitions and names of soil taxa can be kept by different methods, and the methods used are modified from time to time. Some kind of centralized system is needed to obtain a nationwide perspective, to maintain standards for definition of soil taxa, to assemble field and laboratory data, and to disseminate information to the field.

Soil series

Soil series are used for naming most map units in 1st and 2nd order surveys[2/] and in some surveys of other orders in the United States. Over time, the concepts of the series category and of individual series have changed, but more than 12,000 series are now defined and named. These definitions are the framework within which most of the detailed information about soils of the United States is identified with soils at specific places. These definitions also provide the principal medium through which detailed information about the soil and its behavior at one place is projected to similar soils at other places.

Rigorous standards for definitions of soil series insure that names and descriptions for the same kinds of soils are consistent from survey to survey. This is a major objective of the correlation process. The classes of the soil series category are not static. As new knowledge is acquired, definitions of some established series must be modified. New series are defined for newly recognized kinds of soils. Changes in criteria or limits of taxa in higher categories often require modification of definitions of member series.

Keeping records of series names and updating definitions of series is a continuing process. The changes should be accomplished in ways that detract the least from the predictive value associated with the earlier definitions and names. A centralized system for keeping records of soil series names and definitions insures that names and definitions of soil series meet the rigorous standards needed in a national soil survey program.

Official soil series descriptions.—Each soil series must be defined as fully and accurately as existing knowledge permits. This applies to proposed soil series used in an individual survey as well as to established series. To insure that essential information is included and to permit comparison of series definitions, a standard format for recording specific kinds of information is used.

Official soil series descriptions record definitions of soil series and other relevant information about each series. The format and the kind and amount of detail may change from time to time, but certain kinds of information are needed. A detailed definition and a series interpretation record are essential. In addition, information that is descriptive but not specifically definitive is needed to aid the reader in identifying the soil in the landscape and relating it to other kinds of soil.

An official soil series description should include at least the following:

1. The classification of the series at all categorical levels. This indicates the classes that provide limits of properties that are diagnostic for the series as well as for the higher taxa.

2. A description of a typical pedon and its horizons, describing each in as much detail as necessary to recognize its taxonomic class. Horizons that are diagnostic for the pedon should be described.

3. A statement of the ranges of properties of the series. This section also contains statements about the relationship of the series control section and diagnostic horizons to vertical subdivisions of the typical pedon.

4. A statement distinguishing the series from "competing series" with which it might be confused. Competing series are mainly those that share common limits with the series described or are members of the same family.

5. A statement that identifies at least one specific place that represents a norm for the series--a "type location." A type location should be described accurately enough that it can be located in the field.

Descriptive parts of an official soil series description are not required to define the series, but they aid the reader. All parts are not equally important for all soils. Many descriptions include the following:

1. The landform and physiographic position of the series, including its position relative to other landscape elements with which it is associated.

2. Evolution of the landscape. Influences of the major soil forming factors on the genesis of the series should be identified.

3. Parent material--the kind of mineral or organic material in which the soil formed, including kinds of rock from which the regolith was derived if that can be determined.

4. Drainage of the soil by drainage class or other means of description relative to soil moisture regimes. Seasonal wetness or dryness may be important.

5. Other kinds of soil with which the series is closely associated geographically.

6. Major uses of the soil and dominant kinds of vegetation that grow on it. Native plants are identified if known.

7. Rationale for classification. Implicit assumptions related to family classification may be described when laboratory data are not available.

8. Distribution and extent: the known geographic distribution and whether the soil occupies a large, small, or intermediate aggregate area.

9. The year and the survey area where the series was proposed or established.

10. The persons who prepared and approved the series description and the date it was prepared or approved.

11. References to available laboratory data.

12. Interpretations for common uses of the soil.3/

Proposing new series.--A unique kind of soil that does not fit in any known soil series is described and named tentatively. A first draft soil series description is usually prepared in standard format by the party leader of the survey area where the series has been identified or by a supervisory soil scientist for a State in which the series is important.

A name is proposed for the new series, and a request to reserve the name, accompanied by the initial draft description, is forwarded promptly to the office responsible for national records.

The name selected for a new series must be one that is not currently used or reserved for another soil series. The name of a place near the area where the soil is first identified is usually selected. Names that are difficult to pronounce or spell or that have undesirable connotations must be avoided. If a proposed name is rejected, the soil scientist who proposed it is advised to select another. When a name is approved, it is entered in the national list of soil series as a reserved name for a tentative soil series. This name cannot be used for another soil until it is determined that the tentative series is not needed.

The first draft of a tentative series description generally reflects concepts of the soil and its relationships to other kinds of soils in a relatively small area. The description should be reviewed by soil scientists familiar with soils of other areas where the tentative series or others related to it are thought to exist.

Copies of the first draft description and attached interpretations are sent to all soil scientists who are responsible for soil classification and correlation in regions, States, or groups of States that have similar kinds of soil. These soil scientists review the description and interpretations for conflicts with series in the areas for which they are responsible. They recommend adjustments to make the description consistent with the classification and use of soils in their areas. They may recommend that the proposed series be combined with a tentative or established series that the soil closely resembles. The reviewers give special attention to the parts of the description that define ranges of characteristics and that differentiate the series from similar kinds of soil. They also study the description and interpretations for clarity, completeness, and proper use of terminology and verify the classification of the soil.

If the reviewers agree that the series is needed, a revised draft is prepared on the basis of the recommendations and suggestions of reviewers. The revision is usually prepared by the person who wrote the first draft or by a supervisory soil scientist. The revised draft with a summary of comments by reviewers is submitted for additional review by a supervisory soil scientist responsible for regional classification and correlation. After this review and any needed revision, the description is reviewed by supervisory soil scientists of other regions for possible conflicts. A final draft including all needed revisions is then approved, reproduced, and distributed.

Although a series description has been approved, the series usually remains tentative until it has been correlated in a completed soil survey. It is then established as a unique kind of soil of significant extent.

Status of soil series.--A series must be unique among all kinds of soils and must cover a significant area. Normally, about 800 ha is required to justify a series. As knowledge about soils increases, the status of a series may change or the definition of a series may have to be revised. New knowledge sometimes shows that a soil series is no longer needed. The agency that maintains standards for soil classification must keep a record of the status of all soil series and names.

When a name has been reserved for a new series and a draft description of it submitted, the name is entered in the national list. If the series has not been correlated in a specific area, it is identified as a tentative series. A tentative series is still being tested for uniqueness and extent.

If a tentative series is not unique or is of too small extent, the name is dropped from the national list and documents about the series are removed from active files.

Dropped series are no longer a part of the national classification system and the names may be used for another kind of soil.

If a tentative series is found to be a unique kind of soil and to have a significant area, it becomes an established series. A series is usually formally established during the final correlation of a soil survey in which it has been used as a tentative series.

A series is established after (1) it has been found to be a unique kind of soil, (2) it has been shown to occupy a large enough area, (3) an official series description has been reviewed and approved, and (4) the series has been used in the final correlation of at least one soil survey. Under some circumstances, items 3 and 4 may be waived. For example, a tentative series may need to be identified in a research report to be published before the review of the series description is complete or before the series has been established in a final correlation. If the evidence is convincing that the tentative series is unique and extensive, it may be established for the research report.

When the definition of a soil series established at some time in the past is inconsistent with new knowledge or new conventions arising from new knowledge, the official series description must be revised or the series must be removed from the list of established series.

Many definitions of soil series established before the current classification system was adopted in 1965 permitted ranges of characteristics broader than the limits now imposed by diagnostic criteria of higher taxonomic categories. This did not make most established series useless, but it restricted their ranges and required review and approval of revised series. The central concept remained the same for most of these series.

Some series established early in the soil survey of the United States were broadly defined and included what are several kinds of soil according to current concepts. These series have been divided into two or more series to conform with current standards. In some cases to avoid confusion new names were selected for all new series. The old name was removed from use rather than retained for a small segment of the range of properties it formerly implied.

When an established series is removed from the list of series in current use, it is designated an inactive series. The name may not be used again for a different kind of soil, at least until soil surveys using new names have superseded the published surveys in which the name of the inactive series was used. The record of inactive series includes the name of each inactive series, where and when it was established, a copy of the last approved series description, when it was made inactive, and the reasons it was made inactive.

Other taxa

Soil series identified in individual surveys are classified in specific taxa of higher categories. The limits of most properties of soil series are set by the limits of the higher taxa in which they are classified. Soil Taxonomy[4] is the basic reference for identification, classification, nomenclature, and correlation of kinds of soils for categories above the series. It also suggests limits of many properties used in defining series.

During a survey, the taxonomic system is tested and retested many times. The results of these tests are reported at field reviews and at the field correlation. Problems in mapping or identifying soils and inconsistencies between the system and observed properties of the soils are recorded in field review reports and correlation memoranda. After appraising these reports, supervisory soil scientists call any inadequacies to the attention of the office responsible for keeping the system up to date.

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[1] Methods and conventions for describing and characterizing soils in the field will be described in Chapter 4. Chapter 8 will describe special studies for laboratory characterization. Chapter 5 of this Manual will provide conventions and guidelines for defining and naming map units. Soil Taxonomy defines diagnostic properties and taxonomic classes, and official descriptions define soils series.

[2] Orders of soil surveys will be defined in Chapter 2.

[3] Methods and conventions for developing and displaying soil series interpretations will be described in Chapter 11.

[4] United States Department of Agriculture. 1975. Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys. U.S. Dep. Agric. Handb. 436, 754 pp., illus.

Chapter 11
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Chapter 11
Soil Interpretations

Soil Interpretations

Soil surveys are made to help people select the kinds of soil suitable for various land uses, choose uses for the soils they have, select the management or treatment needed for good performance of their soils, and determine the potential of soils in terms of productivity or performance when given practices or technologies are used. Such decisions require soil interpretations. Interpretations represent the application of soil science to practical ends and justify the time and money expended to make the survey. A soil survey without interpretations has practical value only to those who have the background to make interpretations themselves. Most people, however, need to have the interpretations made for them. Many will use interpretations only if they are readily available and easily understood.

Interpreting soils requires knowledge of agronomy, horticulture, forestry, range management, engineering, and other disciplines besides soil science. Specialists in other disciplines work with soil scientists in preparing criteria for predicting soil behavior. Normally, this is done by correlating known performance with key soil properties. The interpretations in published soil surveys must be tested continuously.

Soil interpretations provide users of soil surveys with predictions about the behavior of kinds of soil under stated conditions. Interpretations predict potentials, limitations, management needs, and behavior or production or soils but are not in any sense recommendations for specific parcels of land.

Good land use decisions depend on many factors in addition to the kind of soil. Decisions depend partly on the economic characteristics of a tract. Location in relation to markets and services, the pattern of associated soils, the skill of the operator, credit, and all of the attributes of land as real estate are important.

Reliable interpretations result from a synthesis of (1) basic data about soils, obtained from laboratory research and from field observations and experiments, and (2) the experience of users, especially farmers, ranchers, foresters, and engineers. A combination of evidence is best, so that predictions arrived at by reasoning from basic principles are consistent with those arrived at through experience. The more reliable the data are, the more reliable are the predictions. The more reliable and abundant the data are for interpretation under all reasonable uses, the more dependable are the results through the life of the survey. Cooperation with land-grant universities and other local, state, and federal agencies ensures that all data are available. The soil survey program also exchanges information with researchers in other countries to obtain the benefit of their findings on important kinds of soil.

Interpretations are made for specific purposes,and soil surveys are made to serve those purposes. Interpretations for one use rarely apply accurately to other uses. For example, the land capability classification system characterizes problems encountered in using soils for common field crops and grazing. Serious errors result if this classification is used for other purposes, such as rating soil productivity. Productivity may be high even though problems are severe.

Purposes of interpretations

Interpretations in soil surveys are made--

-- To give limitations and suitabilities of soils for specified uses. The interpretations are most commonly in terms of limitations for use because there are few soil limitations that cannot be overcome if the user is willing to pay the necessary cost. The interpretations specify the soil properties that limit the use and the severity of the limitations created by these properties. Some interpretations specify the relative suitability of soil and identify the characteristics of the soil that determine its suitability.

-- To convert the information assembled about kinds of soil into the forms and terminology used by other disciplines. Soils information expressed in engineering terminology, for example, is directly usable by engineers.

-- To identify the potentials of soils for specific land uses, including the uses common in the area and others that may be feasible. Soil potentials are expressed in terms of relative suitability among the soils in a specified area.

-- To identify the management needed to use different kinds of soil effectively for various purposes. Identification of management concerns and conservation practices that affect production of crops are common interpretations of this type.

-- To predict performance of soils in response to management. Tables of estimated yields and ratings according to suitability for specified uses are among interpretations of this type.

Many kinds of interpretations are given for individual kinds of soil in modern published soil surveys. Some interpretations are presented in tables. Significant interpretations are summarized in the map unit descriptions. Such summaries describe the most important limitations, suitabilities, and potentials of the soil and predict its performance, allowing the user to find much of the information needed about a given kind of soil in one place.

Many interpretations can be summarized on maps that show the geographic distribution of soils having the same limitations, potentials, or management needs. This is done by depicting all soils that behave alike as one kind of unit on the map.

Predictive value of soil surveys

A soil taxon, such as a series or a phase of a series, has a set of properties, each having limits defined for that taxon. Individual soil properties are used by soil scientists in understanding and predicting how specific kinds of soil are likely to behave under specific kinds of use and management. However, it is not any single property, but the interaction of all properties, that makes a kind of soil unique and that determines its behavior.

Single properties typically have poor predictive value by themselves. For example, high shrink-swell potential may be the only significant limiting property for building houses on some kinds of soil, but other soils with high shrink-swell potential have even greater limitations for houses with basements because they are shallow to bedrock. On the other hand, some kinds of soil that have low shrink-swell potential are poor sites for houses because of wetness, flooding, slope, or any number of other characteristics. Some properties--such as slope, depth to rock, and natural drainage--affect practically all uses. Others, such as corrosion potential, affect only a few uses and only under certain conditions.

Each property of a soil must be evaluated in relation to all of the other properties of that soil. The interaction of these properties is taken into account, and many judgements are made in interpreting the soils. Generally, only those properties that are the most limiting for a given use are listed in published surveys. Users must consider the interaction of properties when using data directly to make interpretations.

Delineations on the soil map represent areas on the landscape, and most delineations have inclusions of soils other than the one for which the unit is named. Some of these inclusions differ markedly from the major soil. Soil interpretations made for delineations at a given map scale may be misleading if they are used without supplementary investigation to predict soil performance in areas too small to delineate. A detailed soil survey at a scale of 1:20,000 has delineations mainly several hectares in size. The survey may be interpreted reliably in terms of the general suitability of these areas for housing. Someone interested in a specific 1/10-ha lot for a house can determine from the interpretations that the dominant soil in a given delineation is well suited to homesites, but the person cannot be sure that the lot is on the dominant soil. The lot may be on an included soil that is poorly suited to houses. Thus, for many kinds of land use onsite investigations are needed.

Soil scientists have an obligation to those who use soil surveys to point out the occurrence of included soils and other factors that influence the applicability of and confidence in soil surveys and their interpretations. The heterogeneity in nature is fixed, and failure to recognize it in no way reduces its magnitude.

Forms of Interpretations

Some interpretations focus attention on the kinds of properties that limit given uses of soils and on how severely these properties affect those uses. Other interpretations focus attention on properties that affect the soils' suitability for certain uses. Interpretations commonly rate the soil for the use and list the properties that restrict that use. This format allows users to determine the relevant information quickly.

Ratings commonly reflect the influence of the properties of the upper 2 m of the soil, but reasonable estimates of properties to greater depths can be given for some soils. During the survey many observations are made to depths greater than 2 m. All existing deep excavations are used to observe and record the properties at such depths. However, the nature of the deeper strata is not so well known as that of the soil horizons, and interpretation based on the predicted properties of these strata are less reliable. The limited reliability of these predictions should be noted in the interpretations. Geologists can assist in predicting properties of the material at greater depths.

Soil limitation ratings

Soils are commonly rated according to the degree of limitation for such uses as foundations for light structures, recreation, or waste disposal. Limitation ratings are usually based on the hazards, risks, or obstructions presented by the undisturbed soil. Some approaches also consider the difficulty of overcoming limiting soil properties. If the components of a complex or association differ in degree of limitation, they are rated separately; a summary rating for the whole unit may also be given.

A three-class system is commonly used. The rating signifies the degree to which soil properties limit the specified use. The following definitions are commonly used:

Slight limitations present no more than minor problems for the specified use. The soils give satisfactory performance with little or no modification, and any operations or design beyond what is normal for the use are simple and inexpensive. With normal maintenance, performance should be satisfactory for a period considered generally acceptable for the use.

Moderate limitations do not require exceptional risk or cost for the specified use, but the soil has undesirable properties or site features. Moderate limitations require modification of the soil itself, special design, or special maintenance for satisfactory performance over an acceptable period. The needed measures usually increase the cost of establishing or maintaining the use, but the added cost is generally not prohibitive.

Severe limitations require exceptional cost or risk to adapt the soil to the specified use. The soil properties are so unfavorable that special design, a significant increase in construction cost, and possible increased maintenance are required for satisfactory performance over an acceptable period. A limitation that forces removal and replacement of the soil would be rated severe. A rating of severe does not necessarily imply that the soil cannot be adapted to the use, but the cost of overcoming the limitation is high.

Some soils have such extreme limitations that they must be avoided for certain uses if a reasonable alternate site can be found. Such soils have one or more features so unfavorable for the use that the limitation is extremely difficult and expensive to overcome. For example, bedrock at shallow depth or frequent flooding of long duration are extreme limitations for onsite sewage disposal and underground utilities. A rating of very severe is sometimes applied to such extreme cases.

Limitation ratings are given for each kind of soil. For some areas, small-scale maps can be designed to show the geographic distribution of limitation classes for a specific use. Such maps are useful mainly to show the extent of soil problems. Unless the maps identify the kind of limitation (flooding, wetness, depth to rock), they have limited usefulness for planning. Such a map, made for a single use, is generally not valid for other uses.

Soil suitability ratings

Soils are commonly rated according to their degree of suitability for such uses as roadfill, daily cover for landfills and topsoils. Suitability ratings are based on the characteristics of the soils as they influence any needed excavation and grading as well as performance as finally placed.

A three-class system is commonly used. Good soils have properties favorable for the specified use; good performance and low maintenance cost can be expected. Fair soils have one or more properties that make the soil less suitable than those rated good. Poor soils have one or more properties that are unfavorable for the specified use; overcoming the unfavorable properties requires special design, extra maintenance, or costly alteration.

Other ratings

Ratings of limitations or suitability are not feasible for some uses. For sand and gravel for construction material, a kind of soil may be rated only to show the probability of finding material in suitable quantity. For some uses, the restrictive features may be given without a rating, for example, features affecting use of the soil for irrigated cropland. Merely noting features can be helpful to users, especially if important interactions of properties are not overlooked.

Management needs groups

Interpretations of soils identify the kinds of practices needed to achieve acceptable performance, especially for the most extensive land uses. The most critical management needs are commonly given in the description of the map unit. In addition, management groups can be described for various uses.

Interpretations must clearly identify the kinds of practices needed for different kinds of soil, but they do not make specific recommendations. Rather, interpretations emphasize the general kinds of practices needed. A soil may need artificial drainage to be used for crops. Another soil may need an exceptionally large absorption field for a septic tank system. However, specific statements about how the soil is to be drained or the size of the absorption field are not provided. Such decisions must be determined for each tract according to its specific characteristics and the objectives of the land user. Many other factors must also be considered, such as the pattern of soils within the tract, the ability of the operator, the available resources, and the nature of the operating unit.

Knowledge and technology of soils change. New and better practices are developed, and existing practices are modified to accommodate new technology. Consequently, interpretations that give specific practices would eventually become obsolete.

Technical guides that give details of designs or design criteria for structures and management practices are prepared for those who work with land operations. These guides provide information for kinds of soil and uses common in the area. Some give cost estimates. Technical guides must be revised periodically. Users must adapt the information to the conditions and resources of specific tracts.

Management systems consist of sets of practices, each of which contributes to the effectiveness of the others. A single practice is rarely fully effective unless it is used in combination with other practices that release its full benefit. Alternative systems of management may be about equally effective. Alternative practices can commonly be substituted for others in a set. Nitrogen-fixing legumes or animal wastes, for example, can at least partially substitute for commercial fertilizer in supplying nitrogen to crops.

Groupings of soils according to management needs can present interpretations conveniently. Soils in a capability unit, for instance, have similar problems and management needs for certain types of farming. Other groupings may be more useful for other kinds of farming. Range sites are management groups for grazing. Woodland ordination groups rate soils for production of trees. Other groupings can be made on the basis of similarity of management needs for many other uses. A grouping for one kind of use generally will not serve as an effective grouping for another kind.

Management can be described for these groups of soils. Some sorts of management can be presented in tables; other sorts require narratives. The soils in a group are not expected to have identical management needs. However, the needs described for each group must apply to all of the soils. The broader the groups, generally the less specific are the descriptions of management needs. Specific detail about needs of individual soils can be noted either in the description of the group of in the descriptions of the individual soils.

The number of management groups needed for a kind of interpretation depends on the range of soil properties in the area, the intensity of use, the purpose of the grouping, the audience for which it is intended, and the amount of information available about managing soils for that use. The advantages of management groupings can be destroyed by making the groups either so broad that the soils within a group differ greatly in their needs or so narrow that the number of groups is large and their differences small.

Interpreting Higher Order Surveys and General Soil Maps

The units on higher order maps and general soil maps are mainly associations of contrasting soils. Limitations, management needs, and performance commonly differ greatly among the major kinds of soil in these map units (See Chapter 2). Interpretations of these units requires rating the individual soils and assessing the effects of each on the use, management, and performance of the other soils and of the whole area. These units can be interpreted reliably if the kinds, proportions, and patterns of constituent soils in the map units are well defined.

The level of generalization of a soil map and of the soil taxa in terms of which its units are defined strongly affects the level of generalization at which interpretations can be made. On a 1:50,000 map that shows associations of phases of soil series, the range of properties of each constituent of a map unit is small. The limitations, management needs, and performance of each constituent can be predicted as specifically as for the same kind of soil on a first or second order map unless the phases are defined in terms of broad ranges of slope or texture. If the proportions and patterns of soils in the map units are defined accurately, the effect of each on use of the others and on the map unit as a whole can be predicted reliably.

On a 1:1,000,000 map that shows associations of phases of suborders, the range of properties of each constituent is large. Limitations and potentials of each constituent can be predicted only in general terms, and interpretations of their effects on use, management, and performance of the map unit must be correspondingly general.

General soil maps provide information at the same level at which some land use decisions are made. In turn, the scope of land use decisions depends on the size of the areas for which decisions are needed. Thus, the size of these areas determines what level of gener-

alization is needed for soil interpretations. The size of delineations on the map corresponds with the level of generalization of interpretation for such entities as operating units, communities, and regions. These terms refer to the size of the areas for which unique interpretations are needed, not to the area represented by the whole map.

Operating units, such as farms, and ranches, are mainly a few hundred hectares to several hundred square kilometers in size. Map units are mainly associations of soil series. Soil maps of this kind are used by farm advisors, credit agencies, planners, and others, who are interested in the suitabilities and limitations of soils in individual or contiguous operating units.

At least two steps are required to interpret map units of this kind. First, the individual kinds of soil in each association are interpreted and rated for a given use. Then the interaction among the soils and the combined effects of all of the soils on the use, management needs, and expected performance of the map unit are estimated to arrive at a prediction for the whole association.

At the community level, delineations represent areas of thousands or tens of thousands of square kilometers. The map units are commonly associations of soil families, subgroups, or great groups. Soil properties have a wide range in most delineations. Interpretations must be general, but they provide reliable, informative predictions for their purposes.

Interpretations at this level appraise the soil resources of entire communities, secondary or tertiary watersheds, and other large areas that include many, and in some places diverse, operating units. These maps are used for regional planning and other purposes that require consideration of areas larger than individual operating units. In undeveloped regions, maps of this kind are used to identify large areas that are suitable for development.

The predictions require consideration of the improvements needed to overcome soil limitations. The analysis separates the more permanent type of improvements--such as drainage, irrigation, reclamation of saline or alkaline soils, and flood protection--from the recurrent types--such as fertilizing, using improved seed, land leveling, and maintaining existing drainage and irrigation systems. Predictions specify the particulars of the improvements and are based on intensive studies of sample sites.

The interpretations of a heterogeneous map unit at the community level can be done in either of two ways. If component associations of soil series can be identified, they can be interpreted as for operating units. Then the combined effects of the suitabilities and limitations of the component associations on the use, management, and performance of the entire map unit can be appraised. The extent and potentials of each component and the way the components intermingle must be considered. The procedure is similar to that described for interpreting maps at the level of operating units.

Interpretations can also be derived directly from the characteristics of the taxa that define the map unit. An area might be identified as "Ariguistoll-Arigiaquoll-Haplustoll association on dissected, undulating, loess-mantled plains." The relevant properties of each great group are described and its suitabilities and limitations are predicted. Then the use, management, and performance of the association as a whole can be evaluated on the basis of the proportions and the geographic patterns of the great groups. The final appraisal is necessarily general because much of the local detail is not known.

Usually a combination of both approaches is used to interpret soil associations at the community level. Associations of soil series might not be formally identified as components of the map units, but usually something is known about the local soil pattern based on sample locations. This information is used in evaluating areas dominated by individual taxa. Whatever is known about the geography of these local associations is considered in making predictions about the map unit. For soil maps prepared by generalizing detailed surveys, local associations of soil series can be easily identified and treated as components of map units. As the detail of field investigations decreases in higher order maps, greater dependence must be placed on understanding the kinds, proportions, and patterns of taxa above the series.

Soil maps of regions at scales of up to 1:1,000,000 are made to appraise the soil resources of very large areas. The maps commonly cover continents, large nations, or groups of nations. The delineations represent areas covering tens of thousands to millions of square kilometers and commonly correspond to natural regions. The map units are usually very heterogeneous and are identified as associations of orders, suborders, or great groups.

Interpretations of such units are necessarily general. The kind and specificity of interpretations vary widely, depending on the information available about the kinds of soil and about factors that determine their character and distribution. The information about soils is commonly least abundant, and the delineations least precise, for fifth order maps and for schematic maps made without direct field investigations. Nevertheless, interpretations of such soil maps can be of value if all information is used fully and if its limitations are understood.

The units on many maps of regions are associations of suborders, which indicate many soil properties that are important for broad interpretations. The soil moisture regime, for example, can be identified or inferred for most suborders, such as Udults, Ustults, Xerults, and Aquults. The soil temperature regime can be identified for some, such as Tropepts, and Boralfs. This information can be converted to certain broad interpretations, such as the kinds of plants that grow well.

If the names and descriptions of map units provide information about relief, physiography, parent material, and critical soil properties beyond those implied by the names of the taxa, more interpre-

tations are feasible. For example, the name "Tropepts and Udults on maturely dissected basalt plateaus" allows reasonable estimates of temperature, moisture regime, acidity, texture, slope, runoff, erodibility, drainage, and relative fertility of the principal soils. General predictions about the use of the map unit and some of the main limitations and suitabilities can be derived from such information.

Interpretation of regions involves (1) assembling all of the information available not only about the soils and their distribution but also about attributes of the area that suggest soil properties and distribution, (2) deriving the inferences that affect interpretation, (3) appraising the principal kinds of soil in each map unit for each kind of interpretation, and (4) integrating these appraisals into predictions for the map unit as a whole on the basis of the proportions and patterns of the major constituents.

The procedures are the same in principal as those described for interpreting operating units. However, interpretations at this level depend heavily on inference, which should be verified by observation if possible. the predictions should be at a level of generalization consistent with the confidence the interpreter has in the original data and in inference drawn from them. If much detailed information is available about kinds of soil and their distribution within the region, interpretations can be based mostly on facts rather than on inference.

The units on higher generalized maps derived from more detailed soil survey maps can be described as geopgraphic combinations of associations of soil families, subgroups, or great groups. These combinations can be interpreted by appraising the effects of the less generalized map units on the larger areas.

Soil Potential Ratings

Soil potential ratings provide a systematic means of evaluating the relative suitability of the soils in an area for various land uses by predicting the soils' performance after modern technology has been applied to overcome their limitations. Soil potential is defined as the ability of the soils to produce, yield, or support a given structure or activity at a cost expressed in economic, social, and environmental units of value. The potentials of the soils in an area are presented as ratings, either in a set of classes or on a numerical scale.

In any area, land is needed for certain uses, and it is in the public interest to identify the tracts that have the best potential for these uses. Natural resources have limits, and the potential for development of the natural resources, as well as associated environmental and aesthetic values, is closely related to these limits. For most areas, soil surveys are the most detailed studies of the natural resource base, identifying many soil properties that control other resources. Many of these some soil properties also directly affect land uses.

Presentation of soil limitations alone tends to focus on the avoidance of problems and may result in the rejection of some areas for a given use even though feasible measures are available to overcome the limitation and achieve good performance.

For example, a community may have large areas of nearly level soils that are excellent for farming and are also the best soils for urban or other nonfarm development. The community also has large areas of sloping soils that are poor for farming and that have severe limitations for nonfarm uses because of the slope and the erosion hazard. There is a strong tendency for urban development to proceed on the soils that are best for farming. If farming continues in the areas, it is increasingly shifted to the poorer soils. Such a premature rejection of the sloping soils for urban uses may be a costly error.

Using the soil potential approach in land use planning, a thorough evaluation of the measures needed for the most effective use of the sloping soils for urban uses would show that those measures are not prohibitively expensive and are relatively successful in overcoming the limitations. The nearly level soils have slight limitations for farming and for residential development and would be rated as having high potential for both uses. The sloping soils have severe limitations for both uses, but they would be rated as having low potential for farming and medium or high potential for residential development. Faced with a clear-cut choice, the community could decide to direct urban development to the sloping soils and accept a temporary increase in sediment production during construction--held to a minimum by the latest control practices--as well as slightly higher construction costs in order to perserve the prime farmland.

Soil potential ratings for a survey area are of greatest value in local planning. They indicate which available soils are the best and which the poorest for land uses considered important locally. Individual landowners may need comparative ratings of every soil showing which have the best potential for meeting their objectives. The best soils in a specific tract may be among those with low potential in the survey area. With this information they may decide to change their plans for the land or to find another area that has soils with higher potential.

A similar comparison can be made of the quality of soils within a specified distance of a developing community or city. Planners may need to look closely at what can be done near current development where normal growth would be expected before deciding to discourage growth nearby and encourage it in more distant areas. Ratings can also be developed for larger areas, such as groups of counties, watersheds, states, river basins, or nations. The choice of land uses to be rated and the criteria to be used must be keyed to a clear definition of the objectives and anticipated uses of the soil potential ratings.

At any scale, soil potentials provide a ranking from best to worst among the soils within the areas being considered. Soils that are rated

high within a small area may be rated medium or even low in a larger area. For example, around New Orleans, Commerce soils are among the best for dwellings. They have a severe limitation caused by flooding and a moderate limitation caused by wetness, but they are at higher elevations and have lesser hazards of flooding and wetness than the other soils in the area. They are also free of the subsidence that is characteristic of many of the other soils. Thus they have high potential for dwellings in the New Orleans area. In other parts of the Coastal Plain, however, Commerce soils are among the poorest for dwellings; and in a set of ratings for a group of states, they would have low potential.

In rare cases it may be considered appropriate to rate all of the soils in the area low, or low and medium, for a given land use. The main justification would be that the land use is not considered essential in the areas (or only a few land users consider it important) and, based on experience, the soils are marginal for that purpose. Usually, ratings of soil potential are not made for such purposes.

The choice of land uses to be rated is made by those local authorities not involved in local land use issues. Uses that are considered essential or inevitable in the area should be rated. The soil survey itself may identify potentials that had not been appreciated. For example, it might find that scattered small areas occur where the soils are uniquely suited to walnut trees, and such use might contribute substantially to the economy of the area. For another example, the local authorities may have directed that all new residential development of four or more dwellings be served by central sewage systems. However, if the survey finds that septic tank systems perform well on some soils if lots are at least one-half acre in size, the local planners may change the policy.

Ratings of soil potential are generally made without considering existing transportation systems or other important facilities or attractions. For planning to be most effective, basic investigations of the limitations and potentials of the natural resource base should be kept separate from the effects of previous activities in the area. Of course, consideration of location is essential in later stages of planning.

Procedure for rating soil potential

Identifying important soil properties that influence a land use is the first step in rating the potential of the soil for that use. Both unfavorable properties and those that are favorable are identified. These properties will normally be the same as those considered when soil limitations are rated.

The important properties are identified in two basic ways. First, performance or productivity is observed, sometimes over long periods, on specific kinds of soil so that relationships between properties and response can be noted. Second, research finds many such relationships.

As a part of this step, it is necessary to identify certain critical points in the range of each significant property for each land use. One of these points identifies soils for which the property is not limiting. For example, for the production of soybeans a seasonal high water table more than 60 cm below the surface does not interfere with planting, germination, growth, or harvesting; for alfalfa, this critical depth is much deeper, perhaps 120 cm. Likewise, the critical depth to the seasonal high water table may be 75 cm for dwellings without basements and 2 m for dwellings with basements. No special practices are required where the seasonal high water table is below these depths, but where it is higher there will be some reduction in yield or performance.

As the seasonal high water becomes progressively shallower, yield or performance declines; at some depth the water table so drastically affects yield or performance that the specified use is essentially precluded. This depth is another critical point: Soils that are poorer than this limit generally cannot be used for the purpose without special practices. (Corrective practices may also be needed for soils whose properties are between these two critical points.)

Generally, the first point identifies slight limitations and the latter identifies severe limitations. Soils between the critical points have a moderate limitation. Soils in any category may have good potential, depending on the feasibility of overcoming the limitations and on the quality of the other soils in the area.

The extent to which a given property is limiting, and in many cases the practices that can be used to overcome the limitation, is influenced by other properties of the soil. An example is the low strength of some silty soils of low density. Such soils, if well drained, may not be limited for dwelling foundations; but if the seasonal high water table rises to within one or two feet of the foundation, low-strength soils may be decidedly limited for this use. When limiting soil properties are identified, and when the degree of limitation is being judged, all significant interactions must be carefully considered.

Identifying corrective measure is the second major step in rating soil potential. For most limiting soil properties there are some changes that can be made in the soils, in their management, or in the kind of construction used that will minimize unfavorable effects. For many soils there are alternatives in practices or systems of management that may be about equally effective in maximizing performance.

A single practice may not be fully effective unless it is used in combination with other practices that permit it to function as intended. Such sets of practices are called systems of management. Alternative practices can commonly be substituted for some of those in a set. Growing nitrogen-fixing legumes in the crop rotation and applying animal wastes, for example, can at least partially substitute for nitrogen from commercial fertilizer in crop production. Dwellings can be built without basements on integral slab foundations instead of having reinforced basement walls. All alternatives that appear to be applicable for each land use should be listed during this step.

The identification of practices to overcome soil limitations must involve engineers, biologists, agronomists, and members of other disciplines in whose expertise is the basic understanding of the practices. The main role of the soil scientist is to inform other experts about the nature of each soil in sufficient detail that the applicability of the corrective measures to the soils can be judged properly. Attention is focused on the kind and degree of the limiting soil properties and experience with the corrective measure on similar soils.

The most common source of information about corrective measures is cases in which the practices has been successfully used. To discover that a given practices works on a given kind of soil is the strongest possible evidence of its applicability. That the practice has worked on similar soils that have the same kind and degree of limitation is also good evidence. Of course, research that relates soil properties to the performance of practices is very useful.

One of the principal objectives of soil-related research and field trials is the identification of new practices that can be used on specific soils to maximize production or performance. Ratings of soil potential must identify the kinds of practices required to achieve the potential, including alternative practices as appropriate. Ratings should be dated, and users must recognize that the ratings do not consider practices developed after the ratings were made. As new practices are developed, their impact on the existing potential ratings should be evaluated.

It is also the job of the soil scientist to be fully informed about the results of practices on the same soil or similar soils in other areas. A substantial effort is required to do this, for the field experience or research may have been carried out within the soil scientist's work area or far away. A systematic means of data collection to record the performance of practices on given kinds of soil is essential. With this information the soil scientist can provide valuable assistance to the local specialists, first by relating his or her knowledge of practices that have been successful on given soils elsewhere, and second by indicating those local soils on which specific practices should be effective. Members of the other disciplines may also be familiar with new practices in use elsewhere and should work with the soil scientist to determine if the practices may be useful locally and on which soils.

The soils scientist must avoid the impression that he or she is endorsing or recommending radical departures from current local practice. However, the discussions that lead to developing lists of alternative measures or management systems provide a good opportunity for the soil scientist and the local specialists to learn from each other.

Determining the cost or difficulty of overcoming soil limitations is the third step in rating soil potential. It is not sufficient to consider only the performance of the soil after the corrective measures have been installed. Two soils may have exactly the same potential crop yield, but production costs on one of the soils may be twice that on the

other. This principle also applies to nonfarm uses. A soil that requires special corrective measures costing $3,000 over and above the normal costs would not have the same potential as soils that require no special practices or costs.

The costs of corrective measures and the extent to which these costs should influence ratings of soil potential are determined by local specialists, usually specialists other than the soil scientist. Persons who are well informed about the costs locally of construction, earth-moving, or other pertinent elements required for the installation of practices are consulted. Generally, costs should not be considered until all applicable measures have been identified.

Because costs change, a scale based on the relative costs of corrective measures is generally desirable. An example of such a scale is presented below--

Costs and Cost Indices for Septic Tank Systems

System	Average Cost	Cost Index
Standard field	$1,200	100
Seepage pit	1,200	100
Field with curtain drain	1,450	120
Field with under-drain	1,700	140
Field with under drains and pressure dosing	2,050	170
Field with dentrification barrier and pressure dosing	2,200	180
Mound with trenches	2,400	200
Mound, thick, with trenches	2,700	220
Mound with bed	2,700	220

If very high costs of overcoming the limitations are judged by the local specialists to be prohibitive, the soil is rated as having low potential for that use. Information about costs may be enough of a deterrent to cause landowners to change their plans for use of the land. More importantly, local planners may decide that the use should not be permitted because it far too expensive to install the required corrective measures. Thus the information contributes to good land use by providing a valid basis both for regulation and for planning.

Identifying limitations that exist after measures have been installed is the fourth step in rating soil potential. Some practices are fully successful in overcoming limitations on some soils: Once they have been installed, performance is as good as that of soils that do not have the limitations, or even better. For example, in some areas wetness severely limits crop yields on certain poorly drained soils but not on nearby better drained soils. After drainage, however, the once poorly drained soils become more productive than the others.

For some soils, however, no corrective measures are available at acceptable cost to fully overcome the existing limitations. Although feasible practices may substantially lessen the effects of undesirable soil properties, problems remain, such as undesirable off-site effects. For example, under-drains can lower the seasonal high water table in septic tank absorption fields, but the water in the drains is likely to be contaminated by nitrates from the effluent.

Continuing limitations can be identified by a review of local experience with the practice on specific soils. Local agencies such as the health department may have to interview homeowners, or they may be able to review nuisance complaints and relate continuing limitations to kinds of soil. A systematic method of collecting such data by kinds of soil and specific practices on a multicounty or multistate basis is needed.

Assigning ratings of soil potential can proceed after the prior steps have been completed. The ratings provide a scale of relative quality of the soils in an area, usually a single soil survey area. The relative scale gives a generalized, simple answer to the question, which soils are the best and poorest for a given use? Some soils in an area will normally be rated as having high potential for a given land use, even if all of the soils have severe limitations. Some severely limited soils are more easily treated than others. Soil potential ratings make this important distinction.

Two general kinds of rating system can be used to present soil potentials. One system uses numerical indices to designate the relative potential of the soils, and the other uses qualitatively defined classes. The numerical system shows small differences between soils. The qualitative system places all soils into three to five classes of potential. Generally, the qualitative system is derived from the numerical soil potential indices (SPI) and represents a summary of the numerical system.

Numerical rating systems assign points to those soil properties that influence performance. Some assign penalty points to limiting soil properties or site conditions, and others assign points based on favorable properties or conditions.

The soil potential index (SPI) is developed using the formula:

$$SPI = P - CM - CL$$

In this formula, P represents the standard of performance or yield as locally defined. An index value of 100 is common, but any number can be used. In one case, P was set at 36 to represent yield of soybeans in bushels per acre. The definition of P is based on established standards of management, or production and installation costs, and of maintenance requirements. P is modified by the other factors to account for differences between soils.

CM is the index of costs of corrective measures used to overcome or reduce the effects of soil limitations. Only those measures over and above the standard set established in the definition of P are included in CM.

If feasible corrective measures are not fully successful in overcoming unfavorable effects of soil limitations,the performance of a soil does not meet the standard defined in P. Recognition of such continuing limitations (CL) is important judging the relative quality of soils. An index reflecting costs for annual or periodic maintenance, for inconvenience or aggravation, and for substandard yield is established as CL.

In developing a soil potential index, the latest practices that are judged to be feasible locally are established as corrective measures for individual soils. The soil scientist can be of most assistance by keeping abreast of measures which have been proven effective on specific soils in other areas. Then he or she can help local specialists to recognize important new techniques that are likely to prove effective on soils in the area.

A system developed for rating soil in the Mediterranean area for various crops has some features similar to the soil potential format. Eight textural groups are assigned basic numbers according to their relative quality. These numbers are then adjusted downward according to calcium carbonate content salinity, drainage, soil depth, type of epipedon, slope, and degree of profile development. The size of the adjustment depends on the crop being rated; for example three groups of crops are rated separately for salinity--very sensitive, sensitive, or tolerant to salt. Decimal factors are designated to adjust downward the ratings for unfavorable properties.

In using numerical rating systems, a major concern is ensuring that important interactions are not overlooked. Another problem is the tendency to attribute too much significance to small differences in numerical indices. On a scale of 0 to 100, a difference of 5 or 10 units may not indicate a real difference in performance or productivity between soils. This degree of uncertainty should be considered carefully when numerical systems are used or explained.

Qualitative ratings of soil potential place soils into a few classes by comparing their properties to those necessary to meet specified requirements. The following definitions of a three-class system illustrate common criteria:

High Soil Potential: The soil has a combination of properties that meet or exceed all of the critieria listed below that apply to the land use.

1. The soil has few limitations, or practices for overcoming the limitations are available at reasonable cost.

2. Crop production is profitable and at least average for the area using locally proven management systems or those shown by research or experience elsewhere to be applicable.

3. For other uses, performance of the soil is satisfactory, or as good as or better than local standards, using locally proven practices or systems or those shown by research elsewhere to be applicable.

4. Environmental values, both on and off the site, are maintained at a level that is better than average for the area.

5. After corrective measures have been installed, any continuing soil limitations do not appreciably reduce production, performance, or environmental values.

Medium Soil Potential: The soil has a combination of properties intermediate between those qualifying for high potential and those qualifying for low potential. Production is somewhat below local standards, or cost of corrective measures is high, or continuing limitations after measures have been installed detract from environmental quality or economic return.

Low Soil Potential: The soil has a combination of properties such that at least one of the following criteria is met.

1. Serious soil or site limitations exist and practices for overcoming them are not available or are considered locally to be too expensive.

2. Crop production is substantially below the local average and is economically marginal or submarginal.

3. For other land uses, performance of the soil is below local standards or below the normal expectations of the land user, even under the best available management.

4. Environmental values, on or off the site, are excessive when in use.

5. After corrective practices have been installed, serious continuing soil limitations affect the use.

Some areas need a five-class system. Very high potential distinguishes soils that have few or no limitations affecting the land use. Only standard practices, systems, or designs are needed on these soils. On soils with high potential, then special practices involving some additional cost are needed, although performance may be as good as that on soils that have very high potential.

Very low potential is used for soils so severely limited that they cannot be converted to even marginal performance for the use. In many cases, little effort is required to exclude the land use from soils that

have very low potential because their limitations are obvious. Soils with low potential can be made to perform, though only marginally, at high cost or with serious environmental degradation either on or off the site.

Presenting Potentials

Several kinds of format can be used to present ratings of soil potential. An indication of the kinds of practices needed to achieve the potential is essential. Any continuing hazards should also be identified. If the potentials for a single land use are presented in tabular form, three columns can be used following the names of the soils: Soil potential, Corrective measures needed, and Continuing limitations. If a single sheet is used to present all interpretations for a given soil, the land uses are listed on the left followed by the same three columns. The degree and kind of soil limitation can be presented for each use in the same table. Ratings and other information can also be given in map unit descriptions.

One of the desirable results of the deliberations required to develop a soils potential system is the extensive local contact between members of the disciplines involved. The understanding that results from these discussions is important in translating resource data into rational land use.

Land Use Planning

Land-use planning is the formulation of policies and programs for guiding public and private land use in areas of any size where different uses compete for land. Soil surveys help in land-use planning by (1) serving as an introduction to the natural resources of the area and (2) providing data for evaluation of the environmental and economic effects of proposed land uses.

Soil surveys are interpreted for land-use planning through groupings or ratings of soils according to their limitations, suitabilities, and potentials for specified uses. The interpretations are made by objective evaluation of soil properties. They offer no advice and make no plans. They strongly influence planning decisions, but they do not form the sole basis for decisions. Soil interpretations can be used to identify possible developments and their related economic opportunities and to predict the effect that such developments would have on the environment.

Groupings of soils are sometimes called "land classifications," but "soil classifications" would be a more appropriate term in this context. The word "land" implies many attributes of place and other factors beyond the soil. Planners must consider place, size of area, relation

to markets, social and economic environment, skill of the land users, and other factors besides the soil to prepare a classification for land-use planning.

Regional planning deals with problems of areas that cover several counties or states and that cannot be resolved by local political units acting independently. The principal functions of regional planning are the collection, analysis, and dissemination of basic planning and engineering data on a continuing, uniform, area-wide basis; preparation of a framework of long-range plans for the physical, social, and economic development of the region; and provision of a center for the coordination of the many activities of planning and implementation carried on by the agencies of the governments within the region.

Regional planning requires a broad perspective, and large areas are evaluated for potential uses. Soil maps for these purposes usually have a scale of 1:250,000 or smaller and the map units are generally soil associations. These small-scale maps are commonly generalized from soil survey maps at scales of 1:24,000 or larger, although surveys at scales of 1:63,360 or 1:62,500 can also be used. Skill is needed in generalizing detailed soil maps and their interpretations to show the dominant conditions of large areas without creating a false impression of uniformity. For areas that do not have detailed soil surveys, soil maps are made by reconnaissance methods with units defined as associations. Descriptions and interpretations of the soil resources of large heterogeneous areas must be in terms that planners understand for the information to be used.

Most soil maps for regional planning have delineations the size of communities. Interpretations show the differences between these areas in suitabilities and limitations for the principal competing uses. The distribution of units having similar ratings for a given use are commonly shown on special maps, and the text describes the units and explains the basis for the ratings.

For some purposes, planners need information about the differences in potentials of the soils within the generalized delineations. Tables can be prepared showing how much of each map unit has high, medium, and low potential for specified uses. The table may also describe the effects of the pattern of associated soils of different quality on the use of parcels.

Regional planners commonly need more specific information than generalized soil maps can provide about the suitability of small parcels. For example, they may find an area generally good for recreation, but must be sure that a certain site has soil suitable for a reservoir before completing the regional plan.

Community planning is done by local governmental units such as cities, towns, and counties. Planning at this level deals with

complexes of farms and ranches and with groups of smaller uses such as housing developments, shopping centers, and industrial parks.

Community planners use interpretations of soils and other information to develop recommendations on alternatives for land use, patterns of services, and public facilities. For some purposes, planners need predictions about the general suitability and limitations of areas of a few hundred to several thousand hectares--areas that represent soil resources common to contiguous operating units. For other purposes, they need interpretations of areas as small as a few hectares. Planners at this level commonly need interpretive maps at more than one scale.

Interpretations of small areas for community planning rate limitations, identify needs for management or treatment, and predict potential and performance of individual kinds of soils identified on detailed soil maps.

Interpretations of areas that include entire governmental units estimate the potentials of soils for all competing uses within the community. Maps are smaller in scale, and the units are associations of soil series. Community planners commonly need ratings of the whole association for alternative uses. Special maps showing the distribution of areas having similar potentials or limitations for certain uses may be convenient for planners. The basis for the ratings is described in the text. Information about the amounts and patterns of soils having different potentials within each association can be given in tables or in the text.

Farming

Most farmers have some sort of plan to guide their operations. Some only work out the crop pattern for the coming year; but many have carefully prepared written plans, with maps, for several years in advance that they adjust with the seasons. As agricultural technology becomes more sophisticated, planning becomes more important in farm operation. Conservation planning deals mainly with decisions affecting the area within farm boundaries, but the farmer makes these decisions within the framework of the physical, economic, and cultural environment of the community and region. The skills and preferences of the farmer are also important elements in planning.

In planning, a farmer considers the combination of enterprises that are adapted to the farm and their economic feasibility. The farmer's decisions on the following items depend entirely or partially on proper interpretation of soils information:

1. Use of available soil resources for crops, pasture, farm woodlots, farmstead, etc.

2. The choice and sequence of crops.

3. Control of water and wind erosion.

4. Water management on and in the soil, including drainage, irrigation, conservation, and runoff control.

5. Tillage methods and maintenance of good tilth.

6. Use and conservation of crop residue and other organic materials on the farm and of organic matter in the soil.

7. Control of acidity, alkalinity, and salts, including fertilizing and liming.

8. Protection of crops and livestock from wind, insects, diseases, and other hazards.

9. Control of pollution from pesticides, excess fertilizer, and livestock waste.

The interpretations in soil surveys provide some of the information necessary for these decisions. The farmer converts these interpretations into an operational plan and integrates them into a practical system for the farm.

Interpretations in a soil survey should include (1) soil limitations and qualities that affect farming, (2) suitability of soils for selected farm uses, (3) management needed for good performance, and (4) productivity of the soils for the selected uses. Usually, not all possible interpretations can be given in one publication. Enough should be given for the farmer to be able to make sound decisions.

Soil surveys identify the most important soil characteristics that affect the limitations and qualities of soils for farming. This permits farmers to decide on uses and management for different kinds of soil. Some of the interpretations are the same as those for nonfarm uses, and others concern primarily farming. The following kinds of information are commonly needed. Not all are needed in every region or for every type of farming:

1. Depth to bedrock, pans, or other layers that restrict penetration of roots, water or air.

2. The capacity of the soil to hold water available to plants.

3. Permeability of critical horizons or layers, especially in soils that have limited internal drainage.

4. Natural soil drainage or aeration, commonly expressed as soil drainage class, depth to saturated zones at different seasons, or sequence of soil-water states in the rooting zone. Other

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ways to characterize soil-water relations may be more meaningful for specific survey areas or for certain uses.

5. Tendency to form surface crusts that restrict infiltration of water and emergence of seedlings and other qualities that relate to tilth.

6. Properties that limit or prohibit the use of equipment, including gradient and complexity of slope, coarse fragments, outcrops of bedrock, low strength when wet, and strength or hardness when dry.

7. Susceptibility to erosion by water or wind, considering the characteristics of the soil, slope and climate.

8. Susceptibility to flooding.

9. Salinity and sodicity where either is a problem.

10. Substances toxic to plants or to animals that consume the plants, such as selenium or molybdenum.

11. Deficiencies of plant nutrients, including necessary micronutrients as well as nitrogen, phosphorus, and potassium.

12. The capacity of the soil to store and release plant nutrients.

13. Chemical reaction and its relationship to plant growth and the need for liming.

14. The capacity to retain soluble substances, such as nitrates, that can pollute ground water.

15. Capacity of the soil to absorb and deactivate pesticides.

Most of this information is provided in various places in published soil surveys. Much is given in map unit descriptions, management groups, or capability units. The information should appear in a way that makes its significance clear to the reader. For example, if a soil has "a fragipan at a depth of 18 inches", the text should explain that water movement and root preparation are obstructed by it.

Special interpretive groupings of soils identify the kind and degree of important limitations for farm uses. The capability classification system is an example of such an interpretive system.

A soil survey of a farming area describes the <u>suitabilities and potentials</u> of the soils for locally important farm uses. These uses may include common tilled crops, pasture, and woodland or range. In some areas the potentials for orchards, vegetable crops, speciality crops, or irrigated crops are given. Some surveys rate the suitabilities of soils for especially important individual crops.

Suitability ratings are assigned after appraising soil limitations, measures needed to correct the deficiencies, and predicted production under feasible management. One logical organization for this part of interpretations is to identify the uses first and then follow with management requirements for those uses and predicted performance of soils when management is applied.

The land capability classification system has been used for many years in the United States to show the suitability of soils for important land uses. It is a three-category interpretive system. The two highest categories, class and subclass, give broad perspective of the suitability of map units for certain crops or for pasture. These categories indicate the degree and kinds of limitations for these uses. The system evaluates soils for mechanized farming systems that produce the more common cultivated field crops, such as corn, small grains, cotton, hay potatoes, and field-grown vegetables. It does not apply directly to farming systems that produce crops such as some fruits and nuts that require little cultivation or crops that are flooded, such as paddy rice and cranberries. It also cannot be used for farming systems that depend on primitive implements and much hand labor.

The highest category of this system is the capability class. The capability classes are groups of soils that have the same general suitability for the broad kinds of use common on farms and ranches. Restrictions in use that result from soil properties are given emphasis. There are eight classes.

Classes I, II, III, and IV are suitable for mechanized production of common field crops if properly managed and for production of pasture and woodland. The degree of limitation for production of cultivated crops increase progressively from class I to class IV. Limitations may affect production as well as the risk of permanent soil deterioration, as by erosion.

Classes V, VI, and VII are generally not suited to mechanized production of common field crops without special management, but are suitable for permanent cover such as grasses and trees. The severity of the soil limitations for crops increases from class V to class VII. Areas in class VIII are generally not suitable for crops, pasture, or wood products without management that is impractical. Class VIII areas may have high potential for other uses, such as recreation or wildlife habitat.

The next category of the capability system is the subclass. The subclass identifies the dominant kind of limitation in the class. Class I is not subdivided because soils in this class have few limitations.

Capability subclass "e" identifies susceptibility to erosion, by wind, or water, as the dominant kind of limitation. subclass "w" identifies excess water, including both excess water in the soil and susceptibility to flooding. Subclass "s" identifies limitations within the rooting zone, such as low available water capacity, salinity or sodicity, limiting amounts of stones, layers that restrict rooting, and the like. Subclass "c" identifies limitations related to climate, such as unfavorable soil temperature, a short growing season, or lack of adequate moisture. The system provides guidelines about which subclass to use when two or more kinds of limitations are nearly equally restricting.

The lowest category of the capability system is the capability unit. Capability units are soil groups within a subclass. The soils in a capability unit are enough alike to be suited to the same crops and pasture plants, to require similar management, and to have similar productivity. Units are designated by Arabic numerals.

The purpose of management of farms is the satisfactory production of crops, pasture, or wood products. The management practices needed to do this depend on the nature of the soil. Management practices include both annual and seasonal activities, such as tillage, and lasting measures, such as terraces, and artificial drainage systems.

A combination of practices is called a resource management system. Management practices must be applied in appropriate combinations to achieve safe and efficient production in modern agriculture. The effectiveness of any practice depends on the others used with it. For example, fertilizing is futile if excess water limits plant growth of if pests are not properly controlled.

Some practices can be substituted for others in the management system. Manure may substitute for part or all of the commercial fertilizer. Legumes in the rotation may replace nitrogen fertilizer or reduce the amount needed. Different sets of management practices may be equally effective on a soil. Farm operators must evaluate various combinations of practices and choose those that best fit not only their soils but also their other resources and their skills and preferences.

Management can be discussed in two ways. One way is to give interpretations for each kind of soil in the map unit description. This organization permits the reader to study all of the information about a soil at one place.

The other way of presenting the information is to discuss groups of similar soils. Soils in a management group are similar enough that at least general statements about the following apply to all of the soils:

1. Suitability for the broad kind of agricultural use--crops, pasture, woodland, range.

2. Suitability for kinds of crops or other plants that may be grown. (Since interpretations for grazing and woodland are commonly given separately, crops are usually emphasized in these groups.)

3. Susceptibility to erosion.

4. Limitations to rooting of plants, including not only physical barriers like bedrock but also physical and chemical properties of the soil in the rooting zone.

5. Water relations--degree and periods of wetness or droughtiness in the rooting zone and susceptibility to flooding.

6. Deficiencies or imbalances of plant nutrients in the rooting zone.

7. Soil acidity or alkalinity, salinity, and sodicity.

8. Soil properties that restrict use of farm equipment--slope, stoniness, rock outcrop, capacity to support loads.

9. Capacity to absorb, decompose, and deactivate farm wastes and chemicals.

Not all soils in a management group will have identical potentials, limitations, and management needs. However, soils should be enough alike that statements useful to farmers can be made about the whole group. Variations among the soils in the group can be shown in the group descriptions.

Productivity is the capacity of a soil to produce desired crops. It is expressed in terms of output (harvest) in relation to inputs of production factors. Estimates are made for a specified plant or sequence of plants under a defined set of management practices.

Except for primitive gathering of the products of undisturbed native vegetation, productivity of soil implies response to management. Even in primitive farming, there is some input of labor and material, be it no more than planting seeds with a sharpened stick, using compost, and gathering the products. A soil that has low production under this kind of management may be highly productive under modern farming methods. Interpretations of productivity must define the management being assumed.

Productivity estimates should cover periods long enough to represent seasonal and annual variations in weather. Productivity of crops can be expressed as quantity of product per unit land area, such as kilograms, or metric tons per hectare. Productivity of pasture can be expressed as carrying capacity in standard animal-units per unit area

per season or year, or it can be expressed as live-weight gain. Productivity can also be expressed as a rating or index based on standard yields.

Predicted yields of important crops under a defined level of management on different kinds of soil connect agricultural research and specific tracts of land. Estimates of yield on different kinds of soil under different management systems are needed for farm planning and farm production budgets. These estimates allow productivity of soils to be used as one of the factors affecting land value and permit use of the soil map in land evaluation. They also provide a basis for interpretive groupings of soils for many purposes.

The levels of management for which yields are predicted are chosen to fit conditions in the survey area. In a primitive farming area, yield predictions could be given for management consisting mainly of hand labor for planting, weeding, and harvesting. Such predictions have little usefulness in an area of modern mechanized agriculture. In these areas, however, several levels of management are possible. To show response to management, estimates can be given for two or all three of the following levels:

Level A: The combinations of management practices used most commonly by successful farmers in the area. This level has been termed "ordinary" or "prevailing" management and is considered to apply to most farmers in the area.

Level B: A combination of superior management practices followed by farmers who obtain yields well above the average for the area. This group may be 5 percent of the farmers in some areas to as many as 30 percent in other areas. This level has been termed "exceptional" or "improved" management or a "high" level of management.

Level C: The optimum combinations of management practices that fully apply current knowledge and techniques of crop production.

The sets of management practices must be defined for each level. A "high" level of management provides necessary drainage, erosion control, and protection from flooding: proper planting rates; suitable high-yielding crop varieties; appropriate and timely tillage; control of weeds, plant diseases, and harmful insects; favorable soil reaction and optimum levels of nitrogen, phosphorus, potassium, and trace elements for each crop; effective use of crop residue, barnyard manure, and green-manure crops; and harvesting that incurs the smallest possible loss. For irrigated crops, the irrigated system is adapted to the soils and the crops, good quality irrigation water is uniformly applied as needed, and tillage is kept to a minimum.

Accurately measured crop yields are the most reliable sources of information for predicting yields. For many areas, 10 years of yield records are the minimum needed for reliable averages. For some areas

where weather varies widely from year to year, records are needed for much longer periods. Records of yields are needed for several sites on the same kind of soil to sample the variability of response to management among areas of the same kind of soil.

Adequate data are rarely available for all kinds of soil in a survey area. Consequently, the yield estimates for most soils are based on data for a few benchmark soils for which measured yields or reliable estimates are available. The estimates of yields for benchmark soils are extrapolated to other soils by comparing those soil properties that affect response to management.

Usually, the soils of a survey area are arrayed from best to poorest in terms of their expected production of a given crop. The benchmark soils are located in the array, and their yields are extrapolated to the other soils. These predictions are tested against available records and the judgement of farm advisors, soil conservationists, research scientists, and others who are knowledgeable about crop production in the area. The predictions are then adjusted as necessary.

The final accuracy of yield predictions depends on the completeness of the available information. The degree of exactness that can be justified in the predictions depends on the number of benchmark soils, the amount and reliability of the data, and the amount and reliability of supplementary information and judgement. In some surveys, predictions to the nearest 300 or 400 kg/ha may be as specific as the information warrants for a crop such as wheat. In other surveys, estimates to the nearest 50 kg/ha may be justified.

The data for predicting yields on benchmark soils and for relating other soils to them come from many sources. In some states estimates of yields have been made for benchmark soils by statewide studies. Local conditions in the survey area may require adjustments in these estimates. Yields may also need to be adjusted to account for local differences in management. For many surveys, estimates for benchmark soils in previously surveyed areas can be used with appropriate adjustments for differences in soil, climate, and management.

Farm records that give yields and management practices by fields with known kinds of soil are common sources of data. Records from demonstration farms and pilot research farms are valuable, especially for the higher levels of management. A number of institutions and agencies keep records of crop yields, some of which be can related to specific kinds of soil.

The survey party make notes and observations about crop growth on different kinds of soil under different management during fieldwork. These observations help in comparing relative productivity of various soils. Notes on performance of crops on different kinds of soil in the same field are especially valuable. Farmers can often given reasonably

reliable estimates of total production of a field or group of fields if the harvest was measured.

Sampling the yields of a crop on different kinds of soil within the same field can provide useful data. Since conditions usually have been the same on all of the soils in the field, this technique gives information for comparing different kinds of soil under the same management and weather.

Productivity ratings express the predicted yields of crops as percentages of standard yields. They provide a scale for comparing productivity of soils. Ratings can be used to compare yields of a crop on different kinds of soil nationally or regionally. Ratings lend themselves to mathematical treatment, especially when yields of more than one kind of crop are given in summaries of production.

Productivity ratings are useful for comparing levels of production of crops having yields expressed in greatly different values. For example, on a certain soil yields of corn for silage are 60,000 kg/ha and yields of grain corn are 9,000 kg/ha; however, these yields represent similar levels of production and could be expressed as similar productivity ratings.

Productivity ratings are calculated as follows:

$$\text{Productivity rating} = \frac{\text{Predicted yield per unit area}}{\text{Standard yield per unit area}} \times 100$$

Productivity ratings are calculated for specific crops on specific soils under defined management. Predicted yields can be translated directly into productivity ratings.

Selection of the standard yield for a crop depends on the purpose of the rating. If the rating is being made for nation-wide comparisons, a standard is chosen that represents yields at a high level of management on the best soils for the crop in regions most favorable for its production. If comparison with potential production is wanted, yields under the best combination of practices are used. Whatever standard is chosen, the conditions that it represents must be defined.

Productivity ratings for individual crops can be combined in a general rating for a soil. The individual ratings are weighted by some factor, such as the area occupied by each crop, and an average is calculated that characterizes the general productivity of the soil. Satisfactory weighting is difficult, especially for ratings intended to show the relative potential of different kinds of soil for farming. A soil that has low productivity for most crops of an area may have very high productivity for a single crop, such as high-quality flue-cured tobacco, that is very important locally.

Rangeland

Range is land on which the native vegetation (climax, or natural potential, plant community) is predominantly grasses, grasslike plants, forbs, and shrubs suitable for grazing and browsing. Range includes natural grasslands, savannas, many wetlands, some deserts, tundra, and certain shrub and forb communities. Soil interpretations for range show the suitability of soils for various kinds of range plants, their capacities to produce forage, and the management needed for efficient production. Interpreting soils for range requires close collaboration between soil scientists and specialists in range plants, grazing management, wildlife management, and water control.

Range interpretations can be given by range sites. A range site produces a plant community that is characteristic of that site and different from the communities of other sites in terms of kind of vegetation, proportions of dominant species, or total annual production. Differences must be great enough to influence management.

A range site is the product of all of the environmental factors that bear on the area. Soil, climate, and topography are the most important of these. If climate, topography, and other factors are relatively uniform in an area, the soil generally exerts the greatest influence on the plant community; therefore, range site boundaries usually coincide with soil boundaries. Many sites, however, include several soils. For example, the influence of the soil moisture regime may overwhelm other soil characteristics to determine the production and composition of the vegetation, so that a number of kinds of soil would be in the same site. If a site deteriorates through erosion, reduced fertility, changes in soil moisture relations, or other causes, the site capability may be altered and a new site must be described.

Each range site description commonly gives the following information:

1. The principal kinds of soil in the site (generally by series or phase).

2. The soil properties that are most important to plant growth and development.

3. The plants that are important constituents of the climax community.

4. An estimate of the proportion, by weight, of each important species in the climax community.

5. Estimates of the total annual yield of air-dry forage, expressed as a range of values that reflect climatic variation over many years.

6. The effects of prolonged heavy grazing, fire, or other disturbances on the composition of the plant community. The common invader species are identified.

7. The feasibility of restoring depleted areas, including the potential for planting or seeding suitable species.

Predicted annual yields of forage are usually based on measured values for only some of the range sites and only some of the soils in them. Estimates are made for others by extrapolation. Identifying those soils for which actual measurements are available could be helpful to some users.

Other elements may be needed in interpretations. These include suitability of the plant community for wildlife food and cover; suitability of the soils for impoundments and other forms of water management; special limitations, such as salinity or sodicity; trafficability for vehicles and animals; shelter provided by landforms for animals during inclement weather; reliability of the natural water supply by season; susceptibility of the soils to compaction; susceptibility to surface crusting; special practices needed for reclamation of areas disturbed by mining and mineral exploration; and the amount of cover needed to protect the soil from accelerated erosion (including litter and rock in addition to live vegetation).

Forest

Soil surveys are valuable in modern forest management. Soil surveys provide information about the hazard of soil erosion, the steepness and dissection of relief, the susceptibility of soils to compaction by equipment, soil features that affect the location and construction of roads, and the hydrology of watersheds. Some of these soil properties affect tree harvest,and the survey can be used in predicting the suitability of the various soils for different harvesting systems. Planning for slash disposal after harvest is aided by interpretations of erosion hazard and of the effects of burning on the soils.

Following logging and disposal of slash, new crops of trees are started. Depending on the nature of the soils, past management, and other factors, stands may regenerate naturally or planting may be required. Planting, of course, is necessary when a different species or an improved variety is desired. Planting is also necessary where the soil promotes the rapid growth of undesired shrubs or trees. Interpretations of plant competition are included in many surveys.

Other interpretations predict the soils' response to drainage and fertilization. Draining wet soils may permit the establishment of different forest species and increase the growth rate of trees.

Foresters working with soil scientists identify the trees that are best suited to each kind of soil, predict the productivity of suitable species on each soil, and rate limitations of soils for forest management.

Limitations that are important in forest management can be identified for each soil. The soils are commonly rated according to the degree of the limitation--slight, moderate, of severe--for each of several important aspects of management:

Erosion hazard indicates the susceptibility of the soil to erosion along roads and trails and in loading areas and other areas disturbed by forest management operations.

Equipment limitations are soil-related restrictions on use of equipment generally needed in forest management and harvesting. Equipment use is restricted by such properties as steep slope, many boulders, and low capacity to support vehicles.

Plant competition is the rapid establishment of undesired plants in openings in the tree canopy. These plants compete with desired species for water and nutrients,and such competition affects the success of regeneration or planting. Harvesting methods can be modified to reduce plant competition.

Seedling mortality is the death of seedlings before they can become established. This rating considers soil properties that contribute to seedling mortality, such as droughtiness and surface crusting. The rating is independent of plant competition, which also affects establishment of seedlings.

Windthrow hazard is the chance of trees blowing down. It is an evaluation of soil properties that affect the firmness with which root systems anchor the trees. Properties that affect depth or lateral extend or root systems are important. The rating is usually independent of the probability of high winds unless the soil is typically on landscape positions that are unusually susceptible to high winds.

Soils may also be rated for such factors as susceptibility to compaction during forestry operations, limitations that result from burning, hazards from soil-borne pests and diseases, and limitations imposed by specific soil properties such as wetness.

Published soil surveys for areas in which forestry is important give predictions of the productivity of different kinds of soil for trees. Productivity is commonly expressed as site index or as some measure of the volume of wood produced annually. Site index is based on the average height of dominant and codominant trees of a given species at a designated age. The site index applies to well-stocked, even-aged, unmanaged stands that have not been damaged by past cutting, heavy grazing, repeated burning, or stagnation caused by overstocking.

Data are not always available to determine site index of even one species on all kinds of soil in a survey area. Measurements for key species on benchmark soils are projected to other kinds of soil by comparison of critical properties. The basic data are measurements of tree heights and ages. Trees to be measured must have been free from

suppression and damage. Measurements are made on enough trees per plot to obtain a representative sample that accurately reflects the height and age of the dominant and codominant trees. Enough plots on the same soil or similar soils are studied to obtain a representative sample of soil variability. Site index subidies are made by soil scientists and foresters together.

For a number of species, data are available for converting site index to average annual growth of wood. If such data are available, the survey can include predictions of the potential annual growth. The source of the data and the nature of the relationship used for the conversion (such as log scale) are given.

Soils can be combined for forestry by using an ordination system with a 2- or 3-part designation. The first part of the ordination symbol is a number that denotes the potential productivity of the soil, based on the site index of an indicator tree species. The second part of the symbol, a letter indicates certain characteristics that cause important limitations to forest management. A third part, another number, is sometimes used to distinguish groups of soil that are capable of producing similar kinds of trees and understory vegetation and that need similar management.

A list of trees common to the survey area is given, along with estimates of their productivity on each soil on which they can grow. Also, for each kind of soil a listing is given of trees that are suitable for open-field planting or for interplanting in existing woodland.

The soil maps of some predominantly forested areas have soil associations as map units. The soils in such associations commonly have different limitations, suitabilities, and production potentials for trees. The limitations, suitabilities, and productivity of the individual kinds of soil are interpreted, even though the soils are not delineated separately on the map. The text explains that most of a given soil association is a few principal kinds of soil and that the user need not be concerned with all of the minor soils in a given delineation. The text also describes the landforms or other features that may be helpful in determining the location of individual soils on aerial photographs or in the field. Attention having been limited to the major soils, the user can be told how to recognize the important soil variations that require different trees or different management. The user can be told how to recognize soils that make the best routes for roads and trails. With good explanations of soil patterns and their visible signs, forest managers can apply interpretations for individual kinds of soil in the field.

Understory Vegetation is the vegetation growing under the forest canopy and in some areas can be used by grazing or browsing animals. Some understory products, such as greenery, can be gathered for sale.

The understory vegetation consists of grasses, ferns, shrubs, and other plants. This vegetation can be described in relation to the

individual kinds of soil. The descriptions give the plants to be expected where canopy density is most typical of forest stands having normal production of wood crops.

Recreation

Soil surveys are used in selecting sites and designing facilities for recreation. Many desirable recreation sites are a combination of several kinds of soil in a pattern appropriate to the intended use. The individual soils or the combination must be interpreted for such use. Many factors other than the soils are also important in recreation planning--factors such as esthetic values, location and accessibility to the public, land values, access to water and to public sewer lines, the presence of potential impoundment sites,and relationship to existing recreation areas and facilities.

Soils are commonly rated according to their suitability or limitations for different kinds of recreation and facilities. The interpretations allow comparison of soils at alternative sites and prediction of the measures needed to overcome deficiencies of the soils at specific sites.

The kinds of facilities for which interpretations are needed range from golf fairways, picnic sites, and playgrounds in heavily populated areas to trails and campsites in primitive natural areas. Interpretations for ski slopes and snowmobile trails are needed in some places.

Many recreation areas in the United States are in wild country having only higher order soil surveys. Map units for such surveys are commonly associations of soils that differ markedly in their limitations and suitabilities. Each component of an association is rated separately, and a summary rating for the whole unit is given. The text may rate each soil for such uses as campsites, picnic areas, and trails, but the map does not show the location of each soil within the broad delineations. Interpretations identify the map units in which suitable sites for these kinds of uses are most numerous of most likely. The map unit descriptions also include unique landforms, vegetation, or other surface features that help in indentifying the individual soils in the field.

Whole soil associations on general soil maps or higher order survey maps can be rated in terms of general suitability of large areas for different kinds of recreation, such as hiking or camping. Ratings of this kind must take into consideration the qualities of individual kinds of soil within delineations, the amounts of and patterns of good and poor soils in the association, and the effects of each on use of the others and on the association as a whole. Soils that may be good for campsites, for example, must be discounted if other soils in the area restrict access to them.

Wildlife Habitat

The relationship between soils, vegetation, and wildlife is the foundation of wildlife habitat management. The kinds and numbers of

wildlife that can live in a given area depend on the supplies of food, cover, and water, which in turn depend on the characteristics of the soils. Soils influence wildlife populations primarily through the vegetation and other habitat components that they support. Soil scientists and wildlife biologists can interpret the kinds of soil in an area for the elements that make up different kinds of wildlife habitat. From the appraisal of combinations of elements, the potential of a tract for various kinds of wildlife can be determined.

Early settlers commonly found the most abundant populations of wildlife on the best soils in the ecological zone. Wildlife can be produced on all lands (that is, on all soils), but the quantity and quality of the vegetative elements of wildlife habitat are restricted by the capability to the soils. Wildlife habitat can be created, improved, and maintained by planting suitable vegetation, manipulating existing vegetation, and inducing the natural establishment of desired plants.

Ratings of wildlife habitat serve several purposes. First, ratings, identify the sites that have soils capable of supporting particular habitat elements. Second, they indicate the kind and intensity of management that can be satisfactorily accomplished. Third, the ratings provide a means of considering soil conditions during land-use planning and acquisition of land for wildlife habitat and for parks and other recreation developments. Used with the soil maps, ratings show where management for wildlife can be applied most effectively and which practices are appropriate. The ratings may also show why certain objectives--pheasant production, for example--may not be feasible.

Ratings of soils for elements of habitat are commonly made by extrapolating data for benchmark soils to other kinds of soil. The growth and characteristics of plant communities are affected by such soil properties as depth, texture, particle size, plasticity, permeability, reaction, salinity, organic matter content, frequency and duration of flooding, and depth to the water table.

Present land use and existing vegetation are not considered when rating soils for wildlife habitat. Not only are these factors subject to change, but there is no practical method of determining them from a soil map. The map units of a survey are rated without regard to their position in relation to areas of other soils. Neither do the size, shape or location of soils areas affect the ratings. Presence of wildlife also is disregarded during rating, because of the mobility of wildlife. However, plant communities that serve as winter habitat must be considered, as are other seasonal or year-round vegetative elements of habitat.

Typically, the units on generalized soil maps or the maps of higher order surveys are given general ratings for elements of wildlife habitat by considering all of the soils in the broad units. Interpretations may also rate the individual kinds of soil in the map units.

Building Sites

Construction and maintenance of buildings are primarily the subject of architecture and engineering, but many aspects are related to soils. Properties of the upper 1 or 2 meters of soil are important both for the support of low buildings and for the maintenance of structures and grounds. Large multistory structures are generally supported by footings placed below the depth of soil survey investigations.

Published soil surveys give interpretations of soils for small buildings, utilities, and other uses related to building sites. Both the degree of limitation and the principal soil properties that create the limitations are commonly given. The ratings are predictions of soil performance based on properties, site features, and observed behavior of the soils.

Soil survey interpretations can help in comparing alternative sites for a given use and in planning onsite investigations and testing of selected areas. Soil interpretations can be extremely useful in land-use planning and in selecting building sites that are near areas suitable for utilities, parks, and other associated uses while reserving land that is best suited to farming.

Soil properties that are important for buildings and for accessory installations such as roads and utilities include the following:

Susceptibility to flooding: Areas may be temporarily innudated by overflowing streams, by runoff from adjacent areas, or by tides. Flooding hazard is generally given for the undisturbed landscape.

Permeability: The capacity of the soil to transmit water internally affects is suitability for buildings and grounds and the feasibility of drainage to improve sites.

Shrink-swell potential: Some soils shrink when they are dry and expand when they become wet. This change in volume can damage roads, dams, walls, building foundations, and other structures. The degree of change in volume is related to the amount of active 2:1 lattice clay in the soil and to the the climatic and hydrologic conditions of the site. To shrink and swell, the soil must have a cycle of wetting and drying.

Stability: Some soil may slip and slide down slopes when wet or when loaded by construction.

Erodibility: Soils that are susceptible to erosion by wind or water can lose topsoil, which is valuable for landscaping, and are subject to gullying and other damage. Eroded soil material can also pollute lakes and streams.

Depth to bedrock or other limiting layer: Hard rock or a cemented pan at a shallow depth restricts excavation. Limiting layers can also interfere with growth of plant roots and movement of water.

Susceptibility to frost heaving: Where the temperature goes below freezing, soils that have a saturated zone and properties favorable for capillary movement transmit water to the zone of freezing. Ice lenses form and push upward, heaving pavements, plants, and even whole buildings. Frost heaving damages foundations and cracks walls, streets, and sidewalks.

Susceptibility to salt heaving or sinking: Some soils in very dry areas have underlying layers of salts that expand when hydrated by irrigation water or precipitation. The heaving that results can damage structures. In other soils, cavities can form and cave in as salts are leached away by water.

High water table: Some soils are naturally wet and are saturated near the surface during some seasons. The high water table limits excavation, interferes with growth of plants, and can cause instability under foundations.

Subsidence after drainage: When organic soils and some wet mineral soils are drained, they may subside, causing foundations to break and walls to crack.

Corrosivity: Soils that are strongly acid or high in sulphates corrode uncoated steel or concrete placed below the surface.

Slope: The degree of inclination of the land surface affects costs of excavation and construction and the usefulness of the site after construction.

Capacity to support loads: Some soils tend to settle under loads, especially when saturated. The low strength of such soils reduces their suitability for buildings and roads.

Content of coarse fragments: A high content of rock fragments more than 3 inches in diameter increases excavation costs. Unless removed, the fragments can reduce the usefulness of the site after construction.

Mapped areas usually are substantially larger than building sites and often contain small areas of soils that have properties much different from those of the dominant soil. Users must be informed of the likelihood of such inclusions and the need to locate them.

Predictions apply to the dominant soil without modification of the soil itself or of the surrounding area. Manmade changes can affect the predictions. Areas mapped as naturally wet may have been drained and therefore be not so wet as indicated. Large areas of pavement or other urban developments increase runoff and may create flooding where the survey indicates no such hazard.

Soil surveys give information needed for planning, planting, and maintaining grounds, parks, and similar areas. Many homeowners plan

their own home grounds and can benefit from soil survey information. Particularly important are the suitability of the soil for turf and ornamental trees and shrubs, ability of the soil to withstand trampling and traffic, suitability of the soil for driveways and other surfaced areas, and ability of the soil to resist erosion. A number of chemical properties of soils are also critical for grounds, especially for plantings. Salts or alkali will injure or kill most plants. Acidity favors some plants and injures others, as does high alkalinity. Availability and balance of nutrients are important.

The information provided by soil surveys about these properties can be used to identify potential problems and to suggest what is needed to solve them. Specific interpretations recommending specific plants and treatment for the many kinds of soil require the combined skills of horticulturalists, landscape architects, and soil scientists.

Many lawn and ornamental plantings are made on the exposed subsoil or substratum in leveled areas or on excavated material that has been spread over the ground. Soil surveys describe the properties of these materials. Interpretations can be made in terms of suitability of the materials for lawns and other plantings, the amount of topsoil that must be added, and other treatments that are necessary for satisfactory establishment of vegetation. Interpretations of this kind are also important for highway departments, which establish and maintain large areas of plantings on subsoil material in rights-of-way.

Roads and Utilities and Construction Material

Local roads and streets, parking lots, and similar structures are supported by soil. Pipelines and conduits are commonly buried in soil. Soil material is used for such purposes, as topsoil, roadfill, and aggregate for concrete. Soil interpretations predict the suitabilities and limitations of different kinds of soil for these uses. Some of the properties that affect these uses are discussed in the previous section, "Building Sites."

Soil interpretations cannot predict in detail the performance of highways, major streets, and similar structures. Such structures require onsite testing of the soil; failure is extremely costly in terms of repair or replacement. Highway engineers and soil scientist can collaborate in making some of the sophisticated interpretations needed along proposed routes of highways. Data about soil properties can also be used directly by engineers.

Soil interpretations can be used to predict problems likely to be encountered along proposed routes. They can be used along with hydrologic and other data to estimate potential runoff so that needed capacities can be predicted for culverts and bridges. Obstacles, such as bedrock, and unstable soils that require special treatment or removal can be tentatively identified from soil surveys, although additional investigations will be required.

Because they show the extent of soils that behave alike, soil surveys can reduce the number of borings and engineering tests needed,

particularly for the upper 5 or 6 feet of the soil. Soil surveys in conjunction with engineering tests are used to identify soils that can be stabilized in place for the road base and to identify the likely problem areas where gravel or crushed stone will be needed. Soil surveys are also used in locating suitable deposits of aggregate. Information from soil surveys can be used with other information to determine methods of stabilizing cuts and fills and to plan landscaping along rights-of-way.

Certain soil properties affect the cost of installation and length of service of buried pipelines and conduits. Shallow bedrock, for example, greatly increases installation cost. Buried metal corrodes, and the rate of corrosion is related to such factors as soil wetness, differences in soil aeration from place to place along the line, electrical conductivity,and acidity. Contrast in properties between adjacent horizons further influences corrosion in some soils. Soil properties also affect the cathodic protection provided by sacrificial metal buried with pipes. Fragments of rock can break protective coatings on pipes, exposing the spots to corrosion. Shrinking and swelling of some soils may preclude the use of utility pipes that could be broken by changes in soil volume.

Soil surveys are used to locate material that can be excavated and transported for many purposes. Organic soil material is used widely as horticultural mulch, potting soil, and soil conditioner. Mineral soil material of good physical condition, usually rich in organic matter, is applied to lawns, gardens, roadbanks, and other places as topsoil. Material that compacts readily and has high strength and low shrink-well potential is used as base material under roads and other foundations. Gravel and sand are used for concrete, road surfacing, gravel filters in drainage fields, and other uses.

Soils can be rated as probable or improbable sources of these materials. The quality of a material at a specific site cannot always be determined at the required level of accuracy from a soil survey, but the soil map shows the location and extent of material that may be suitable. Onsite investigations can be made to determine the quality of the deposit. Survey information can also be used to estimate the suitability of soils for various kinds of construction material.

Waste Disposal

Soil is used to absorb or cover wastes of many kinds and to filter and purify the leachate from them. The effluent from septic systems is distributed in filter fields. Solid wastes are deposited in sanitary landfills and covered with soil material. Liquid and sludge from sewage treatment plants are applied to the soil for disposal, as are solid and liquid wastes from factories that process farm products. Liquid wastes are stored and treated in lagoons made of soil material. Industries of various kinds, some of which produce toxic wastes, increasingly are considering land application.

Many kinds of waste can be used to improve soil productivity. The potential for soil improvement depends on the nature of the soil and the characteristics of the waste. Appropriate timing and proper rates of application are necessary in using wastes to improve the soil. Where reuse, rather than disposal, is the objective, small quantities are applied on large areas, so the potential for pollution is greatly reduced.

The interpretation of soils for use or disposal of waste involves an understanding of the properties of different kinds of waste and the problems inherent in disposing of or using them in different kinds of soil. The transformations of wastes in the soil and the movement of contaminating substances to bodies of water are complicated processes. Health concerns are commonly involved, and eutrophication can result if nutrients from wastes reach bodies of water.

Kinds of soil differ immensely in their capacities to absorb, decompose and deactivate wastes without contaminating ground or surface water or the atmosphere and without altering the level of pollutants in the soil that could inhibit the growth of crops of other desirable plants.

Published soil surveys give limitations and suitabilities of soils for selected means of waste disposal. As the demand for disposal or reuse of wastes in soil increases and standards for water quality become more stringent, more interpretations for waste disposal systems will likely be needed. More specific interpretations may be needed for disposal and reuse of animal wastes, food processing wastes, sewage treatment products, and industrial plant wastes, all of which include a variety of potential contaminants.

Interpretations include ratings of the limitation or suitability of soils for waste disposal, estimates of safe levels of application (loading), and predictions of benefits or damage to the soil and to plants. Currently some kinds of interpretation, such as safe loading rates for different kinds of wastes, can be made with precision for only a few kinds of soil. Research is needed to determine for benchmark soils the behavior of critical constituents of waste and of the decomposition products. Nevertheless, important predictions can be made from existing knowledge about the effects of many critical soil properties on disposal of most wastes. As an obvious example, areas susceptible to flooding are poor places for disposal of almost any kind of waste.

The following relationships influence the suitability of a soil for disposal of most kinds of waste:

Feasibility of distributing wastes and mixing them into the soil: Steep slope, stoniness, rock outcrops, wetness, and other soil properties limit or prevent spreading and mixing of solid wastes or surface spreading or injection of liquid wastes.

Rate at which the soil can absorb wastes at different times: Slow infiltration limits the rate at which liquid wastes can be applied on the surface. Slow permeability limits the rate at which liquid wastes can be spread or injected. Depth of the soil over a hardpan or bedrock limits the amount of liquid waste that a soil can absorb in a given period. Periodic freezing or saturation limits times when wastes can be applied.

Capacity of the soil to retain and deactivate pollutants: Soils differ in their capacity to retain pollutants until deactivated or used by plants. Nitrates, for example, pollute ground water in some places; very rapidly permeable soils transmit nitrates to ground water before they can be absorbed by plants. Phosphates are important in eutrophication of surface water; erodible soils and saturated or frozen soils allow runoff to carry phosphates to streams. Soils having limited capacity above slowly permeable layers might allow water that is carrying pollutants, possibly including pathogens, to emerge at the surface and enter streams.

Loading capacity: Kinds of soil differ widely in the rate at which wastes can be applied without contributing pollutants to ground or surface water. Loading capacity is especially critical where closely spaced houses depend on septic tanks and where large numbers of livestock on a small area produce large quantities of waste.

Effects on the soil and on plants: Large quantities of waste may either improve or degrade physical, chemical, or biological properties of soils, depending on the kind of waste and the kind of soil. For example, heavy loading with liquid waste saturates some kinds of soil and makes them useless for growing some plants. On the other hand, heavy loadings can be used effectively to irrigate and fertilize other kinds of soil. Animal wastes have long been recognized for improving cropped soils, but the effects differ according to the kind of soil. Chemical contaminants in some industrial wastes can sterilize the soil. Large quantities of waste make large changes in the soil environment. For example, massive loading with liquid waste can drench the soil faster than the hardest rains. This creates a greatly different environment and drastically changes soil processes. The long-term effects on the soil need to be assessed.

The first step in making interpretations of soils for disposal of wastes is usually to determine how disposal systems for each kind of waste have performed on specific kinds of soil in the area. Experience may have been acquired in practical operations or by research. If performance can be determined for benchmark soils, it can be predicted for other kinds of soil by comparing critical properties. Soil scientists and specialists in other disciplines determine what properties are critical and how to appraise their effects. Limiting values of critical properties can be determined through experience and may be used in making interpretations where data on soil performance is scarce or lacking.

Water Management

Soil-water relations affect many land uses. The use and management of water are affected by properties of the soil.

Soil surveys provide information useful to geologists, hydrologists, and engineers about the location and use of subsurface water. Soils information is most useful for estimating the amount of water in unconsolidated material at relatively shallow depths.

"Ground water" refers to deep-seated zones of saturation that are below the depth of soils investigations. Most interpretations that relate to ground water depend on disciplines other than soil science. Soil surveys have little value for predicting the amount of water in bedrock or at great depths, although inferences can be drawn from soil data in some areas. Soil surveys do describe soil properties that are significant for estimating rates of infiltration and percolation of water to deep aquifers. This information is useful in appraising the potential for recharge of ground water from surface water.

A seasonal high water table, is a zone of saturation at the highest average depth during the wettest season. It is at least 6 inches thick, persists in the soil for more than a few weeks, and is within 6 feet of the soils surface. Most published surveys in areas where some soils have saturated zones give the kind of water table, its level in the soil, and the time of year when it affects use and management.

Three kinds of seasonal high water table are recognized within the soil: apparent, perched, and artesian. Another kind is above the soil surface much of the time causing ponding. An apparent seasonal high water table is the level at which water stands in a freshly dug, inlined borehole after adequate time for adjustments in the surrounding soil. A perched water table is one that exists in the soil above an unsaturated zone. A water table may be inferred to be perched on the basis of general knowledge of the water levels of an area, the landscape position, the permeability of soil layers, and from other evidence. To prove that a water table is perched, the water levels in boreholes must be observed to fall when the borehole is extended. Artesian water table is one that exists under hydrostatic head beneath an impermeable layer, when the impermeable layer has been penetrated by a cased borehole, the water rises. The final level of the water in the cased borehole may then be characterized as an artesian water table. Ponding is standing water in a closed depression. The water is removed only by percolation, transpiration, or evaporation.

Other information about the water table may be important. In some kinds of soil an apparent water table falls rapidly from its highest level to depths at which it would have no bearing on soil use or management. A perched water table may disappear entirely. In other soils, the water table persists within 200 cm of the surface for long periods. The presence or absence of water in the lower part of the soil is significant for some uses. The specific times when the water table is above some critical depth are very important for certain uses, such as septic tank absorption fields.

Depth to a high water table is measured from the surface of the soil to the top of the water standing in a borehole. Depth to the water table for a soil is usually reported as a range that covers the variation with time and topography: "20 to 50 cm." In some soils, water stands above the surface part of the time, so the higher level is reported as a positive value: "+10 to 5cm," meaning that the high water ranges from 10 cm above the surface to 5 cm below.

The time of year that the high water table is present is also described. "The high water table is at a depth of 20 to 50 cm from February through May" means that the water table will be between those depths a considerably length of time during the period of February to May. It does not necessarily mean that the water table is between those depths for the entire four-month period.

Natural soil drainage classes and patterns of soil-water states (Chapter 4) also describe soil-water relations over time. They are less precise than the information typically provided about the water table, but they give information about a broader range of conditions.

Soils information is used in predicting the suitability of soils for ponds and reservoir areas and as material for embankments, dikes, and levees. Soil surveys identify favorable and hazardous properties in the upper 2 m of soil. Engineers who are expert in pond design and construction cooperate with soil scientist in making these interpretations. The main criteria for pond reservoir areas are the seepage potential of the soil, which is determined by permeability, and the depth to fractured or permeable bedrock, pans, or other layers that are difficult to excavate. Seepage potential indicates how well the pond will hold water.

Estimates of grain-size distribution, liquid limit, plasticity index, and other soil properties are given for critical layers of each soil in most surveys. These estimates can be used by engineers to appraise the soil excavated from the pond or reservoir area or from nearby areas for use in earthern dikes.

Soils information can be used together with hydrometerological and land-use data to predict runoff to a pond site, erodibility of the soils in the watershed, and the rate of accumulation of sediment in the pond.

Impoundments fed by surface water and contained by earthen dikes have somewhat different soil requirements than those that are excavated and fed by ground water (aquifer fed). Separate interpretations are commonly given for the two kinds of pond.

Predictions of runoff are essential for watershed planning and for other planning operations. The kind of soil is one of several factors that determine runoff. Hydrologic groups classify soils by their capacity to take in water at the surface and to transmit it internally under standard conditions. The classification is based on the minimum rate of infiltration on bare soil after prolonged wetting. Vegetation, rainfall intensity, and other factors are disregarded in determining a

soil's hydrologic group, although they are important in estimating runoff.

There are four hydrologic groups:

Group A (low runoff potential): Soils having high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well drained to excessively drained sands or gravel. These soils have a high rate of water transmission.

Group B: Soils having moderate infiltration rates when throughly wetted. They consist chiefly of moderately deep to deep, moderately well drained to well drained soils of moderately fine to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C: Soils having slow infiltration rates when thoroughly wetted. They consist chiefly of soils having a layer that impedes downward movement of water and soils that are moderately fine textured to fine textured. These soils have a slow rate of water transmission.

Group D (high runoff potential): Soils having very slow infiltration rates when thoroughly wetted. These soils are clay with a high swelling potential, or have a high water table, or have a claypan or clay layer at or near the surface, or are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

Infiltration rate is the rate at which water enters the soil at the surface. Transmission rate is the rate at which the water moves within the soil. The transmission rate used is that of the soil in its characteristic natural setting after thorough wetting.

The descriptions given for the hydrologic groups are typifying examples against which soils are compared. Except for group A, which must have high rates of both infiltration and transmission, combinations of intake and transmission rates other than those given qualify a soil for a group. Either intake or transmission can limit internal movement of water. For example, some well drained, coarse textured soils have slowly permeable layers in the lower part of the profile that impede water transmission. Very coarse layers in finer textured soils also impede downward water movement. Some fine textured soils have large connecting pores or continuous channels and thus rapidly dispose of water internally, even when wet. The combined effects of properties that influence infiltration and properties than influence internal transmission of water determine a soil's hydrologic group.

Unlike permeability classes, hydrologic groups describe water transmission in the soils' natural setting. A soil may have a high water table even though the soil material to an undetermined depth is rapidly permeable. Such a soil transmits water slowly and is in hydrologic group D. If such a soil is drained to the extent that the water

other groups. Soils of arid regions that are normally dry but have a high apparent water table after through wetting, as by irrigation, also, are in group D. Physiographic position and deep layers are considered if they are characteristic of the soil. Evidence of periodic wetness in humid regions and accumulations of salts related to water transmission in arid regions are examples of the kinds of evidence to be considered.

Soils are placed in hydrologic groups by series. Adjustments can be made for some features that define phases. Surface configuration is table no longer retards water transmission, it is placed in one of the an attribute of the series and is not differentiated further. Slope and texture of the surface layer vary within a series and may affect infiltration. Therefore, the series classification is a relatively broad generailization that expresses a norm. Different hydrologic groups can be assigned to phases of the series if factors such as stones on the surface, texture of the surface layer, or amount of previous erosion vary widely within the series and produce a wide range in infiltration and runoff.

Irrigation and drainage

Interpretations of soils for installation, use and maintenance of irrigation and drainage systems depend on engineering, hydrology, economics, and related disciplines in addition to soil science. The interpretations show which soils are most responsive to irrigation or drainage and give information needed to design the most economical systems. The interpretations also predict the performance of soils after they have been drained or irrigated.

Many soils perform very differently after being drained or irrigated. Irrigation and drainage change the moisture regime of a soil. In arid regions, deep layers that contain soluble salts or that are impervious to water may have little or no influence on the behavior of the soil until it is irrigated.

Soils to be irrigated must also be drainable. Otherwise salts cannot be leached out of the upper part of the soil and will build up to toxic levels, or the soil may quickly become waterlogged.

Soil interpretations predict performance of the soils after irrigation or drainage and the difficulty of overcoming new problems. In addition, interpretations guide the selection of crops and management systems for the treated soil.

In humid regions, irrigation makes little change in the environment of the soil. Many irrigation systems are designed only to supplement rainfall. Many use portable equipment, and most apply water by sprinkling. However, many new systems in humid regions are the trickle type, which can prevent many management problems. In humid areas, interpretations usually consider such factors as infiltration, hydraulic conductivity, water retention, erodibility, slope, microtopography, stoniness, soil depth, and properties that affect the response of crops

to supplemental water. Important considerations are (1) feasible application rates for water, (2) potential for waterlogging, (3) possibility of erosion by irrigation water, (4) physical obstructions to use of equipment, (5) susceptibility to flooding, and (6) chance of drought.

Interpretations for irrigation in arid and semiarid regions are much more complex. Irrigation drastically changes the environment of the normally dry soils and affects some kinds of soil differently than it does others. In addition to the soil properties that are important in humid regions, salinity and sodicity can be significant. Quality of water is extremely important, and water of poor quality affects different soils differently. Minor variances in slope and elevation are critical for soils that conduct salt-laden water to low places where both salt and water may concentrate. Irrigation systems are diverse, including flooding, furrow, drip, and various kinds of sprinkler systems. Systems that move on wheels, such as center-pivot installations, create tracks that may start erosion.

Soil-water relations are of special importance in irrigation. Soil properties that affect growth of plants also are of prime importance. In addition to infiltration rate, hydraulic conductivity, and available water capacity, the following characteristics are important for irrigation:

Effective rooting depth: Most irrigated crops do well in a rooting zone of 90 cm. A shallower rooting zone restricts crop selection and requires more precision in irrigation and crop management.

Bulk density: A dense subsoil can cause adverse drainage conditions and impair root growth. In medium- and fine-textured soils, bulk density of more than 1.65 c/m^3 is unfavorable.

Texture: Soils of all textural classes can be successfully irrigated. Good management and some additional costs are needed for soils at the extreme ends of the textural range. Soils high in swelling clays should not be allowed to dry out and crack. On coarse sands, special systems are required that can deliver water over a large area and can be moved quickly.

Reaction: (pH): In addition to identifying a need for lime, soil reaction may indicate characteristics unfavorable for irrigation. A pH above 8.5 may indicate the presence of significant amounts of exchangeable sodium. Few soil having pH of less than 7.5 have salt problems.

Cation exchange capacity: Cation exchange capacity shows the ability of the soil to retain and supply nutrients. Cation exchange capacity above 8 to 10 meq per 100 g of soil in the upper 30 cm is usually satisfactory. Soils that have low cation exchange capacity (less than 3 meq per 100 g) are poorly suited to most crops.

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Salinity and sodicity: Soils that are high in sodium require special management. Salinity is particularly a problem where drainage conditions are unfavorable for the removal of soluble salts by flushing.

Other properties may influence the suitability of the soil for irrigation. Structural stability is low in clayey soils that have a high content of expanding clay minerals and contain more than 15 percent exchangeable sodium. Large amounts of carbonates or gypsum in the soil can limit the potential for irrigation, especially in arid regions. Calcic and petrocalcic horizons limit or restrict root growth and can make land leveling troublesome. Soils that have a shallow gypsic horizon have low potential productivity. In addition, excess water percolating through the soil may dissolve the gypsum and cause sinking and subsidence.

Detailed or highly detailed (first-order) soil maps are needed in most irrigated areas. Soils are normally examined to greater depths than usual in these surveys. Knowledge of water movement through underlying layers is essential. For example, the soil scientist must estimate the thickness of soil material that can be safely removed in leveling. The collaboration of engineers is needed in preparing many interpretations for irrigation.

Ratings of each soil according to suitability or limitations for irrigation are given along with the kind of limitation. Irrigation management can be given for groups of soil that have similar potentials and limitations and for which systems can be designed. Crop yields can be predicted both with and without irrigation.

Drainage is the removal of excess water from the surface of the soil or the rooting zone. In areas of high rainfall, drainage of slowly permeable soils can be improved by smoothing or shaping the surface. More permeable soils respond to subsurface drainage, open ditches, or combination sytems.

The capacity of a soil to transmit water vertically and horizontally is the most important internal property affecting drainage. Unstable structure, abrupt changes in texture, pans or cemented layers,and impervious rock influence water movement. Other properties such as stoniness and slope, affect installation and functioning of drainage systems.

Drainage engineers working with soil scientists can provide design criteria for specific soils, including spacing and depth of subsurface drains, depth and width of open ditches and slope of their sides, and allowable gradient. For deep ditches, detailed information about deeper soil layers is required to determine requirements for channel stability. Observations and records of stability of existing channels in similar soils elsewhere can provide data for determining design criteria in the survey area.

Soils of coarse silty texture tend to move into and clog subsurface drain . Amount and kind of clay are critical for mole drainage systems.

Very coarse textured soils may be made droughty by drainage. Some wet soils contain sulfides that oxidize to sulfates on exposure to air, causing extreme acidity after drainage. Wet organic soils subside after drainage.

Smoothing and grading improve drainage by increasing runoff. These practices are used with subsurface systems. They are also used to improve drainage of soils having such slow hydraulic conductivity that subsurface drainage is ineffective. Soil slope is especially critical for surface drainage, but most of the properties mentioned for subsurface drainage systems are also important.

Recording, Retrieveing, and Coordinating Soil Interpretations

Soil interpretations are issued in many forms besides the published soil survey. A report can be prepared for part of a survey area as soon as that part has been mapped but before the entire area has been completed. Interpretations of special or temporary interest are sometimes prepared but may not be included in the published survey. Interpretations intended specifically for soil conservationists are commonly included in technical guides, which are separate from the published soil survey. Much of the interpretive information, however, will appear in the final publication. (See Chapter 12).

Soil interpretation begins with the mapping and descriptive legends. Interpretations are included with the descriptive legend in the soil handbook for use while the survey is in progress. The soil handbook is revised as additional information is developed, and it provides the basis for the first draft of the manuscript for the published soil survey. (See Chapter 6).

Automatic data processing systems have immensely increased the opportunities for organizing soil interpretations. Interpretations stored in data banks can be manipulated by the computer to produce groups of soil that have the same limitations or potentials for given uses, classes of soil properties, kinds of uses, needed practices, productivity, and the like. These groups can be retrieved singly or in combinations as tables, listings, or diagrams. Soil map data also can be stored. From the stored data, the computer can print maps that show the distribution of soils that have different limitations, suitabilities, management needs, and so forth. (See Chapter 12).

The use of automatic data processing contributes to maintaining uniformity and consistency in soil interpretations. When data are processed by people, a given interpretation need not be expressed in precisely the same terms in one area as in another. Computers, however, are not capable of resolving the differences between undefined parts of overlapping classes. Therefore, the data must be recorded in consistent form using standardized terms. The requirements of automatic data processing have led to standardization of formats for interpretations that are to be recorded. Standard defined terms, or codes for them, are entered on a form. Quantitative values are entered where appropriate. These data can then be transferred to the information data bank.

APPENDIX GT.7B
WALKLEY-BLACK PROCEDURE

obtained if dichromate methods are applied to soils containing significant amounts of carbonized materials. Dry combustion methods are most appropriate for soils containing large amounts of elemental C.

29-3.5.2 WALKLEY-BLACK PROCEDURE (Walkley, 1946; Peech et al., 1947; Greweling & Peech, 1960)

29-3.5.2.1 Reagents.

1. Potassium dichromate ($K_2Cr_2O_7$), 1*N*: Dissolve 49.04 g of reagent-grade $K_2Cr_2O_7$ (dried at 105°C) in water, and dilute the solution to a volume of 1,000 ml.
2. Sulfuric acid (H_2SO_4), concentrated (not less than 96%): If Cl^- is present in soil, add Ag_2SO_4 to the acid at the rate of 15 g/liter.
3. Phosphoric acid (H_3PO_4), concentrated.
4. *o*-Phenanthroline–ferrous complex, 0.025*M*: Dissolve 14.85 g of *o*-phenanthroline monohydrate and 6.95 g of ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) in water. Dilute the solution to a volume of 1,000 ml. The *o*-phenanthroline–ferrous complex is available under the name of Ferroin from the G. Frederick Smith Chemical Co. (Columbus, Ohio).
5. Barium diphenylamine sulfonate: Prepare a 0.16% aqueous solution. This reagent is an optional substitute for no. 4.
6. Ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) solution, 0.5*N*: Dissolve 140 g of reagent-grade $FeSO_4 \cdot 7H_2O$ in water, add 15 ml of conc sulfuric acid (H_2SO_4), cool the solution, and dilute it to a volume of 1,000 ml. Standardize this reagent daily by titrating it against 10 ml of 1*N* potassium dichromate ($K_2Cr_2O_7$), as described below.

29-3.5.2.2 Procedure. Grind the soil to pass through a 0.5-mm sieve, avoiding Fe or steel mortars. Transfer a weighed sample, containing 10 to 25 mg of organic C, but not in excess of 10 g of soil, into a 500-ml wide-mouth Erlenmeyer flask. Add 10 ml of 1*N* $K_2Cr_2O_7$, and swirl the flask gently to disperse the soil in the solution. Then rapidly add 20 ml of conc H_2SO_4, directing the stream into the suspension. Immediately swirl the flask gently until soil and reagents are mixed, then more vigorously for a total of 1 min. Allow the flask to stand on a sheet of asbestos for about 30 min. Then add 200 ml of water to the flask, and filter the suspension if experience shows that the endpoint of the titration cannot otherwise be clearly discerned. Add 3 to 4 drops of *o*-phenanthroline indicator, and titrate the solution with 0.5*N* $FeSO_4$. As the endpoint is approached, the solution takes on a greenish cast and then changes to a dark green. At this point, add the ferrous sulfate heptahydrate drop by drop until the color changes sharply from blue to red (maroon color in reflected light against a white background). Make a blank determination in the same manner, but without soil, to standardize the $Cr_2O_7^{2-}$. Repeat the determination with less soil if >75% of the dichromate is reduced.

Calculate the results according to the following formula, using a correction factor $f = 1.30$ or a more suitable value found experimentally:

$$\text{Organic C, \%} = \frac{(\text{meq } K_2Cr_2O_7 - \text{meq Fe } SO_4)(0.003)(100)}{\text{g water-free soil}} \times f. \quad [13]$$

29-3.5.2.3 Comments. Ferrous ammonium sulfate is also a suitable titrant for excess $Cr_2O_7^{2-}$ in conjunction with the Walkley-Black method. The Smith and Weldon (1941) modification involving complete reduction of $Cr_2O_7^{2-}$ with Fe^{2+}, and subsequent back-titration of excess Fe^{2+} with MnO_4^- solution may also be used to estimate unreacted $Cr_2O_7^{2-}$. Other oxidation-reduction indicators that have provided satisfactory results include barium diphenylamine sulfonate and *N*-phenylanthranilic acid. The amounts of $Cr_2O_7^{2-}$ reduced to Cr^{3+} by reaction with soil organic matter may also be estimated colorimetrically.

29-3.5.3 MODIFIED MEBIUS PROCEDURE

29-3.5.3.1 Special Apparatus.

1. Erlenmeyer flasks (125 ml) fitted with female standard-taper 24/40 ground-glass joints (Corning 5000 or Kimble 26510).
2. West condensers (30 cm) fitted with male standard-taper 24/40 ground-glass joints at the lower end (Corning 2800 or Kimble 18190).
3. Electric hot plate extraction unit (six plates per unit) fitted with individual rheostat controls (Labconco 60300, Precision 65500, Lab-Line Multi-Unit Extraction Heater, or equivalent).

29-3.5.3.2 Reagents.

1. Potassium dichromate solution ($K_2Cr_2O_7$), 0.5*N*: Dissolve 24.5125 g of $K_2Cr_2O_7$ (oven-dry) in 200 ml of deionized water, and dilute to 1 liter.
2. Sulfuric acid (H_2SO_4), concentrated, not less than 96%.
3. Ferrous ammonium sulfate hexahydrate solution [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$], 0.2*N*: Dissolve 78.390 g of $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in 50 ml of conc H_2SO_4, and dilute to 1 liter with deionized water (must be standardized daily because of slow oxidation).
4. Indicator solution: Dissolve 0.100 g of *N*-phenylanthranilic acid and 0.107 g of sodium carbonate (Na_2CO_3) in 100 ml of water.

29-3.5.3.3 Procedure. Weigh an amount of < 100-mesh soil (≤ 0.5 g) containing not greater than 8 mg of organic C into a 125-ml Erlenmeyer flask. Add exactly 10 ml of 0.5*N* $K_2Cr_2O_7$ solution and 15 ml of conc H_2SO_4 (H_2SO_4 may be added by burette). Attach the flask to the West condenser, and place on a preheated electric hot plate. Include a blank in each group of five soil samples to be heated and at least two unboiled blanks (unboiled blanks are unheated mixtures of 10 ml of 0.5*N* $K_2Cr_2O_7$ and 15 ml of conc H_2SO_4) for each day that analyses are performed. The normality of the $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ solution is determined by titrating the unboiled blank. Gently boil each sample for 30 min, and then insert an asbestos pad between the hot plate and bottom of the Erlenmeyer flask. Allow the flask to cool for about 15 min, and rinse the inside of the condenser with de-

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APPENDIX GT.7C
ORGANIC CARBON

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Table 29-2. Comparison of methodologies used for determination of organic C in soils.

Method	Principle	Advantages	Disadvantages
Difference between total C and inorganic C	Total C and inorganic C are determined on separate samples: Organic C = Total C − inorganic C.	Useful if total C and inorganic C are routinely determined	Two separate analyses are required. Total C determination requires special equipment. Organic C calculated by difference has some inherent error.
Determined as total C after removal of inorganic C	Total C is determined in soil sample after removal of inorganic C with an acid pretreatment: Organic C = total C.	Accurate if dolomite is absent from soil	Not all dolomite in soil may be removed by acid treatment. Specialized equipment needed.
Dichromate oxidation without external heat	Dichromate oxidizes organic C to CO_2 in acid medium. Amounts of $Cr_2O_7^{2-}$ reduced is quantitatively related to organic C present. Not all organic C in samples is oxidized when external heat is omitted, and a correction factor is required.	Very rapid and simple No special equipment required	Incomplete oxidation of organic C necessitates use of a correction factors, which often results in erroneous values. Chloride, Fe^{2+}, and MnO, interfere with method. It assumes soil organic C has an average valence of 0.
Dichromate oxidation with external heat	This is the same as the dichromate method above except that all organic C in the sample is oxidized, and no correction factor is required.	Rapid and simple Complete oxidation of organic C occurs	Chloride, Fe^{2+}, and MnO, interfere with method. Some specialized equipment is needed. It assumes soil organic C has an average valence of 0.

29-3 ORGANIC CARBON

29-3.1 Introduction

Carbon is the chief element present in soil organic matter, comprising from 48 to 58% of the total weight. Therefore, organic C determinations are often used as the basis for organic matter estimates through multiplying the organic C value by a factor. For many years the *Van Bemmelen factor* of 1.724 was used based on the assumption the organic matter contains 58% organic C. However, a number of studies have shown that the proportion of C in soil organic matter is highly variable for a range of soils, and thus any constant factor selected is an approximation at best. Recent evidence suggests that the factors most appropriate for converting organic C concentrations to organic matter contents are 1.9 and 2.5 for surface and subsoils, respectively (Broadbent, 1953). Thus, the factor varies not only from soil to soil but also between horizons in the same soil. This finding suggests that it is most appropriate to determine and report the organic C concentration in a soil rather than convert the analytically determined organic C value to organic matter content through use of an approximate correction factor.

Organic C may be determined by (i) analysis of a soil for total C and inorganic C and subtraction of the inorganic C concentration from the total C present, (ii) a total C determination on the sample after destruction of inorganic C, and (iii) reduction of $Cr_2O_7^{2-}$ by organic C compounds and subsequent determination of unreduced $Cr_2O_7^{2-}$ by oxidation-reduction titration with Fe^{2+} or by colorimetric techniques. Table 29-2 summarizes the principles, advantages, and disadvantages of several methods used for determination of organic C in soils. All current methods have inherent problems associated with them, and the investigator should use the method most applicable to the soils analyzed and the required accuracy of the results.

In this section, procedures are described for the determination of organic C in both calcareous and noncalcareous soils based on the difference between total C and inorganic C concentrations. Two methods are also given for organic C estimations based on destruction of inorganic C compounds prior to total C determinations. In addition, two rapid dichromate oxidation procedures are described. The Walkley and Black (1934) method that omits heating the samples is given because it is simple, rapid, widely used, and requires minimal equipment even though the results obtained cannot be considered quantitative. Many soil testing and soil survey personnel have found use for a method that gives an approximate organic C concentration. The Mebius (1960) technique that involves extensive heating of the chromic acid–soil mixture is given because it is quantitative and represents the best combination of digestion reagents, heating procedure, and titration reagents of the modern dichromate methods. Dichromate procedures are widely used in soil investigations because of their simplicity and rapidity compared with wet or dry combustion. However, the rapid $K_2Cr_2O_7$ methods are subject to interference by oxidizable or reducible soil constituents such as Cl^-, Fe^{2+}, and MnO_2.

-3.2 Organic Carbon as Calculated from Total Carbon Determinations

Methods previously described for total C are basic for many of the pro-lures used to determine organic C in soils. However, soils may contain th organic and inorganic C, and thus total C analysis procedures recover th forms of C. In noncalcareous soils and soils not recently limed, the tal C can be considered to be organic C. With calcareous or recently limed ils, organic C may be estimated as the difference between total C and in-ganic C concentrations.

-3.2.1 ORGANIC CARBON IN NONCALCAREOUS SOILS

Prepare soil samples, and conduct a total C determination by dry or t combustion using titrimetric, gravimetric, volumetric, infrared, or ermal conductivity techniques to quantitate evolved CO_2 as described in ction 29-2. Report the total C determined as percent organic C in the sam-e (i.e., total C = organic C).

-3.2.2 ORGANIC CARBON IN CALCAREOUS SOILS

Prepare soil samples, and conduct a total C determination on the mple by dry or wet combustion techniques as described in section 29-2. etermine inorganic C on a separate sample by one of the quantitative ethods described in section 11-2. Calculate the percent organic C in the mple from the relationship

$$\% \text{ organic C} = \% \text{ total C} - \% \text{ inorganic C}. \quad [8]$$

29-3.3 Wet and Dry Combustion Techniques for Organic Carbon in Calcareous Soils

In contrast to noncalcareous soils, inorganic C must be removed from lcareous or recently limed soils before the analysis if wet or dry combus-on techniques are used to directly measure the organic C present.

Inorganic C is conveniently removed before wet combustion by retreating the sample contained in a digestion flask with a mixture of dilute H_2SO_4 and $FeSO_4$. The $FeSO_4$ is added to the mixture to minimize oxida-ion and decarboxylation of organic matter by added H_2SO_4 or by MnO_2 resent in soil (Allison, 1960). After pretreatment, the digestion flask con-aining soil is transferred to the combustion train, and a total C determina-ion is carried out as described in section 29-2.3.

Inorganic C removal is generally more difficult before determination f organic C by dry combustion techniques. Treatment of soil at room emperature with H_2SO_3 followed by heating to remove excess H_2SO_3 is ormally used to decompose inorganic C compounds (Piper, 1942; Bremner, 1949); however, several difficulties are apparent with the proce-lure. Little destruction of organic matter occurs during room temperature

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treatment of samples with H_2SO_3, but some decarboxylation is possible as the sample is heated (Bremner, 1949). It is difficult to decide when all inorganic C has been removed and when H_2SO_3 treatment should be discontinued. It is doubtful that dolomite is completely decomposed by the relatively mild H_2SO_3 treatment employed (Allison, 1965). Nommik (1971) suggested that inorganic C may be effectively removed from soil samples by treatment with a metaphosphoric acid solution for 30 min at room temperature and 30 min at 130°C. However, Nommik's procedure has not been evaluated with a variety of soils.

29-3.3.1 TEST FOR PRESENCE OF INORGANIC CARBON

Place finely ground soil on a spot plate, and moisten with a few drops of water. Add 4*N* HCl dropwise to the wetted sample, and observe any effervescence. Allow sufficient time for dolomite to react (~5 min). If inorganic C is absent from the soil, proceed with organic C (total C) analysis as per section 29-2. If inorganic C is present or the test is not definitive, proceed as described below.

29-3.3.2 PRETREATMENT PRIOR TO WET COMBUSTION

29-3.3.2.1 Special Apparatus. See the special apparatus listed in section 29-2.3.3.1.

29-3.3.2.2 Reagents.

1. Digestion reagent for carbonates (H_2SO_4-$FeSO_4$): Dissolve 57 ml of conc sulfuric acid (H_2SO_4) and 92 g of ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) in 600 ml of deionized water, cool, and dilute to 1 liter.
2. Potassium dichromate ($K_2Cr_2O_7$), reagent grade, pulverized.
3. Other reagents as described in section 29-2.3.3.2.

29-3.3.2.3 Procedure. Prepare soil samples as described in section 29-2.3.3.3. Transfer a sample of known water content and containing 20 to 40 mg of C (but not more than 2 g of soil) to a 100-ml Kjeldahl digestion flask. Using 3 ml of the H_2SO_4-$FeSO_4$ digestion acid, wash down any soil that adheres to the neck of the flask. Place the flask in a rack or beaker, and allow the sample to digest at room temperature with occasional turning of the flask for at least 20 min or until effervescence appears to cease. Then hold the flask upright over a flame 1 cm high, and boil the contents slowly for 1.5 min to destroy any remaining carbonate. Rotate the flask continu-ously during boiling to avoid excessive frothing. Allow the sample to cool.

Insert a long-stemmed funnel into the flask, and add 2 g of pulverized $K_2Cr_2O_7$. Immediately connect the flask to the reflux condenser (Fig. 29-2), and proceed with the determination of organic C as directed in section 29-2.3.3.3 beginning with the third sentence.

Report the C present in the pretreated sample as percent organic C.

29-3.3.2.4 Comments. The 3 ml of 2*N* H_2SO_4-5% $FeSO_4$ used in this procedure replaces the 3 ml of distilled water used in the total C procedure

tained if dichro.. ..e methods are applied to soils containing significant ıounts of carbonized materials. Dry combustion methods are most appro-iate for soils containing large amounts of elemental C.

3.5.2 WALKLEY-BLACK PROCEDURE (Walkley, 1946; Peech et al., 1947; Greweling & Peech, 1960)

29-3.5.2.1 Reagents.

Potassium dichromate ($K_2Cr_2O_7$), 1*N*: Dissolve 49.04 g of reagent-grade $K_2Cr_2O_7$ (dried at 105°C) in water, and dilute the solution to a volume of 1,000 ml.

Sulfuric acid (H_2SO_4), concentrated (not less than 96%): If Cl^- is present in soil, add Ag_2SO_4 to the acid at the rate of 15 g/liter.

Phosphoric acid (H_3PO_4), concentrated.

o-Phenanthroline–ferrous complex, 0.025*M*: Dissolve 14.85 g of *o*-phenanthroline monohydrate and 6.95 g of ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) in water. Dilute the solution to a volume of 1,000 ml. The *o*-phenanthroline–ferrous complex is available under the name of Ferroin from the G. Frederick Smith Chemical Co. (Columbus, Ohio).

Barium diphenylamine sulfonate: Prepare a 0.16% aqueous solution. This reagent is an optional substitute for no. 4.

Ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) solution, 0.5*N*: Dissolve 140 g of reagent-grade $FeSO_4 \cdot 7H_2O$ in water, add 15 ml of conc sulfuric acid (H_2SO_4), cool the solution, and dilute it to a volume of 1,000 ml. Standardize this reagent daily by titrating it against 10 ml of 1*N* potassium dichromate ($K_2Cr_2O_7$), as described below.

29-3.5.2.2 Procedure. Grind the soil to pass through a 0.5-mm sieve, oiding Fe or steel mortars. Transfer a weighed sample, containing 10 to mg of organic C, but not in excess of 10 g of soil, into a 500-ml wide-outh Erlenmeyer flask. Add 10 ml of 1*N* $K_2Cr_2O_7$, and swirl the flask ntly to disperse the soil in the solution. Then rapidly add 20 ml of conc $_2SO_4$, directing the stream into the suspension. Immediately swirl the flask ntly until soil and reagents are mixed, then more vigorously for a total of min. Allow the flask to stand on a sheet of asbestos for about 30 min. hen add 200 ml of water to the flask, and filter the suspension if experi-ice shows that the endpoint of the titration cannot otherwise be clearly dis-rned. Add 3 to 4 drops of *o*-phenanthroline indicator, and titrate the solu-on with 0.5*N* $FeSO_4$. As the endpoint is approached, the solution takes on greenish cast and then changes to a dark green. At this point, add the rrous sulfate heptahydrate drop by drop until the color changes sharply om blue to red (maroon color in reflected light against a white back-ound). Make a blank determination in the same manner, but without soil, standardize the $Cr_2O_7^{2-}$. Repeat the determination with less soil if >75% f the dichromate is reduced.

Calculate the results according to the following formula, using a cor-ction factor f = 1.30 or a more suitable value found experimentally:

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$$\text{Organic C, \%} = \frac{(\text{meq } K_2Cr_2O_7 - \text{meq } FeSO_4)(0.003)(100)}{\text{g water-free soil}} \times f. \quad [13]$$

29-3.5.2.3 Comments. Ferrous ammonium sulfate is also a suitable titrant for excess $Cr_2O_7^{2-}$ in conjunction with the Walkley-Black method. The Smith and Weldon (1941) modification involving complete reduction of $Cr_2O_7^{2-}$ with Fe^{2+}, and subsequent back-titration of excess Fe^{2+} with MnO_4^- solution may also be used to estimate unreacted $Cr_2O_7^{2-}$. Other oxidation-reduction indicators that have provided satisfactory results include barium diphenylamine sulfonate and *N*-phenylanthranilic acid. The amounts of $Cr_2O_7^{2-}$ reduced to Cr^{3+} by reaction with soil organic matter may also be estimated colorimetrically.

29-3.5.3 MODIFIED MEBIUS PROCEDURE

29-3.5.3.1 Special Apparatus.

1. Erlenmeyer flasks (125 ml) fitted with female standard-taper 24/40 ground-glass joints (Corning 5000 or Kimble 26510).
2. West condensers (30 cm) fitted with male standard-taper 24/40 ground-glass joints at the lower end (Corning 2800 or Kimble 18190).
3. Electric hot plate extraction unit (six plates per unit) fitted with individual rheostat controls (Labconco 60300, Precision 65500, Lab-Line Multi-Unit Extraction Heater, or equivalent).

29-3.5.3.2 Reagents.

1. Potassium dichromate solution ($K_2Cr_2O_7$), 0.5*N*: Dissolve 24.5125 g of $K_2Cr_2O_7$ (oven-dry) in 200 ml of deionized water, and dilute to 1 liter.
2. Sulfuric acid (H_2SO_4), concentrated, not less than 96%.
3. Ferrous ammonium sulfate hexahydrate solution [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$], 0.2*N*: Dissolve 78.390 g of $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ in 50 ml of conc H_2SO_4, and dilute to 1 liter with deionized water (must be standardized daily because of slow oxidation).
4. Indicator solution: Dissolve 0.100 g of *N*-phenylanthranilic acid and 0.107 g of sodium carbonate (Na_2CO_3) in 100 ml of water.

29-3.5.3.3 Procedure. Weigh an amount of < 100-mesh soil (≤0.5 g) containing not greater than 8 mg of organic C into a 125-ml Erlenmeyer flask. Add exactly 10 ml of 0.5*N* $K_2Cr_2O_7$ solution and 15 ml of conc H_2SO_4 (H_2SO_4 may be added by burette). Attach the flask to the West condenser, and place on a preheated electric hot plate. Include a blank in each group of five soil samples to be heated and at least two unboiled blanks (unboiled blanks are unheated mixtures of 10 ml of 0.5*N* $K_2Cr_2O_7$ and 15 ml of conc H_2SO_4) for each day that analyses are performed. The normality of the $Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$ solution is determined by titrating the unboiled blank. Gently boil each sample for 30 min, and then insert an asbestos pad between the hot plate and bottom of the Erlenmeyer flask. Allow the flask to cool for about 15 min, and rinse the inside of the condenser with de-

APPENDIX GT.7D
MANOMETRIC METHOD

te in the dilute -water extract and sulfate that is associated with psum in the saturation extract less the sulfate in the saturation extract presents the amount of gypsum in the soil.

The content of gypsum in soil is a criterion for gypsic and petrogypsic rizons and for the mineralogical class at the family category (Soil Survey aff, 1975). Subsidence of soils through solution and removal of gypsum n crack building foundations, break irrigation canals, and make roads even. Failure can be a problem in soils with as little as 1.5% gypsum. If ment releases Al in the presence of gypsum and other soluble sulfate salts, ghly hydrated ettringite [$Ca_6 \cdot Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$] may form, creat- extremely high pressures that deteriorate and crack slab structures, irri- tion canals, and building foundations.

11-2 CARBONATE

11-2.1 Introduction

Inorganic carbonate either accumulates in soils by pedogenic forma- n or is inherited from calcareous parent material. Some soils in arid and niarid areas may contain as much as 40% or more of calcite equivalent. A all amount of inorganic carbonate may be added to acid soils in the form limestone, marl, and calcareous shells. Pedogenic carbonate and calcare- amendments are generally segregated in the matrix of the soil (Gile, 1). Hence, the soil sample should be finely ground before analysis.

Many methods for determining total inorganic carbonates, calcite, and omite have been proposed. Excellent reviews of the methods for calcite dolomite and their limitations are presented in papers by Petersen et al. 66) and Petersen and Chesters (1966).

Methods involving quantitative determinations of total inorganic car- ate include (i) neutralization of the carbonate with acid and back titra- of the excess acid; (ii) determination of Ca and Mg in an acid leachate; dissolution of carbonate in acid and determination of the evolved CO_2 measuring the volume or pressure of the CO_2 or by titrimetry, sample ght loss, infrared spectrometry, gas chromatography, and thermo- vimetry.

Quantities of calcite and dolomite have been determined by differential rmal analysis, x-ray diffraction techniques, chemical analysis, and analy- of differences in the rate of dissolution of calcite and dolomite in acid.

The difference in the rate of dissolution of calcite and dolomite in HCl been used for many years to differentiate the two minerals qualitatively. elopment of quantitative methods was difficult because calcite and omite decompose simultaneously though at vastly different rates, de- ding on the particle size and crystalline nature of the soil carbonates and stones.

A quantitative manometric method (Skinner & Halstead, 1958; Skinner ., 1959; Turner & Skinner, 1960) measures the CO_2 evolved from the

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reaction of calcite and dolomite in excess HCl at frequent intervals and at constant temperature until the reaction is completed. The logarithm of the amount of CO_2 equivalent to unreacted carbonate is plotted against time. After the rapid and complete dissolution of calcite in 60 sec, the curve for dolomite assumes a much smaller slope and is linear for a period of time. Extrapolation of this linear portion of the curve to zero time gives the amount of CO_2 equivalent to the dolomite initially present. The CO_2 from calcite is obtained by difference from the total CO_2.

A quantitative volumetric method (Dreimanis, 1962) measures the volume of CO_2 from the reaction of the carbonate minerals and excess HCl using the Chittick apparatus (AOAC, 1980). Calibration of the Chittick apparatus under a particular set of conditions permits correction for the effect of temperature, concentration of the acid, and partial pressure of CO_2 on its solubility in the acid. Calcite and dolomite are differentiated by reading the volume of CO_2 at two different times. The content of calcite and dolomite in soils and limestones is calculated from empirical graphs relating the volumes of CO_2 that are evolved from known amounts of calcite or dolomite.

11-2.2 Modified Van Slyke Manometric Method

11-2.2.1 PRINCIPLES

The volume of CO_2 that evolves from the reaction of inorganic carbonates with excess HCl changes proportionately as the temperature and pressure deviate from standard conditions. Theoretical considerations of this reaction are discussed by Martin and Reeve (1955). The modified Van Slyke method is named after one of its developers, who constructed a Hg manometric apparatus that determined total as well as inorganic C (Van Slyke & Folch, 1940). The method was modified by I. C. Frost (Rader & Grimaldi, 1961) to measure primarily inorganic carbonate-CO_2 with a simplified apparatus using an aqueous manometer.

Carbon dioxide is generated by the action of 10% HCl (wt/wt) on the sample. The volume of the liberated CO_2 plus the air present in the reaction flask is measured at a definite temperature and atmospheric pressure. The combined gases are then scrubbed free of CO_2 by passage through an alkali solution. The volume of the residual gases is again measured at the same temperature and pressure. The volume of CO_2 is the difference in the observed volumes. The weight of CO_2 is then calculated from its volume at standard temperature and pressure and is used to calculate the content of inorganic C, carbonate, or calcite equivalent.

11-2.2.2 METHOD (Adapted from Rader & Grimaldi, 1961)

11-2.2.2.1 Apparatus.

Refer to Fig. 11-1 for the following numerical references in the apparatus assembly.

Gas burette (n[redacted], 100-ml Van Waters no. 32221-000 or equivalent.
Gas burette condenser (no. 2), made from large glass tubing 5.9 cm o.d., 5.4 cm i.d. by 70 cm long, capped with no. 11½ rubber stoppers.
Acid delivery system and condenser, 2-liter acid reservoir (no. 3), 100-ml separatory funnel with stopcock I (no. 4).
Condenser (200 mm), with expansion bulk (no. 5): Attach condenser to the separatory funnel as a custom-made unit.
Glass sample vial (no. 6), round-bottom centrifuge tube 25 by 89 mm with a 30-ml capacity.
Three-way stopcock II, T-base, capillary, with Teflon plug, Van Waters no. 59263 or equivalent.
Thermometer (no. 7) total immersion, 0 to 100°C range, 1°C divisions.
Auto bubbler gas adsorption pipette (no. 8), Van Waters no. 31930-007 or equivalent.
Leveling bulb reservoirs (no. 9 and 10), 250-ml capacity, Van Waters no. 36685-046 or equivalent.
Bunsen burner (no. 11).
Tygon tubing, 6.4 mm (1/4 inch) i.d., 1.6-mm (1/16-inch) wall.

11-2.2.2.2 Reagents.

Hydrochloric acid (HCl), 10% (wt/wt).
Sulfuric acid (H_2SO_4) solution, 20% (wt/wt), 5 mg of methyl red indicator to facilitate reading of gas burette.
Sodium hydroxide (NaOH) solution, 30% (wt/wt).
Calcium carbonate ($CaCO_3$), primary standard grade.

11-2.2.2.3 Procedure.

Assemble the apparatus as shown in Fig. 11-1. Turn stopcock II to position a. Fill the gas burette by adding 200 ml of the sulfuric acid solution to leveling bulb reservoir no. 9 and raising the bulb until the burette and connecting tubing are filled with H_2SO_4 solution up to stopcock II. Leveling bulb no. 9 is now in position a. Fill the auto bubbler no. 8 up to the check valve by adding 200 ml of NaOH solution to leveling bulb reservoir no. 10 and raising it until the burette and connecting tubing are filled with NaOH solution up to stopcock II. Maintain a slow flow of cold tap water through the gas burette condenser no. 2 until a constant temperature is attained on the immersion thermometer no. 7.

Place 0.5 to 1 g of sample into sample vial no. 6, add two boiling chips, and secure sample vial to the rubber stopper by applying a slight upward twisting pressure.

Turn stopcock II to position b. Apply a partial vacuum to the system by lowering leveling bulk no. 9 to the bottom of the burette (position b). Open stopcock I to allow 15 ml of 10% HCl to flow into the sample vial. If large amounts of carbonate are present, this step must be done slowly. Before all the HCl has drained from the separatory funnel no. 4, close stopcock I so that the system remains closed to the atmosphere.

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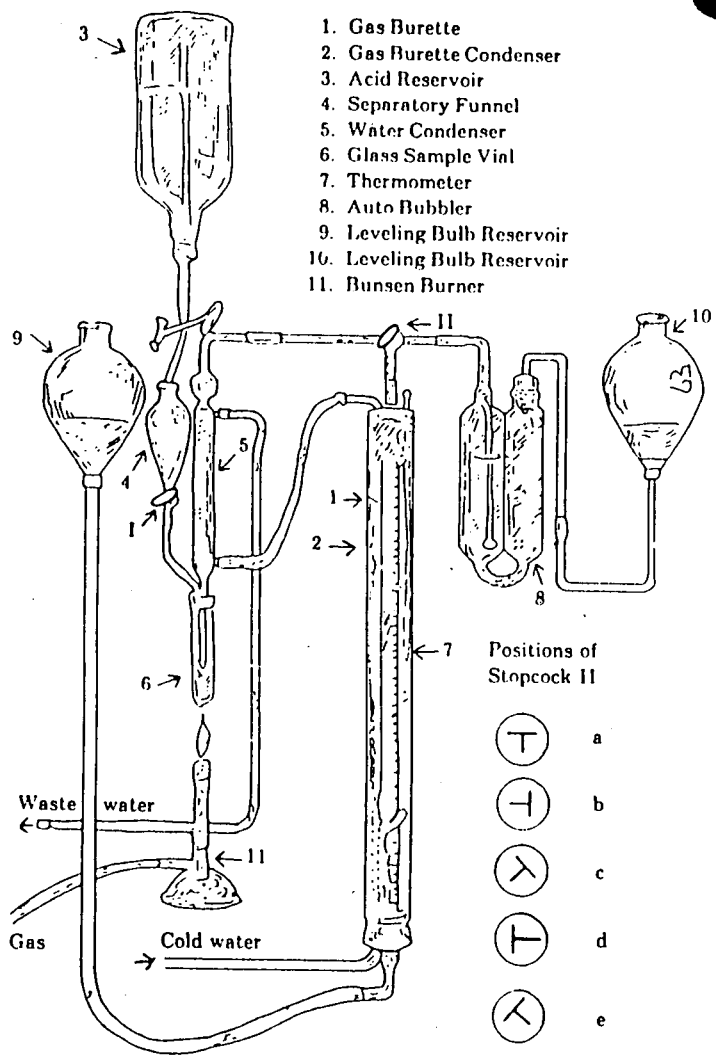

Fig. 11-1. Apparatus for gasometric determination of CO_2.

4. Heat the bottom of the sample vial for approximately 2 min until the reaction is complete. The two boiling chips should smooth out the boiling and keep the sample from boiling past condenser no. 5.
5. When the boiling stops, fill separatory funnel no. 4 with water (never allow air to enter the system). Open stopcock I and fill the sample vial, condenser, and delivery tube to stopcock II with water. Make sure no gas remains in this area.
6. Turn stopcock II to position c and move reservoir no. 9 over the gas burette no. 1. Position reservoir no. 9 so that the liquids in the two containers are at the same level. This procedure will equalize the pressure and result in atmospheric pressure on the gas in gas burette no. 1. Read and record the volume of gas in gas burette no. 1.

Elevate reservoir no. 9, and turn stopcock II to position d. This procedure allows the gas in the gas burette to bubble into the concentrated NaOH solution in reservoir no. 10. When the acidic solution from the gas burette no. 1 reaches the entry of the auto bubbler no. 8, lower reservoir no. 9 until the basic solution reaches stopcock II. Repeat this procedure three times to ensure that all the CO_2 has been absorbed by the basic solution.

Flush all the gas into the gas burette no. 1 by raising the NaOH solution slowly to stopcock II. Turn stopcock II to position e and make the second gas reading, equalizing the pressure as before.

In preparation for the next determination, return leveling bulb no. 9 to position a. Remove sample vial no. 6. Turn stopcock II to position b while holding a waste water container under the condenser no. 5.

Run duplicate determinations for each sample. If < 5 ml of CO_2 is produced for a given sample, run a larger sample up to a maximum of 2 g. If more CO_2 is produced than can be determined with the gas burette, reduce the sample size accordingly.

The entire procedure should be initially checked out by running $CaCO_3$ standards until the observed volume of CO_2 agrees with the theoretical volume.

11-2.2.2.4 Calculations.

Determine the volume of CO_2 in the sample by subtracting the second volume (step no. 8) of gas from the first volume (step no. 6).
To convert the volume of CO_2 at the observed temperature in the gas burette condenser no. 2 and barometric pressure to the percent of inorganic carbonate C in the sample, calculate the following:

$$\%\ \text{inorganic carbonate C} = \left(\frac{\text{ml } CO_2}{\text{g sample}}\right)\left(\frac{273°K}{\text{Observed temp., °K}}\right)\left(\frac{\text{Barometric pressure, mm Hg}}{760\ \text{mm Hg}}\right) \times \left(\frac{12\ \text{g/mol}}{22.414\ \text{liters/mol}}\right)\left(\frac{1\ \text{liter}}{1{,}000\ \text{ml}}\right)(100).$$

To calculate % inorganic carbonate, insert 60 g/mol for the 12 g/mol in the previous calculation. Likewise, when calculating % calcite, dolomite, or magnesite, substitute the molecular weight of the compound for the molecular weight of C as in the following example:

$$\%\ \text{calcite equivalent} = \left(\frac{\text{ml } CO_2}{\text{g sample}}\right)\left(\frac{273°K}{\text{Observed temp., °K}}\right)\left(\frac{\text{Barometric pressure, mm Hg}}{760\ \text{mm Hg}}\right) \times \left(\frac{100\ \text{g calcite mol}}{22.414\ \text{liters/mol}}\right)\left(\frac{1\ \text{liter}}{1{,}000\ \text{ml}}\right)(100).$$

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11-2.2.2.5 Comments. The precision of the method is limited by the inherent error in the reading of the gas burette. This method may be applied to all types of soils and sediments. The detection limit is 0.01% carbonate using a 2-g sample with a 100-ml graduated gas burette. This limit can be varied by changing the size of the graduated gas burette and sample container.

Sulfides and sulfites form gaseous H_2S and SO_2, respectively, in the presence of acid and heat. These gases are evolved along with the CO_2 and produce a positive error. Certain aromatic organic acids are also decarboxylated when heated in acid, thus producing additional CO_2 to give a positive error; however, the errors due to the presence of sulfides, sulfites, and decarboxylation of organic compounds are usually negligible in soils and sediment materials. Siderite (iron carbonate, $FeCO_3$) is the only carbonate mineral that is not completely decomposed by this procedure. Siderite is usually not present in soils and sediments (R. L. Malcolm. 1978. Personal communication).

11-2.3 Gravimetric Method

11-2.3.1 PRINCIPLES

Inorganic carbonates are decomposed by treating the soil sample with 2*N* H_2SO_4 containing $FeSO_4$ as an antioxidant to prevent release of CO_2 from organic matter. The air stream containing evolved CO_2 is purified by passing it through a series of traps to remove water and extraneous constituents, after which the evolved CO_2 is absorbed in a Nesbitt absorption bulb. The CO_2 is determined by weighing the bulb before and after absorption as described for total C in section 29-2.3.3.3.

11-2.3.2 METHOD (Allison, 1960; Allison & Moodie, 1965)

11-2.3.2.1 Special Apparatus. The apparatus is the same as for total C by wet combustion shown in Fig. 29-2 and described in section 29-2.3.3.1.

11-2.3.2.2 Reagents.

1. Digestion acid for carbonates: Dissolve 57 ml of conc sulfuric acid (H_2SO_4) and 92 g of ferrous sulfate heptahydrate ($FeSO_4 \cdot 7H_2O$) in 600 ml of distilled water. Cool the solution, dilute it to 1,000 ml, and keep it well stoppered. This solution is approximately 2*N* in acidity and contains 5% $FeSO_4$ to serve as an antioxidant.
2. Absorbent for carbon dioxide (CO_2): Mikhobite, Caroxite, Ascarite, Indicarb, or other suitable absorbent.

11-2.3.2.3 Procedure. Transfer a soil sample containing not more than 250 mg of calcite equivalent into a 100-ml Kjeldahl flask, and connect the flask to the reflux condenser (Fig. 29-2). Weigh the Nesbitt bulb, attach it to the system, and open the valve at the top of the bulb. Pour 25 ml of the digestion acid into the funnel at the top of the condenser, and cover the fun-

APPENDIX GT.7E
SATURATED PASTE TECHNIQUE

various methods minimizes need for sample collection and chemical analysis, especially when monitoring salinity changes with time and characterizing large field or project situations. For the latter, use of EM and four-probe techniques are recommended with supplemental use of the other methods as needed. Only methods for obtaining aqueous extracts of soil samples are dealt with in this section.

The following sections describe methods for determining soluble salts in water and soils using various methods and procedures for obtaining aqueous extracts of soil samples.

10-2 SATURATION EXTRACT AND OTHER AQUEOUS EXTRACTS

10-2.1 Principles

For some needs, knowing the composition of solutes in soil water at field water contents is desirable. However, present methods of obtaining soil water samples at usual field water contents are not practical for routine purposes. Thus, soil solution extracts often must be made at higher than normal water contents. Because the absolute and relative amounts of various solutes are influenced by the soil/water ratio at which the extract is made (Reitemeier, 1946), the ratio must be standardized to obtain results that can be applied and interpreted universally. Soil salinity is conventionally defined and measured on aqueous extracts of saturated soil pastes (U.S. Salinity Laboratory Staff, 1954). This soil/water ratio is used because it is the lowest reproducible ratio for which enough extract for analysis can be readily removed from the soil with pressure or vacuum and because it is often related in a predictable manner to field soil water contents. For these reasons, crop tolerance to salinity is often related to the electrical conductivity, or total electrolyte concentration, of the saturation extract (U.S. Salinity Laboratory, 1954).

Other extraction ratios, 1:1, 1:5, etc., are easier to use than that of saturation, but they are not so well related to field soil water contents. Errors from peptization, hydrolysis, cation exchange, and mineral dissolution also become greater for such extracts. As a compromise, Sonnevelt and van den Ende (1971) recommended a 1:2 volume extract. When relative changes rather than absolute solute concentrations are monitored, these wider extraction ratios may be used to advantage.

Once soil extract samples are obtained, laboratory chemical analyses are carried out to determine the electrical conductivity of the extract (σ_e) and the concentrations of major solutes (section 10-3).

10-2.2 Reagent

1. Sodium hexametaphosphate [$(NaPO_3)_6$] solutions, 0.1%: Dissolve 0.1 g of $(NaPO_3)_6$ in water, and dilute the solution to 100 ml.

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10-2.3 Procedure

10-2.3.1 SATURATION EXTRACT

Weigh 200 to 400 g of air-dry soil of known water content into a plastic container having a snaptight lid. Weigh the container plus contents. Add distilled water to the soil with stirring until it is nearly saturated. Allow the mixture to stand covered for several hours to permit the soil to imbibe the water, and then add more water to achieve a uniformly saturated soil-water paste. At this point, which is generally reproducible to within ± 5%, the soil paste glistens as it reflects light, flows slightly when the container is tipped, slides freely and cleanly off a spatula, and consolidates easily by tapping or jarring the container after a trench is formed in the paste with the side of the spatula. After mixing, allow the sample to stand (preferably overnight, but at least 4 hours), and then recheck the criteria for saturation. Free water should not collect on the soil surface, nor should the paste stiffen markedly or lose its glisten. If the paste is too wet, add additional dry soil to the paste mixture. Upon attainment of saturation, reweigh the container plus contents. Record the increase in weight, which is the amount of water added. Calculate the saturation water percentage from the weight of oven-dry soil and the sum of the weights of water added and that initially present in the air-dry sample. After allowing the saturated soil paste to stand 4 or more hours, transfer it to a Büchner or Richards (1949) filter funnel fitted with highly retentive filter paper. Apply vacuum, and collect the filtrate in a test tube or bottle. If the initial filtrate is turbid, refilter or discard it. Terminate the filtration when air begins to pass through the filter. Add 1 drop of 0.1% $(NaPO_3)_6$ solution for each 25 ml of extract.

10-2.3.2 EXTRACTS AT SOIL/WATER RATIOS OF 1:1 AND 1:5

Weigh a sample of air-dry soil of appropriate size, and transfer it to a flask or bottle. Add the required amount of distilled water, stopper the container, and shake it in a mechanical shaker for 1 hour. If a mechanical shaker is not available, shake the container vigorously by hand for 1 min at least 4 times at 30-min intervals. Filter the suspension using highly retentive filter paper. (Discard or refilter the initial filtrate if it is turbid.) Add 0.1% $(NaPO_3)_6$ solution at the rate of 1 drop/25 ml of extract.

10-2.4 Comments

The weight of soil required will depend on the number and kind of determinations to be made on the extract, the analytical methods employed, and the salt content of the soil. In general, from one fourth to one third of the water in saturated soil pastes can be removed by vacuum filtration.

Soil samples should not be oven-dried before extracting for determination of soluble salts, because heating to 105°C converts at least a part of the gypsum ($CaSO_4 \cdot 2H_2O$) to plaster of paris ($CaSO_4 \cdot 1/2H_2O$). The latter hydrate has a higher solubility in water than does the former.

In determin[illegible]is of extract water contents when a low ratio of soil to water is used, it is desirable to correct for the water content of the air-dry soil. For example, an air-dry sample containing 2% water on an oven-dry basis can be adjusted to a soil/water ratio of 1:1 by adding 98 ml of water to 102 g of air-dry soil. At soil/water ratios of 1:5 or greater, no correction is ordinarily made for water in the air-dry sample.

Special precautions should be taken in preparing a saturated soil paste with peat and muck soils or very fine or very coarse-textured soils. If possible, peat and muck soils should not be allowed to dry following collection because their saturation water content changes. Peat and muck, especially if coarse or woody, require an overnight imbibition period to obtain a definite endpoint for the saturation point. After the first wetting, pastes of these soils usually stiffen upon standing. Adding water and remixing then give a mixture that usually retains the characteristics of a saturated paste. With fine-textured soils, enough water should be added immediately, with a minimum of mixing, to bring the sample nearly to saturation. This minimizes the formation of clumps of soil during stirring, speeds the mixing process, and helps attain a more definite endpoint. Care should also be taken not to overwet coarse-textured soils. The presence of free water on the surface of the paste after standing is a very important indication of oversaturation in the case of coarse-textured soils. Even small amounts of free water can lead to appreciable errors in saturation paste water contents for these materials.

Sodium hexametaphosphate is added to the extract to prevent the precipitation of $CaCO_3$ from the extract upon standing. The quantity of $NaPO_3)_6$ solution added increases the Na concentration ~0.5 ppm, or 0.02 meq/liter, which is inconsequential compared with the possible loss of $CaCO_3$. Alternatively, a subsample of the extract could be immediately diluted twofold and used for the Ca and alkalinity determinations.

Alternative methods of preparing the saturated soil paste have been described by Longenecker and Lyerly (1964), who proposed wetting the soil sample on a capillary saturation table, Beatty and Loveday (1974) and Loveday (1972), who recommended predetermining the amount of water at saturation on a separate soil sample using a capillary wetting technique, and Allison (1973), who recommended slowly adding soil to water (oversaturation method). Similar results are obtained with these methods. The choice of method is primarily one of personal preference.

Thymol can be added to the paste to minimize the effect of microbial activity on saturation extract composition during equilibration (Carlson et al., 1971).

The extracts should be stored at ~4°C until analyzed.

10-3 SOLUBLE CONSTITUENTS IN SOIL WATERS AND AQUEOUS EXTRACTS

The major solutes of interest found in soil waters and aqueous extracts of salt-affected soils are Ca^{2+}, Mg^{2+}, Na^+, K^+, CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^-, and H_3BO_3. There are many satisfactory analytical methods for determining these solutes. These methods range from wholly auton[illegible]. to manual. The choice of which to use is usually determined by the number of samples being processed and the availability of analysts, automated equipment, or both. The methods described here are those in common use in laboratories having typical modern but not fully automated instrumentation. Methodology more suited to laboratories without such conveniences was given previously by Bower and Wilcox (1965).

10-3.1 Sequence of Analyses

Alkalinity and pH determinations should be made immediately on fresh extracts or on the solutions treated with hexametaphosphate. Next, electrical conductivity, σ, should be determined; it is a useful means of estimating total salt concentration (meq/liter $\cong 10\ \sigma$, in deci-Siemens per meter, dS/m). The cations can be determined in any sequence. After any three of the four major cations have been determined, the appropriate aliquot for the remaining cation can be estimated by deducting the sum of the three concentrations, in milliequivalents per liter, from $10\ \sigma$, in deci-Siemens per meter. Among the anions, NO_3^- and Cl^- determinations are normally made after alkalinity since they are simpler to measure than SO_4^{2-}. After that, SO_4^{2-} is determined; the appropriate aliquot is estimated from the difference between ($Ca^{2+} + Mg^{2+} + Na^+ + K^+$) and (alkalinity + $NO_3^- + Cl^-$). Finally, B is determined. Concentration of this solute is negligible compared with that of the major cations and anions, but it is still extremely important because of its pronounced toxicity even in small concentrations to many plants.

10-3.2 pH and Alkalinity

10-3.2.1 APPARATUS

1. Automatic potentiometric titrator.
2. Single probe combination pH electrode.

10-3.2.2 REAGENTS

1. Standard buffer solutions, pH 4.00 and 7.00.
2. Standard hydrochloric acid (HCl), approximately 0.0200*N*.

10-3.2.3 PROCEDURE

With electrode immersed in standard pH buffer, set the potentiometer to the pH (7.00) of the first buffer solution. Rinse electrode, and repeat calibration using the second pH buffer. Rinse electrode, immerse in 1 to 20 ml of sample solution (contained in a 50-ml plastic beaker along with a microsize, Teflon-coated magnetic stirring bar), and initiate the automatic titration operation using the full titration curve display mode. The initial potential recorded on the strip chart gives the sample pH. The volumes of titrant delivered to produce inflection points for CO_3^{2-} and HCO_3^- are ob-

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ned from the ti[redacted]n curve (pH vs. volume of standard acid delivered m automatic burette).

3.2.4 CALCULATIONS

$$CO_3^{2-} \text{ in meq/liter} = 2P\,N\,1{,}000/\text{aliq}$$

ere P is the number of milliliters of standard HCl of normality N to reach CO_3^{2-} inflection point (pH = 8.3), and aliquot is the sample volume in Iliters.

$$HCO_3^{-} \text{ in meq/liter} = (T - 2P)\,N\,1{,}000/\text{aliquot}$$

ere T is the total number of milliliters of standard HCl of normality N to ch the HCO_3^- inflection point (pH = 4.5), P is the number of milliliters standard HCl required to reach the CO_3^{2-} inflection point, and aliquot is sample volume in milliliters. The blank is determined using CO_3^{2-} free tilled water.

10-3.3 Electrical Conductivity

For this determination, use a direct readout from a temperature compsating conductivity meter.

3.3.1 APPARATUS

Conductivity meter.
Conductivity flow cell with automatic temperature compensation.
Vacuum line and suction flask.

3.3.2 REAGENT

Standard potassium chloride (KCl) solutions, 0.010 and 0.100*N*: For 0.010*N* solution (1.412 dS/m at 25°C) dissolve 0.7456 g of KCl in distilled water, and add water to make 1 liter at 25°C. For 0.100*N* solution (12.900 dS/m at 25°C), use 7.456 g of KCl.

3.3.3 PROCEDURE

Rinse and fill the conductivity cell with standard KCl solution. Adjust conductivity meter to read the standard conductivity. Rinse and fill the l with the soil extract or water sample, and read the σ, corrected to 25°C, ectly from the digital display.

3.3.4 COMMENTS

Because of marked differences in the equivalent weights, equivalent nductivities, and proportions of major solutes in soil extracts and water mples, the relationships between σ and salt concentration or between σ

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and osmotic pressure are only approximate. They are still quite useful, however. These relationships are:

1) Total cation (or anion concentration), meq/liter $\cong 10 \times \sigma$, in dS/m.
2) Salt concentration, mg/liter $\cong 640 \times \sigma$, in dS/m.
3) Osmotic pressure, bars at 25°C $\cong 0.39 \times \sigma$, in dS/m.

10-3.4 Soluble Cations

Determine Ca^{2+}, Mg^{2+}, Na^+, and K^+ using an atomic absorption spectrometer or by methods outlined in sections 13-3.3.2 and 13-3.3.4 for K, 13-4.3.3 and 13-4.3.5 for Na, and 14-3.1 for Ca and Mg. If large numbers of samples are to be routinely analyzed, it is extremely helpful to have this unit equipped for automatic sample transport, sequencing, siphoning, reading, and recording.

10-3.4.1 APPARATUS

1. Atomic absorption spectrometer.
2. Sampling and sequencing system.
3. Acetylene gas (C_2H_2), commercial grade.

10-3.4.2 REAGENTS

1. Suppressant solution for Ca^{2+} and Mg^{2+}: Add 29.0 g of lanthanum oxide (La_2O_3), 250 ml of conc hydrochloric acid (HCl), and enough distilled water to make up to 500-ml volume. Add sufficient to aliquot and diluent (distilled water) to give 10% (by volume) of this $LaCl_3$ solution in the final solution.
2. Suppressant solution for Na^+ and K^+: Add 6.358 g of lithium chloride (LiCl) and make to 1 liter in distilled water (0.15*N*). Add enough to aliquot, and diluent (distilled water) to give 10% (by volume) of this LiCl solution in the final solution.
3. Standard cation solutions: Ca^{2+} (0-0.4 meq/liter), Mg^{2+} (0-0.1 meq/liter), Na^+ (0-1.0 meq/liter), and K^+ (0-0.1 meq/liter).

10-3.4.3 PROCEDURE

Adjust the atomic absorption spectrometer controls and settings for the cation to be run as recommended by the manufacturer. Set the atomic absorption spectrometer readout to read the upper and lower standard solutions. Then initiate transport/readout system, which automatically positions a sequence of samples, siphons and aspirates the samples in the air-acetylene flame, and reads and records (as a digital printout) the concentration of the cation in the aspirated solution. Standard solutions are inserted into the sampling rack every 20 samples to ensure stability of instrument calibration during the automated run. Two-hundred samples can be processed per hour without attendance after the automatic sample processing system is initiated. Alternatively, the same sequence of operations can be performed by hand.

DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or **Type** All Information (Except Signatures)

INFORMATION ONLY

1. Date	25.
02/04/94	DMR. No. 94-DMR-000229 SEED 2-11-94

Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
E42-ER-OPS, GT.08, Rev.3	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
C. H. Hayes/x6905/na/Bldg. 080	Surface Soil Sampling

6. Document Type ■ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☐ Intent Change ☐ Nonintent Change ■ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1)	35	Sec. 6	Second paragraph, first sentence: Change the text from "Form GT.8A, Surface Soil Data Collection Form..." to "Form FO.14C (Rev. 09/16/93), Surficial Soil Sample Form (see page 40 in this procedure)..."
2)	35	Sec. 6	Second paragraph, third sentence: Change "Form GT.8B" to "Form GT.08A (Rev 3)".
3)	40	form	Remove the reference ("GT.08B, Rev. 3") at the bottom of the Surficial Soil Sample Form.
4)	41	form	Label the Surface Soil Sampling Field Activities Report form at the bottom right with the footnote reference : "Form GT.08A, Rev.3"

12 Justification (Reason for Modification, EJO#, TP#, etc.)

1,2: The text needs to be corrected to coincide with the forms located on pages 40 and 41 of this procedure

3: This form already has a reference number, "FO.14C" located in the top right corner, below the header.

4: This form needs a reference number.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
EQS	M.C. Brooks (RR) M.C. Brooks	2-15-94
SME	M.Z. Litaor M.Z. Litaor	2-15-94

16. Originator's Supervisor (print/sign/date)
R.S. Luker / R.S. Luker 2/9/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
M.Z. Litaor/x8583/na/Bldg. 080	0202	ENV-GT	02/10/94	3/14/94

22. Accelerated Review? Yes ☐ No ■

23. ORC Review
ORC Review not required

24. Responsible Manager (print, sign, date)
M.E. Levin / M.E. Levin 2-14-94

2-16-94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

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DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

INFORMATION ONLY

SURFACE SOIL SAMPLING

EG&G ROCKY FLATS PLANT	Manual:	4-E42-ER-OPS
ERM OPERATIONS PROCEDURE MANUAL	Procedure No.	GT.08,Rev.3
	Page:	1 of 41
	Effective Date:	12/20/93 ~~12/8/93~~
	Organization:	Environmental Restoration Management

ROCKY FLATS PLANT

4-E42-ER-OPS-GT.08

Revision 3

Surface Soil Sampling

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

Approved By: W S Barker 12/13/93
(Manager, Remediation Projects, Management) (Date)
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Responsible Organization: Environmental Restoration Management

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JAN 18 [illegible]

EG&G ROCKY FLATS PLANT	Manual:	4-E42-ER-OPS
ERM OPERATIONS PROCEDURE MANUAL Vol. III : Geotechnical	Procedure No.	GT.08,Rev.3
	Page:	1A of 41
	Effective Date:	3/14/94
	Organization:	Environmental Restoration Management

LIST OF EFFECTIVE PAGES

94-DMR-000229

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6-6A	01/28/94	94-DMR-000133
9	01/28/94	94-DMR-000133
11-13	01/28/94	94-DMR-000133
35	~~02/ /94~~ 3/14/94	94-DMR- 000229
39	01/28/94	94-DMR-000133
40	~~02/ /94~~ 3/14/94	94-DMR- 000229
41	~~02/ /94~~ 3/14/94	94-DMR- 000229

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1.0 PURPOSE

This standard operating procedure describes procedures that will be used at the Rocky Flats Plant (RFP) to sample near-surface soils. Near-surface soils is defined as those soils between the ground surface and 1-meter (3.3 ft.) in depth. The procedure is divided into two primary sections: one for obtaining surface scrapes according to several protocols for assessing radionuclide contamination (Section 5.0) and another for more generalized sampling of near-surface soils, and other surface areas for nonradionuclide analyses (Section 6.0).

2.0 SCOPE

This procedure describes personnel responsibilities and qualifications, sampling equipment and procedures, decontamination, and documentation procedures.

The procedure is applicable to samples collected by Environmental Restoration Management (ERM), and its subcontractors, during field work. The implementation of the specifics of this procedure is determined by the requirements in the site-specific field sampling plan (FSP).

This procedure implements the requirements of the Inter-Agency Agreement (IAG) and the ERM Quality Assurance Project Plan (QAPjP).

3.0 PREREQUISITE

Personnel sampling surface soils will be scientists, engineers, or field technicians trained to conduct hazardous waste site work, as required by 29 CFR1910.120. These personnel will also have experience under the direct supervision of a qualified individual as specified in 3-21000-ADM-02.01, Rev.0 and 02.02, Rev.0; and be trained in the appropriate application of the standard operating procedures. The field team and field supervisor shall:

- Obtain from EG&G or its designee the appropriate documentation for radioactive material screening.
- Review the site-specific FSP and applicable procedures.
- Review the site-specific Health and Safety Plan and applicable procedures.

The required personal protective equipment for sampling surface soils will be detailed in the health and safety plan for the specific work task being conducted.

4.0 METHODS FOR SURFACE RADIONUCLIDE SOIL SAMPLING

The purpose of surface soil sampling at the RFP can be related to one or more specific objectives. These are as follows: 1) resuspension availability, which determines if radionuclides are present in the top-soil that could become resuspended in the air and thus pose a migration pathway by inhalation; 2) deposit inventories, which determine the amount of accumulated radionuclides deposited on the ground; 3) distribution of contaminants, which defines the areal distribution of contaminants; and 4) deposition increment, which defines the distribution with depth of radionuclides in the top 6 inches of soil to verify the results of the HPGe surveys.

To meet these objectives there are four radionuclide, surface soil sampling methods employed at RFP: 1) Colorado Department of Health (CHD) method, designed to sample for resuspension availability; 2) Rocky Flats (RF) method, designed to sample for deposit inventories; 3) Grab Sampling method for under asphalt and concrete, or where contamination may have occurred from a given point source, designed to sample for contaminant distribution; and 4) Vertical Soil Profile method, designed to sample for deposition increment.

Any or a combination of these sampling methods may be used as specified in the site-specific FSP. It should be noted that the CDH or RF methods are normally used in unpaved areas. However, grab sampling (spade and scoop) for radionuclides may be necessary for some RFP locations were the CDH or RF methods are not appropriate. Such as where contamination may have occurred from a given point source, or where a point source may have contaminated a very small or localized area. The sample type, basis for collection and required methodology can be determined by consulting the applicable workplan.

The primary considerations for acquiring surface soil samples for radionuclide analysis include the following:

- Sample handling should be minimized.
- The sample will be placed in an airtight 1-liter, wide-mouth glass, container immediately after collection.
- The sample will be properly labeled.

Field personnel are referred to procedure FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples for further details. Above-surface plant parts and coarse material (pebbles, rocks, and stones) will be removed by the sampling team. The soil samples will be classified according to procedure GT.1, Logging Alluvial and Bedrock Material. For surficial profiling samples, the sampler will collect representative samples, including organic material and coarse material. All sampling equipment will be protected from the ground surface with plastic sheeting.

4.1 SOIL SAMPLING WITH THE CDH METHOD

4.1.1 Introduction

The CDH sampler is one method for collecting soil samples for radionuclide analysis at the RFP. The CDH sampler was designed to sample radionuclides in the top-soil that could become resuspended in the air and thus pose a migration pathway by inhalation. The sampler is designed to obtain a sample from the upper surface 1/4 inch deep from an area 2 inches wide and 2 3/8 inches long, as shown in Figure GT.8-1.

Sampling locations will be described in the FSP. Some samples will be composited to obtain representative samples of large areas and others will be single-location samples. Sampling techniques for either type of sample are the same before compositing.

4.1.2 Equipment and Materials

The following is a list of equipment used for radionuclide contaminated soil sampling:

- CDH soil sampler;
- stainless steel scoop;
- stainless steel lab spoon;
- stainless steel mixing bowl or pan equivalent;
- sample containers;
- sample labels;
- wash and rinse tubs;
- phosphate-free, lab-grade detergent (e.g., Liquinox);
- distilled water;
- plastic sheeting;
- sample locations (map and/or list);
- measuring tape or wheel;

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- Brunton compass;
- lawn or garden spade;
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan;
- logbook; and
- cooler with ice or ice packs.

4.1.3 Sampling Plot Layout

A specified number of samples will be collected and composited from within sample plots. Under this scenario, the target locations of the samples will be described by an evenly spaced grid as specified in the site-specified FSP.

Preliminary location of sampling points will be achieved by staking and flagging the points. The sample points will be located by taping, use of a measuring wheel, or by pacing, combined with the use of Brunton compass. The sample plot layout will attempt to achieve location accuracies of within + or - 10 feet of the proposed work plan data acquisition points, as specified in procedure GT.17, Land Surveying. After all of the samples are collected within a sample plot; the southwest corner of the sample plot will be surveyed using standard surveying methods or global positioning system (GPS) methodologies. Refer to procedure GT.17, Land Surveying, or GT.27, GT.28, and GT.29 for GPS, for methods and acceptable uncertainty and range for the distance measurements made. Sample locations will be marked with a permanent identification, as designated in the FSP, so that the area may be located and resampled at a later date.

The planned locations of sample points may be revised (i.e., offset) when obstacles are encountered within the plot. If pavement, disturbed ground, or other obstacles are present that would jeopardize sample integrity or endanger the samplers, the grid may be adjusted to allow the specified number of samples to be obtained from a smaller area. When practical, the originally planned grid spacing will be maintained; however, this cannot be done if a relatively large portion of a plot cannot be sampled. All offset locations will be documented on a sketch complete enough to be able to relocate each sample location within an accuracy of 10 feet. Survey checks will be made to document the accuracy of the offset sample points.

The sampling plot layout for a single-location sample will follow the procedures as described in the site-specific FSP.

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4.1.4 Procedures

The following procedures will be used for the CDH sampler:

1. Always use a clean sample container appropriate for the type of sample being collected. Refer to procedure FO.13, Containerization, Preserving, Handling and Shipping of soil and water samples for the appropriate type of container.

2. Label the sample container into which the soil sample is to be placed. Refer to procedure FO.13, Containerization, Preserving, Handling, and Shipping of soil and water samples for the type of information to be included on the label.

3. Carefully remove vegetation and any undesirable top layer of surfacial material to the desired sample depth with a decontaminated steel lawn or garden spade. Undesirable material is defined as; rocks, gravel, pebbles, scree, road base, paving material, vegetation or other organic material.

4. Make sure that the soil sampling template is decontaminated and dry, then place it on the ground and push it into the soil so that the soil surface is even with the upper surface of the sampling template.

5. At the back end of the template (the end farthest from the curved scoop at the front of the template), place the sampling spade in the soil 1/4 inch deep, up to the rolled edges on the flanges on each side of the spade, so that the rolled edges face the front edge of the template. Refer to Figure GT.8-1.

6. Gently, but firmly, draw the sampling spade forward, so that the soil is drawn to the curved scoop at the front of the sampling template.

7. Lift the spade, place it at the back of the template again and draw it forward once more to ensure that the entire volume that is defined by the template (1/4 inch deep by 2 inches wide by 2 3/8 inches long) is collected into the curved scoop at the front of the template. Repeat as necessary to obtain a complete sample.

8. Taking care not to spill any of the soil that has been collected, lift the template up from the ground. Place the curved scoop at the front of the template inside the sample container and tip the sampling template up

to pour the soil into the container. Brush any soil that adheres to the scoop into the sample container.

9. Close the container.

10. After samples are placed in sample containers, the outside of the container will be wiped clean of excess material and it will be placed in a plastic bag.

11. Transfer the samples to the sample manager. Refer to procedure FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples for the proper paperwork and sample transfer methods. This documentation is a QA record and must go into the ERM records center.

12. Either use another set of clean sampling equipment or decontaminate equipment after use and between sample locations. For specific decontamination guidelines, consult procedure FO.3, General Equipment Decontamination. Decontamination according to these procedures is not necessary between composite sample points; however, excess dirt or mud should be cleaned from the equipment.

Duplicate samples will be obtained by offsetting the primary sample location 6 inches to 2 feet upwind or in a direction technically more appropriate and placing the duplicate samples in a separate jar. The location of the duplicate will be documented on the data collection form. The duplicate sample will be composited and containerized following the same procedures as for the primary sample. The frequency of duplicate samples will be defined in the FSP or the Quality Assurance Addendum (QAA).

4.2 SOIL SAMPLING WITH THE RF METHOD (JIG AND SCOOP)

4.2.1 Introduction

The purpose of sampling is to determine the amount of accumulated plutonium that has been deposited on the ground. This determination is accomplished by collecting a sample volume of 5,000 cm^3 of soil in situ. The jig outlines a square area with 10-cm sides and is driven 5 cm into the soil to cut three sides of the sample (Figure GT.8-2). At the fourth side, soil is removed from outside the jig's perimeter. The scoop is used to finish the cut on both the fourth side of the sample and the bottom surface. Ten samples should be collected at each location and composited.

In very rocky areas, good sample geometry (shape) cannot be achieved with the jig. In those cases, the jig and the metric rule should be used to gauge the desired sample size. Rocks and soil are pried or chiseled out of place for collection.

4.2.2 Equipment and Materials

The following is a list of equipment used for the RF method.

- soil sampling jig (10 X 10 X 5 cm);
- spare sampling jig parts;
- stainless steel scoop;
- stainless steel bowl;
- brushes, wire, and paint;
- wash bucket, and paper towels;
- phosphate-free, lab-grade detergent (e.g. Liquinox)
- distilled water;
- plastic bags;
- paint cans, 1 gallon new;
- hammer;
- miscellaneous cold chisels;
- pointed cement trowel;
- black waterproof (permanent) marking pens;
- metric rule;
- wood block (10 X 10 X 30 cm);
- site selection plan (FSP);
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan;
- logbook;
- cooler with ice or ice packs;
- plastic sheeting; and
- sample containers and labels.

4.2.3 Sampling Plot Layout

A site selection plan as described in the applicable FSP should be used to specify the general site location. The plan must provide adequate information for the sample collection crew to locate each specific site. Sample locations will be marked with an identification sign, as designated in the FSP, so that the area may be located and resampled at a later date. Permission to collect samples and mark the site should be obtained from the appropriate EG&G department or the landowner. Sample collection crews will be accompanied by supervision for all sampling activities to ensure that specified procedures are followed.

The following general site selection criteria should be considered:

- undisturbed location for the time interval of interest;
- near the center of a large, flat, open area;
- not subject to excessive runoff during heavy rain;
- light to moderate vegetation and permeable soil; and
- not in an area of mechanical disturbance.

Consideration of these criteria will depend on the nature of the study. For example, in some instances it may be necessary to investigate an area of mechanical disturbance.

If a sample site is not available that meets the criteria described in the FSP, the location can be moved up to one-half the distance to the next grid sample location or within 10 feet of a staked sample location which is not part of a grid. If the sample location must be moved further than this distance, regulatory agency concurrence will need to be obtained. Any movement of sample locations will be documented on the surface soil data collection form and in the field crew supervisors logbook.

All selected sites should be located on a map.

4.2.4 Procedures

Ten soil samples should be collected at each site and composited for analysis. Samples should be collected at the center and corners of two one-meter squares that are spaced one meter apart. Figure GT.8-3 illustrates this sample collection spacing. The following procedures will be used for the RF method:

1. Place the sampling jig on the ground, and using the wood block and hammer, drive the jig into the soil to a depth of 5 cm.

2. With minimal disturbance to the soil inside the jig, use a scoop, trowel, or chisel to remove the soil from around the open side of the sample jig. Soil should be removed to a depth that will allow easy removal of the sample.

3. Discard the soil removed from outside the jig.

4. Remove soil samples from the interior jig with scoop/trowel and place it in a 10-mesh metal sieve that has a plastic bag attached to the bottom to receive the soil that passes through the sieve. After all 10 samples (5 samples from each of the two 1-meter square templates) have been placed into the sieve, attach the sieve cover and seal with tape. Sieving may be done in stages if all 10 soil samples cannot be placed into the sieve at the same time.

5. Label the sample container into which the soil sample is to be placed. Refer to procedure FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples, for the type of information to be included on the label, and the appropriate type of container.

   This documentation is a QA records and must go into the ERM records center.

Shake the sieve for several minutes. If the soil is moist, gently crush soil aggregate with fingers, while wearing proper personal protective equipment as prescribed in the applicable Health and Safety Plan, and continue shaking until all soil matrix has passed through the sieve. Discard large particles (cobbles, stones, etc.) that do not pass through the sieve into original disturbed area.

6. In order to reduce the volume of the sieved sample to the quantity required for laboratory analysis, and still maintain a representative sample; place <u>all</u> sieved soil into stainless steel pan. Mix soil thoroughly with a scoop/trowel. Divide sieved soil into quarters. Subsample each quarter equally so the total amount of subsampled soil to be used for <u>analysis</u> does not exceed 1 kg or one 1-gal paint can. Place each of the four subsamples into one plastic bag. Place plastic bag in metal 1-gal paint can. Leave about 1 inch headspace in paint can.

7. Place residual sieved soil from quartering inside plastic bag, and place bag inside another paint can. If residual soil exceeds volume of one 1-gal paint can, place excess residual sieved soil back into original disturbed area.

8. Store residual sieved soil for potential use at a later date.

9. Decontaminate sieve between uses following procedure FO.3, General Equipment Decontamination.

4.3 GRAB SAMPLING (SPADE AND SCOOP)

4.3.1 Introduction

Surface soil samples can be collected for radionuclide analyses using grab sampling (spade and scoop) methods.

Sampling locations and the number of soil samples will be described in the specific Field Sampling Plan for each project. Equipment, sample plot layout, and sampling procedures are described in the following sections.

4.3.2 Equipment and Materials

The following is a list of equipment for contaminated soil sampling:

- spade (long handle);
- stainless steel hand auger (optional);
- mason trowel;
- stainless steel scoop;
- stainless steel lab spoon;
- sample labels;
- sample containers;
- wash/rinse tubs;
- phosphate-free, laboratory-grade detergent (e.g., Liquinox);
- distilled water;
- plastic sheeting;
- sample locations (map and/or list);
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan;
- photoionization detector (PID) or flame ionization detector (FID);
- logbook;

- measuring tape or wheel;
- Brunton compass;
- cooler with ice or ice packs; and
- shovel.

4.3.3 Sampling Plot Layout

Sample locations are described in the Field Sampling Plan for each project. Permission and clearance for collecting samples will need to be coordinated with the appropriate EG&G department or the landowner for the specific area. Utilities will be cleared before any intrusive work.

Preliminary location of sampling points will be achieved by staking and flagging the points. The sample plot layout will attempt to achieve location accuracies of within + or - 10 feet of the proposed work plan data acquisition points, as specified in procedure GT.17, Land Surveying. After all of the samples are collected within a sample plot; the southwest corner of the sample plot will be surveyed using standard surveying methods or global positioning system (GPS) methodologies. Refer to procedure GT.17, Land Surveying, or GT.27, GT.28, and GT.29 for GPS, for methods and acceptable uncertainty and range for the distance measurements made. The sample location will be sketched on a field map. Sample locations will be marked with an identification sign, as designated in the FSP, so that the area may be located and resampled at a later date.

The sample points will be surveyed by taping, use of a measuring wheel, or by pacing, combined with the use of Brunton compass. Regardless of the method used, survey checks will be made to verify the accuracy of the measurements.

Photographs of the surrounding area and the soil will be at the discretion of the field crew supervisor. If a significant feature or something out of the ordinary is encountered that may effect sampling and should be documented; then a photograph will be taken. Photography shall be coordinated with the RFP photography department at least one week in advance of the sampling event.

4.3.4 Procedures

The following procedures will apply for surface-soil sampling with a spade and scoop.

1. Carefully remove vegetation and any undesirable surfical material to the desired sample depth with a decontaminated steel lawn or garden

spade. Desired sample depth will be specified in the project specific work plan.

2. Using a decontaminated stainless steel scoop or trowel, remove and discard the thin layer of soil from the area that contacted the shovel.

3. Remove debris and coarse materials such as pebbles, rocks, and stones.

4. Collect the appropriate quantity of sample using a stainless steel spoon or scoop.

5. Transfer the sample into an appropriate sample container with a stainless steel lab spoon or equivalent. Refer to procedure FO.13, Containerization, Preserving, Handling and Shipping of Soil and Water Samples for the type of container.

6. Label the sample container with the appropriate sample information including date and time, the sampler's initials, the sample identification, and sample location. Record information on the field data collection form. Handle samples according to procedure FO.13, Containerization, Preserving, Handling and Shipping of Soil and Water Samples. This documentation is a QA record and must go into the ERM records center.

4.4 SOIL SAMPLING WITH THE VERTICAL SOIL PROFILE METHOD

4.4.1 Introduction

The purpose of vertical soil profile sampling is to define the distribution of radionuclides in the top 6 inches of soil to verify the results of the HPGe surveys. This step is accomplished by collecting discrete soil samples at 2-inch intervals corresponding to depths from: 0 to 2 inches, 2 to 4 inches, and 4 to 6 inches. Sampling intervals of two-inches is required to define the extent of radiological contamination within discrete layers of the surface soil to verify the results of the HPGe surveys. There are four procedures for obtaining these samples: 1) collection from the surface downward, 2) collection from the side wall of a small excavation, 3) collection by coring, and 4) collection from beneath concrete or asphalt pavement. Use of any of the following procedures will depend on site conditions at the time of sampling. The specific procedure chosen to meet site conditions will be documented on the surface soil data collection form and in the field supervisors log book.

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Sampling locations and the number of soil and quality assurance samples will be described in the FSP. Equipment, sample plot layout, sample procedures and site restoration is described in the following sections.

4.4.2 Equipment and Materials

The following is a list of equipment used for vertical soil profile sampling:

- Brunton compass;
- measuring tape or wheel;
- stainless steel scoop, spoon or trowel;
- tap water, or deionized, distilled water;
- wash and rinse tubs;
- phosphate free, lab-grade detergent (e.g. Liquinox)
- spray bottle or orchard sprayer;
- shovel;
- sledge hammer (optional)
- pick (optional);
- corer (optional);
- chalk marker;
- concrete saw (optional);
- wet-vac (optional);
- plastic sheeting;
- sample containers;
- sample labels;
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan;
- logbook; and
- cooler with ice or ice packs.

4.4.3 Sampling Plot Layout

The sample location will be determined from the results of the HPGe survey. Permission and clearance for collecting samples will need to be coordinated with the plant manager or landowner for the specific area. Utilities will be cleared before any intrusive work.

Each sample location will be located within ± 10 feet (as specified in procedure GT.17, Land Surveying) of the proposed work plan location by measuring its distance to a permanent landmark using a measuring wheel, or measuring tape, and a Brunton compass. The sample location will be sketched on a field map.

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Sample locations will be marked with a permanent identification, as designated in the FSP, so that the area may be located and resampled at a later date.

Photographs of the surrounding area and the soil will be at the discretion of the field crew supervisor. If a significant feature or something out of the ordinary is encountered that may effect sampling and should be documented; then a photograph will be taken. Photography shall be coordinated with the RFP photography department at least one week in advance of the sampling event.

A small area measuring about 24 by 24 to 36 by 36 inches will be selected for the sample location. The planned location may be offset by up to 3 feet, but should be placed as close to the original location as possible. If a large cobble is encountered below the ground surface, the soil sample may be collected from either side of the cobble. The presence of cobbles and where the sample was collected around the cobble will be documented in the data collection form and the field supervisors log book.

4.4.4 Procedures For Sampling From Surface Downward

1. Use a stainless scoop/trowel to collect a 500 gram sample from the surface, 0 to 2 inches, sample and place in a 500 mL sample container; include organic material and coarse sample material that is encountered during sampling. Collect sample uniformly in thickness. If necessary, the soil may be moistened with tap water (or deionized, distilled water, if the sample is to be split for inorganic metals analysis) using a spray bottle or orchard sprayer, to enhance sample collection by preventing fine soil particles from becoming airborne.

2. Collect the next sample from a depth interval of 2 to 4 inches below the first sample interval (0 to 2 inches) using the method in Step 1 above.

3. Collect the last sample from a depth interval of 4 to 6 inches below the second sample interval (2 to 4 inches) using the method in Step 1 above.

4. Backfill the sample location with any residual excavated material on the same day that the initial excavation and sampling is performed.

Either use another set of clean sampling equipment or decontaminate the sampling equipment between each step following procedure FO.3, General Equipment Decontamination.

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4.4.5 Procedure For Sidewall Sampling (use when large soil components prevent excavation from surface downward)

1. Dig a small excavation (maximum depth equal to 12 inches). Stockpile excavated material near excavation on plastic sheeting.

2. Scrape the upper few inches (0 to 3 inches) of soil from one side of the pit with a stainless steel scoop/trowel to expose a fresh surface and prevent cross-contamination. If necessary, the soil may be moistened with tap water, (or deionized, distilled water, if the sample is to be split for inorganic metals analysis) using a spray bottle, or orchard sprayer, to enhance sample collection by preventing fine soil particles from becoming airborne.

3. Use a stainless steel scoop/trowel to collect a 500 gram sample from the sidewall surface, 0 to 2 inches in the depth and place in a 500 mL sample container; include organic material and coarse sample material encountered during sampling. Collect a sample of uniform thickness and depth into the sidewall.

4. Scrape the next lower few inches (2 to 5 inches) of the pit sidewall below the first sample interval (0 to 2 inches) with a stainless steel scoop/trowel.

5. Collect the next sidewall sample from a depth of 2 to 4 inches below the first sample interval (0 to 2 inches), following Step 3 above.

6. Scrape the last lower few inches (4 to 7 inches) of the pit sidewall below the second sample (2 to 4 inches) with a stainless steel scoop/trowel.

7. Collect the last sidewall sample from a depth interval of 4 to 6 inches below the second sample (2 to 4 inches), using the method in Step 3 above.

8. Backfill the excavated material on the same day that the initial excavation and sampling is performed.

Either use another set of clean sampling equipment or decontaminate the sampling equipment between each step following procedure FO.3, General Equipment Decontamination.

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4.4.6 Procedures For Coring

1. Use a hand-powered, stainless steel "cookie cutter" type corer to collect a 500 gram sample from the top 0 to 2 inches and place in a 500 mL sample container; include organic material and coarse sample material encountered during sampling. Collect the sample uniformly from the surface to a 2-inch depth. If necessary, the soil may be moistened with deionized, distilled water using a spray bottle, or orchard sprayer, to enhance sample collection by preventing fine soil particles from becoming airborne.

2. Collect the next core sample from a depth interval of 2 to 4 inches below the first sample interval (0 to 2 inches), using the method in Step 1 above.

3. Collect the last core sample from, a depth interval of 4 to 6 inches immediately below the second sample interval (2 to 4 inches), using the methods in Step 1 above.

4. If the sample displays a tendency to fall out of the corer while extracting it, the sampling technician should attempt to cover the bottom of the corer with a stainless steel spoon as it is extracted from the soil so the depth specific sample will fall onto the spoon and can then be transferred to the sample container.

5. Backfill the sample location with any residual excavated material on the same day that the initial excavation and sampling is performed.

Either use another set of clean sampling equipment or decontaminate the sampling equipment between each step following procedure FO.3, General Equipment Decontamination.

4.4.7 Procedure For Sampling Under Asphalt and Concrete

1. Measure and mark a 24-by 24-inch or 36-by 36-inch area on the asphalt or concrete at the selected sample location using a chalk marker.

2. Cut on the line marked in chalk using a water-lubricated concrete saw; use precaution to avoid cutting into and disturbing the underlying soils. Cut all sides of the marked area.

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3. If the use of a wet-dry vacuum satisfies the applicable health and safety plan requirements for control of airborne contamination, collect excess water using a wet-vac, if needed, to prevent the migration of water that may be contaminated from contact with contaminated concrete or asphalt. Any water collected will be placed with the used decontamination water and disposed at the decontamination pad.

4. Use a sledge hammer, or a pick and shovel for asphalt, to carefully break the concrete/asphalt into large pieces. Take care to prevent crushing the concrete/asphalt into small pieces that would interfere with sampling the underlying soil. Remove the pieces of concrete/asphalt from the sample area.

5. Sample the underlying soil using any one of the methods outlined in Sections 4.4.4, 4.4.5, or 4.4.6.

6. Repair the asphalt or concrete by filling the core hole with asphalt patch or premix concrete, leveling it with the surrounding surface. A permanent identification marker will be placed so that the area may be located and resampled at a later date if necessary.

Either use another set of clean sampling equipment or decontaminate the sampling equipment between each step following procedure FO.3, General Equipment Decontamination.

Procedures for minimizing dust generation and personal protective equipment are described in the applicable Health and Safety Plan.

4.5 SURFACE SOIL SAMPLING BELOW ASPHALT OR CONCRETE

4.5.1 Introduction

The purpose of sampling surficial soil under asphalt or concrete is to determine if chemical contamination or radionuclides are present in the soils underlying these covers and determine their concentration, if present. This step is accomplished by removing a small amount of the asphalt or concrete overlying the surface soil at the designated sampling location, and then collecting a grab sample of the soil.

Sampling locations, the number of soil samples and quality assurance samples and any potential sampling problems will be described in each projects Field Sampling Plan. The following sections describe the sampling equipment,

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sample plot layout, and sampling procedure for collecting surface soil samples from below asphalt or concrete.

4.5.2 Equipment and Materials

The following is a list of equipment required for surface soil sampling below asphalt or concrete.

- field map;
- Brunton compass;
- measuring tape or wheel;
- steel posts (optional);
- identification signs (optional);
- landscaping nails (optional);
- surveyor's tape (optional);
- stainless steel scoop or trowel;
- steel lawn or garden spade;
- deionized, distilled, high purity water;
- wash and rinse tubs;
- plastic sheeting;
- phosphate free, lab grade detergent (e.g. Liquinox)
- spray bottle or orchard sprayer;
- shovel;
- pick;
- sledge hammer;
- concrete core drill (optional);
- chalk marker;
- wet-dry vacuum (optional);
- portable generator (optional);
- asphalt patch;
- sample containers and labels;
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan;
- logbook; and
- cooler with ice or ice packs.

4.5.3 Sampling Plot Layout

Surface soil sample locations are tentatively identified in the FSP for each OU. Permission and clearance for collecting samples will require coordination with the appropriate EG&G department or the landowner for a specific area. Additionally, a utility clearance will be conducted at each sampling location

before asphalt or concrete coring. Each sample location will be determined within ± 10 feet (as specified in procedure GT.17, Land Surveying) of the proposed work plan location by measuring its bearing and distance to a permanent landmark using a Brunton compass and a measuring wheel or tape. The sample location will be sketched on a field map. Sample locations will be marked with an identification sign, as designated in the FSP so that the area may be located and resampled at a later date.

Photographs of the surrounding area and condition of the soil will be at the discretion of the field crew supervisor. If a significant feature or something out of the ordinary is encountered that may effect sampling and should be documented; then a photograph will be taken. Photography will be coordinated with the RFP photography department at least one week before the sampling event.

The planned locations may require slight adjustments depending on site conditions at the time of sampling. If obstacles are encountered (such as large cobbles), locations will be offset as close as possible to the original location, up to a maximum of 3 feet. The presence of large cobbles and where the sample was collected around the cobble will be documented in the data collection form and the field supervisors logbook.

4.5.4 Sampling Procedure

1. Use a Brunton compass and tape measure to determine individual sampling locations and a sampling grid. Mark the identified locations with chalk.

2. Cut a small diameter (2 to 4 inches) core of the asphalt or concrete using a water-lubricated, power coring device. Use caution to avoid cutting into and disturbing the underlying soils.

3. If the use of a wet-dry vacuum satisfies the applicable health and safety plan requirements for control of airborne contamination, collect excess water using a wet-dry vacuum to prevent the migration of water that may be contaminated from contact with contaminated asphalt or concrete. Any water collected will be placed with the used decontamination water and disposed at the decontamination pad.

4. Remove the asphalt or concrete core from the sampling area taking care to prevent crushing the material into small pieces. The small pieces could interfere with sampling the underlying soil.

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5. Carefully remove any fill material from directly beneath the asphalt or concrete, which may be overlying the original soil surface, with a decontaminated steel lawn or garden spade.

6. Remove debris and coarse materials such as pebbles, rocks and stones.

7. Using a stainless steel scoop or spoon, transfer the desired sample quantity into an appropriate sample container. Refer to procedure FO.13, Containerization, Preserving, Handling and Shipping of Soil and Water Samples for the type of container.

8. Label the sample container with the appropriate sample information including date and time, the samplers initials, the sample identification and sample location. Record information on the field data collection form. Handle samples according to procedure FO.13, Containerization, Preserving, Handling and Shipping of Soil and Water Samples. This documentation is a QA record and must go into the ERM records center.

9. Either use a clean set of sampling equipment or decontaminate sampling equipment after use and between sample locations, following procedure FO.3, General Equipment Decontamination.

10. Repair the asphalt or concrete by filling the core hole with asphalt patch or premix concrete, leveling it with the surrounding surface. A permanent identification marker will be placed so that the area may be located and resampled at a later date if necessary.

    Duplicate samples will be obtained by moving from the primary sample location 6 inches to 2 feet upwind or in a direction technically more appropriate and repeating the sampling procedure. The location of the duplicate will be documented on the data collection form. The Field Sampling Plan specific to each project will detail the number of duplicate samples required.

4.6 ASPHALT OR CONCRETE SAMPLING FOR RADIONUCLIDES

4.6.1 Introduction

The purpose of sampling asphalt or concrete is to determine if radionuclides are present within and/or adhering to these cover materials and determine their concentration, if present. This is accomplished by removing a small amount of

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the asphalt or concrete at the designated sampling location, containerizing the sample, and submitting it for analysis.

Sampling locations and the number of asphalt or concrete samples and quality assurance samples will be described in the specific Field Sampling Plan for each project. Equipment, sample plot layout, and sampling procedures for collecting asphalt and concrete samples, procedures for sample handling, and sample site restoration is described in the following sections.

4.6.2 Equipment and Materials

The following is a list of equipment required for asphalt or concrete sampling.

- field map;
- Brunton compass;
- measuring tape or wheel;
- steel posts (optional);
- identification signs (optional);
- landscaping nails (optional);
- surveyor's tape (optional);
- stainless steel trowel;
- stainless steel bowl;
- stainless steel hand auger (optional);
- deionized, distilled, high-purity water;
- wash and rinse tubs;
- phosphate free, lab-grade detergent (e.g. Liquinox);
- plastic sheeting;
- spray bottle or orchard sprayer;
- hammer;
- chisel;
- shovel;
- pick;
- concrete saw (optional);
- concrete core drill (optional);
- chalk marker;
- wet-dry vacuum (optional);
- portable generator (optional);
- large ziplock bags;
- aluminum foil;
- asphalt patch;
- plastic wrap;

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- 1-gallon paint cans;
- sample labels;
- cooler with ice or ice packs;
- logbook; and
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan.

4.6.3 Sampling Plot Layout

Asphalt or concrete sample locations are tentatively identified in the Field Sampling Plan for each project. Permission and clearance for collecting samples will need to be coordinated with the appropriate EG&G department or the landowner for the specific area. Additionally, a utility clearance will be conducted at each sampling location before asphalt or concrete coring or cutting. Each sample location will be located within ± 10 feet (as specified in procedure GT.17, Land Surveying) of the proposed work plan location by measuring its bearing and distance to a permanent landmark using a Brunton compass and a measuring wheel or measuring tape. The sample location will be sketched on a field map. Upon completion of sampling at each location, the location will be marked with an identification sign, as designated in the FSP, so that the area may be located and resampled at a later date if necessary.

Photographs of the surrounding area and the condition of the asphalt or concrete will be at the discretion of the field crew supervisor. If a significant feature or something out of the ordinary is encountered that may effect sampling and should be documented; then a photograph will be taken. Photography shall be coordinated with the RFP photography department at least one week in advance of the sampling event.

The planned locations may require slight adjustments depending on site conditions at the time of sampling. If obstacles are encountered (such as large cobbles), locations will be offset as close as possible to the original location, up to a maximum of 3 feet. The presence of large cobbles and where the sample was collected around the cobble will be documented in the data collection form ad the field supervisors logbook.

4.6.4 Procedures For Asphalt or Concrete Coring or Cutting

1. Use a Brunton compass and tape measure to locate individual sampling locations and/or sampling grid. Mark the identified locations with chalk.

2. For core sampling (Section 4.6.5), cut a small diameter core (2 to 4 inches) completely through the asphalt or concrete using a water lubricated, power coring device.

3. For sampling the top and bottom one-fifth of the asphalt or concrete cover material (Section 4.6.6), multiple concrete cores will need to be cut in order to obtain sufficient sample quantity. Mark the selected sample location. Cut asphalt or concrete cores (as described in Step 2) from immediately surrounding the sample location, cutting the subsequent cores adjacent to and as close as possible to the previous core cut.

4. If the use of a wet-dry vacuum satisfies the applicable health and safety plan requirements for control of airborne contamination, collect excess water using a wet-dry vacuum, if needed, to preclude the migration of water that may be contaminated from contact with contaminated asphalt or concrete. Any water collected will be placed with the used decontamination water and disposed at the decontamination pad.

5. Sample the multiple asphalt or concrete cores as detailed in Section 4.6.6.

4.6.5 Procedures For Sampling Asphalt or Concrete Core

1. Label a large ziplock bag with the project identification number, OU number, sample site identification number, sample collection date and time, and name of sample collector.

2. Remove the asphalt or concrete core from the cut. Clearly mark the core to indicate the top surface. First wrap the core in aluminum foil. Next, wrap the aluminum covered core in plastic wrap. Insert the wrapped core into the labeled ziplock bag.

3. Complete necessary paperwork (chain-of-custody, etc.) and transfer the sample to the sample manager. This documentation is a QA record and must go into the ERM records center.

4. Repair the asphalt or concrete by filling the core hole with asphalt patch or premix concrete to the same height as the surrounding surface. A permanent identification marker will be placed so that the area may be located and resampled at a later date if necessary.

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5. Either use another set of clean sampling equipment or decontaminate all sampling equipment after use and between sample locations using procedures detailed in procedure FO.3, General Equipment Decontamination.

4.6.6 Sampling the Top and Bottom One-Fifth of Asphalt or Concrete

1. Label a clean, 1-gallon paint can with the sample site identification, sample collection date, and name of sample collector.

2. Remove one of the asphalt or concrete cores that were cut, (as detailed in Section 4.6.4, Step 3) from the core drill.

3. Measure and mark the top one-fifth and bottom one-fifth of the total thickness of the asphalt or concrete core.

4. Using a hammer and chisel, chip away the top one-fifth of the core sample, trying to chip as large of pieces as possible. Collect this top one-fifth of the core material in a 1-gallon paint can until 1- to 1.5-kg of sample is obtained.

5. Repeat Step 4 on the bottom one-fifth of the core sample and collect material in a separate 1-gallon paint can.

6. Repeat Step 2 through 5 until the desired sample quantity (see Step 4) is obtained.

7. Repair the asphalt or concrete as per Section 4.6.5, Step 4.

Duplicate samples will be obtained by offsetting from the primary sample location 6 inches to 2 feet upwind or in a direction technically more appropriate and repeating Section 4.6.4, and either Section 4.6.5, or 4.6.6 procedures. The location of the duplicate will be documented on a data collection form.

4.7 COMPOSITING OF SOIL SAMPLES

Compositing of samples will be required for some tasks. This will be done by emptying the sample container(s) into a large stainless steel pan and stirring by using a stainless steel scoop or spoon to thoroughly mix the sample(s). The soil will be scraped from the sides, corners, and bottom of the pan, rolled to the center of the pan, and mixed. The sample will then need to be quartered and

moved to the four corners of the mixing pan. Each quarter of the sample will then be mixed individually. Each quarter will then be rolled to the center of the mixing pan and the entire sample mixed together again. This procedure will be repeated as necessary to provide a homogenous sample before being placed in the sample container(s).

5.0 METHODS FOR NONRADIONUCLIDE SURFACE SOIL SAMPLING

Soil sampling for nonradionuclide samples will be done with either a stainless steel scoop or spoon. For depth-specific sampling, a manual operated stainless steel hand auger may be used. Methods for asphalt and concrete removal are described for sampling beneath these barriers. Methods for wipe and destructive samples for polychlorinated biphenyls (PCBs) are also described in this section. The primary consideration for acquiring samples in the field include the following:

- Sample handling should be minimized.
- Sample/air contact should be minimized.
- The sample will be placed in an air-tight container immediately after collection.
- Depth-specific samples acquired with a hand auger will be labeled and marked with the appropriate depth.

The sample type, basis for collection and required methodology can be determined by consulting the applicable work plan.

For further information on sample handling, refer to procedure FO.13, Containerization, Preserving, Handling, and Shipping Soil and Water Samples, and the site-specific FSP.

5.1 GRAB SAMPLING (SPADE AND SCOOP)

Surface soil samples can be collected for nonradionuclide analyses using grab sampling (spade and scoop) methods.

Except for the analytical methods, the procedure for nonradionuclide grab sampling (spade and scoop) is identical to the radionuclide procedure. Therefore, refer to Section 4.3 for the complete procedure.

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5.2 SAMPLING WITH A HAND AUGER

5.2.1 Introduction

A hand auger will be used to collect depth-specific surface soil samples up to a total depth of 1-meter below ground surface. Sampling locations and the number of soil samples will be described in the specific Field Sampling Plan for each project. Equipment, sample plot layout, sampling procedures, and sample handling are described in the following sections.

5.2.2 Equipment and Materials

The following is a list of equipment for nonradionuclide contaminated soil sampling:

- spade (long handle);
- stainless steel hand auger;
- mason trowel;
- stainless steel scoop;
- stainless steel lab spoon;
- sample labels;
- sample containers;
- wash/rinse tubs;
- phosphate-free, laboratory-grade detergent (e.g., Liquinox);
- distilled water;
- plastic sheeting;
- locations (map and/or list);
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan;
- photoionization detector (PID) or flame ionization detector (FID);
- logbook;
- measuring tape or wheel;
- Brunton compass;
- ice chest with ice or ice packs; and
- shovel.

5.2.3 Sampling Plot Layout

Sample locations are described in the Field Sampling Plan for each project. Permission and clearance for collecting samples will need to be coordinated

with the appropriate EG&G department or the landowner for the specific area. Utilities will be cleared before any intrusive work.

Each sample location will be located within ± 10 feet (as specified in procedure GT.17, Land Surveying) of the proposed work plan location by measuring its distance to a permanent landmark using a measuring wheel, or measuring tape, and a Brunton compass. The sample location will be sketched on a field map. Sample locations will be marked with an identification sign, as designated in the FSP, so that the area may be located and resampled at a later date.

After all of the samples are collected within a sample plot; the southwest corner of the sample plot will be surveyed using standard surveying methods or global positioning system (GPS) methodologies. Refer to procedure GT.17, Land Surveying, or GT.27, GT.28, and GT.29 for GPS, for methods and acceptable uncertainty and range for the distance measurements made.

Photographs of the surrounding area and the soil will be at the discretion of the field crew supervisor. If a significant feature or something out of the ordinary is encountered that may effect sampling and should be documented; then a photograph will be taken. Photography shall be coordinated with the RFP photography department at least one week in advance of the sampling event.

5.2.4 Procedures

The following procedures will apply for subsurface soil sampling with a stainless steel hand auger.

1. Carefully remove vegetation and any undesirable surfical material or fill material to the desired sample depth point with a decontaminated steel lawn or garden spade.

2. Using a decontaminated stainless steel scoop or trowel, remove and discard the thin layer of soil from the area that contacted the shovel.

3. At each sample location, a borehole will be advanced with a decontaminated 2 3/4-inch outside diameter stainless steel hand auger to the initial target depth interval as specified in the FSP. Most boreholes will have three target depth intervals at 10 to 14 inches, 22 to 26 inches, and 34 to 38 inches. Surficial soils will be defined as those between the ground surface and 1-meter in depth.

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4. The auger will be withdrawn from the boring and the sample will be transferred to a decontaminated stainless steel pan where it will be thoroughly mixed with a stainless steel spoon. The sample will then be transferred to a precleaned, wide-mouth 8-ounce jar, labeled, and placed in a cooler.

5. The crew will then use a hand auger to reach the next target depth. The sampling process will be repeated.

6. Decontaminate all sampling equipment between sampling depths following procedure FO.3, General Equipment Decontamination.

7. Label the sample container with the appropriate sample information including date and time, the sampler's initials, the sample identification number, sample location, and depth interval. Record the information on the field data collection form. Handle samples in accordance with procedure FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples. The documentation is a QA record and must go into the ERM records center.

5.3 SAMPLING BELOW ASPHALT OR CONCRETE

Except for the analytical methods, the procedure for nonradionuclide surface-soil sampling below asphalt or concrete is identical to the radionuclide procedure. Therefore, refer to Section 4.5 for the complete procedure.

5.4 WIPE AND PAVEMENT SAMPLING FOR POLYCHLORINATED BIPHENYLS

5.4.1 Introduction

Sampling of nonporous (sealed concrete, tile, stainless steel surfaces, etc.) and porous surfaces (concrete and asphalt) is required to determine if surface areas have been contaminated with PCB-contaminated oils. The following sections describe methods for the collection of grab samples from nonporous hard surfaces (wipe samples), and porous surfaces such as concrete, wood, and asphalt (destructive samples) for PCB analysis.

Specific sampling locations and number of soil and quality assurance samples will be described in the FSP section of the work plan for each operable unit.

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5.4.2 Equipment and Materials

The following is a list of equipment required for sampling:

- Whatman 40 ashless filter paper or Whatman 50 smear tabs or precleaned 3 by 3 inch gauze pads;
- steel forceps;
- rubber gloves;
- 100 cm^2 template;
- solvent (isooctane from the laboratory) to wet sample filer or gauze;
- hammer;
- chisel;
- pick;
- drill (optional);
- logbook; and
- appropriate health and safety equipment as specified in the applicable Health and Safety Plan.

5.4.3 Sampling Plot Layout

The sampling plot layout and location will be described in the Field Sampling Plan for each project. Care will be taken to select as smooth a surface as possible to ensure that a representative sample is collected. The sample area will correspond to a 100 cm2 area marked by a template.

Permission and clearance for collecting samples will be coordinated with the appropriate EG&G department or the landowner for the specific area.

Each sample location will be located within ± 10 feet (as specified in procedure GT.17, Land Surveying) of the proposed work plan location by measuring its distance to a permanent landmark using a measuring wheel, or measuring tape, and a Brunton compass. The sample location will be sketched on a field map. Sample locations will be marked with a permanent identification sign so that the area may be located and resampled at a later date.

Photography of the surrounding area and the sample location will be at the discretion of the field crew supervisor. If a significant feature or something out of the ordinary is encountered that may effect sampling and should be documented; then a photograph will be taken. Photography shall be coordinated with the RFP photography department at least one week in advance of the sampling event.

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5.4.4 Collection Procedures for Wipe Sampling

1. Place the 100 cm^2 template over the sample location to outline the area to be wipe sampled.

2. Apply the laboratory solvent (isooctane) to the Whatman filter paper or sterile gauze pad so that the paper or pad is evenly moistened.

3. Wipe the surface of the area inside the template thoroughly with the moistened Whatman filter paper or precleaned gauze pad using rubber gloves or steel forceps to hold the filter paper/gauze pad.

4. Place the filter paper/gauze pad into the appropriately marked sample jar as described in the FSP.

5. Label the sample container with the appropriate sample information including date and time, the sampler's initials, the sample identification number, and sample location.

6. Record information on the field data collection form. Handle samples according to procedure FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples. This documentation is a QA record and must go into the ERM records center.

7. Collect a duplicate sample, in accordance with the FSP, by moving to a location 6 inches to 2 feet upwind or in a direction technically more appropriate and placing the duplicate sample in a separate jar. The location of the duplicate will be documented on a data collection form. Decontaminate all sampling equipment using the procedures described in Step 6 and Section 6.0 before collecting the duplicate sample.

8. Either use another set of clean sampling equipment or decontaminate all sampling equipment thoroughly using the procedures described in Section 6.0. A final rinse of all sampling equipment shall be conducted using the laboratory-provided solvent.

5.4.5 Procedures for Destructive Sampling of Concrete

Because porous surfaces will absorb PCBs, wipe sampling will not be used to sample these surfaces. Instead, a discrete sample will be chiseled, drilled, or sawed from the surface to remove sufficient sample for analysis. The following procedures will be used for destructive sampling:

1. Use a chisel, pick, or drill, to remove a surface sample measuring 1 cm deep.

2. Collect enough sample to fill an 8-ounce precleaned jar that is appropriately labeled as described in the FSP.

3. Label the sample container with the appropriate sample information including date and time, the sampler's initials, the sample identification, and sample location.

4. Record information on the field data collection form. Handle samples according to procedure FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples. This documentation is a QA record and must go into the ERM records center.

5. Collect a duplicate sample, in accordance with the FSP, by moving to a location 6 inches to 2 feet upwind or in a direction technically more appropriate and placing the duplicate sample in a separate jar. The location of the duplicate will be documented on a data collection form.

6. Either use another set of clean sampling equipment or decontaminate all sampling equipment thoroughly following procedure FO.3, General Equipment Decontamination.

7. Repair the asphalt or concrete by filling the core hole with asphalt patch or premix concrete to the same height as the surrounding surface. A permanent identification marker will be placed so that the area may be located and resampled at a later date if necessary.

Due to the difficulties in collecting a destructive sample from a concrete roof, swipe samples will be used to sample PCBs in these locations.

Procedures for personal protective equipment and general health and safety are described in the applicable Health and Safety Plan.

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6.0 RECORDS

All records for field investigations are subject to requirements set forth in RFP Sitewide QAPjP. All of the forms described in this section and any additional records as defined in the QAPjP 17, Section 2 need to be turned over to the project manager within 10 days of completion. The project manager is responsible for transmittal of the completed records within 30 days of completion as specified in 3-21000-ADM-17.01.

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~~Form GT.8A, Surface Soil Data Collection form~~ Form FO.14C (Rev.09/16/93), Surficial Soil Sample Form (see page 40 of this procedure), will be completed for each sample location and for composite samples with the northwest corner of the composite area for the X, Y location. The information needed includes sample number, date, time, location code, purpose, sample location, composite information, collection method, sampling team members, volume collected, headspace reading, if applicable, and Chain of Custody (COC) number. ~~Form GT.8B~~ Form GT.08A (Rev.3), Surface Soil Sampling Field Activities Report, will be used for collection of samples for compositing. The form should include project identification, date, sampler, location, grid description and time.

Chain-of-custody procedures for all sampling is detailed in procedure FO.13, Containerization, Preserving, Handling and Shipping of Soil and Water Samples.

All photographs will be numbered, dated, labeled with the project number, site and sample location number; and kept in the project files.

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7.0 REFERENCES

The following is a list of references reviewed before writing this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Colorado Department of Health Radiation Counting Facility Operating Procedure. Version 1.0 "Soil Sample Collection-Surface." July 1989.

Field Manual For Grid Sampling of PCB Spill Sites to Verify Cleanup. EPA/560/5-86-017. May 1986.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

PCB Spill Cleanup Policy. 40 Code of Federal Regulation, Part 761, Subpart G.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

Rockwell International Rocky Flats Plant Environmental Restoration Program, Quality Control Plan. January 1989.

SOP FO.3, General Equipment Decontamination;

SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water samples;

SOP FO.16, Field Radiological Measurements;

SOP GT.1 Logging Alluvial and Bedrock Material;

SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques; and

SOP GT.7, Logging of Test Pits and Trenches.

The Environmental Survey Manual. DOE/EH-0053. Volumes 1-4. August 1987.

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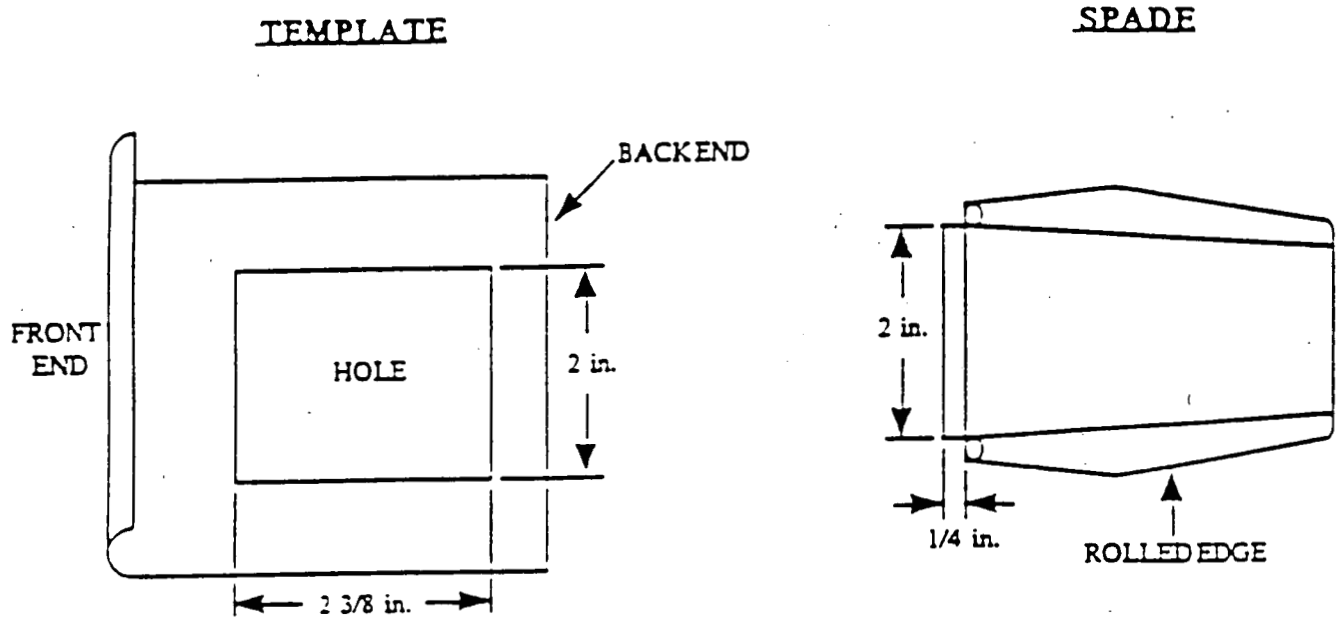
Figure GT.8-1 CDH Soil Sampling Device Critical Dimensions



NOT TO SCALE

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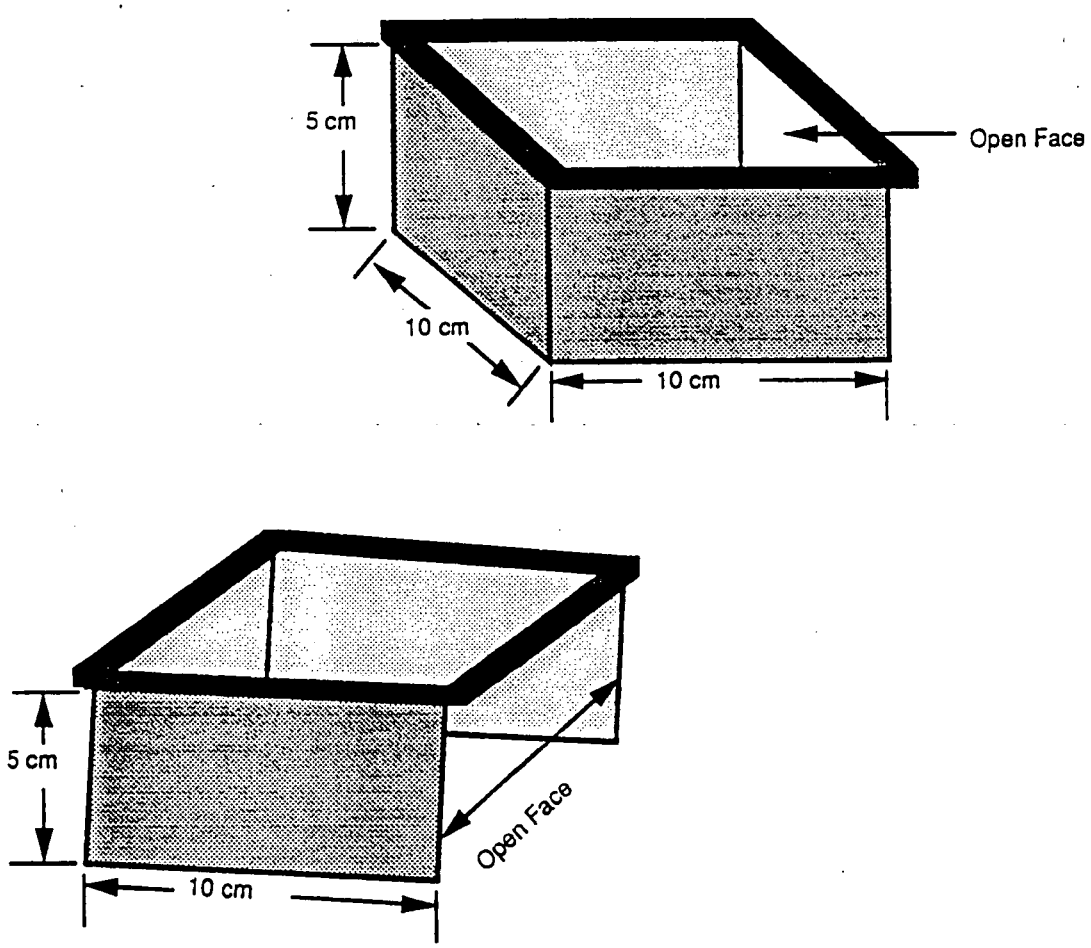
Figure GT.8-2 RF Soil Sampling Device Critical Dimensions



NOT TO SCALE

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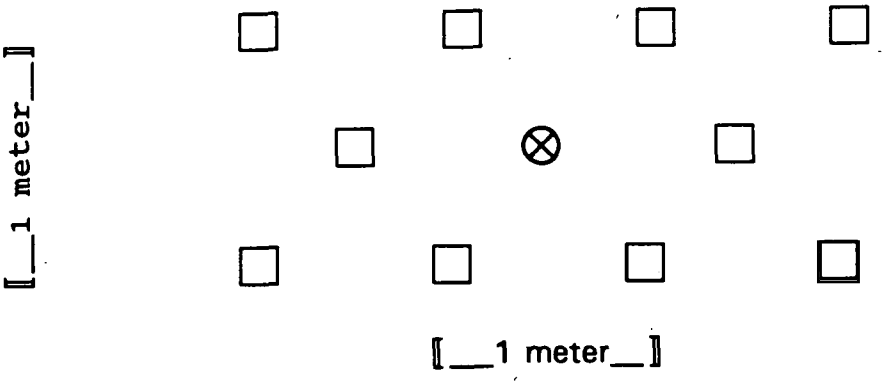
Figure GT.8-3 RF Method Soil Sampling Location Spacing



⊗ - Sample Location

□ - Subsample Location

U.S DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM FO.14C
SURFICIAL SOIL SAMPLE FORM Revision 16 SEP 93

Sample Collection Form

Project Number: Type: SS
Sample Number:
Contractor:
Station Code:

Collection Date: Quarter: Disposition:
Colection Time: Purpose:
Sample Location:
Composite: (Y/N)
Composite Desc:
QC Type: Partner:
Collection Method:

Sample Team Leader:
Member:
Member:
Volume Collected: Units:
Prepared By:

Surface Soil Sample Form

Depth of Take	Start	End
	in	
	in	
	in	
	in	

Headspace Reading
Comments

Sample Crew Member: _____
Print Name

_____
Signature Date

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SURFACE SOIL SAMPLING FIELD ACTIVITIES REPORT

Project Name	
Site Identification	**Date**
Sampler	

SAMPLE POINT	GRID LOCATION	TIME	COMMENTS

COMPLETED BY:		
PRINT NAME	SIGNATURE	DATE
SUBCONTRACTOR:		

94-DMR-000229

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DOCUMENT MODIFICATION REQUEST (DMR)

INFORMATION ONLY

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

Date	25.
March 18, 1994	DMR. No. 94-DMR-000431

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.09/Rev2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
M.G.Sell/8693/D5934/080	Soil Gas Sampling and Field Analysis

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
			Add the following sentence after the first sentence of each of the identified sections: continuing calibration verification shall be perform
1	8	5.1.2	Calibration of instruments involved in soil gas analysis shall occur at the beginning of each working day and, after that, every eight hours or after 20 samples, whichever is more frequent. a batch of continuing calibration verification shall be performed,
	10	5.2.2	Calibration of instruments involved in soil gas analysis shall occur at the beginning of each working day and, after that, every eight hours or after 20 samples, whichever is more frequent. a batch of continuing calibration verification shall be performed
	26	6.1	Calibration of instruments involved in soil gas analysis shall occur at the beginning of each working day and, after that, every eight hours or after 20 samples, whichever is more frequent. a batch of
2	26	6.1	Add the following sentence to the end of the paragraph in section 6.1. Soil gas analysis should address an adequate level of precision. Soil gas precision values for analysis of duplicate samples can exceed a relative percent difference of 40 percent. Relative percent difference values for duplicate samples will be within the 40% range unless stated otherwise in the project specific work plan.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. According to EPA Method 502.2, "Volatile Organic Compounds in Water by Purge and Trap Capillary Column Gas Chromatography with Photoionization and Electrolytic Conductivity Detectors in Series", a working calibration curve or calibration factor must be verified each working day by the measurement of one or more calibration standards. Standard Operating Procedure FO-15, "Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs), Rev 2", also requires calibration at the end of each day. PIDs and FIDs must also be checked "periodically" during operation to ensure response to contaminants. EPA Method 502.2 requires analysis of a laboratory fortified blank with each batch of samples or one laboratory fortified blank for every 20 samples if a batch includes more than 20 samples. This DMR is intended to clarify when calibration must occur.

2. Soil gas duplicate samples results may exceed the precision range of 40%. A statement or statements are needed to clarify this issue of precision criteria for soil gas duplicate samples, because of the wide variability inherent within the particular sampling approach and analytical method being employed.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	R.G. Smith	3/22/94
EQS	Mark Brooks (RR)	3-24-94
RPM	Wanda Busby	3/22/94
EOM	Marla Broussard	3/24/94
SM	D.D. Stagg	3/23/94
SPP	S.R. Keith	3/29/94

16. Originator's Supervisor (print/sign/date)
R.S. Luker 3.18.94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
R.G. Smith/8705/5135/080-643	0202	ENV-GT	03/23/94	04/11/94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
ORC Review not required; this nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print, sign, date)
Stephen H. Singer 3/29/94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA
DOCUMENT CLASSIFICATION REVIEW WAIVED
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

93D00731.001

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DOCUMENT MODIFICATION REQUEST (DMR)

INFORMATION ONLY

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

1. Date	25.
7/19/94	DMR. No. 94-DMR- 001521 Date 8/23/94

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
21000-OPS GT.9, Rev. 2	N/A
4. Originator's Name/Phone/Page/Location G. Anderson/8504/4013/080	5. Document Title Soil Gas Sampling and Field Analysis

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☐ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	14	5.3.1	Add the following sentence to the end of the identified section: For the soil gas surveys in OUs 8, 10, 12, 13, and 14, the procedures for sampling of soil gas and on-site volatile organic compounds analysis by the modified EPA Method 524.2 is presented in Appendix GT.9B as a reference.
2	18	5.3.1.3	Add the following sentence to the end of the last paragraph of the identified section: For the soil gas surveys in OUs 8, 10, 12, 13, and 14, the procedures for sampling of soil gas and on-site volatile organic compounds analysis by the modified EPA Method 524.2 is presented in Appendix GT.9B as a reference.
3	~~A-2~~ B-1	Appendix Cover	Add the following two SOPs to GT.9, Rev. 2 as Appendix GT.9B: 1) Walsh Standard Operating Procedures For Obtaining Soil Gas And Soil Samples, 2) Volatile Organic Compound Analysis Of Air And Soil Gas Samples By Thermal Desorption And Gas Chromatography/Mass Spectrometry.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

Clarification of soil gas procedures for Industrial Area Operable Unit work

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
EOM	Marla Broussard	8/23/94
~~IA/OU~~	~~Bruce Peterson~~	
EQS	Charlie Hayes	8/10/94
QAPM	R J LUKER	8.23.94

16. Originator's Supervisor (print/sign/date)
BRUCE D. Peterson 8/23/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
GREGG A. ANDERSON 8/10/94	0243	989252		9/2/94

22. Accelerated Review?	23. ORC Review
Yes ~~No~~	NOT REQUIRED

24. Responsible Manager (print, sign, date)
GREGG A. ANDERSON 8/8/94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER D.B. HOFFMAN, CLASSIFICATION OFFICER
JUNE 11, 1991

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INFORMATION ONLY

SOIL GAS SAMPLING AND FIELD ANALYSIS

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.9, Rev. 2
	Page:	1 of 27
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
SOIL GAS SAMPLING AND
FIELD ANALYSIS

Approved By:
(Name of Approver) 5/12/92 (Date)

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REVIEWED FOR CLASSIFICATION/UI
By
Date May 15, 1992

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94-DMR-001521

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18	09/02/94	94-DMR-001521
26	04/11/94	94-DMR-000431
B-2	09/02/94	94-DMR-001521

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TOTAL NUMBER OF PAGES: 47

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to conduct soil gas field surveys or headspace measurements of organic vapors in environmental samples. It also provides procedures for dynamic and passive collection of soil gas samples to be used in identifying volatile organic compounds (VOC) present at Individual Hazardous Substance Sites (IHSS) on the RFP site. The requirements for application of these procedures to a given site will be specified in applicable project plans.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel performing VOC field surveys and/or monitoring with flame ionization detector (FID) or photoionization detector (PID) portable vapor meters, and/or collecting soil gas samples will be scientists, engineers, or field technicians with appropriate field experience and training provided under the supervision of another qualified person.

Only qualified personnel will be allowed to operate portable gas chromatographs (GCs) or vehicle-mounted GCs in mobile laboratories. Required qualifications vary depending on the activity to be performed. In general, qualifications will be based on education, previous experience, on-the-job training, and supervision by qualified personnel. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

Rockwell International. Rocky Flats Plant Environmental Restoration Program, Quality Control Plan. January 1989.

Schuring, D.G. "Soil Gas Testing." HAZMAT World. August 1989. pp 36-39.

The Environmental Survey Manual. DOE/EH-0053. Volumes 1-4. August 1987.

Barsky, J.B., S.S., Que Hee and C.S. Clark. American Industrial Hygiene Association Journal. (46). 1985. p. 9.

Callendar, A.B. and A. Bohrnerud. Proceedings of the Woodward-Clyde Consultants Professional Development Central Symposium. St. Louis, Missouri. 1986.

Hutzler, N.J., L.T. Londo and T.C. Crittenden. Proceedings of the ASCE Conference, Minneapolis, Minnesota. American Association of Civil Engineers. 1982. p. 720.

Jury, W.A., W.F. Spencer and W.J. Farmer. Journal of Environmental Quality (12). p. 558, 1983.

Kerfoot, H.B. and C.L. Mayer. Ground Water Monitoring Review (6). p. 74. 1986.

MacKay, D. and W.Y. Shiu. Journal of Physical Chemistry Reference Data (10). p.1175. 1981.

Marrin, D.L.. Proceedings of the 1985 Hazardous Materials Management Conference West. Long Beach, California. p. 112. Tower Conference Management Company. 1985.

Marrin, D.L. and H.B. Kerfoot. Environmental Science & Technology (21). In press. 1987.

Marrin, D.L. and G.M. Thompson. Journal of Ground Water (25). p. 21. 1987.

Spittler, T.M., L. Fitch and S. Clifford. Proceedings of the Symposium on Characterization and Monitoring of the Vadose Zone. Las Vegas, Nevada. p. 134. National Water Well Association. 1983.

Swallow, J.A. and P.M. Gschwend. Proceedings of the 3rd National Symposium on Aquifer Restoration and Groundwater Monitoring. Columbus, Ohio. p. 327. National Water Well Association. 1983.

Thompson, G.M. and D.L. Marrin. Ground Water Monitoring Review (7). 88, 1987.

Vorhees, K.J., J.C. Hickey and R.W. Klusman. Analytical Chemistry (56). 1984. p. 2604.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil Water Samples
- SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)

5.0 PROCEDURES AND EQUIPMENT

The concentration of a Volatile Organic Compound (VOC) in soil gas is a complex function of the distribution of the organic compound and its interaction with the soil. This interaction depends on a number of soil parameters including soil particle size and mineralogy, soil lithology, heterogeneity, organic content, moisture, and temperature.

Volatile organic contaminants in soils above the water table (vadose zone) can be present in the gas phase in unsaturated pore spaces, in the water contained in the unsaturated soils, and sorbed on the soil particles. The VOC contamination is the sum of the VOCs contained in all three phases. The partitioning of the VOC between gas, liquid, and adsorbed phases is dependent on both the soil properties and the chemical properties of the compound. Thus, given the chemical properties of the VOC and measurements, or reasonable estimates, of relevant soil parameters, soil-gas data can be used to provide semiquantitative estimates of the VOC contamination in soils.

The sampling and analysis of soil gas can be used as a rapid field screening technique for health and safety evaluations of potentially contaminated soils, to aid in the placement of monitoring wells,

to identify VOCs, to evaluate the areal extent of soil contamination, and to estimate the effectiveness of remedial measures.

The sampling and analysis of soil gas can be performed by several different methods. A field survey of work sites and materials can be performed using a portable organic vapor meter. The field survey provides information on total organic vapor concentrations in the air around the work site. A more detailed analysis on the location of VOC contaminated soil may be accomplished by performing field measurements of soil headspace samples. This technique allows the measurement of the total organic vapor concentration from a specific soil sample. Soil gas samples may also be obtained by pumping directly from a probe inserted in the ground, collecting the gas, and analyzing it. This technique of in situ soil gas sampling allows for the identification and quantification of specific volatile organic compounds.

This procedure will discuss the methods used for the following types of soil gas surveys:

- Field surveys
- Field measurements of headspace samples
- In situ soil gas sampling
    - Dynamic
    - Passive

5.1 FIELD SURVEYS

Field surveys of work sites, site activities, and site materials for volatile organic vapors will be accomplished by using direct reading instruments, such as the photoionization detector (PID) portable vapor meter and the flame ionization detector (FID) portable vapor meter. Field surveys will be used as rapid field screening techniques for health and safety, and for site evaluation before and during the excavation of potentially contaminated soil. These procedures may be used to aid

in the placement of monitoring wells, and in the evaluation of the areal extent of soil contamination.

5.1.1 Equipment

- Portable PID or FID
- Calibration gas standards of known concentration as specified in SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)

5.1.2 Instrument Calibration and Operation

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See SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs), for instrument operational and calibration requirements. Calibration of instruments involved in soil gas analysis shall occur at the beginning of each working day and, after that, continuing calibration verification shall be performed every eight hours or after a batch of 20 samples, whichever is more frequent.

A factor which will affect total organic vapor concentration measurements is the type of detector which is used (e.g., FID vs. PID). Generally, the FID will be most appropriate for aliphatic hydrocarbons and certain oxygenated solvents while the PID will be more sensitive to aromatic and halogenated hydrocarbons. PID lamps of different ionization energies will respond with varying degrees of sensitivity to the same gases, and are significantly affected by high humidity. Generally, the FID response is proportional to the number of carbon-hydrogen bonds, and can, therefore, be used to estimate concentrations of total hydrocarbons.

5.1.3 Survey Procedures

The following procedures will be used to measure compounds detectable by PIDs and/or FIDs in performing field surveys:

1. Check the battery charge. Batteries should be recharged for the time frame specified in the operating manuals for both the PID and FID instruments. Usual length of operating time between charges is 8 to 12 hours.

2. FID fuel and/or combustion air-supply gauges should be monitored to ensure sufficient gas supplies.

3. Hold instrument probe close to the area to be sampled. The low flow sampling rate of the instrument provides only localized readings. Use a slow, sweeping motion to prevent the bypassing of variable concentration areas, and to allow for instrument response lag time.

4. Record observations, PID and/or FID measurements, source location, and description, date, time, weather, sample ID, operator, and other pertinent information in the field book. Perform routine maintenance, as described in detail in the operating manual. Clean the sample probe and/or in-line filters (in front of detector) when high background readings are exhibited after prolonged use. Use of pipe cleaners or clean air blown backward through filters is normally adequate. Do not use organic solvents.

5.2 FIELD MEASUREMENTS OF HEADSPACE SAMPLES

The field analysis of soils for organic vapors can be enhanced by obtaining a sample of contaminated soil, placing the soil sample in a confined space, and allowing volatization of organic compounds, followed by collection of a sample of the air space above the soil sample. This is referred to as headspace analysis, and is accomplished by half-filling a sample container with a soil sample to be analyzed. VOCs present in the soil pores will diffuse into the remaining unfilled air space within the container at approximately the same concentration as in the soil sample. Physical

characteristics of the soil (e.g., temperature, grain size, moisture content, organic carbon content) may have a significant effect on the headspace analysis results, and, therefore, estimates of these parameters should be recorded at the time the measurement is taken. If a PID or FID is used for the headspace analysis, record the results on the appropriate forms, Form GT.9A or GT.9B.

Headspace analyses are useful in that they can provide real-time data to aid in soil removal operations, where decisions regarding the extent of soil excavation and its disposal must be determined on-site. In addition, headspace analyses of soils encountered during investigations can be screened for health and safety purposes.

5.2.1 Equipment

- Portable PID or FID
- Calibration gas standards of known concentration as specified in SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)
- Split-spoon sampler, hand auger, or other soil sampling apparatus
- Wide-mouth sample jars with screw-cap lids
- Aluminum foil

5.2.2 Instrument Calibration and Operation

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See SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs), for instrument operational and calibration requirements. Calibration of instruments involved in soil gas analysis shall occur at the beginning of each working day and, after that, continuing calibration verification shall be performed every eight hours or after a batch of 20 samples, whichever is more frequent.

A factor which will affect total organic vapor concentration measurements is the type of detector which is used (e.g., FID vs. PID); see Subsection 5.1.2 for discussion.

5.2.3 Sampling Procedure

The following procedure will be used to measure those compounds present in the container headspace detectable by a FID/PID:

1. Collect soil sample using a split-spoon sampler, hand auger, or other apparatus which will yield a soil core or intact sample. Be careful not to disturb the sample soil during sampling since doing so may release VOCs that are present. Half fill a wide-mouthed sample jar with the soil sample. Cover the container opening with aluminum foil and screw the jar lid down tightly. Granular soils should be broken apart by shaking the jar. Cohesive soils should be broken by crushing the sample as it is placed in the jar, and quickly covering.

2. Let the sample sit for 1 hour at ambient temperature before taking a reading. If the sample is collected during cold weather when ambient temperatures are below 25°C, or if more immediate results are desired, the volatization process should be accelerated by placing the container into a warm environment, such as near a vehicle's air heater or in a warm-water (70° F) bath for approximately 30 minutes.

3. Following the warming period, remove the jar lid and insert the probe of the FID or PID through the foil cap (by making a hole in the foil just large enough to accept the probe), and take a reading.

5.3 IN SITU SOIL GAS SAMPLING

In situ soil gas sampling is performed by pulling air samples with a vacuum pump directly through a hollow probe in the ground. Analysis of samples can be accomplished by multiple methods. This technique allows for the identification and quantification of specific volatile organic compounds.

In situ soil gas samples can be collected by dynamic or passive methods. Dynamic soil gas sampling involves extracting a volume of soil gas from the ground and analyzing the sample. A hollow steel rod is driven into the ground, and the soil gas sample is withdrawn with a vacuum extraction pump. The major advantages of dynamic soil gas testing are rapid data availability and the ability to distinguish between soil and groundwater contamination sources by vertical soil gas profiling.

Passive soil gas sampling generally involves implanting adsorption devices in the shallow surface soil and allowing them to adsorb VOC vapors from the soil for a period of days or weeks. After exposure, the devices are dug out and sent to a laboratory for analysis. This sampling methodology is probably the least expensive, but requires a considerable amount of time, and is less versatile than dynamic sampling methods.

Pertinent site-specific and compound-specific factors which influence the collection and interpretation of soil gas are required to be identified and evaluated in order to develop a comprehensive sampling program.

Sampling along an established grid is recommended at sites where the source(s) or general orientation of a subsurface plume are unknown. Where data are available which identify the source areas or plume characteristics, delineation of contaminant edges is most effectively achieved by establishing a transect parallel to the direction of groundwater flow and sampling outward from the suspected source. Soil gas probes should not be located less than 50 feet apart because the resolution of most soil gas detection techniques can be exceeded.

In order to effectively design the soil gas surveys and interpret the results, the subsurface transport and fate of VOCs should be considered. These factors can have a significant effect on the presence and concentration of VOCs in the soil atmosphere. Both physical and microbiological processes can influence soil gas investigations.

Partitioning of the contaminant between gaseous and aqueous phases is the physical process which permits contaminants mixed with water below the surface to be detected in soil gas. The air-water partitioning coefficient can be dependent on both the vapor pressure and aqueous solubility of a compound. Generally, low molecular weight organic compounds (i.e., hydrocarbons, halogenated hydrocarbons, ketones) are most readily detected in soil gas. Compounds possessing vapor pressures less than 1 mm Hg at 25°C will probably not be detected in soil gas. Vapor pressures provide an estimate of the diffusion coefficient and, thus, the "mobility" of the compound in the gas phase.

Soil gas analyses are highly quantitative and specific for individual compounds, but the extrapolation to groundwater contaminant concentrations are not quantitative. Soil gas measurements usually represent an indirect measure of the parameter of interest (e.g., groundwater plumes, extractable hydrocarbon concentrations in soil, sources of subsurface leaks). Variables such as geology, soil moisture content, and the air/water partitioning coefficient of the particular contaminant all affect the relationship between soil gas concentrations and groundwater contaminant concentrations. Water, either in the vadose zone (i.e., a very wet clay or a perched water zone) or in the saturated zone (a contaminated zone below clean water), is the major impediment to vapor movement. Soil gas techniques are relatively ineffective for confined aquifers or soils overlain by strata that are impermeable to gas diffusion.

5.3.1 Dynamic Sampling

Dynamic soil gas sampling investigations can be performed using either hand-driven or mechanically-driven probes and relatively inexpensive field instruments or sophisticated laboratory

equipment. These techniques require the installation of a probe or soil boring in the vadose zone of a soil followed by withdrawal of the soil gas by a vacuum pump. Soil gas samples may be collected in gas sample bags, syringes, or on adsorption media. Samples collected in gas sample bags or on adsorption media must be analyzed at a nearby or on-site laboratory due to short sample holding times. Syringe samples must be analyzed on location immediately after collection.

A procedure for sampling of soil gas and on-site volatile organic compounds analysis by the modified EPA Method 502.2 is presented in Appendix GT.9A as a reference. For the soil gas survey in OUs 8, 10, 12, 13, and 14, the procedure for sampling of soil gas and on-site volatile organic compounds analysis by the modified EPA Method 524.2 is presented in Appendix GT.9B as a reference.

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5.3.1.1 Soil Gas Probe Installation

Dynamic or grab sampling techniques require the installation of a probe in the vadose zone of a soil followed by withdrawal of the soil gas by a vacuum extraction pump. The probes are usually constructed of 1/4 to 1 inch diameter steel pipe and are equipped with perforations near the tip, or with a detachable drive point. Soil gas probes must be cleaned with steam or hot water and soap before use (see SOP FO.3, General Equipment Decontamination). A sufficient number of interchangeable sampling components should be available so that decontamination does not need to be performed in the field.

Multiple soil gas sampling intervals may be sampled at one location in order to identify contaminant profiles. The soil gas sampling can also be performed in augured boreholes or through the center of hollow-stem augers by driving the probe at least 2 feet deeper than the augured depth.

Required Equipment and Apparatus

- Soil gas probe(s), tips (if needed), and drive pipe(s)

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- A manual or powered probe driver that is able to drive the probe into the ground and remove the probe after a sample is taken
- Vacuum pump with gauge to extract soil gas
- Hammer drill capable of drilling through asphalt and concrete (if required)
- Power source for hammer drill, power probe driver, and vacuum pump
- Adaptor for soil gas probe with appropriate valves and tubing

Procedures

1. Clear the area to be sampled for utilities, cables, pipes, etc. Clear the surface area to be sampled of grass, leaves, and debris.

2. Using a manual or mechanical driver, drive a cleaned/decontaminated probe with drive pipe(s), as needed, into the ground to the desired depth (minimum is usually 3 feet). Probes placed in augured boreholes should be driven at least 2 feet deeper than the augured depth. If refusal occurs significantly before the sampling depth is reached, remove the probe. Clear another sampling point within 1 foot of the first point and drive a clean probe again. If refusal occurs, eliminate the area within 10 square feet as a sampling point.

3. Once the sampling depth is reached, an entry on the Soil Gas Survey Form (Form GT.9D) and the Soil Gas Survey Map (Form GT.9C) will be made denoting the depth, time, and location of the sample. The probe will then be lifted 1-2 inches to expose the air sampling slots in the drive point.

4. Attach the adaptor with tubing and stainless steel sampling manifold to the top of the probe/driving pipes.

5. Connect adaptor tubing to the vacuum gauge on the low-pressure side of the vacuum pump. An in-line liquids trap, programmable mass flow controller equipped with a solenoid valve and timer are very useful additions, but are not required.

6. Run the vacuum pump before sample collection to purge the system and displace the ambient air in the soil gas prove, drive pipe(s), and tubing.

7. Purge the probe and silicone rubber tube connecting system. The vacuum gauge installed on the low-pressure side of the vacuum pump will be used to evaluate whether a representative soil gas sample can be withdrawn from the subsurface. Generally, if the applied vacuum exceeds 12 inches of mercury, the soil is either water saturated or does not have a sufficient air-filled porosity to produce a meaningful sample.

8. Collect samples from the tubing/manifold on the low-pressure side of the vacuum pump.

9. Record time vacuum pump is operated before sample collection, and pressure reading (vacuum gauge) of gas in the soil gas probe line, at the time of sampling.

10. The drive pipe(s) and soil probe will be removed at each location after the soil gas has been analyzed. The hole will be backfilled (if necessary) with a native soil or a soil/bentonite mixture to avoid creating a migration pathway. After the removal of the soil probe, the distance between the sampling location and a known point

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will be measured and recorded on the soil gas survey map (Form GT.9C) and a flag left at the sampling location for subsequent surveying.

5.3.1.2 Sampling for Total Organic Vapor Analysis

In the simplest sampling/analysis technique, an organic vapor monitor such as a PID or FID is used. A piece of tubing of appropriate length is attached to the probe adaptor manifold and the PID/FID. A direct reading of the soil vapor gas total organic concentration may then be made after the PID or FID instrument has pumped sufficiently for the gas sample to reach the detector.

Required Equipment and Apparatus

- Field analytical instrument capable of detecting total organic vapors such as a flame ionization detector (FID) or photoionization detector (PID)
- Accessory tubing between instrument and manifold (maximum length 12 inches)

Collection and Analysis Procedures

1. After purging the system, attach sampling tube from the instrument to the manifold valve port and open the manifold valve.
2. Allow the instrument to pump for a sufficient length of time to displace the ambient air in the sampling tube and instrument before taking a reading.

P5.3.1.3 Sample Collection for Laboratory Analysis

Sampling/analysis of grab samples may also be accomplished by pumping the soil gas from the probe and collecting the gas in a Tedlar bag. Alternatively, the soil gas may be pumped through a charcoal or Tenax trap. The VOCs in the soil gas are adsorbed onto the charcoal or Tenax. These samples must then be analyzed at an on-site laboratory since the holding times for these collection methods are short (1 to 8 hours). Analytical methods typically include the use of gas chromatography (GC) and/or mass spectrometry (MS).

Specific analytical methods and calibration procedures, standards concentrations, detectors, temperature programs, etc. are dependent on the method of analysis and analytes of interest. Specific analytical methods and procedures will be detailed in applicable project work plans. For the soil gas surveys in OUs 8, 10, 12, 13, and 14, the procedures for sampling of soil gas and on-site volatile organic compounds analysis by the modified EPA Method 524.2 is presented in Appendix GT.9B as a reference.

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Required Equipment and Apparatus

- Gas collection bags such as Tedlar, carbon sorption, or Tenax sample tubes with accessory tubing (if required)
- Low-flow air sampling pumps, such as Gillian (if required)
- Adapter for the soil gas probe with appropriate tubing
- Vacuum pump to extract soil gas

Collection and Analysis Procedures

1. Run the vacuum pump to purge the system and displace the ambient air in the soil gas probe, drive pipe(s), and tubing. Attach a Tedlar bag and unclamp the flexible

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tubing, collecting the gas sample in the bag. The bag will then be disconnected, sealed, and transported to the laboratory for analysis.

2. To collect a sample by adsorption, insert a Tenax trap or other sampler into the sample chamber and attach it to the manifold after the probe and adaptor system have been purged. Divert soil gas flow through the sample chamber. Record flow pressure, elapsed time, and volume of flow, if mass flow controller is used.

5.3.1.4 Sample Collection for Field Gas Chromatographic Analysis

An alternative grab sampling technique requires soil gas to be pumped through the soil probe, collected with a syringe, and immediately injected into a field gas chromatograph or a gas chromatograph located near the sampling site. This method allows for real-time results, and is particularly useful.

Specific analytical method calibration procedures, standards concentrations, detectors, temperature programs, etc. are dependent on the method of analysis and analytes of interest. Specific analytical methods and procedures will be detailed in applicable project work plans.

Required Equipment and Apparatus

- Mobile or field gas chromatograph (GC) and associated support equipment required to properly operate the GC
- A power source and an enclosed area for the GC
- Appropriate calibration gas standards for the GC and all associated equipment needed to perform the calibration

- Sample container(s) with septum(s)

Collection and Analysis Procedures

1. Collect the soil gas sample with a glass syringe by inserting the syringe into the extraction line near the top of the soil gas pump, on the intake side of the pump (see Figure GT.9-1).

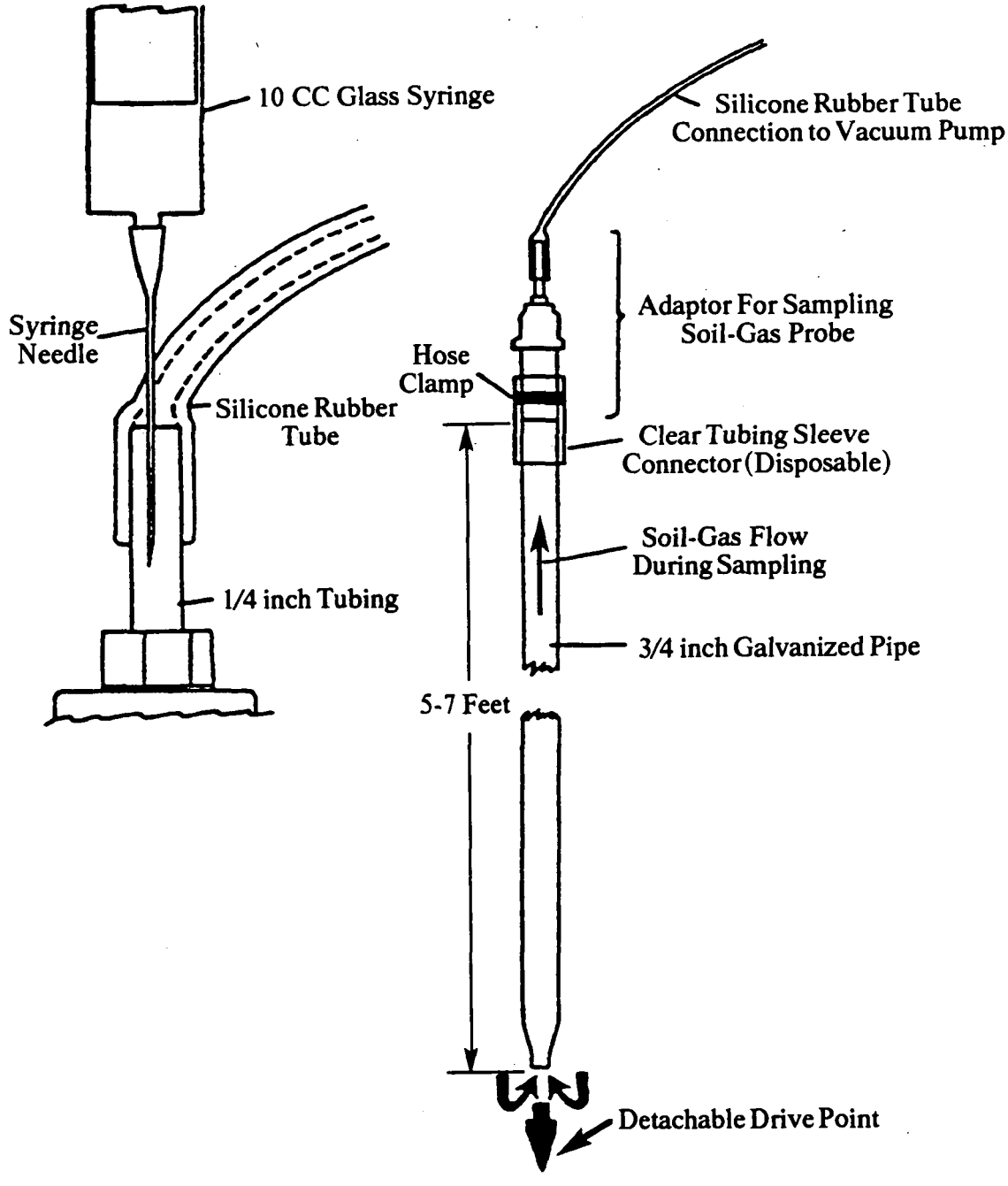
5.3.2 Passive Sampling

While other passive techniques may be available, this procedure is directed toward the use of Petrex tubes as the representative technique since their utility has been demonstrated in past studies at RFP. The Petrex passive sampling technique is a direct method for trapping and identifying VOCs emanating from either soil (vadose zone) or groundwater contaminated locations. The collector consists of highly sensitive sorbents (such as activated charcoal) chemically fused to the tip of a wire. The collectors are arrayed, generally in a grid pattern, throughout the survey site, normally at a depth of approximately 1 foot (see Figure GT.9-2). The collectors reside for a measured period, which can range up to 30 days, to assure time-integrative gas collection (as opposed to instantaneous collection with grab samples). The collectors are retrieved following the time-integrative collection period, and are then sent to a laboratory for analysis by mass spectrometry.

The most critical aspect of collector placement is to prevent exposing the collector to contaminants other than those in the soil gas. Smoking around the collectors, even when sealed, may contaminate them. Hands must be kept free of organics, including insect repellent, sunblock, gasoline, motor oil, cosmetics, smoke residues, etc. The lip and inside of the tubes, caps, and cap liner must not contact any contaminants. The tubes must be stored in a clean area away from contaminants. They must not be stored near gasoline cans, oily rags, etc., or in areas where exhaust fumes or cigarette smoke is present.

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.9, Rev. 2
	Page:	21 of 27
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

FIGURE GT.9-1
SOIL GAS SAMPLING PROBE AND ADAPTOR



Taken from Marrin and Thompson, 1987

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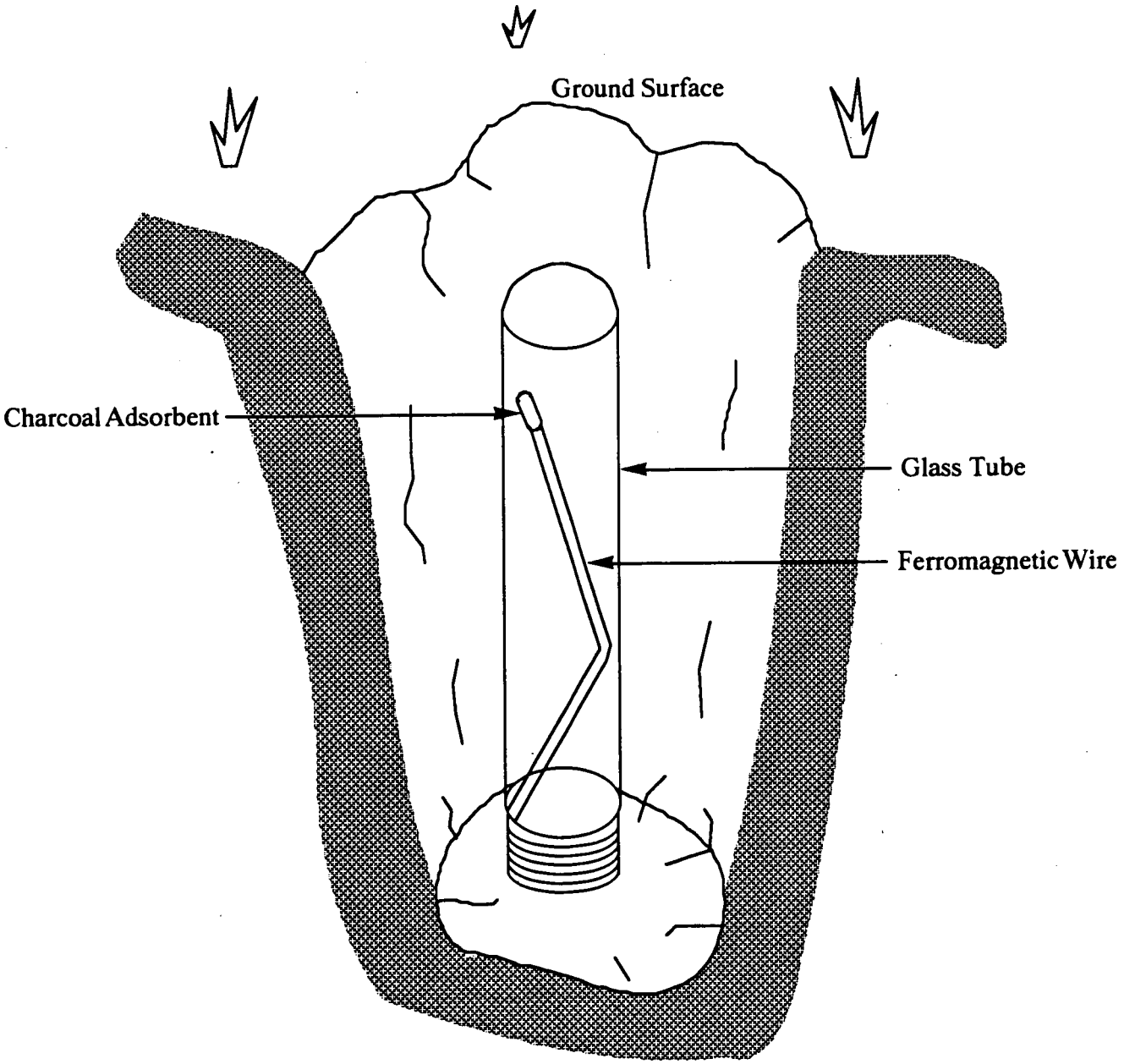
FIGURE GT.9-2
PETREX PASSIVE SAMPLING COLLECTOR



NOT TO SCALE

5.3.2.1 Required Equipment

- Hand auger, slide hammer, shelby tube, etc. or some other hole maker
- Petrex tubes

5.3.2.2 Installation and Collection Procedures

1. Clear the surface area to be sampled for shallow utilities, cables, pipes, etc. Clear the area to be sampled of grass, leaves, or debris; be careful not to walk or drive over the area.

2. Using a cleaned/decontaminated tool, make a hole into the ground to the desired depth (usually 10-12 inches). If refusal occurs significantly before the sampling depth is reached, remove and clean the tool. Clear another sampling point within 1 foot of the first point and insert the hole maker again. If refusal occurs, eliminate the area within 10 square feet as a sampling point.

3. Dig a sample location 10-12 inches deep and approximately 2-4 inches in diameter. Do not contaminate the soil.

4. Unwrap a Petrex sampling tube and remove the cap and black seal liner. Immediately place the sampler (vertically with open end down) into the sample location hole. The sampler tube must be at least 2 inches below ground surface. Immediately cover the sampler with soil (see Figure GT.9-2).

5. If the black liner has come out of the cap, replace it and return the cap to one of the clean plastic bags provided.

6. Mark the sample location with flagging or other type of locator. Note the sample location on a base map and enter information on Form GT.9C, and in a field notebook.

7. Retrieving samples - (should be done at recommended time intervals).

   a) Remove the soil until the tube is exposed.

   b) Take the cap from sealed plastic bag. Check for the black liner inside the cap. If the liner has fallen out, replace it.

   c) Remove the tube from the hole. If the wire falls out of the tube or if the tube is broken, use tweezers to handle the wires.

   d) Wipe off the tube and threads thoroughly with a clean, dry cloth. If the tube threads and lip are not properly cleaned, the cap will not seal and the sample will become contaminated.

   e) Seal the tube with a cap making sure the black liner is seated to the tube lip. If the cap does not thread easily, use a different cap. Cap must be sealed tightly against liner.

   f) Place a sticker on the cap top and number it. Number sequentially starting with 1. Use only numbers to identify samples. Use only one number per tube. Underline all numbers for easy identification. Do not duplicate cap numbers. The Petrex tube distributor, Northeast Research Institute, Inc.

(NERI), will number all second and third wire tubes appropriately.

g) Record the number or numbers of the sampler corresponding to the location on the base map and field notebook. Also, record in field notes any samples which have more than one wire per tube.

h) Do not place tape, sticker, or glue on the glass tube. Stickers provided will adhere if placed on a dry cap.

8. When packaging exposed tubes, do not use styrofoam or popcorn packing as this can potentially introduce a contaminant. Enclose tubes in two plastic bags and wrap each package tightly with bubble wrap. Complete NERI-WEST Submittal Forms, provided by NERI, to be shipped with samples. Samples are to be placed in sealed containers. Packaging, labeling, and preparation procedures for shipment are specified in SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples.

6.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality Assurance (QA) and Quality Control (QC) activities will be accomplished according to the Quality Assurance Project Plan (QAPjP) and the project-specific Quality Assurance Addendum (QAA).

In addition to adhering to the requirements of the site-specific Field Sampling Plan (FSP) and any supplementary site-specific procedures, the minimum QA/QC requirements for this sampling activity are the following:

- QC Samples -- The number and types of QC samples including duplicate samples, field blanks, equipment blanks, and trip blanks will be collected or prepared as specified in the QAA.

- Verification -- Verification activities are required for the above practices, including surveillance and periodic record audits. These activities will be documented and become part of the completed project records.

6.1 QA/QC SAMPLES FOR FIELD GC ANALYSIS

Frequency of calibration, method blanks, replicates, etc. are dependent upon project Data Quality Objectives (DQOs), and must be addressed in the project-specific Quality Assurance Addendum (QAA). Calibration of instruments involved in soil gas analysis shall occur at the beginning of each working day and, after that, continuing calibration verification shall be performed every eight hours or after a batch of 20 samples, whichever is more frequent. Soil gas analysis should address an adequate level of precision. Soil gas precision values for analysis of duplicate samples can exceed a relative percent difference of 40 percent. Relative percent difference values for duplicate samples will be within the 40% range unless stated otherwise in the project specific work plan.

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7.0 DOCUMENTATION

For each soil gas location, a permanent record of the implementation of this SOP will be kept by documenting field observations and data. Observations and data will be recorded with black waterproof (permanent) ink on the attached forms; the Photoionization Detector Field Data Form (Form GT.9A), the Flame Ionization Field Data Form (Form GT.9B), the Soil Gas Survey Map (Form GT.9C), and the Soil Gas Survey Form (Form GT.9D). Observations may also be documented in a bound weatherproof field notebook with consecutively numbered pages. This information will include the following:

- Sampler's name (form)
- Date and time of sample collection (form)

- Sampling identification (form)
- Weather conditions (notebook)
- Sampling depth (form)
- Driving characteristics of the soil probe (notebook)
- Description of the surface features (drainage, facilities, etc.), soils, any contamination noted, and trenches or any other feature that may impact the soil gas measurement (notebook)
- Vacuum pressure when extracting a sample (form)
- Type of sample (gas, liquid, or mixed) (form)
- Compounds and concentration of the organics measured on the GC and any replicate or blank analysis performed (form)
- All calibrations performed (form)
- Any unusual responses of the instrument (form)
- Length of time the vacuum was applied to the sample probe before a sample was taken (notebook)
- Estimated concentration and recorded retention time of all chromatographic peaks, including those that represent unknown compounds (GC chromatographs)

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PHOTOIONIZATION DETECTOR FIELD DATA FORM

PHOTOIONIZATION DETECTOR FIELD DATA

Facility Code _____ Log Date _____

Location ID _____ Location Type _____

Logger Code _____ Field Rep _____

Photoionization Detector Instrument: Serial No. _____

Manufacturer _____ Model _____

Date/Time Calibrated _____ Acceptance Code _____

CALIBRATION GASES:

TYPE/CYLINDER NO.	CONCENTRATION (PPM)/SPAN
1	1
2	2

Comments:

Time (HH:MM)	Drilling Depth (ft)	Observed Reading (ppm)					Sample ID	Comments
		DH	HS	EZ	D	OT		

Acceptance Codes: A-Acceptable R-Reconnaissance U-Unacceptable N-Not Determined

Location Types:		Observed Reading:	
BH - Borehole	SB - Sample Bottle	DH - Downhole	BZ - Breathing Zone
TP - Test Pit	SL - Surface Location	HS - Headspace	D - During Drilling
SS - Soil Sample	WL - Well		OT - Other
	OT - Other		

Completed By: _____

Print Name Signature Date

Subcontractor: _____

FLAME IONIZATION DETECTOR FIELD DATA FORM

FLAME IONIZATION DETECTOR FIELD DATA

Facility Code _____ Log Date _____

Location ID _____ Location Type _____

Logger Code _____ Field Rep _____

Flame Ionization Detector Instrument: Serial No. _____

Manufacturer _____ Model _____

Date/Time Calibrated _____ Acceptance Code _____

CALIBRATION GASES:

TYPE/CYLINDER NO.	CONCENTRATION (PPM)
1	1
2	2

Comments:

Time (HH:MM)	Drilling Depth (ft)	Observed Reading (ppm)					Sample ID	Comments
		DH	HS	EZ	D	OT		

Acceptance Codes: A-Acceptable R-Reconnaissance U-Unacceptable N-Not Determined

Location Types:
BH - Borehole
TP - Test Pit
SS - Soil Sample
SB - Sample Bottle
SL - Surface Location
WL - Well
OT - Other

Observed Reading:
DH - Downhole
HS - Headspace
BZ - Breathing Zone
D - During Drilling
OT - Other

Completed By: _____
Print Name Signature Date

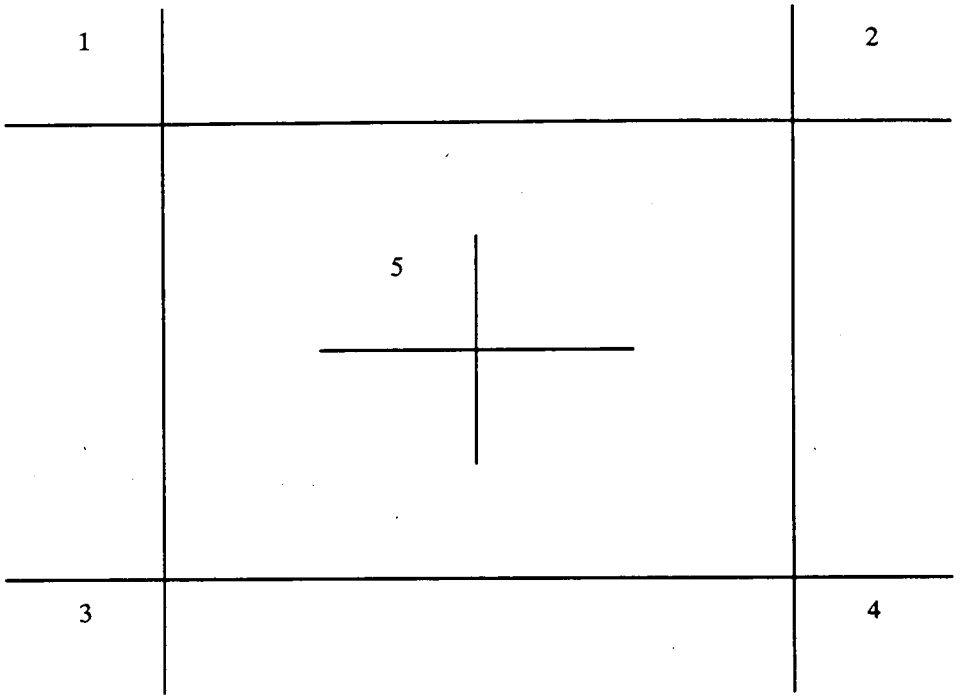
Subcontractor: _____

SOIL GAS SURVEY MAP

OU No: _____ IHSS No: _____ Date: _____

Sample Team Members: _____

GRID BLOCK



Coordinates: 1 _____ 2 _____

3 _____ 4 _____

5 _____ 6 _____

7 _____ 8 _____

Completed By: _____

Print Name Signature Date

Subcontractor: _____

SOIL GAS SURVEY FORM

Survey Instrument Data				
Number	Model Number	Serial Number	Calibration Factor	Background (ppm)

Technician: Date:

SURVEY DATA

Time	Sample Depth (ft)	Sample Number	Map Intersect Sample Location	Field Reading 1 (ppm)	Field Reading 2 (ppm)	Comments

Completed By: _____
Print Name Signature Date

Subcontractor: _____

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APPENDIX GT.9A
VOLATILE ORGANIC SAMPLING AND ANALYSES IN SOIL GAS, SOILS, WATER, AND ATMOSPHERE BY MODIFIED EPA 502.2

APPENDIX GT.9A
VOLATILE ORGANIC SAMPLING AND ANALYSES IN SOIL GAS, SOILS, WATER, AND ATMOSPHERE BY MODIFIED EPA 502.2

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VOLATILE ORGANIC SAMPLING AND ANALYSES IN SOIL GAS, SOILS, WATER, AND ATMOSPHERE BY MODIFIED EPA 502.2

HYDRO GEO CHEM, INC.

Hydro Geo Chem, Inc.
1430 North Sixth Avenue
Tucson, Arizona 85705
(602)623-6981

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VOLATILE ORGANIC ANALYSES SAMPLING AND IN SOIL GAS, SOILS, WATER, AND ATMOSPHERE BY MODIFIED EPA 502.2

HYDRO GEO CHEM, INC.

INTRODUCTION

On site analysis of volatile organic compounds VOC's is increasingly important to environmental assessments. The ability to perform real-time chemical analysis during investigations of potentially contaminated soils, water, and air allows field decisions to be made regarding the depth and areal extent of the investigation.

The applications of on-site VOC analysis include soil analysis for evaluation of subsurface spills and leaking tanks; atmospheric analysis for evaluation of VOC emissions from landfills, contaminated soils, and industrial facilities; water analysis for identification and definition of the vertical and areal extent of groundwater VOC plumes; and soil gas surveys, the sampling and analysis of VOC's in the soil atmosphere in order to determine the vertical and areal distribution of VOC's in site soils.

Because VOC's are readily transported in soils by diffusive and advective processes, soil gas surveys have proved to be a powerful technique to determine whether spills have taken place on the site, to locate these spills, and, if subsurface conditions are favorable, to find and delineate groundwater VOC plumes by the presence of VOC's in overlying soils.

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The analytical requirements for real-time mobile-laboratory analysis are different than the conventional VOC analyses prescribed by EPA protocols. The laboratory productivity, that is, the number of analyses required per unit time, must be much greater for the mobile facility. Otherwise, the value of using the data to modify the investigation is diminished.

Despite the need for greater productivity, the other analytical requirements for detection limits, variety of analytes, and freedom from laboratory contamination are if anything, more stringent than those of fixed laboratory facilities.

Summary of Method

The following sampling and analytical protocol has been adapted by Hydro Geo Chem to meet these stringent requirements of on-site VOC analysis.

In summary, the analytical method consists of the recently approved EPA 502.2 protocol. Table 1 lists the compounds can be analyzed using EPA 502.2 protocol. We have modified this protocol to allow greater throughput and to minimize the potential for laboratory contamination. These modifications include temperature programming and flow changes to reduce analytical time, the use of gas rather than water-solution standards, purging of VOC bottles directly rather than using a conventional water purging apparatus (this technique has recently been independently developed and used in EPA Region 5 RI/FS studies), dynamic stripping rather than

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Table 1. Compounds Detectable by Hall/PID Analysis

Benzene
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
n-Butylbenzene
sec-Butylbenzene
tert-Butylbenzene
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
2-Chlorotoluene
4-Chlorotoluene
Dibromochloromethane
1,2-Dibromo-3-chloropropane
1,2-Dibromoethane
Dibromomethane
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,1-Dichloropropene
Ethylbenzene
Hexachlorobutadiene
Isopropylbenzene
p-Isopropyltoluene
Methylene chloride
Naphthalene
n-Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,2,3-Trichlorobenzene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
1,2,4-Trimethylbenzene
1,3,5-Trimethylbenzene
Vinyl chloride
o-Xylene
m-Xylene
p-Xylene

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solvent extraction of soils, and splitting of the sample injection stream to allow simultaneous analysis on a separate gas chromatograph of other compounds not analyzed by the 502.2 protocol.

The sampling methods included in the protocol have been designed to allow accurate, contamination-free sampling of soils, water, atmosphere, and soil gas. These methods offer a detection limit of 0.1 µg/kg (soil), 0.01 µg/l (soil gas or water), 0.001 µg/l (atmosphere) for any compounds listed in Table 1. Additional, simultaneous analysis is provided for total petroleum hydrocarbons, methane, and total chlorinated hydrocarbons. The following sections document the materials, apparatus, and procedures used.

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1. SAMPLING

1.1 Scope and Application

This section covers the materials, equipment and procedures utilized by Hydro Geo Chem, Inc. for collecting soil gas, atmospheric, soil, and shallow groundwater samples in the field.

1.2 Sampling Equipment

1.2.1 Sampling Probes

Sampling probes are 7 foot sections of 1" galvanized pipe or 1" hardened steel drill pipe with Acme threads. The points are machined, high carbon steel and are left behind when the pipe is hydraulically pulled back to expose the formation to pumping. Figure 1 shows our probe design. The probes are driven to the sampling depth using one of two drive point rigs. Both rigs are mounted on 1988, Ford F-450 flat-bed duallys. One rig uses a hydraulically-activated 235 lb hammer with a 3 foot, free-fall displacement. The other rig uses a mounted hydraulic 250 ft/lb, 1,000 blow/min driver. Both rigs are capable of driving sampling pipe to a depth in excess of 35 feet under normal driving conditions. Each drive point rig is equipped with hydraulic out riggers, pipe racks and steam cleaner. The probes are removed using a hydraulically activated pulling dog. Latex gloves are worn during handling and assembling of the sampling apparatus.

1.2.2 Sampling Adaptors

Soil gas samples are collected from the probes via adaptors constructed of stainless steel pipe caps brazed to stainless steel tubing connected to an inline stainless steel bellows valve.

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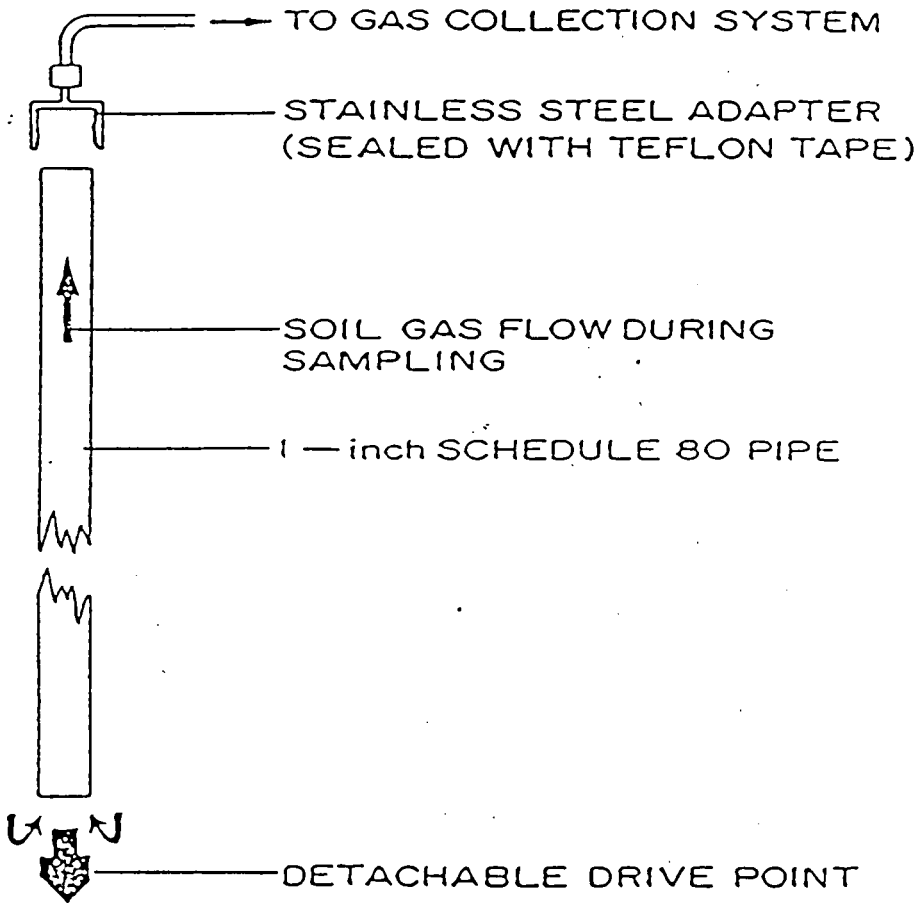

SOIL GAS SAMPLING PROBE

Figure 1

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1.2.3 Sample Holders

When sampling is performed, this valve is connected to a stainless steel sample holder containing a glass cartridge (Supelco) filled with a three layer packing of various types of adsorptive hydrophobic carbon (see Figure 2). The soil gas is passed through these layers, the first, Carbotrap, absorbing "heavy" volatiles such as dichlorobenzene, the second, Carbopack B, the lighter volatiles such as TCE and DCE, and the third, Carbosieve III, the ultralights such methylene chloride or vinyl chloride. Because the most mobile constituent, vinyl chloride, has a breakthrough volume of 158 liters, these cartridges are rated to absorb at least 158 liters of soil gas or atmospheric gas before breakthrough of any of the priority pollutants listed in EPA method 601, 602, or 624. Table 2 shows some breakthrough volumes for the types of carbon sorbents making up the adsorbtion the cartridge. Thus the sampling capacity of this technique far exceeds that of syringe collection. The high capacity is necessary to meet typical client specifications.

1.2.4 The water sampling train is constructed entirely of stainless steel consisting of a 1 foot length of 3/4" well screen and seven foot lengths of 1/4 stainless steel tubing.

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SAMPLE COLLECTION

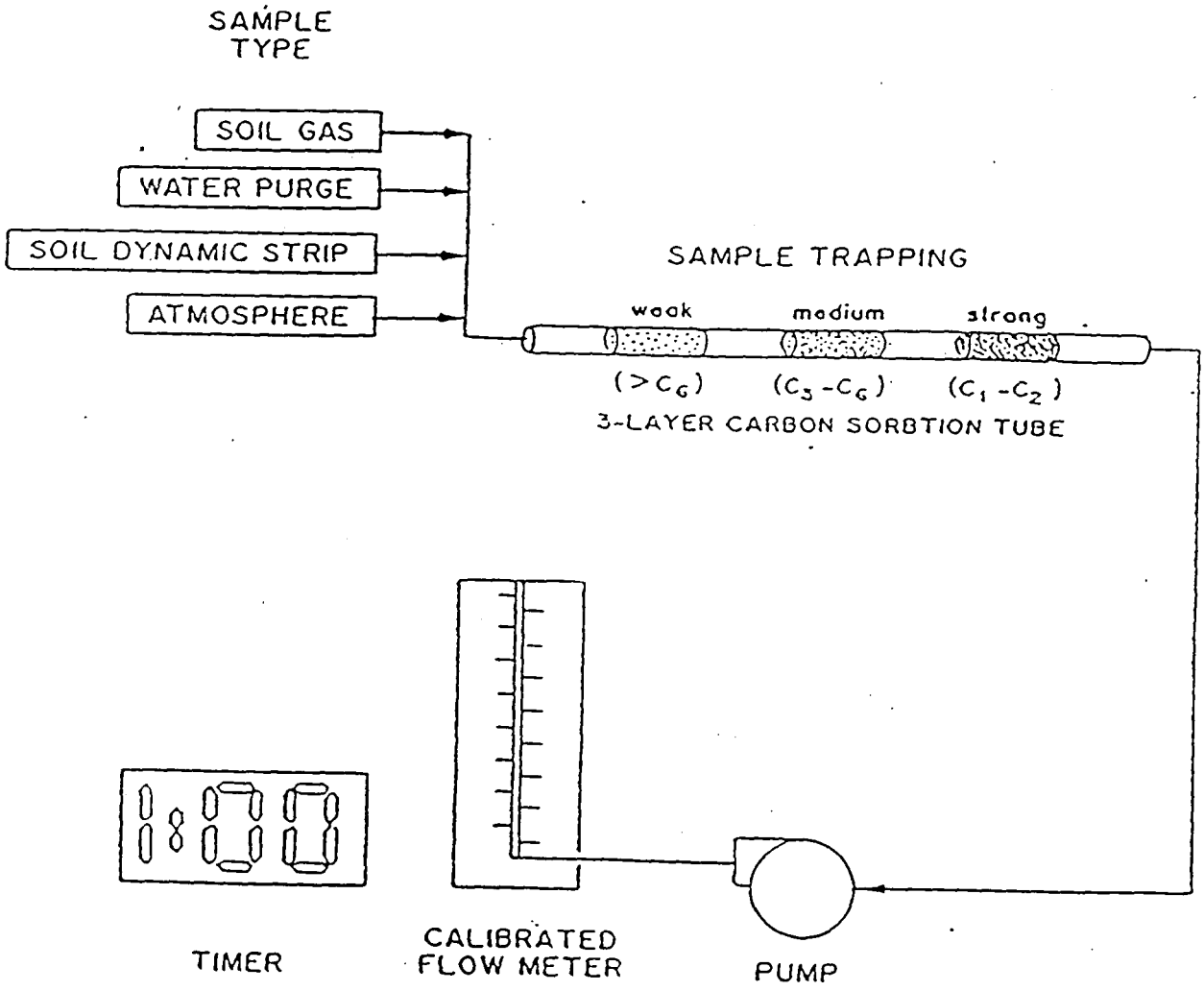

Figure 2

Table 2

Breakthrough Volumes (in Liters) for US EPA TO-1 Hydrocarbons on the Carbosieve™ S-III/Carbopack B/Carbotrap C Thermal Desorption Tube

Hydrocarbon	Carbosieve S-III (125 mg)	Carbopack B (200 mg)	Carbotrap C (300 mg)
Vinyl Chloride	158		
Chloroform		1.1	
1,2-Dichloroethane		0.4	
1,1,1-Trichloroethane		2.7	
Carbon tetrachloride		4.7	
1,2-Dichloropropane		6.8	
Trichloroethylene		2.5	
Bromoform		1.7	
Tetrachloroethylene		2.2	
Chlorobenzene		316	
n-Heptane		262	
1-Heptene		284	
Benzene		2.3	
Toluene		130	
Ethylbenzene		4060	12.9
p-Xylene			11.2
m-xylene			11.0
o-xylene			11.0
Cumene			27.8

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1.3 Sample Collection

1.3.1 Soil Gas Sampling

After purging 3 probe volumes from the system, the valve on the adaptor is shut off and the stainless steel sample cartridge housing is Swagelok-attached to a programmable mass flow controller equipped with a vacuum regulated oiless diaphragm vacuum pump. The flow controller is typically programmed to pump 200 ml of soil gas at a flow rate between 100 and 200 ml/min. When the total flow volume has been obtained, a solenoid valve is automatically closed and the sample collection is complete. The mass flow meter delivers sample volumes between 20 and 5000 standard ml with less than 2% error independent of temperature and vacuum conditions.

1.3.2 Atmospheric Sampling

Atmospheric samples are collected by positioning the probe in the area of interest, setting the pumping rate, and programming the mass flow controller. If desired, the probe can be moved through a sampling volume at a specified rate to collect an integrated sample. No purging is necessary for atmospheric samples.

1.3.3 Soil Sampling

Soil samples are collected at specified intervals using a 1.5 foot split spoon sampler with multiple brass liners. No liquids (i.e., drilling mud, water, foam) are permitted during the drilling procedure if soil samples for contaminant analyses are required. If samples are to be analyzed by the mobile laboratory, approximately 20 grams of the sample are removed from the brass sleeve using a stainless steel spatula and placed in a pre-weighed vial containing a known amount of water. All soil samples to be sent out for analysis are retained in the original brass tubes (2.5 inch diameter, 6 inches long). Immediately following removal of the brass tubes from the sampler, the center tube is first capped with aluminum foil and plastic slip caps. The slip caps are then duct taped to the brass tube to maintain a proper seal. Samples are labeled and placed in a zip lock plastic bag and stored in a cooler with dry ice.

1.3.4 Water Sampling

The water sampling train is described in Section 1.2.4. The well screen is attached to the stainless tubing and lowered into the probe. A stainless steel bottle is connected to the tubing and a Tygon line leading to the diaphragm pump is attached to the bottle. The transparent Tygon tubing is used to determine when the bottle is filled and any bubbles in the line have cleared. Excess water, which serves to purge the sampling train, is

intercepted by a vacuum flask in the Tygon line. The valve is then shut off and the bottle is disconnected from the sampling line and Tygon tubing. Opening the valve allows each of three weighed 40 ml VOC bottles to be filled to overflowing. No air bubbles are allowed to pass through the sample as the vials are filled. These are then immediately capped with a teflon-lined septum cap and stored in an inverted position at 4°C. The inverted position keeps liquid in contact with the septum, thus preventing diffusion of volatiles through the septum/glass seal. If necessary, additional 40 ml VOC bottles will be collected liquid full for outside laboratory analysis. The 40 ml VOC vials are purchased precleaned to EPA specifications from ICHEM.

An alternative method used to collect water samples involves the use of 3/4" stainless steel bailers. These are lowered down the probe by a nylon cord that is replaced before each sampling.

1.4 Decontamination of Equipment

1.4.1 Prior to each use, each soil sampler, brass liner, and auger flight or drill stem is steam cleaned with a dilute sodium-triphosphate solution and stored on racks above ground. Care is taken with this equipment to eliminate both soil-surface and cross-hole contamination. Vinyl or latex surgical gloves are worn during handling and assembly of the sampling apparatus.

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1.4.2 Probes, points, well screens, and tubing are steam cleaned prior to sampling. Adaptors and stainless steel bottles are heated to 120°C and held for 1 hour at that temperature. Carbon packed desorption cartridges are purged at 400°C with helium for 8 minutes. Cartridge holders are heated and purged at >200°C for 20 minutes.

1.4.3 Separate storage areas are provided for used and cleaned equipment. No equipment is reused without cleaning.

2. ANALYSIS

2.1 Scope

This section covers the equipment, materials, and procedures used to determine the presence and concentrations of various volatile organic compounds in the soil gas, atmospheric, soil, and shallow groundwater samples.

2.2 Detection Limits

The typical limits of detection specified are for water, soil gas, and atmospheric samples, respectively, 0.01, 0.01, and 0.001 µg/l. The applicable concentration range of this method is influenced by sample size and instrument limitations. Refer to Summary of Method for details.

2.3 Apparatus and Equipment

2.3.1 Gas Chromatographs

Hydro Geo Chem uses one of two mobile laboratories to provide on-site analyses. The first mobile laboratory is housed in a 30 foot motorized step van. The second mobile lab is contained in a 22 foot trailer. Varian 3400 and 3700 gas chromatographs are provided in our mobile laboratories (a stand-alone vehicle that operates separately from the drive point rig, thereby allowing efficient operation of both). These chromatographs are connected in parallel to an Envirochem thermal desorber (Model 850) which accepts the glass sorbtion tubes used to collect the soil gas, atmospheric, or gas purged water samples. Figure 3 is a schematic of the analytical apparatus. Helium flow is opposite to the flow direction of sample collection. The

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MOBILE LABORATORY
SAMPLE ANALYSIS

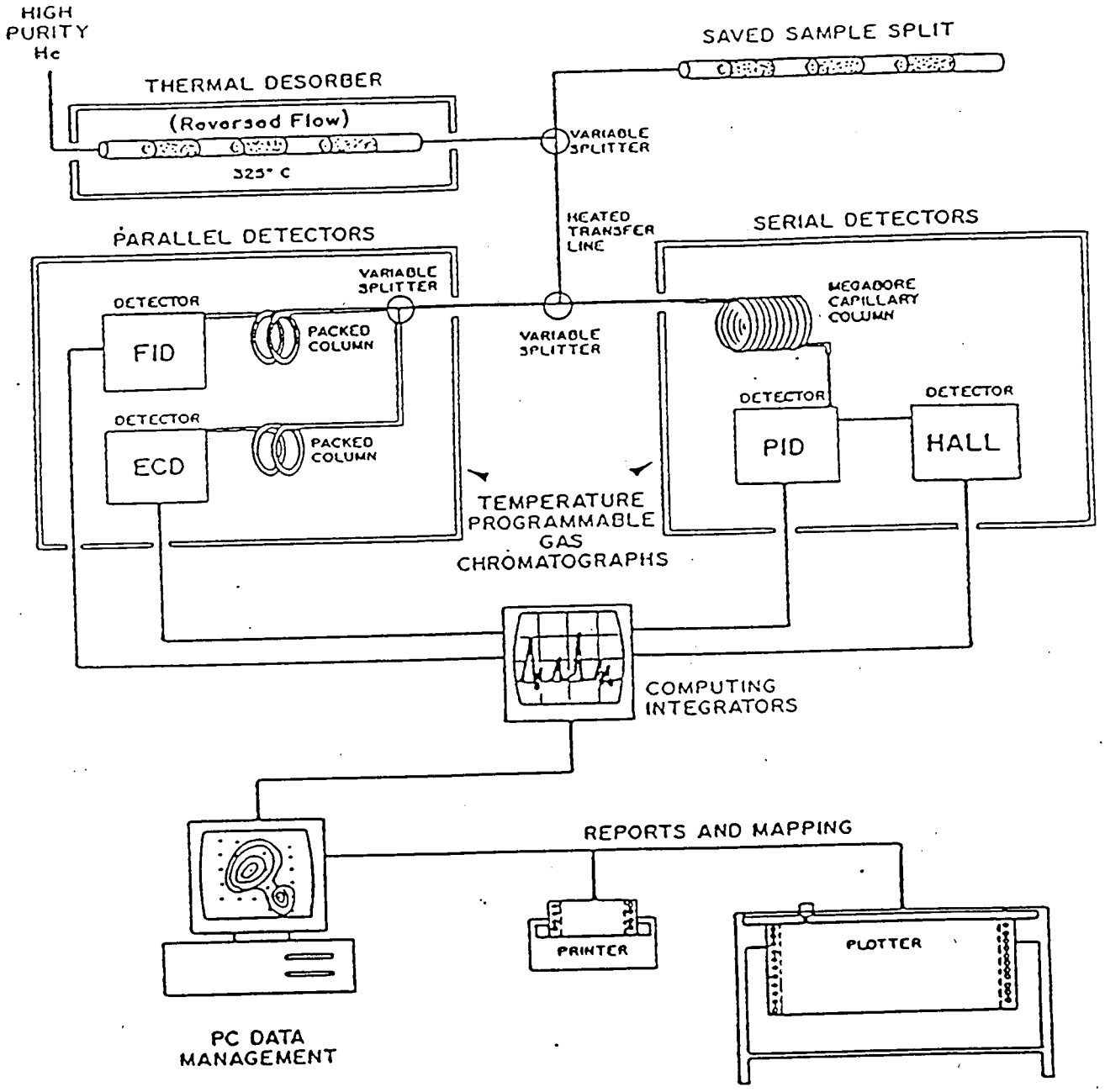

Figure 3

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thermal desorber rapidly heats the sample sorbtion tube releasing the volatile organic compounds into the chromatograph by heating the tube to 380 ±4°C in 26 ±2 seconds. Compounds are transferred to the analytical columns via heated (250°C) nickel lines.

The Varian 3400 chromatograph is equipped with cryogenics capable of cooling the column oven to below 0°C using carbon dioxide.

The carrier gas is helium at 20 ml/minute. This gas flow is split between the transfer lines in the desorption unit by use of a flow metering valve (SGE1230400). The carrier gas flow is augmented with an additional 25 ml/minute helium before entering the photoionization detector (PID) to optimize response of both PID and Hall electrolytic conductivity (Hall) detectors.

2.3.2 GC Columns

A DB 624 Megabore column, 30m x 0.53mm (J&W Scientific) is used in the Varian 3400 chromatograph. The helium flow rate is adjusted to approximately 7.0 ml/minute at the metering valve. The temperature program varies with the client needs. A typical temperature program is as follows: the column temperature is held at 2°C for 3 minutes, then programmed to 35°C at 15 ml/minute, no hold time, to 145°C at 8 ml/minute, no hold, to 230°C at 35 ml/minute.

The 3700 GC is equipped with an OV 101 on Chromosorb W-HP 80-100, 18" x 29" packed column (Varian) used for total hydrocarbon analysis. It is also equipped with a 1/8" x 18" Carbosphere, 60/80 mesh, used to analyze for nonsorbable gases. These columns are operated isothermally at 200°C.

2.3.3 Detectors

2.3.3.1 A photoionization detector (PID) equipped with a 10.2ev lamp (Tracor Model 1703) is used.

2.3.3.2 A Hall electrolytic conductivity detector (HECD) (Tracor Model 700A) is also used. Operation conditions are as follows:

Reaction tube:	Nickel 1/16" OD
Reactor temperature:	900°C
Reactor base temperature:	250°C
Electrolyte:	n-propylalcohol
Electrolyte flow rate:	0.7 ml/min
Reaction gas:	hydrogen at 35ml/min.
Carrier gas plus make up:	helium at 32ml/min.

2.3.3.3 Hydro Geo Chem also has available in the mobile laboratory an Electron Capture Detector, ECD (Varian).

2.3.3.4 A Flame Ionization Detector, FID (Varian), is also provided.

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2.3.4 Integrators

Three computing integrators are utilized depending on analysis requirements. These include PC-compatible/Nelson Analytical Chromatography software package and two computing integrators, Spectrophysics 4200, and a Varian 3400 integrator.

2.3.5 Purge and Trap Apparatus

An in-house designed and built purging apparatus (Figure 4) is used in the analysis of soil and water samples. High purity, inert (He or N_2) gas is bubbled through the sample at 200 ml/min. for 10 minutes. Purged sample components are trapped in a Supelco thermal desorption tube.

2.3.6 Standards and Reagents

2.3.6.1 Standards are prepared from stock mixtures of neat reagent grade compounds by adding a measured pipetted volume of each compound to be analyzed to the mixture and determining the weight added by difference. An aliquot volume of the final mixture is then weighed to establish density (weight/volume). Weighing is done on a 0.1 mg Mettler balance calibrated according to manufacturers guidelines with weights traceable to NBS standards. Certified mixtures of vinyl chloride in nitrogen and methane in nitrogen purchased from Matheson Gas Products, Cucamonga, California are used to standardize these compounds.

PURGE APPARATUS
FOR SHALLOW WATER SAMPLES

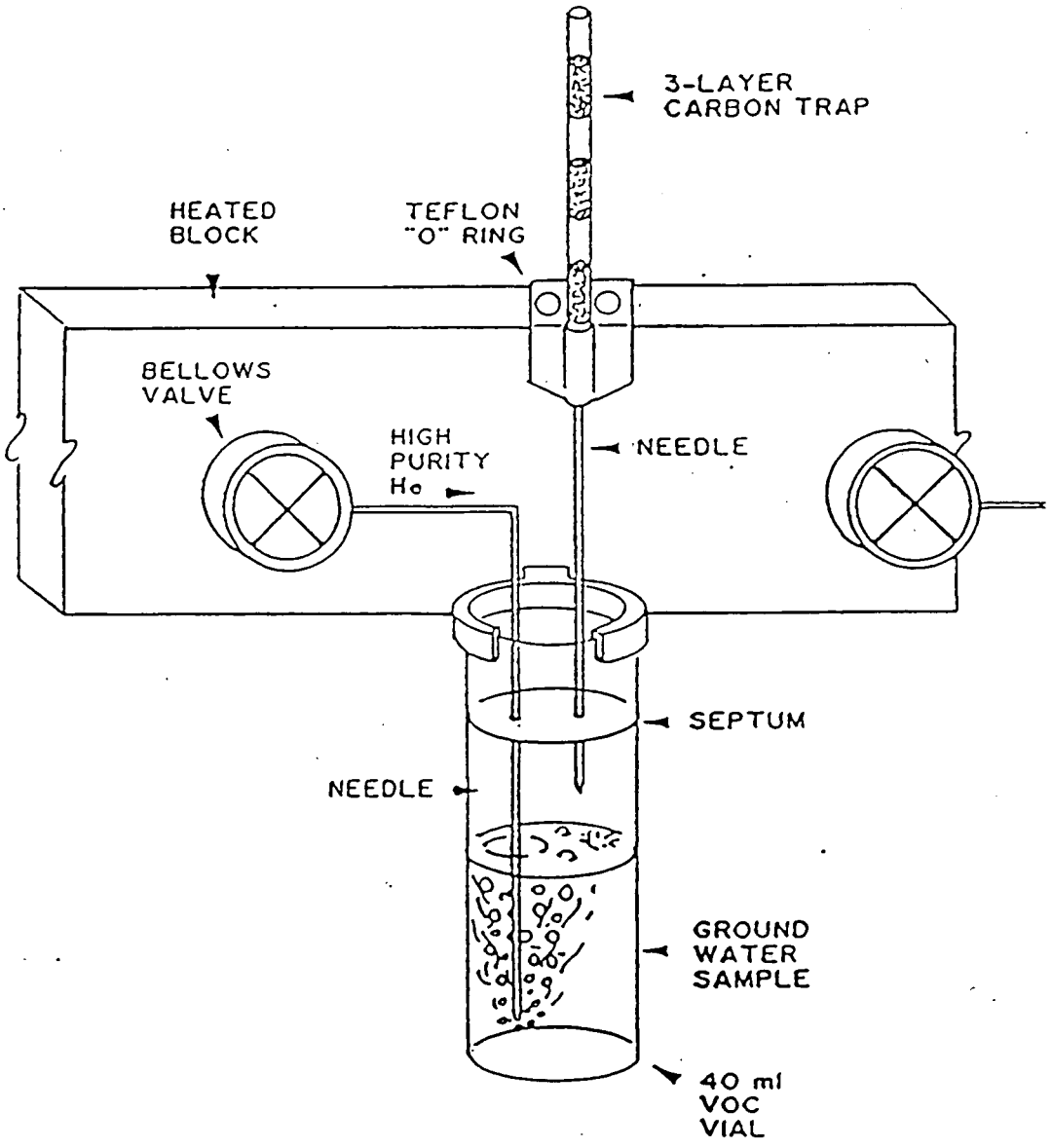

Figure 4

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2.3.6.2. VOC-free water used in purging soil samples is prepared from distilled water degassed by boiling >1 hour.

2.4 Standardization and Calibration

2.4.1. Calibration

Standards for calibration are prepared as outlined in Section 2.3.6.1. A measured volume of the standard mixture is injected into a nitrogen-filled 1-liter glass, gas bottle through a septum side port. After heating the bottle to achieve volatilization and mixing of the standards, measured volumes are extracted with a gas syringe and injected into a 200 ml/min helium gas stream leading to a carbon packed sorbtion cartridge. After 2 minutes, this cartridge is inserted into the thermal desorber and analyzed exactly as the samples.

The amount of the standard stock solution injected into the gas bottle and the type of gas injection used are dependent upon the required mass of analyte. A set of calibration standards containing the method analytes and internal standard in the range of 0.05 µg/l to 500 µg/l based on a 200 ml soil gas sample are analyzed as outlined in Section 7 of the QAPP.

Area response versus the concentration injected of each analyte and the internal standard are tabulated. Response factors (RF) for each analyte is calculated.

Spectra Physics calculation of RF is:

$$RF = A_s(C_{is})/A_{is}(C_s)$$

where A_s = area of analyte to be measured

A_{is} = area of internal standard

C_{is} = concentration of internal standards, µg/l

C_s = concentration of analyte, µg/l

Varian 3400 calculation of RF

$$RF = C_s(A_{is})/A_s(C_{is}) \times 10{,}000$$

A calibration curve is prepared for each analyte. If the RF is constant (SD less than ±15%) over the working range, the average RF is used.

New calibration curves are generated as needed or every three months.

2.4.2. Standardization

Analysis of a standard is performed at the beginning of each day. Daily standards are prepared in the same manner as the calibration standards (Section 2.3.6.1).

The amount of injected standards shall be in the range of 0.1 to 1 μg which corresponds to soil gas analysis of 200 ml samples to 0.5 to 10 μg/l, for atmospheric samples of 2000 ml, to 0.05 to 1 μg/l, and for water, to 5 to 100 μg/l. These standards shall be analyzed at least three times. If the area of any analyte varies from the response determined by the calibration curve or the average RF by greater than ±20%, the system is recalibrated. A standard having similar detector response to that observed during analysis of field samples is run after every tenth sample. When water is to be analyzed, two water standards containing a concentration in the range of 20 μg/l are prepared by injection of a stock standard into VOC vials half filled with VOC-free water.

2.5 Quality Control

2.5.1 System Blank

2.5.1.1 Soil Gas

A random selected sampling cartridge is analyzed daily to demonstrate that interferences from cartridges or the analytical system are under control. If interference is found at unacceptable levels, an unpacked cartridge is analyzed to determine if the interference is due to the cartridge or to the

analytical system. Appropriate measures are taken to eliminate such interferences.

2.5.1.2. Water

At the beginning of each day, the chemist fills a sampling container with reagent water and proceeds to handle it as an actual sample is handled in order to demonstrate that the system and water are interference-free. If VOC's are detected, appropriate measures will be taken to correct the problem.

2.5.1.3. Soil

System blanks are unable to be performed on soil because interference-free soil is not available and the procedure is not feasible.

2.5.2 Field Blanks

2.5.2.1 Soil Gas

Prior to each day's soil gas or atmospheric sampling, field blanks of the entire sampling apparatus are taken and analyzed to check background contamination in the sampling system and cartridges. Sampling cartridges are attached to both the inlet and outlet end of a sampling probe. The sample collected in the discharge end cartridge is representative of sampling train

contamination only while the intake cartridge provides a measure of the atmospheric concentrations. Additional field blanks are collected prior to any reuse of recleaned sampling equipment.

2.5.2.2. Water

A sampling container will be filled with interference-free water in the field in the same manner as water samples are collected. This sample, now designated as a field blank, is returned to the laboratory for analysis. If VOC's are detected, sample collection procedure will be reviewed. If necessary, sampling equipment will be thoroughly decontaminated.

2.5.2.3. Soil

Collection of field blank soil samples is not feasible due to the nature of the matrix and because interference-free soil is not available.

2.5.3 Duplicate Samples

Duplicate soil gas, atmospheric, or shallow groundwater samples are collected from each sampling location. Duplicate analyses are performed on at least 10% of the samples collected, or if the initial analysis is outside QA specifications. Duplicate analyses are not performed on soil samples because it would require homogenization of the sample, tend to release

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volatiles from the sample, and therefore, limit the accuracy of the results.

2.5.4 Trip Blanks

2.5.4.1. Soil Gas

An unused sample cartridge is transported into the field with the sampling equipment. The trip blank cartridge is handled in the same manner as a sample, but a sample is not collected through this cartridge. The trip blank is returned to the lab with the other samples and analyzed. If VOC's are detected, sample handling and transport procedures are subsequently reviewed. If no VOC's are detected, this cartridge is also used as a system blank.

2.5.4.2. Water

A sampling container is filled with water determined to be interference-free and taken into the field. The trip blank container is handled in the same manner as other water samples but is not used to collect an actual sample. The trip blank is then returned to the laboratory for analysis with the other samples. If VOC's are detected, sample handling and transport procedures are reviewed and sampling equipment is decontaminated as necessary.

2.5.4.3. Soil

Trip blanks for soil sampling are not used because uncontaminated soils without background levels of organics are not available and the trip blank procedures are not feasible.

2.5.5. Matrix Spike Duplicate

2.5.5.1. Soil Gas

The standard calibration procedure for soil gas analysis, the matrix being the activated carbon in the sample collection cartridges only, accounts for matrix spike duplicates.

2.5.5.2. Water

Once per day a duplicate field sample is with a calibration standard of known concentration. This spiked sample is then processed and analyzed in the same manner as all samples. The difference between the reported concentration per compound and the concentration of the spike are then compared to the previous analysis of the unspiked sample duplicate.

2.5.5.3. Soil

Because a spike cannot be effectively and uniformly distributed throughout a soil sample, matrix spike duplicates are unreliable indicators and therefore not collected.

2.5.6 Chromatographic Information

On the first page of each day's chromatograms, the following system parameters are noted:

A) Gas flows for H_2, N_2, and air

B) Tank pressures for H_2, N_2, and air

C) Temperatures
   1. Injector
   2. Columns
   3. Detector
   4. Thermal desorber oven
   5. Thermal desorber transfer lines
   6. Thermal desorber desorption temperature and duration

D) Integrator parameters

   1. Attenuation
   2. Peak markers
   3. Baseline offset

E) Column(s)

   1. Type
   2. Length and diameter
   3. Packing material
   4. Temperature

F) Operator

G) Date

If any system parameters change, the chromatograms shall be stamped and changes noted.

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2.5.7 Internal Quality Control

All chromatograms are reviewed internally by a chemist other than the chemist performing the analysis.

2.5.8 Outside Quality Control Audits

Samples are sent to independent laboratories for analysis periodically as a quality assurance check.

2.5.9 Sample Chain of Custody

All samples are labeled with the following information:

1) Sample identification number
2) Date and time of sample collection
3) Name of sampler

In addition to labeling the samples, a field data/chain of custody form is completed in duplicate for each sample (Figure 5). At the time of sample collection, the field sampler signs the custody form and records the date, time and other pertinent information. The sample is then transferred to the laboratory, where the individual receiving the sample for analysis signs the original custody form and records the date and time. This Soil Gas Field

Figure 5

HYDRO GEO CHEM, INC. SAMPLE INFORMATION AND TRANSFER FORM
-- Original to Mobile Lab -- Copy Kept in Field Notebook

Location #:_____ Sample #:_____ Data Base File:_____

Location Description:_____

Sampler (Signature):_____Soil?__Water?__Soil Gas?__Atmospheric?__

Weather:_____ Barometric Pressure:_____

Wind Direction/Speed:_____ Air Temp (°F):_____

Surface Conditions:_____ Soil Temp (°F):_____

Time/Date:_____ Cartridge(s)#:_____

Probe Depth:_____ Probe #:_____ Probe Volume:_____

Adapter #:_____ Cylinder #:_____ Vacuum Gage Reading:_____

Sample Size:_____ Pump Flow Rate & Duration:_____

Purge Flow Rate & Duration:_____ Notes:_____

_____

Lab Receipt: (Signature):_____ Time/Date:_____

Compound Analyzed	Measured Concentration (µg/l) 1st	2nd	Chromatogram #
DCM			
Chloroform			
CCl_4			
VCl			
1,1 DCE			
trans-1,2 DCE			
cis-1,2 DCE			
TCE			
PCE			
1,1 DCA			
1,2 DCA			
1,1,1 TCA			
Benzene			
Toluene			
Ethylbenzene			
Xylenes			

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Data Sheet (Chain of Custody Form) is then filed in a notebook with the hard copy of the analytical results and eventually becomes part of the the final evidence file. The copy is retained in the field notebook.

2.6 Procedures

2.6.1 Typical chromatographic equations are summarized in Section 2.7.

2.6.2 The system is calibrated daily as described in Section 2.4.1.

2.6.3 Water Samples

Approximately half of the water sample is disposed of and the vial resealed. This sample is weighed to determine volume and purged with 200 ml/min N_2 for 10 minutes. The purged volatile compounds are trapped on a carbon packed desorption cartridge.

2.6.4 Soil Samples

Soil samples collected for in-house analysis are placed in a water bath (90°C) after being well agitated. These samples are purged in the same manner as water samples. The samples are weighed before purging to determine sample mass.

2.6.5 Gas Samples

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The thermal desorption tubes on which the samples are collected are placed in the thermal desorber and heated to 380 ±4°C with a helium flow of 20 ml/min. at the same time that the GC temperature program is initiated and data acquisition started. The trapped materials are desorbed and carried through the heated transfer lines to the GC columns where separation occurs (Figure 3).

2.7 Calculations

2.7.1 Each analyte in the sample chromatogram is identified by comparing the retention time of the suspect peak to retention times generated by the calibration standards on the appropriate detector. When applicable, the relative response of the alternate detector to the analyte is determined. The relative response should agree to within 20% of the relative response determined from the standards.

2.7.2 Quantitation is usually performed on the detector which exhibits the greater response if both detectors respond to an analyte. In cases where greater specificity or precision would result, the analyst uses his/her professional judgement in determining the alternate detector.

2.7.3 The concentration of the unknowns is determined by using the calibration curve or by comparing the peak height or area of the unknowns to the peak height or area of the standards as follows:

$$C_u = A_u/A_{is} \times C_{is}/RF$$

where C_u = concentration of the analyte in sample in $\mu g/l$

C_{is} = concentration of the internal standard in $\mu g/l$

A_u = peak area of the analyte

A_{is} = peak area of the internal standard

RF = relative response factor

2.7.4 The results for the unknown samples are reported in $\mu g/l$. The results are rounded off to the nearest 0.01 $\mu g/l$ or 2 significant figures.

94-DME-152J

APPENDIX GT.9B
WALSH STANDARD OPERATING PROCEDURES FOR OBTAINING SOIL GAS AND SOIL SAMPLES, AND VOLATILE ORGANIC COMPOUND ANALYSIS OF AIR AND SOIL GAS SAMPLES BY THERMAL DESORPTION AND GAS CHROMATOGRAPHY/MASS SPECTROMETRY

WALSH STANDARD OPERATING PROCEDURES FOR OBTAINING SOIL GAS AND SOIL SAMPLES, AND VOLATILE ORGANIC COMPOUND ANALYSIS OF AIR AND SOIL GAS SAMPLES BY THERMAL DESORPTION AND GAS CHROMATOGRAPHY/MASS SPECTROMETRY

1.0 REFERENCES

1.1 Test Methods for Evaluating Solid Waste, SW-846, third edition, Volume 1B: Laboratory Manual, Physical/Chemical Methods, Method Numbers 5030, 8000, and 8260.

1.2 Methods for the Determination of Organic Compounds in Drinking Water, EPA-600/4-88/039, Revised July, 1991: Method 524.2.

1.3 Compendium of Methods for the Determination of Organic Compounds in Ambient Air, EPA/600/4-89/017, June 1988: Methods TO-1, and TO-2.

2.0 SCOPE AND APPLICATION

This method is used for the detection and quantification of organic compounds collected in air sampling tubes, particularly vadose zone soil-gas samples. This SOP serves as a guideline for the analyst but does not take the place of a proper training program.

3.0 SUMMARY OF METHOD

Measured volumes of air or soil gas samples are and passed through adsorbent traps where the volatile analytes are deposited. Each trap is sealed and delivered to the laboratory. This trap is heated and back-flushed with carrier gas to desorb the analytes and carry them onto a cryogenically cooled trap. The cryo-trap is then headed and the analytes are driven onto a chromatographic column. These analytes are subsequently detected by a mass selective detector. Compounds are identified by their mass spectra and comparison of relative retention times with those of a calibration standard. They are quantified using relative retention times with those of a calibration curve. Analytes quantified at or above the statistically determined detection limits.

4.0 SAMPLE HANDLING, PRESERVATION, AND REPORTING

4.1 Samples are collected on Carbotrap 300 traps and sealed within glass tubes which are provided. Refer to the WALSH Soil Gas Sampling Procedure for further details.

4.2 Samples must be analyzed within 14 days of collection.

4.3 Samples from the Rocky Flats Soil gas survey in conjunction with Jacobs Engineering Group will be analyzed within 4 days of collection.

4.4 Analytical data will be reported to Jacobs Engineering Group by both electronic means (computer diskette) and hard copy on a twice a week basis.

5.0 SAFETY

5.1 Many of the analytes are known carcinogens. Precautions should be taken with all samples and standards such that they are considered carcinogenic.

5.2 Solvent resistant gloves and safety glasses are required when handling carbon trap samples and standards.

5.3 Standards and solvents must be handled only in an operable fume hood.

5.4 Avoid contact with solvents and standards.

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5.5 Refer to the WALSH Health and Safety Plan for further details.

6.0 INTERFERENCES

6.1 Airborne contamination in the form of extraction solvents present a major problem. A minimum of one reagent blank should be run during the course of daily sequence, and all interfering compounds be quantified.

6.2 Carry-over contamination of the thermal desorber and gas chromatographic systems present a more controllable problem than airborne contamination, especially when samples with any individual compounds higher than approximately 3 µg/L. Thorough bakeout of thermal desorber and sample tubes will alleviate this problem. If encountered, these high level samples should be immediately followed by a blank.

7.0 APPARATUS AND EQUIPMENT

7.1 Sample Preparation

7.1.1 Gas Tight Syringes - Assorted sizes.

7.1.2 Static Dilution Flasks - 1.0L.

7.1.3 Adsorbent Traps - Carbotrap 300 or equivalent.

7.2 Thermal Desorption System - System consisting of thermal desorption device, cryogenic trap, and heater. Designed to accept 7 inch x 0.25 inch sample tubes.

- Tekmar Aerotrap 6000 or equivalent.

7.3 Gas Chromatograph

7.3.1 Analytical system complete with gas chromatograph suitable for thermal desorption sample introduction.

- HP-5890 or equivalent.

7.3.2 Capillary Column (equivalent acceptable)

- DB-VRX; J&W Scientific; 0.33mm x 60m, 1.8 µ film thickness.

7.3.3 Detector

- Mass Spectrometer - HP 5972 or equivalent.

7.4 Data Collection - Data system capable of acquiring and storing raw data from the mass spectrometer.

- HP Vectra 486/66U or equivalent.

7.5 Data Reduction - Software capable of reducing raw data into hard copy and electronic media for reporting to the Jacobs Engineering Group.

- HP Enviroquant Software for GC/MS or equivalent.

7.6 Miscellaneous

7.6.1 Drying Oven.

7.6.2 Freezer.

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7.6.3 Refrigerator.

7.6.4 Analytical Balance.

7.6.5 Ultra High Purity Helium.

7.6.6 Liquid Nitrogen.

8.0 REAGENTS

8.1 Methanol (Purge and Trap Grade Methanol)

9.0 STANDARDS

9.1 All standards must be less than 2 years old. Stock standards and unopened standards in methanol are stored in the freezer at less than 0° C. Working standards should be made up as needed.

9.2 Initial and Daily Calibration

9.2.1 502.2/8260 Analyte List (equivalent acceptable)

- Restek VOACYL III - 2.5 µg/ml in nitrogen.

- Restek Custom 502.2 Calibration Mixes #2-6 - 20,000 µg/ml in methanol.

9.3 Internal Standard (equivalent acceptable)

9.3.1 Restek Custom 8260 Internal Standard Mix - 20,000 µg/ml in methanol.

9.4 Surrogate Standard (equivalent acceptable)

9.4.1 Restek Custom 8260 Surrogate Standard Mix - 20,000 µg/ml in methanol.

9.5 Laboratory Control Standard (LCS)/Matrix Spiking Solution (equivalent acceptable)

- Restek Custom VOA Matrix Spike Mix - 20,000 µg/ml in methanol.

9.6 Standard Preparation: Working standards are prepared by injecting high concentration standard solutions #2 - #6 into a precleaned 1L static dilution bottle with glass beads. The contents of the VOACYL III may be injected directly onto the adsorbent rap. Prior to instrument calibration the dilution bottle should be heated to 65°C and shaken to evaporate all liquids.

10.0 PROCEDURE

10.1 Preparation

10.1.1 Thermal desorption tubes must be conditioned at 375°C for a minimum of 8 hours prior to use.

10.1.2 Liquid Nitrogen must be available for cryo trap.

10.2 Instrument Conditions

10.2.1 Typical Aerotrap Conditions

- Tekmar Aerotrap 6000

Sample Sweep Time: 4 minutes

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Sample Sweep Condition:	Pre-Cool
Sample Desorb Temperature:	30°C
Sample Desorb Time:	8 minutes
Sample Tube Bake Temperature:	375°C
Sample Tube Bake Time:	8 minutes
Cryo Trap Temp:	-190°C
Trap Desorb Temperature:	240°C
Trap Desorb Time:	4 minutes
Trap Desorb Preheat:	200°C
Trap Bake Temperature:	260°C
Bake Time	6 minutes
Cryo Trap:	#19-Glass Beads

10.2.2 Typical Gas Chromatograph Conditions

- DB-VRX Column

Carrier:	Helium
Electronic Pressure Control Conditions:	Varied (See Below)
Initial Temperature:	40°C
Initial Time:	8 minutes
Oven Program Rate:	8°C/minute
Final Temperature:	230°C
Final Time:	2 minutes
Total Run Time:	32.75 minutes

- Electronic Pressure Control Conditions

Initial Pressure:	12.6 PSI
Initial Time:	0 minutes
Pressure Program Rate 1:	99 PSI/minute
Pressure 2:	50 PSI
Time 2:	0.25 minutes
Pressure Program Rate 2:	99 PSI/minute
Pressure 3:	12.6 PSI
Time 3:	7.04 minutes
Pressure Program Rate 3:	0.57 PSI/minute
Pressure 4:	26.2 PSI
Time 4:	0.89 minutes

10.2.3 Typical Detector Operating Conditions

- Mass Spectrometer: HP 5972	Scan (2.2 scans/second)
Acquisition Mode:	35-350 AMU
Mass Range:	
Tuning Criteria:	
Tune Evaluation Standard:	4-Bromofluorobenzene
Mass Intensities:	
Mass 50:	15 to 40% of mass 95
Mass 75:	30 to 60% of mass 95
Mass 95:	base peak
Mass 96:	5 to 9% of mass 95
Mass 173:	<2% of mass 174
Mass 174:	>50% of mass 174
Mass 175:	5 to 9% of mass 174
Mass 176:	95 to 101% of mass 174
Mass 177:	5 to 9% of mass 176

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10.3 Daily Quality Control Preparation

10.3.1 Daily Calibration Standard: A standard verification of the initial calibration curve must criteria for SPC and CC Compounds

- From a known concentration Static Dilution Bottle which has been heated to 65°C draw a known amount of air standard.
- Inject directly into clean air sampling tube.
- From a second Static Dilution Bottle which has been kept under the same conditions, draw a known amount of Internal/Surrogate standard mix and inject onto the same trap.
- From a VOACYL III stored at room temperature draw an aliquot of the gases and inject onto the trap.
- Desorb and analyze trap contents for instrument calibration.

10.3.2 Daily Reagent Blank: Blank samples used to quantify system contamination. A minimum of one reagent blank should be run in the course of a daily sequence. Blanks should contain less than the reporting limit for all analytes with the exception of common laboratory contaminants (methylene chloride, acetone, toluene).

- Draw 250 µg/L of IS/SS into a Gastight syringe from a heated Static Dilution Bottle.
- Connect clean, conditioned sample tube to air pump and being flow.
- Transfer IS/SS into air sampling tube.
- Desorb and analyze trap.

10.3.3 Laboratory Control Standard (LCS): Standard which contains the parameters of interest is used to judge overall system performance and stability. Only used for EPA level 3 - 5 data.

- Draw 250 µL of IS/SS and 250 µL of LCS into Gastight syringes from heated Static Dilution Bottles.
- Connect clean, conditioned sample tube to air pump and being flow.
- Transfer IS/SS and LCS into air sampling tube.
- Repeat for LCS 2.

10.3.4 Matrix Spike: Sample which is spiked with the LCS solution is run to show any matrix interference problems that may exist with a particular sample. An MS should be performed once for every 20 samples and for every matrix present in a sample set. Matrix spikes are run only when EPA level 3 - 5 data is specified.

- Draw 250 µL of LCS into Gastight syringes from heated Static Dilution Bottles.
- Connect sample tube containing a sample to air pump and begin flow.
- Transfer IS/SS and LCS into air sampling tube.

10.4 Sample Preparations:

- Draw 250µL of IS/SS into a Gastight syringe from a heated Static Dilution Bottle.
- Connect sample tube containing a sample to air pump and being flow.

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- Transfer IS/SS into air sampling tube.

11.0 CALIBRATION

11.1 A three point calibration curve is used to determine the linear range of the GC/MS for EPA levels 1 and 2. A five point curve is used when EPA levels 3 - 5 are required. The calibration curve determines the working range of the instrument thus the low standard should be within 5 - 10 times the instrument detection limit. Response factors (RFs) and retention times are tabulated using computer data system.

- Typical Calibration Analyte amounts:

  - 0.100 µg, 0.500µg, 1.00µg, and 2.00µg for a 3 point curve.

  - 0.100µg, 0.200µg, 0.500µg, 1.00µg, and 2.00µg for a 5 point curve.

11.2 Calibration Acceptance Criteria

11.2.1 Using data collection software, tabulate RFs and retention times. Calculate linear fits to the calibration curve.

11.2.2 All parameters must meet the quality control criteria listed in the quality control section.

12.0 CALCULATIONS

12.1 Relative Response Factors (RRF):

$$RRF = \frac{\text{(Conc. Int. Standard [µg/l] (Area Analyte)}}{\text{(Area Int. Standard) (Conc. Analyte [µg/l]}}$$

12.2 Analyte Concentrations:

$$Conc. = \frac{\text{(Area Analyte) (Conc. Int. Standard)}}{\text{(Area Int. Standard) (RRF) (Dilution Factor)}}$$

13.0 QUALITY CONTROL

13.1 Daily reagent blanks are run to verify the cleanliness of the system. Blanks should contain less than the reporting limit for all analytes with the exception of common laboratory contaminants (methylene chloride, acetone, toluene).

13.1.1 If blanks contain analytes other than common laboratory contaminants at a concentration greater than the reporting limit, they must be re-prepared and re-analyzed to meet the requirements.

13.1.2 If blanks contain common laboratory contaminants at a concentration greater than the reporting limit, the reporting limit will be raised by two times the blank concentration.

13.2 The initial calibration must have a minimum of five points for each analyte if EPA levels 3, 4, or 5 are required, or three points if EPA levels 1 or 2 are necessary. The calibration curve should define the working calibration range. The maximum percent relative standard deviation of the curve for CCCs must not exceed 50%. The minimum relative response factor for SPCCs must not be lower than 0.200 (0.150 for Bromoform).

If all requirements for the initial calibration are not met, a new initial calibration must be run until all requirements are met.

13.3 A daily calibration standard is run to verify the initial calibration curve every 12 hours of instrument operation. SPCCs must have a minimum RRF of 0.200 (0.150 for Bromoform) and CCCs must have a maximum %RPD of 50%.

13.3.1 If any analyte is out of the acceptable recovery range, the calibration standard must first be re analyzed.

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13.3.2 If any analyte is consistently out of the acceptable recovery range, corrective action should be taken to determine the root of the problem and a new initial calibration curve should be run and the daily calibration standard should be re analyzed.

13.4 For EPA levels 3 - 5 an LCS containing the parameter of interest should be run for every 20 samples analyzed. Use laboratory generated control limits to initiate corrective actions.

$$RPD = \frac{[(\text{Initial Sample Result} - \text{Duplicate Sample Result}) * (100)]}{\text{Average of the Two Results}}$$

13.4.1 If the LCS has any analyte out of the acceptable recovery range, it must be re analyzed.

13.4.2 If any analyte is consistently out of the acceptable recovery range, a new stock solution of LCS should be opened and analyzed. If any analyte remains out of the acceptable recovery range, a new initial calibration should be run and the LCS must be re analyzed.

13.5 For EPA levels 3 - 5 one matrix spike and duplicate must be run for every 20 samples analyzed. Recoveries should fall within laboratory defined control limits.

13.5.1 When the analyte concentration is three times the spike concentration or greater, the spike recovery is not reported because it exceeds the calibration range.

13.5.2 Matrix spike recoveries which are out of the acceptable range are evaluated by the analyst and noted in the raw data file. No actions are taken unless determined otherwise by an experienced analyst.

13.6 Internal standard recoveries for all samples and spikes should fall within -50% to +100% of the daily continuing calibration.

13.6.1 If a sample internal standard recovery is out of the acceptable recovery limits, the sample should be re-analyzed.

13.6.2 If a sample is re-analyzed and the internal standard recovery is still out of the acceptable recovery range, the data should be reported and matrix interference should be noted in the raw data file.

13.7 Surrogate standard recoveries for all samples and spikes should fall within 40% to 180% of the daily continuing calibration.

13.7.1 If a sample surrogate standard recovery is out of the acceptable recovery limits, the sample should be re-analyzed.

13.7.2 If a sample is re-analyzed and the surrogate recovery is still out of the acceptable recovery range, the data should be reported and matrix interference should be noted in the raw data file.

13.8 Samples must be analyzed within the 14 day holding time which begins on the date of sampling.

13.8.1 If holding times are exceeded, results are considered unusable for regulatory work.

13.8.2 For non-regulatory work, detection limits and positive results are considered estimated values and the holding time exceedance is noted in the raw data file.

13.9 The laboratory established retention times should be used as a guide for identification of analytes. Analytes should fall within +/- 0.05 of the daily continuing calibration standard relative retention times. Internal standards should fall within 0.5 minutes of the retention times in the continuing calibration standard.

13.9.1 If an analyte falls outside of this retention time window, a qualified analyst should determine if the analyte should be reported.

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13.9.2 Analyte retention times are updated daily with the daily calibration standard and throughout the run using the internal standard as reference peaks.

13.10 Refer to the most recent detection limit study for analyte reporting limits.

13.11 For EPA level 3 - 5 data trip blanks should be prepared by conditioning and sealing thermal desorption trap in the lab and have it accompany a set of traps out into the field. Upon it's return the trip blank should be analyzed to determine whether or not there exists any cross-contamination.

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Table 1

System Performance Check Compounds (SPCC)

Chloromethane
1,1-Dichloroethane
Chlorobenzene
Bromoform
Bromobenzene

Continuing Calibration Check Compounds (CCC)

Vinyl Chloride
1,1-Dichloroethene
1,2-Dichloropropene
Toluene
Ethyl Benzene

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Table II

EPA Data Quality Levels

Level 1:	Field screening or analysis using portable instruments. Results are often not compound specific and not quantitative but results are available in real time.
Level 2:	Field analysis using sophisticated analytical instruments; in some cases the instruments may be set up in a mobile or on-site laboratory. a wide range in the quality of data can be generated. Quality depends on the use of suitable calibration standards, reference materials, and sample preparation equipment; and the training of the operators. Results are available in real time to several hours.
Level 3:	Analyses performed in an offsite analytical laboratory using standard documented procedures. The laboratory may or may not be a CLP laboratory.
Level 4:	CLP routine analytical services. All analyses are performed in an offsite CLP laboratory following CLP protocols.
Level 5:	CLP data and evidence of adherence to protocols is provided to agency or client.

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SOIL GAS SURVEY AND SHALLOW SOIL SAMPLING
APPENDIX B
TARGET ANALYTE LIST

Acetone
Benzene
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
n-Butylbenzene
sec-Butylbenzene
tert-Butylbenzene
Carbon disulfide (708)
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
2-Chlorotoluene
4-Chlorotoluene
Dibromochloromethane
1,2-Dibromo-3-chloropropane
1,2-Dibromoethane
Dibromomethane
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethene
cis-1,2-Dichloroethene
trans-1,2-Dichloroethene
Dichloromethane (728)
1,2-Dichloropropane
1,3-Dichloropropane
2,2-Dichloropropane
1,1-Dichloropropene
Ethylbenzene
Hexachlorobutadiene
Hydrogen sulfide (687)
Isopropylbenzene
Methane (687)
Methylene chloride
Methyl ethyl ketone (1,415)
Napthalene
n-Propylbenzene
Styrene
1,1,1,2-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethene
Toluene
1,2,3-Trichlorobenzene
1,2,4-Trichlorobenzene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
1,2,4-Trimethylbenezene
1,3,5-Trimethylbenzene
Vinyl chloride
o-Xylene
m-Xylene
p-Xylene

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Note: Compounds listed with numbers in parentheses are compounds not detectable using the 502.2 method. The numbers in parentheses indicate the number of analyses for the particular compounds that are required. All other compound analyses will total 1,578 by EPA 502.2. The Subcontractor shall propose appropriate methods to detect the additional compounds at the specified detection limits.

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Category 2	Organization:	Environmental Management

TITLE:
BOREHOLE CLEARING

Approved By: _____ 5/12/92
(Name of Approver) (Date)

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for clearing drill sites and intrusive work sites within Individual Hazardous Substance Sites (IHSSs). Geophysical clearing will be implemented to ensure that selected locations are free of buried metal objects to a depth of 18 feet and metal utility lines. This SOP describes geophysical administrative clearance techniques, and geophysical data reduction and analyses that will be used for field data collection and documentation.

The geophysical techniques that are employed involve electromagnetic (EM) techniques, a magnetic locator, and ground penetrating radar (GPR). EM and magnetic surveys can be used for identifying areas where subsurface metal objects might be located. The techniques indicate contrasts in conditions due to variations in the electrical conductivity or magnetic properties of subsurface materials. GPR is useful for detection of shallow variations in the subsurface dielectric constant.

A magnetic locator can be used when the clearing depth-of-interest is 18 inches or less. EM techniques and a magnetic locator will both be used when the clearing depth-of-interest is deeper than 18 inches. Generally, GPR is applicable to depths of 0-6 feet at the RFP site.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Oversight and supervision of the geophysical surveys will be conducted by EG&G personnel. Project staff performing these surveys will be trained geophysicists or trained personnel with a significant amount of geophysical field experience. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

The subcontractor's project manager is responsible for obtaining administrative borehole clearance.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

RCRA Facility Investigation Guidance. EPA. Interim Final. May 1989.

4.2 INTERNAL REFERENCES

A related SOP cross-referenced by this SOP is:

- SOP GT.18, Surface Geophysical Surveys

5.0 GEOPHYSICAL EQUIPMENT AND PROCEDURES

5.1 INTRODUCTION

Borehole clearing using geophysical methods will be employed within an IHSS where buried trenches are known to exist or where buried metal may be present. Surface geophysical surveys have been conducted at the RFP. Research of these previous geophysical surveys should be exhausted prior to conducting the following procedures.

Instruments used for geophysical clearing will be recalibrated and recertified, if required. The date of the manufacturer's last calibration and certification will be documented on the Borehole Clearing Analysis Form (Form GT.10A).

Each instrument will have a field calibration check prior to and after field use. Personnel performing the field calibration check should refer to the manufacturer's instructions. An example of a field calibration check would be to use the instrument over a known buried object. If the instrument does not respond appropriately, the instrument should be returned to the manufacturer for recalibration and recertification.

Geophysical methods have limitations which must be considered when implementing a geophysical survey. In some instances, the limitations may be sufficient to make the geophysical results ambiguous or non-conclusive. Therefore, it is imperative that an experienced geophysical operator conduct the clearing of boreholes.

Electromagnetics, magnetics, and GPR are influenced by surface cultural features, such as fences, power lines, and metallic debris. These cultural effects can be mitigated by the use of a directional magnetic locator, which responds to a magnetic gradient. However, if borehole clearing is being performed within 40 to 50 feet of a cultural feature, reliable geophysical clearing may be difficult to achieve. In cases where a site cannot be definitively cleared, the location will be moved to the nearest clearable location.

5.2 ELECTROMAGNETICS

An EM survey can be used to detect ferrous and nonferrous metals as well as areas of high inorganic contamination. This method involves the induction of electrical current into the ground. A small alternating current passing through a transmitter coil produces a primary magnetic field. Through inductive coupling, the primary magnetic field produces small eddy currents in the

subsurface which, in turn, create their own secondary magnetic field. The receiver coil senses both the primary and secondary fields. This results in an output voltage that is linearly related to the terrain conductivity. The instrument then converts the voltage to a ground conductivity value which can be recorded by a strip recorder or digital logger. Electrical conductivity is a function of the soil or rock composition, the porosity and permeability of the rock units, and the conductivity of the fluids filling the pore spaces. The conductivity values are subsequently plotted on a map so that their variation over the site can be analyzed.

A Geonics EM-31, EM-38, or equivalent ground conductivity meter will be used for the EM surveys. Through the use of the horizontal dipole mode (HDM), the EM-31 has a depth penetration to 9 feet. When deeper penetration is required, the vertical dipole mode (VDM) will be used in addition to the HDM. This scenario will provide high resolution detection of objects to 9 feet and will allow detection of larger metal objects to 18 feet. The size of a metal object that can be detected is proportional to the depth of burial. For shallow investigation (less than 9 feet), the HDM provides the greatest resolution and can normally detect objects as small as a 1-foot length of rebar. By monitoring the in-phase component of the induced magnetic field, small amounts of subsurface metal can be detected. For high resolution of depths less than 5 feet, the EM-38 can be used. Table GT.10-1 summarizes instrument modes and applications.

Table GT.10-1
EM INSTRUMENT MODE APPLICATION

Instrument	Mode	Depth of Penetration (ft)	Approximate Size of Detected Object
EM-31	HDM	9	1-foot piece of rebar
	VDM	18	Steel drum
EM-38	HDM	2.5	
	VDM	5	

5.2.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete an EM survey:

- A Geonics EM-31, EM-38, or equivalent terrain conductivity meter
- Digital logger and/or analog strip recorder (when data collection is over large grid area)
- Appropriate health and safety equipment
- Wood stakes or lath
- Flagging
- Field notebook
- Black waterproof (permanent) pens
- Form GT.10A, Borehole Clearing Analysis (see Section 7.0, Documentation).

5.2.2 Field Procedure

A standard field procedure for conducting an EM survey is initiated by a reconnaissance survey of each drill site. The survey will involve a review of existing magnetic data at the site, a review of the site utility plans, an acknowledgement from the telephone and utility site locators that the site is clear of these utilities, and a field check for overhead wires, pipes, or other objects that may restrict drilling operations. Note surface conditions of the site on Form GT.10A (see Section 7.0, Documentation) including excessive and/or large metal objects on the ground surface and large variations in topography. Following the instrument manufacturer's instructions, initiate a site survey traverse on an approximate 1-foot grid, clearing a minimum of 6 feet around the drilling location stake. When anomalous values indicative of buried metal are observed, record the anomaly on Form GT.10A. If an anomaly is not present, document the results on Form GT.10A.

Drilling locations with anomalous values will require moving the location to the nearest "clear" area. By using the above procedures, determine an area within 50 feet of the original drilling location that is free of anomalies. Mark the new drilling location with a wood stake and document the new location on Form GT.10A. Notify the project site manager of the new location.

For larger areas or for locating buried trenches or pits, follow a surveyed grid pattern when traversing with the EM instrument. If the grid is not surveyed prior to the EM traverse, place a wood stake marker at the end of each traverse and document the marker location on the field data record (Form GT.10A). All EM traverses should be documented on a field map during the survey. For larger areas, a portable computer may be required to quickly analyze the data and facilitate the location of additional survey lines.

5.3 MAGNETIC LOCATOR

A magnetic locator detects magnetic fields associated with certain objects. The depth of investigation depends on the size of the object. The Schonstedt magnetic locator, for example, can detect well casings up to 15 feet deep; however, a 1 1/4-inch nail can be detected only to a depth of 8 inches.

A magnetic locator responds to the magnetic gradient between two magnetic field sensors (A and B). If no anomalies exist, the magnetic field between sensors A and B is balanced, and a 40 Hz frequency signal is heard on the magnetic locator's audio output. This frequency output (40 Hz) is the ambient magnetic field of the earth. However, when the magnetic field becomes stronger at sensor A (located at the bottom of the locator) than at sensor B, the output signal increases in frequency. When the tip of the locator is directly over the ferrous object, the audio signal increases to its highest frequency.

5.3.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete a geophysical survey:

- Schonstedt Model GA-52B magnetic locator or equivalent
- Appropriate health and safety equipment
- Wood stakes or lath
- Flagging
- Field notebook
- Black waterproof (permanent) pens
- Form GT.10A, Borehole Clearing Analysis (see Section 7.0, Documentation)

5.3.2 Field Procedure

The field procedures for a magnetic survey are the same as the procedures described for the EM survey (Subsection 5.2.2).

5.4 GROUND PENETRATING RADAR

Ground penetrating radar (GPR) has been used for mapping shallow geologic interfaces, delineating shallow bedrock, locating voids in concrete or limestone, and finding buried pipeline or reinforcement bars.

GPR involves a system that transmits electromagnetic pulses into the ground from an antenna near the surface. These pulses are reflected from a variety of subsurface interfaces back to a receiver. As the antenna is towed along a survey line, the GPR signals are processed and displayed on a graphic recorder. The displayed data is a two-dimensional continuous profile along the surveyed

line depicting time versus distance. The display is very similar to a geologic section, except that the record is a time section rather than a depth section.

GPR has excellent resolution of subsurface features when favorable conditions exist. However, actual depth penetration is highly site-specific and depends on the near-surface soil conductivity. Highly conductive soils, such as clays, can reduce penetration to less than three feet. Less conductive materials, such as limestone, will allow depth penetration of 30 - 50 feet.

5.4.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete a GPR survey:

- GSSI SIR System-3 or equivalent radar system
- Flagging
- Lath or wooden stakes
- Field notebook
- Black waterproof (permanent) pens
- Tape measure (200 feet minimum) (Note: for relatively smooth surfaces, a measuring wheel can be substituted)
- Extra paper for profile recorder
- Extra stylus(s) for profile recorder

- Form GT.10A, Borehole Clearing Analysis (See Section 7.0, Documentation)

5.4.2 Field Procedure

A standard field procedure for collecting GPR data is described below. Prior to GPR data collection, two preliminary procedures must be conducted. These are:

- Design appropriate field parameters, given the purpose of the survey (orientation of lines or grid, grid spacing, frequency or antenna, antenna shielding, etc.).

- Locate endpoints along each line in addition to any other points of interest, and denote these locations in the field with lath or other wood stakes.

Design of appropriate field parameters must consider the following:

- The antenna and associated transmitter frequency used must optimize the penetration depth and required resolution given the survey purpose. Typical frequencies are 80 Mhz, 100 Mhz, 120 Mhz, 300 Mhz, 500 Mhz, and 1000 Mhz. Higher frequency antennas allow greater subsurface resolution, but penetration is reduced over that of lower frequencies. To optimize results, surveys should be designed to have a minimum of two antenna frequencies available. For most clearing applications, a 300 Mhz or 120 Mhz antenna will be appropriate.

- For grid areas, intraline spacing affects resolution; a spacing of 2 to 20 feet is commonly used for clearing applications. Actual spacing chosen must consider overall project objectives.

- Method of antenna towing must be evaluated given the site conditions. For smooth surfaces or terrain, the antenna can be towed directly on the surface. For areas with significant vegetation or surface stones and rocks, the antenna may need to be suspended 6-18 inches above the ground or carried in a plastic non-conductive wagon to prevent antenna damage and potentially dubious GPR data collection.

- Antenna shielding will be considered and appropriate shielding provided given the site conditions. Surface features such as fences, power lines, etc. can cause interfering reflections on the radar record.

A standard field procedure for conducting a GPR survey is described below.

1. Perform a visual survey along the proposed lines. The visual survey will include a review of site utility plans; check for overhead wires; check for manhole covers, buried cables, buried gas line indicators, or cased monitoring wells; and have site locators confirm the presence of any possible telephone and utility features. Note features in the field notebook.

2. In the field notebook, note excessive amounts of large pieces of metal on the ground surface.

3. In the field notebook, note large nearby variations in topography or building (within 50 feet).

4. Note moisture content of surveyed media, in addition to relative clay content, as these will affect penetration depths.

5. Conduct a test line using manufacturer's procedures. Instrument settings must be optimized to obtain appropriate data given project goals. Specific recording parameters that must be optimized include, but are not limited to, the following:

- Radar scan speed
- Signal range gain
- High and low pass filter settings
- Time range for recording
- Transmitter pulse rate
- Recording printer speed
- Antenna towing speed

Instrument settings should be varied during the test line to determine the optimum recording parameters. When possible, the test line should be conducted over a known buried feature in the survey area to help instrument setting optimization, and help calibrate penetration depths.

6. Initiate site survey traverse. Beginning at the GPR line endpoint, tow the antenna along the line with appropriate speed determined from test line, and use optimum instrument settings determined from the test line. Continue the above procedure for the entire line and subsequent grid lines.

7. If hard copies of each line of data from the printer are made, label all notations on the record to correspond to notes made in the field notebook, including recording parameters.

8. Permanent copies of this GPR data must be retained digitally on tape or disk, or on hard copy plots.

5.5 DATA ANALYSIS

When the anticipated hazards are isolated pieces of metal, borehole locations will be cleared to a minimum of 6 feet around the drilling location stake. In these cases, data will not be retained for later analysis, but the results will be documented on Form GT.10A. If an anomalous area within 6 feet of the borehole location stake is identified, the borehole location will be changed to an anomaly-free area within 50 feet of the original borehole location to minimize the possibility of contact with any anomalous material below the surface.

When the hazard is buried trenches or pits, larger areas will have to be geophysically surveyed to clear borehole locations. In these cases, electromagnetic data will be collected with a digital data logger. The data will be transferred to a personal computer for analysis. Adjustments to the boring location (if required) will be made after the data are analyzed and interpreted.

In both of the above cases, Form GT.10A will be used to document the procedures and reasoning for the relocation or approval of a borehole location.

At all times, geophysical data will be collected and interpreted in a conservative and prudent manner. Additionally, appropriate levels of caution will be exercised by all field crews involved in intrusive activities, even on geophysically "cleared" boring locations.

6.0 ADMINISTRATIVE BOREHOLE CLEARANCE

Administrative borehole clearance will be required for drilling operations at the RFP and will consist of excavation authorization. Copies of the required forms are included in Section 7.0, Documentation.

6.1 RADIOLOGICAL WORK PERMIT

Radiological work permits will be required for drilling operations in Radiologically Controlled Areas, which may include IHSSs. These permits will be issued by the Radiological Engineering Department. These permits will remain valid until completion of the work for which the permit was issued.

Daily work permits will be required for drilling operations within the Protected Area (PA).

The Radiological Work Permit will be kept at the drill site in the contamination reduction or support zone.

6.2 SOIL DISTURBANCE ASSESSMENT AUTHORIZATION

Operations involving drilling or excavating will require approval from the Soil Disturbance Assessment Committee prior to beginning work.

Initiation of the process begins by contacting the EG&G Environmental Operations Division and completing the Soil Disturbance Assessment Committee Evaluation Form (see Section 7.0, Documentation) with the project-specific information.

Approval by the Soil Disturbance Assessment Committee is required for each project and will be valid for a period of 60 days.

A copy of the approval form will be kept at the work site in the contamination reduction or support zone.

A Land Use Request Form (see Section 7.0, Documentation) will be required for excavation and/or drilling work in the RFP buffer zone.

7.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting field observations and data. The date of the manufacturer's most recent calibration and certification will be documented if this information is available. Field calibration checks, geophysical observations, and data will be documented on the Borehole Clearing Analysis Form (Form GT.10A). Administrative clearances will be documented on the Environmental Management excavation authorization. The Soil Disturbance Assessment Committee Evaluation Form and Land Use Request form are attached.

BOREHOLE CLEARING ANALYSIS

Project Name: _____

Date: _____ Operator: _____

Survey Type: _____ Instrumentation: _____

Date of Last Calibration and Instrument Certification: _____

Field Calibration Dates: _____

Location (Borehole ID and Coordinates, if Available)	Surface Condition	Max. Depth of Interest (Ft)	Anomaly Present (Y/N)	Comments or Action

Completed By: _____
Print Name Signature Date

Subcontractor: _____

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT

SOIL DISTURBANCE ASSESSMENT COMMITTEE EVALUATION FORM

The purpose of this information is to assist the committee in identifying the potential hazard(s) associated with this soil disturbance.

REQUESTOR: Name _____ Group _____ Phone/Pager _____

JOB TITLE: _____ CHARGE # _____

Will the disturbance occur in or near an INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS, formerly SWMU)? _____

Are overhead utilities present? _____

Are underground utilities present? _____

Will a utility outage be required? _____

IS THE EXCAVATION FOR:

Trenching _____ Sampling _____ Driven rods/posts _____

Grounding _____ Post holes _____ Other types _____

IF SAMPLING: Soil removal by hand? _____ Drilling? _____

Depth of drilling _____ Diameter _____

IF CONSTRUCTION:

Hand digging only? _____

Will mechanical equipment be required? _____ What type? _____

Depth of excavation _____ Length of excavation _____

Width of excavation _____ Will shoring be required? _____

Requestor shall fill out this form and submit it along with information required in SOIL DISTURBANCE GUIDELINE to EXCAVATION ADMINISTRATOR.

R.J. LaBorde
T130F
X2538, D-0719

After completion the Excavation Package will be forwarded to FE for utility determination. The package must then be signed by FE, EM, and CS. A copy of the Excavation Package will be included as an appendix in the Integrated Work Control Package.

Prior to the start of work, the Excavation Specialist will survey the jobsite for utility interferences and give a field briefing to the supervisors and workers. The briefing will give details on any known hazards and/or precautions. The Excavation Package and/or the Integrated Work Control Package (IWCP) will then be signed by the Excavation Specialist.

The Excavation Specialist is responsible for inspecting the site daily when personnel entry is required. Upon completion of the inspection, the person that performed the inspection will initial the Rocky Flats Soil Disturbance Approval Form (see attached). This form will be maintained with the IWCP as part of the Excavation Package.

DOCUMENT MODIFICATION REQUEST (DMR)

PAGE 1 of 1

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures)

INFORMATION ONLY

1. Date	25. DMR No.
11-18-93	93-DMR-000962

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.11, R2	N/A

4. Originator's Name/Phone/Pager/Location	5. Document Title
P. A. Kiefer, X8698, 080	Plugging and Abandonment of Wells

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one): ☐ New ☐ Revision ☒ Intent Change SUPD 12-16-93 ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	3	4.2	Add reference as identified on attached.
2	12	9.0	Change requirements of Well/Borehole Abandonment Form as identified on attached
3	FORM GT.11A (rev.2)		Eliminate. Information will be recorded on GT.5A (rev.3)

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Eliminate GT.11A (rev.2), as all information will be recorded on GT.5A (rev.3) which is a combination of GT.5A(rev.2) , and GT.11A(rev.2).

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.D. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	T. P. Lovseth	11-22-93
SM	P. A. Kiefer	11-18-93
EQS	M. C. Brooks	12-3-93

16. Originator's Supervisor (print/sign/date): D. D. Stagg 22Nov93

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
T. P. Lovseth	3003	ENV-GT	12/7/93	1-10-94

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review: ORC Review Not Required

24. Responsible Manager (print,sign,date): Stephen H. Sluger 12/17/93

27 RF-47940 (5/93)

REVIEWED FOR CLASSIFICATION / UCNI
BY NA 12/6/93

DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions.
Print or Type All Information (Except Signatures) INFORMATION ONLY

1. Date	25.
March 31, 1994	DMR. No. 94-DMR-000561 SUPI 5.6.94

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.11/Rev2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
J.A. Paschis/x8644/NA/080	Plugging and Abandonment of Wells

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	2	2.0	Add the following two paragraphs at the end of Section 2.0: This procedure also establishes the administrative requirements for incorporation of the State of Colorado, Department of Natural Resources, Office of the State Engineer, Division of Water Resources, Rules and Regulations, 2CCR 402-2 into well abandonment activities. Prior to beginning any plugging and abandonment procedures, the Project Manager shall notify Environmental Science and Engineering, Geosciences Division. This prior notification will allow for the final opportunity to perform any necessary sampling and/or hydrologic measurements.
2	3	4.1	Modify the following reference to include the CCR number: Colorado Division of Water Resources, Board of Examiners of Water Well Construction and Pump Installation Contractors. Revised and Amended Rules and Regulations of the Board of Examiners of Water Well Construction and Pump Installation Contractors, 2CCR 402-2. 1988. 29pp.
3	12A	9.0	Add the following paragraph at the end of Section 9.0: The Well/Borehole Abandonment Form No. (GT.5A, Rev. 3) and a State of Colorado, Well Abandonment Report (State of Colorado, Form No. GWS-9, 7/89) will be completed and provided to the ERM Geosciences Division. The Geosciences Division will submit the Form No. GWS-9 to DOE for review, approval, and transmittal to the State of Colorado, Division of Water Resources.
4	12A	10.0	Add the following new section: **10.0 APPENDIX** Following well abandonment, the individual/company responsible for plugging the well will provide the information disclosed on the form in Appendix 1, as requested to comply with Section 9.0.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. Provide information about state requirements for well abandonment activities.
2. Expand reference to state regulatory statute relative to well abandonment.
3,4. Provides information of type of documentation and where to file forms.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	Tim Lovseth Tim O'R Lovseth	4/8/94
EQS	Mark Brooks	4-28-94
RPM	Wanda Busby	4/12/94
EOM	Marla Broussard	4/15/94
ETT	Gary Anderson Gary Anderson	29 APR 94
SPP	Steve Keith	4/18/94

16. Originator's Supervisor (print/sign/date)
Stephen H. Singer Stephen H. Singer 4/7/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
Tim Lovseth/8706/5134/080	0202	ENV-GT	03/21/94	5.6.94 SUPI

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
Not required; this nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print, sign, date)
Mark E. Levin 4/29/94 M.E. Levin

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

INFORMATION ONLY

PLUGGING AND ABANDONMENT OF WELLS

EG&G ROCKY FLATS PLANT EMD MANUAL OPERATION SOP	Manual: Procedure No.: Page: Effective Date:	5-21000-OPS GT.11, Rev. 2 1 of 12 05/06/94
Category 2	Organization:	Environmental Management

TITLE:
PLUGGING AND ABANDONMENT OF WELLS

Approved By:
/S/ J.E. Evered 3/2/92
(Name of Approver) (Date)

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1.0 TABLE OF CONTENTS 1
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Category 2	Organization:	Environmental Management

APPENDIX

WELL ABANDONMENT REPORT, STATE OF COLORADO FORM NO. GWS-9, 7/89 . . . . . 12B

LIST OF EFFECTIVE PAGES

Pages	Effective Date	Change Number
1A	01/10/94	93-DMR-000962
2	05/06/94	94-DMR-000561
3	05/06/94	94-DMR-000561
3A	01/10/94	93-DMR-000962
12	01/10/94	93-DMR-000962
12A-B	05/06/94	94-DMR-000561
Form GT.11A	01/10/94	93-DMR-000962
Appendix 1	05/05/94	94-DMR-000561

TOTAL NUMBER OF PAGES: 16 (including appendix)

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to plug and abandon (P&A) wells. Plugging refers to the physical process of filling the well cavity with grout while abandonment refers to the completion and documentation of all requirements of this SOP. Abandonment involves plugging the well with grout and all related activities and documentation as described in this SOP. For the purpose of this SOP, a well is defined as a ground penetration intended for monitoring the chemical, physical or potentiometric properties of groundwater, a ground penetration intended for production of groundwater, or a ground penetration of unknown status. Abandonment of boreholes, which are defined as ground penetrations drilled primarily for obtaining geologic and environmental information, is addressed in SOP GT.5, Plugging and Abandonment of Boreholes.

This procedure also establishes the administrative requirements for incorporation of the State of Colorado, Department of Natural Resources, Office of the State Engineer, Division of Water Resources, Rules and Regulations, 2CCR 402-2 into well abandonment activities.

94-DMR-00056

Prior to beginning any plugging and abandonment procedures, the Project Manager shall notify Environmental Science and Engineering, Geosciences Division. This prior notification will allow for the final opportunity to perform any necessary sampling and/or hydrologic measurements.

3.0 PERSONNEL QUALIFICATIONS

Personnel overseeing the abandonment of wells will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Nielsen, and J.E. Denne. Handbook of Suggested Practices for the Design and Installation of Ground Water Monitoring Wells. EPA 600/4-89/034. National Water Well Association. 1989. 398 pp.

Colorado Division of Water Resources, Board of Examiners of Water Well Construction and Pump Installation Contractors. Revised and Amended Rules and Regulations of the Board of Examiners of Water Well Construction and Pump Installation Contractors, 2CCR 402-2. 1988. 29 pp.

U.S. Environmental Protection Agency. RCRA Ground Water Monitoring Technical Enforcement Guidance Document. Office of Solid Waste and Emergency Response. OSWER-9950.1. 1986. 317 pp.

U.S. Environmental Protection Agency. Manual of Water Well Construction Practices; Office of Water Supply. EPA-570/9-75-001. 1975. 156 pp.

94-DMR-000561

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.6, Handling of Personal Protective Equipment

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
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Category 2	Organization:	Environmental Management

- SOP FO.7, Handling of Decontamination Water and Wash Water
- SOP FO.8, Handling of Drilling Fluids and Cuttings
- SOP FO.10, Receiving, Labeling, and Handling Environmental Materials Containers
- SOP FO.11, Field Communications
- SOP FO.14, Field Data Management
- SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques
- SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing
- SOP GT.4, Rotary Drilling and Rock Coring
- SOP GT.5, Plugging and Abandonment of Boreholes
- SOP GT.10, Borehole Clearing

93-DMR-60062

5.0 EQUIPMENT AND PROCEDURES

Several field activities will be conducted in the process of well abandonment that are addressed in other SOPS, primarily within Volume I -- Field Operations and Volume III -- Geotechnical.

5.1 MATERIALS AND EQUIPMENT

The following materials and equipment may be used:

- Drill rig and associated equipment
- Reduced pH bentonite grout (American Colloid "Pure Gold", or approved equivalent).
- Concrete
- Portable metal tanks for concrete flushing and mixing
- High pressure steamer/spray
- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Drums for containment of borehole effluent and sediment
- Weighted tape measure
- Mirror

- Spotlight
- Health and safety monitoring equipment and personal protective equipment according to the Health and Safety Plan
- Well plugging and abandonment form

5.2 PROCEDURES

Equipment for plugging and abandoning boreholes will be used according to the pertinent requirements of SOP GT.2, Drilling and Sampling Using Hollow-Stem Auger Techniques and SOP GT.4, Rotary Drilling and Rock Coring. These requirements include use of contaminant-free lubricants only, and visual monitoring of equipment for hydraulic and/or fuel or oil leaks. All procedures will be conducted according to the Site Health and Safety Program Plan. If necessary, project-specific requirements will be addressed in a project-specific work plan.

Several methods of well abandonment are addressed in the following sections. Selection of the appropriate method of abandonment for a given well must be addressed in the project-specific work plan, based on information compiled for the well. Factors to be considered in selecting the abandonment method include:

- Casing material
- Casing condition
- Diameter of casing and borehole
- Type and quality of original seal
- Depth of the well
- Plumbness of the well
- Hydrogeologic setting

- Location and type of zone(s) where contamination occurs

The method selected for well abandonment should be consistent with the following purposes of well abandonment:

- Prevention of groundwater and soil contamination via the well
- Prevention of intermixing of subsurface water via the well
- Conservation of hydraulic characteristics of hydrogeologic units
- Minimization of physical hazards

Regardless of the method selected for well abandonment, all wells will have the original pad removed (if present) at the start of abandonment operations. Concrete well pads will be monitored for chemical and radiological contamination. Contaminated areas will be marked with paint sticks and then the pads will be broken up using appropriate tools, such as sledge hammers, pick axes, or jackhammers, in such a way as to isolate the contaminated areas. The underside of the pad will then be monitored for chemical and radiological contamination and all contaminated areas will be marked as above. All uncontaminated materials from well pads will be sent to the landfill. All contaminated materials will be decontaminated in the field. After decontamination, the materials will be monitored and clean material will be sent to the landfill. Material that is not monitored as clean will be stored in drums on pallets at the site pending further characterization. Drums will be labeled as per SOP FO.10 Receiving, Labeling, and Handling Environmental Materials Containers.

5.2.1 Abandonment Requiring Casing Removal

If casing removal is specified in the work plan, four methods may be considered:

- Casing pulling
- Casing destruction

- Overdrilling
- Overcoring

5.2.1.1 Casing Pulling

Casing may be pulled using hydraulic jacks or the lifting capabilities of the drilling rig. A vibration hammer may also be used to augment the pulling. A high viscosity bentonite drilling mud may be placed in the casing to minimize collapse of the borehole walls as the casing is pulled. After the casing has been pulled, the borehole must be reamed to a diameter larger than the original hole to remove the annular materials in order to promote a good seal between the borehole wall and the new grout.

5.2.1.2 Casing Destruction

Destruction of the casing can be accomplished by drilling out the casing in place. Either hollow-stem auger or rotary drilling methods may be appropriate. A pilot bit or guide attached to the lead auger or tricone bit is advanced within the well casing as a guide in drilling out the casing. A high viscosity bentonite drilling mud may be placed in the casing and periodically added as the boring is advanced. Thorough removal of the annular grout should be undertaken, either by drilling the boring to approximately the same diameter as the original borehole, or by reaming the borehole to destroy the casing after making the initial run.

5.2.1.3 Overdrilling

For the purpose of this SOP, overdrilling refers to the use of hollow-stem augers to drill around the well casing. The hollow-stem auger should have an inside diameter of at least two inches larger than the well casing, and the auger flights should be at least the same diameter as the original borehole. The augers will be drilled to the full depth of the original boring. If possible, the casing will be pulled

with the augers in place. If the casing should become stuck within the hollow stem, water may be forced down the casing and out the screen in an attempt to free the casing. If this procedure fails, the casing must be pulled simultaneously with the augers. Reaming will be necessary after the casing is pulled to remove any remaining annular materials and debris.

5.2.1.4 Overcoring

For the purposes of this SOP, overcoring refers to the use of drilling equipment to overcore the well casing with a core bit. The core bit should have an inside diameter at least two inches greater than the outside diameter of the well casing. The casing will be overcored to its total depth and pulled prior to or simultaneously with the drill rods. The boring will then be reamed to a diameter larger than the original hole to remove annular materials and debris.

5.2.2 Abandonment Without Casing Removal

If specified in the work plan, the well may be abandoned with the casing left in place. Wells which do not penetrate a confined hydrostratigraphic unit (HSU) may be grouted as addressed in Subsection 5.2.3. Wells penetrating more than one aquifer or contaminant zone may also be abandoned with the casing left in place. If, however, documentation of the well does not clearly indicate that the casing opposite each confining layer or between two contaminant zones has been properly grouted, or if the well is otherwise known to be nonviable due to absent or inadequate grouting, the casing in such intervals must be perforated or ripped. These intervals will require pressure grouting.

5.2.3 Grouting

Unless specified in the work plan due to site-specific conditions, grout shall consist of American Colloid Company "Pure Gold" grout, or approved equivalent, mixed in a powered mechanical grout mixer according to the manufacturer's recommendations. The grout will contain at least 30 percent

solids by weight and have a minimum density of 9.9 pounds per gallon after mixing. A mud balance will be used to check grout density prior to pumping for each borehole. Grout will be emplaced by pumping through a tremie pipe or drill stem, with the bottom end of the pipe always being maintained below the top of the grout slurry within the well. It is advantageous to begin the grouting process with hollow-stem augers or temporary casing in the borehole, removing sections as the grouting progresses in order to minimize borehole collapse. Grout should be applied in as nearly as continuous a procedure from bottom to top as is practical to minimize segregation, dilution and bridging problems. If possible, the tremie pipe should be kept near the bottom of the well, and the grouting continued until it is purged from the borehole undiluted.

To abandon wells in HSUs with high permeability, clean sand may be placed by tremie pipe up to the static water level (in unconfined HSUs) or to the confining layer (in confined HSUs). A seal of hydrated bentonite will be placed above the sand. After allowing sufficient time for the hydration of the bentonite seal, the well will be grouted to the surface as described above.

5.2.4 Surface Protection

If casing is left in place, a water-tight cover must be permanently fixed to the top of the casing. Remaining casing may be cut off a minimum of one foot below ground level provided the permanent cover is attached and original surface contours are restored.

For all wells, concrete will be placed above the top of the bentonite grout, after allowing sufficient time (24 hours minimum) for the grout to set. This concrete should extend three to five feet below the ground surface. At the surface, the concrete will consist of a slab, shaped within a concrete form at least six inches thick (vertical dimension), with a diameter no less than two feet greater than the diameter of the well. The form should be dug slightly into the ground so that the surface of the finished concrete slab will be one or two inches above the ground surface. Welded wire fabric (10-gauge or heavier 6-inch x 6-inch) shall be placed at mid-depth in the slab.

When the concrete slab is semi-hard, a stainless steel or aluminum plate with well ID and date of abandonment will be anchored to the surface of the slab. The date on which abandonment of the well was completed will also be written in the surface of the concrete while semi-hard.

6.0 EQUIPMENT DECONTAMINATION

Pertinent decontamination procedures described in SOP FO.3, General Equipment Decontamination, and SOP FO.4, Heavy Equipment Decontamination, will be followed. Decontamination and wash water will be handled according to SOP FO.7, Handling of Decontamination Water and Wash Water.

7.0 HANDLING AND STORAGE OF MATERIALS

The materials removed as part of the well abandonment process will include:

- Large solids (e.g., lengths of semi-intact well casing)
- Small solids (e.g., drill cuttings, old grout, destroyed well casing)
- Liquids (e.g., drilling fluids, excess grout and formation water)

The following describes the methods which will be followed to handle and store these materials.

7.1 CASING

Casing pulling, overdrilling, and overcoring will result in the recovery of intact lengths of casing from the borehole. Casing will be cut into manageable (e.g., 20 feet) lengths as it is removed from the borehole and further cut into sections no more than 5 feet. The casing will be screened for radionuclides and volatile organic compounds (VOCs). The casing will be cleaned with a brush to remove major dirt and/or debris.

All casing determined to be above any VOC or radiological background level will be wrapped in plastic sheeting or plastic bags, taped shut, and transported to the central decontamination station. The casing will be decontaminated using a high pressure, hot-water washer.

After cleaning and/or decontamination, the casing will be screened and stacked into piles on plastic tarp and covered with another tarp until routed for the appropriate method of disposal.

7.2 SMALL SOLIDS AND SEMI-SOLIDS

These materials (e.g., small pieces of casing, concrete, drill cuttings, etc.) will be handled according to SOP FO.8, Handling of Drilling Fluids and Cuttings.

7.3 LIQUIDS

Liquids displaced from the borehole during grouting will be collected and handled according to SOP FO.5, Handling of Purge and Development Water, and SOP FO.8, Handling of Drilling Fluids and Cuttings. This will require provisions at the ground surface to collect fluid, such as a portable "keyhole" pit or berm around the top of the borehole or casing discharging into a tank. In deep boreholes when relatively large quantities of fluids are anticipated, more elaborate measures such as grading the area and constructing lined pits, may be required to control displaced environmental materials. This will be addressed in a project-specific work plan.

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM GT.11A (REV. 2)

WELL PLUGGING AND ABANDONMENT FORM

1. **Well Specifics:**
   - a. Well Id. No. _____
   - b. Reported Well Depth (feet) _____
   - c. Field Well Depth (feet) _____
   - d. Number of Screens _____
   - e. Screened Interval(s) (feet) _____
   - f. Screen Diameter(s) (in.) _____
   - g. Screen Type(s) (SS or PVC, etc.) _____
   - h. Casing Diameter(s) (in.) _____
   - i. Casing Type (PVC, steel, etc.) _____
   - j. Stickup or Flush Mount _____
   - k. Penetrates Confining Layer(s) (Y or N) _____
   - l. Aquifer(s) Monitored _____

2. **Reason for Abandonment:**

   _____

   _____

3. **Abandonment Specifics:**
   - a. Date Abandonment Started _____
   - b. Date Abandonment Completed _____
   - c. ID Number of Field Book Used _____
   - d. Site Personnel _____

     _____
   - e. Drilling Method Used _____
   - f. Grout Used _____
   - g. Casing Removed (Y or N) _____
   - h. Metal Detection Plate Installed (Y or N) _____
   - i. Concrete Pad Inscription _____

     _____
   - j. Briefly Describe Abandonment Method:

     _____

     _____
   - k. Disposition of Materials Removed From Well: _____

     _____

4. **Comments or Problems Encountered:** _____

   _____

Completed By: _____

Print Name Signature Date

Subcontractor: _____

Attach one copy of Well Abandonment Log to this form when completed. Attach one copy of the Well Construction Log (if available) to this form when completed.

8.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance (QA) and quality control (QC) activities will be accomplished according to applicable project plans as well as quality requirements presented in this SOP.

9.0 DOCUMENTATION

93-DNR-000962

Information required by this SOP will be documented on the ~~Well Plugging and Abandonment Form (Form GT.11A), and Drilling Field Activity Daily Log or logbook~~ Well/Borehole Abandonment Form (Form GT.5A). Environmental materials handling will be documented according to SOP FO.8, Handling of Drilling Fluids and Cuttings. The information will be recorded in a logbook.. The Well/Borehole Abandonment Form will include, but not be limited to, the following information:

- Project, crew and ~~borehole identifications~~location code
- Weather conditions
- Equipment descriptions (rig, tremie, pump, etc.)
- Water level in borehole prior to abandonment (if any)
- Borehole depth/diameter
- Volume of grout placed
- Type/length/diameter of casing/screen removed
- Type/depth/diameter of casing/screen left in place
- ~~End of day status (i.e., partially complete, cap set, etc.)~~
- Chronological record of activities

93-DNR-000962

Information on Form GT.5A shall be entered into the field data capture program (Datacap) when released. See procedure FO.14, Field Data Management. Copies of the completed Well Abandonment Forms, signed by the task manager, will be delivered to the EG&G project manager.

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Category 2	Organization:	Environmental Management

94-DMR-00056

The Well/Borehole Abandonment Form No. (GT.5A, Rev. 3) and a State of Colorado, Well Abandonment Report (State of Colorado, Form No. GWS-9, 7/89) will be completed and provided to the ERM Geosciences Division. The Geosciences Division will submit the Form No. GWS-9 to DOE for review, approval, and transmittal to the State of Colorado, Division of Water Resources.

10.0 APPENDIX

Following well abandonment, the individual/company responsible for plugging the well will provide the information disclosed on the form in Appendix 1, as requested to comply with Section 9.

APPENDIX
Sheet 1 of 1

WELL ABANDONMENT REPORT
STATE OF COLORADO FORM NO. GWS-9, 7/89

FORM NO. GWS-9 7/89 | STATE OF COLORADO
OFFICE OF THE STATE ENGINEER
818 Centennial Bldg., 1313 Sherman St., Denver, Colorado 80203
(303) 866-3581 | For Office Use only

TYPE OR PRINT IN BLACK INK

WELL ABANDONMENT REPORT

ABANDONED WELL NUMBER IF REGISTERED _____

1. INDIVIDUAL/COMPANY RESPONSIBLE FOR PLUGGING

NAME(S) _____
Mailing Address _____
City, St. Zip _____
Phone ( ) _____

2. ACTUAL WELL LOCATION: COUNTY _____

PROPERTY ADDRESS _____
(Address) (City) (State) (Zip)

____1/4 ____1/4, Sec. ____ Twp. ____ ☐N. ☐S., Range ____ ☐E. ☐W. ____P.M.

Distances from Section Lines ____ Ft. from ☐N. ☐S. Line ____ Ft. from ☐E. or ☐ W. Line

3. I (we), report that an existing well was plugged and abandoned for the following reason(s):

☐ The well was plugged and abandoned as required under the conditions of approval of Well Permit No. _____

☐ The well was not in use and was abandoned.

☐ Other (please explain) _____

SAMPLE

4. The well was plugged and abandoned according to the Water Well Construction and Pump Installation Rules on _____, 19 ____.

5. The well was plugged with the following materials placed at the indicated intervals:

AMOUNT AND TYPE OF MATERIAL	METHOD OF PLACEMENT	INTERVAL
		from ____feet to ____ feet
		from ____feet to ____ feet
		from ____feet to ____ feet
		from ____feet to ____ feet
INTERVALS OF CASING REMOVED/RIPPED IN FEET		from ____feet to ____ feet
		from ____feet to ____ feet

6. I (we) have read the statements made herein and know the contents thereof, and that they are true to my (our) knowledge. [Pursuant to Section 24-4-104 (13)(a) C.R.S., the making of false statements herein constitutes perjury in the second degree and is punishable as a class 1 misdemeanor.]

Name/Title (Please type or print)	Signature	Date

– INFORMATION – It is the responsibility of the well owner to have the well properly plugged and abandoned. The well construction contractor is responsible for notifying the well owner of the plugging and abandonment requirement. This form may be reproduced by photocopy or word processing means.

INFORMATION ONLY

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.15, Rev. 2
	Page:	1 of 5
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
GEOPHYSICAL BOREHOLE LOGGING

Approved By:
[signature] 5/12/92
(Name of Approver) (Date)

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6.0 DOCUMENTATION 5
6.1 EQUIPMENT CALIBRATION 5

REVIEWED FOR CLASSIFICATION/UCNI
By [signature]
Date March 4, 1992

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for conducting downhole geophysical logging. Geophysical logging may be accomplished by employing a variety of downhole instruments. Geophysical logging methods may include, but are not limited to, temperature log, caliper log, density log, focused log, induction log, micro log, neutron log, sidewall neutron log, spontaneous potential log, acoustic log, variable density and full-waveform sonic log, dip log, gamma ray log, or collar log.

Accurate and dependable quantitative analysis of the data requires that the logging operation be of the best possible quality. The following sections describe all procedures that will be used to collect and document downhole geophysical data.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Oversight and supervision of geophysical logging operations will be conducted by an EG&G or subcontractor representative. Downhole logging is to be performed by a qualified and reputable firm with geophysical logging expertise.

Prior to any geophysical logging operation, the EG&G or subcontractor representative will contact the manager and/or supervisory operator of the logging service company to review the logging program and supply the information necessary to have all applicable equipment at the drill site when required. An appropriate suite of downhole logs will be agreed upon based on the project-specific objectives presented in the work plans. The subcontractor will have ultimate responsibility for data quality.

4.0 REFERENCES

4.1 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.16, Field Radiological Measurements

5.0 PROCEDURES

The use of geophysical logging will be discussed in the project work plans. Given the project-specific objectives and the subsurface information required, an appropriate suite of logs will be proposed and agreed upon. The EG&G or subcontractor representative will subsequently provide the logging service company with all pertinent information required to conduct the downhole logging (e.g., objectives, types of lithologies, etc.). The logging company will maintain access to any additional logging equipment requested by the EG&G or subcontractor representative and will provide the additional logging service within eight hours of the request.

The subcontractor will notify the appropriate EG&G personnel of the initiation of downhole logging activities, including Security and Radiological Engineering-approved contractor Environmental Health and Safety Specialists. Prior to entry onto the RFP, downhole instruments will be examined by Security. Particular emphasis will be placed on checking the downhole instruments that have radioactive sources. The logging service company will be required to present documentation of downhole source certification. If a radioactive source will be used, the logging truck will carry the appropriate placards, and the source container will be appropriately labeled.

When the logging service company arrives at the drill site, the EG&G or subcontractor representative will review the logging program with the logging operator and provide information necessary for completing the Borehole Geophysical Logging Form (Form GT.15A). Logging Units will be computerized and logs will be digitally recorded on tape or disk. The tapes or disks will become the property of EG&G and their final disposition will be determined at the end of the project.

Field prints of all logs will be made; no portion of the log run, including calibration steps, will be destroyed. Field prints will be collected by the subcontractor's representative at the end of each day. Every effort will be made to complete logging in one day.

The EG&G or subcontractor representative, as well as any appropriate EG&G personnel, will have access to the logging unit at all times in order to monitor logging activities. The subcontractor's field supervisor is responsible for notifying the logging company as soon as a hole is available for logging. Holes should be left open for as little time as possible. In the event of a stuck tool, every effort will be made to recover the tool. If the tool contains a radioactive source and cannot be recovered, State of Colorado guidelines will be followed in order to recover as much of the tool as possible, or the tool will be cemented in place.

After completion of logging activities in a given borehole, all logging equipment will be decontaminated in accordance with SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination. Radiation monitoring activities will be conducted by Radiological Engineering-approved contractor Environmental Health and Safety Specialists. If required, monitoring will be conducted for geophysical logging equipment and personnel before they leave the work area. All radiation monitoring will be done in accordance with SOP FO.16, Field Radiological Measurements and the Health and Safety Program Plan.

6.0 DOCUMENTATION

Logging information will be documented on the Geophysical Borehole Logging Form (Form GT.15A). Prior to releasing the logging operator, the EG&G or subcontractor representative will check these forms for completeness. Forms will be completed in the field without transcribing from a field book or other document. This technique reduces offsite work hours for the geologist or geophysicist, reduces the chance for errors in manual copying, and allows the completed document to be field-reviewed immediately after logging.

High quality, reproducible logs will be submitted by the logging service company to the subcontractor's office within 10 working days after the logging run is completed.

6.1 EQUIPMENT CALIBRATION

The geophysical logging company will calibrate all logging equipment before and after the logging run. The geophysical logging company will provide documentation to the subcontractor of all shop calibrations, surface calibrations, and calibrations performed before and after the logging run. The geophysical logging company will possess documentation of downhole instrument source certification for any radioactive tools.

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM GT.15A (REV. 2)

GEOPHYSICAL BOREHOLE LOGGING FORM

Project Name: _____

Weather Conditions: _____ Date: _____

Borehole Identification: _____

Logging Subcontractor: _____

Hole Conditions: _____
Fluid in Hole: Yes ___ No ___
Fluid Temp (°F): _____
Fluid Resistivity: _____

Casing: Yes____ No ___
Type of Casing: _____
Casing ID (In.): _____
Bit Size (In.): _____

LOG RUNS

- ☐ Induction
- ☐ Natural Gamma
- ☐ Neutron
- ☐ Spontaneous Potential
- ☐ Short-Normal Resistivity
- ☐ Long-Normal Resistivity
- ☐ Caliper
- ☐ Temperature
- ☐ Gamma-Gamma Density
- ☐ Full-Waveform Sonic
- ☐ Other _____

LOG TYPE	DEPTH (Feet)		TIME (Hour)	
	From	To	Begin	End

Comments: _____

_____

Completed By: _____
Print Name Signature Date

Subcontractor: _____

(4011-930-0073-930)(GT15REV.2)(03/02/92)

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DOCUMENT MODIFICATION REQUEST (DMR)

Refer to 1-A01-PPG-001 for Processing Instructions. INFORMATION ONLY
Print or Type All Information (Except Signatures)

1. Date	25.
March 31, 1994	DMR. No. 94-DMR- 000560 SURV 9.6.94

2. Existing Document Number/Revision	3. New Document Number or Document Number if it is to be changed with this Revision
5-21000-OPS-GT.17/Rev2	NA

4. Originator's Name/Phone/Page/Location	5. Document Title
J.A. Paschis/x8644/NA/080	Land Surveying

6. Document Type ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one)
☐ New ☐ Revision ☒ Intent Change ☐ Nonintent Change ☐ Editorial Correction ☐ Cancellation

8. Item	9. Page	10. Step	11. Proposed Modifications
1	3	5.1	Insert the following paragraph after the first paragraph of Section 5.1: and TPL 4/5/94 For surveying new well installations, not piezometers, the land surveyor will be supplied with a copy of the approved Well Installation Notification Form (GT.6A) by the requesting Project Manager. The form will be used to locate the new well site in the field and to verify the location code (well number) assigned by the Environmental Science and Engineering, Geosciences Division.
2	6	6.0	Reword the last sentence of Section 6.0 as follows: A numerical printout of all coordinates for the location code (well number) and data provided on 3 1/2" diskette along with a base map will be delivered to the Environmental Science and Engineering, Geosciences Division within ten working days of the completion of field surveying.

12. Justification (Reason for Modification, EJO#, TP#, etc.)

1. Form GT.6A provides land surveyor with general field locality and verifies controlled location code of new well requested to be surveyed.

2. Clarifies objects (well parts) to be coordinate-surveyedand revises ES&E to be receiver of survey documentation.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print and Sign (if applicable)	15. Date (if applicable)
SME	Tim Lovseth Tim Lovseth	4/6/94
EQS	Mark Brooks Mark E. Brooks	4-28-94
RPM	Wanda Busby W Busby	4/12/94
EOM	Marla Broussard Mbroussard	4-15-94
ETT	Gary Anderson Gary M Anderson	29 APR 94
SPP	Steve Keith S R Keith	4-19-94

16. Originator's Supervisor (print/sign/date)
Stephen H. Singer Stephen H Singer S. H. Singer 4/7/94

17. Assigned SME/Phone/Page/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
Tim Lovseth/8706/5134/080	0202	ENV-GT	03/21/94	6.6.94 SURV

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review
Not required; this nonintent change was processed as an intent change to expedite the DMR process.

24. Responsible Manager (print, sign, date)
Mark E. Levin M E Levin M.E. Levin 4/29/94

REVIEWED FOR CLASSIFICATION/UCNI
BY NA
DATE NA

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93D00733.DMR

INFORMATION ONLY

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Category 2	Organization:	Environmental Management

TITLE:
LAND SURVEYING

Approved By:
/s/ J. E. Evered 05/12/92
(Name of Approver) (Date)

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Pages	Effective Date	Change Number
1	05/06/94	94-DMR-000560
3-6	05/06/94	94-DMR-000560
6	09/02/93	DCN 93.01

TOTAL NUMBER OF PAGES: 6

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TITLE:
LAND SURVEYING

Approved By: /s/ J. E. Evered 05/12/92
(Name of Approver) (Date)

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LIST OF EFFECTIVE PAGES

Pages	Effective Date	Change Number
1	05/06/94	94-DMR-000560
3-6	05/06/94	94-DMR-000560
6	09/02/93	DCN 93.01

TOTAL NUMBER OF PAGES: 6

2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to perform land surveying associated with all Environmental Management (EM) activities. Accurate and dependable land surveying techniques are necessary to insure acquisition and documentation of data pertaining to the surface topography, geologic lithology, hydrogeologic and atmospheric regimes at the site. Reliable land surveying data are essential to determining accurate horizontal and vertical locations of data acquisition (sampling) points and to tie these points into established map coordinates of the surrounding area. This SOP describes procedures to be used during the preliminary placement of sampling points and land surveying requirements to accurately locate the points prior to, or after, the data acquisition event.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Oversight and supervision of the sampling point location and land surveying operations will be conducted by an EG&G or subcontractor representative. Preliminary location of the points may be performed by either EG&G or subcontractor personnel familiar with the project site and trained in the use of primary surveying equipment (e.g., Brunton compass, tape measures, plumb bobs). However, the actual land surveying activities required to document the sampling point locations for the project record will be performed by a professional land surveying subcontractor. The land surveying activities will be conducted by, or under the direct supervision of, a licensed Colorado Professional Land Surveyor.

Prior to any land surveying operation, the EG&G or subcontractor representative will schedule a meeting with himself, the cognizant plant surveyor, and the manager and/or supervisory team leader of the surveying subcontractor to review the surveying program and supply the information necessary to complete the surveying program (e.g., list and location of wells or borings to be surveyed, approximate length and location of geophysical lines, etc.). Appropriate project-specific

objectives presented in the work plans will be discussed at this time. The subcontractor will have the ultimate responsibility for surveying data quality.

4.0 REFERENCES

4.1 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP GT.6, Monitoring Wells and Piezometer Installation
- SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Excavations
- SOP GT.8, Surface Soil Sampling
- SOP GT.10, Borehole Clearing

5.0 PROCEDURES

5.1 PRELIMINARY LOCATION OF SAMPLING POINTS

The proposed locations of the data acquisition points will have been discussed in the project work plans with the locations indicated on project site maps/figures and/or described in the text. EG&G and subcontractor personnel will review the proposed sampling points prior to actual location in the field and come to final agreement regarding them.

For surveying new well installations, not piezometers, the land surveyor will be supplied with a copy of the approved Well Installation Notification Form (GT.6A) by the requesting Project Manager. The form will be used to locate the new well site in the field and to verify the location code (well number) assigned by the Environmental Science and Engineering, Geosciences Division.

94-DYR-000560

Preliminary location of the sampling points prior to sampling will be achieved by staking and flagging the points. These activities will, in most cases, be performed by the subcontractor and/or EG&G personnel and will attempt to achieve location accuracies of ± 10 feet of the proposed work plan data acquisition points. Once the sampling activity is performed, the accurate location of the sampling point(s) will be determined by precise land surveying methods.

In the following example, a soil boring sampling point is to be established to obtain split spoon samples of suspected contaminated soils in proximity of an RFP Operating Unit. The staking and flagging procedures employed for such a sampling event are representative of any data acquisition program at RFP and are presented herein to illustrate the generic procedures to be used in all EM programs. Predrilling staking and flagging will be performed as follows:

A stake and orange flagging will be placed in close proximity to the preliminary sampling point location as identified on the project map. If a more precise placement is dictated (such as to place a monitoring well directly downgradient of a buried pipe etc.), a Brunton compass and steel tape will be used. The predrilling site should be located within approximately five feet either direction of the map location and marked with a stake and orange flagging.

If the preliminary location falls in an unfavorable site, a stake and green flagging will be placed in close proximity noting footage and direction to actual preliminary site location. The EG&G project manager or designee will then make the determination as to final placement of the borehole and relocate the site with a stake and orange flagging. Each stake will have the borehole number clearly marked in permanent ink. EG&G EM staff will field check each borehole location and approve the sites prior to the initiation of drilling.

The above procedures provide satisfactory site placement accuracy to conduct data and/or sample acquisition events. All site measurements pertaining to location obtained during the event (i.e., horizontal and vertical distance offsets) are subsequently related back to this staked location. Land

surveying methods, discussed in the next subsection, are then used to precisely tie the staked location into regional surveyed databases.

NOTE: It is critical that the flagged stakes used to preliminarily locate a data acquisition site be preserved intact during and after, the sampling event until the accurate land survey of the point is completed. The stake represents the only historical reference point for the sampling event and must be protected. If the stake must be destroyed during the sampling event (e.g., a soil boring or trench is placed at the staked location), three appropriate offset stakes must be installed and documentation of the offsets (both horizontal and vertical) recorded in log books. Once a sampling event is completed, the original staked location will be reestablished and staked from this documented offset information.

5.2 FINAL LOCATION OF SAMPLING POINTS

Before the final survey begins, the EG&G or subcontractor representative will schedule a meeting with himself, the cognizant plant surveyor, and the manager and/or supervisory team leader of the surveying contractor to review the surveying program as previously clarified by the contract for surveying services. Any information needed to complete the surveying program (e.g., list and location of sample sites to be surveyed, latest plant survey control diagram to be used during the survey, site access, etc.) will be supplied. Any other specific project objectives will also be discussed.

The minimum relative accuracy for surveying will be 0.1 foot horizontally and vertically. Monitoring wells may be located to the 0.01 feet in elevation because water level measurements are usually estimated to the 0.01 foot.

Final location of the sample sites will be physically marked by setting a marked stake at the exact location. If a monument already exists, the location of the monument will be surveyed. For abandoned borehole sites, the locating point will be at the center of the grout cap. For well sites,

horizontal measurements will be taken to the well center. Three elevation measurements will be made: the elevation of the ~~grout or~~ base of the concrete apron ~~adjacent~~ (ground level) to the north side of the well casing, the elevation of the top of the well casing, and the elevation of the top of the protective casing. All elevation measurements will be made on the north side of the well.

The final locations of the sample sites will be reported in a northing, easting, elevation, description format as clarified in the contract for surveying services.

6.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting field observations and data in a bound, weatherproof field notebook with consecutively numbered pages. The original field notebook and copies will be submitted when the project is complete. A xerox copy of all associated field surveying records will be delivered with the final product as clarified by the contract for surveying services. A numerical printout of all coordinates for the location code (well number) and data provided on a 3 1/2" diskette along with a base map will be delivered to the ~~EG&G or subcontractor representative~~ Environmental Science and Engineering, Geosciences Division within ten working days of the ~~final~~ completion of field surveying.

DCN 93.01

ENVIRONMENTAL MANAGEMENT
DOCUMENT CHANGE NOTICE

INFORMATION ONLY

Procedure Number 5-21000-OPS-GT.18, Revision 2

Title	Date	DCN Number
Surface Geophysical Surveys	11/22/93 CR	5-21000-OPS-GT.18 DCN 93.02

Expires 11/22/94 Procedure Revision Required ☐ Yes ☐ No

Scope Limitation None

Item Number	Page	Step or Paragraph	Changes (Use DCN CONTINUATION SHEET for Additional Space)
1	24	5.5(new)	Add Section 5.5, Time Domain Electromagnetic Metal Detection, attached.

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

DOCUMENT CLASSIFICATION REVIEW WAIVER
PER R.B. HOFFMAN, CLASSIFICATION OFFICE
JUNE 11, 1991

Justification (Reason for Change - Provide Numbers to Reference Corresponding Items Above)

Previous geophysical surveys conducted in areas located near overhead powerlines (e.g., the IHSS 133 group in OU5) were unsuccessful in defining the extent of pits and trenches due to interferences from the powerlines. The TDEM method is capable of detecting buried metallic materials without interference from the powerlines.

Concurrence	Organization	Req	Date	Concurrence	Organization	Req	Date
[signature]	QAPM	X	11/2/93	[signature]	User	X	10/20/93
[signature]	EQS	X	10/28/93	[signature]	USER		10/20/93
[signature]	EQS	X	10/28/93				

Approval of Responsible Manager	Date	Is Posting Reqd? ☐ Yes ☐ No	If Yes, By What Date?	Date Posted
[signature] for W.S. Busby	20-Oct-93			

DCN Form 001

NOV 22 1993

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5.5 Time Domain Electromagnetic Metal Detection

5.5.1 Introduction

EM61

The time domain electromagnetic (TDEM) metal detection method, is a newly developed (1993) method of providing a rapid means of determining the existence of surface and buried metallic objects. The method is superior to the magnetic method because it is sensitive to all types of metals. By use of electromagnetic induction and a small transmitting coil, a time varying current is produced. When this current is shut off, eddy currents are induced in the subsurface, both in conductive buried objects and the surrounding soils and fill materials. The receiver coils measure late in time such that currents in the soils have dissipated and currents are only remaining in highly conductive buried objects. It is the voltage associated with the currents remaining in buried objects that are measured by the TDEM metal detector. Thus, the TDEM metal detector, the Geonics EM61, can provide information about the existence of metallic objects in the subsurface, and may also provide the extent and an estimation of the depth of burial of metallic objects. The instrument can provide information about the lateral extent of buried metallic objects, in the presence of power lines and other cultural features.

This section of the SOP specifies procedures for surveys utilizing the Geonics EM61. The instrument utilizes a single transmitter with a frequency of 75 hertz. A square current waveform is used with equal periods of on and off time. Measurements of secondary voltage are measured and recorded in 2 coils spaced 40cm apart at 450 microseconds after turn off. In addition, the x and y position of the measurement is recorded such that profiles or contours of the measured voltages can be constructed. Algorithms are currently being developed attempting to provide an estimate of the depth of buried metallic objects.

5.5.2 Survey Design

5.5.2.1 List of Necessary Equipment

RR 10/28/93

The following is a list of equipment that will be necessary to complete the TDEM metal detector survey:

- Geonics EM61 TDEM Metal Detector
- Digital data logger
- Measuring tapes
- Wooden stakes or lath and environmentally safe marker paint

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- Flagging
- Survey compasses
- Field notebook and pens

5.5.2.2 Field Procedures

JRE 10/24/93

A standard field procedure for conducting the EM61 survey is described below. Prior to data collection, two preliminary procedures must be conducted. These are:

- Design the appropriate field parameters given the purpose of the survey.

- Survey the locations of the baseline and positions along the lines at an appropriate distance (to be determined in the field) using wooden stakes, lath or marker paint. On the wooden stakes or lath, coordinates of the grid will be marked.

Design of appropriate field parameters will consider the following:

- Spacing between stations determines the degree of resolution achievable; a spacing of 10 to 100 feet is commonly used: however, spacing as small as 2 feet may be required for extremely shallow targets or to aid in lateral resolution in very complex environments. Actual station spacing of the EM61 measurements can easily be chosen as small as .6 feet due to the configuration of the measuring wheel and data logger.

- For grid areas, interline spacing affects resolution; a spacing of 5 to 25 feet is commonly used. Spacing of as little as 2.5 feet is possible.

- The definition of an anomaly with EM61 ~~are~~ is RE 10/28/93 any reading above background. Background should be near zero. A single anomalous point reading can indicate a small metallic object near the surface. However this one point may be insignificant under the scope of the project. Pin flags from previous surveys can cause an anomaly. For the purpose of defining pits or trenches, more than 3 continuous readings above background may indicate an anomalous area which could be associated with burial of metallic objects. It will be the judgement of the interpreter to determine what types of anomalies are significant for meeting the survey objectives.

A standard field procedure for conducting the EM61 TDEM metal detector survey consists of :

1. Assemble and check instrument, battery and function. The instrument is factory calibrated and also has an auto nulling feature when the instrument

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is turned on. Because of the sensitivity of the instrument, measuring in nannovolts, the null reading can be +/- several nannovolts. This is monitored by the operator during the survey.

2. Initiate the site survey traverse with the EM61 following the manufacturer's recommended procedures. Establish line and station increments in the data logger and begin collection of data.

3. Perform a visual survey along the proposed lines, this can be done prior to or during the survey. The visual survey will include a check of any feature (fences, surface metal, survey monuments, well heads, etc.) that could cause an anomaly. If a previous visual survey has been completed, notes or a map may be used as a guide, and additional features that may have been placed since the previous survey will be noted on the map or in the field notebook. These features can be noted by the EM61 survey operator or an assistant. RR 10/28/93

4. The data is automatically recorded in the data logger and visually monitored by the operator. A summary of lines covered during the survey is maintained by the operator or an assistant in the field notebook.

5. Data stored on the EM61 data logger is transferred to a PC computer when the memory is full or at the end of a survey session.

6. Check line and station coverage from dumped data files versus notes. Correct errors in line numbers or station numbers. Correction of errors is documented in the field notebook.

5.5.3 Data Processing and Interpretation

A standard procedure for processing and interpretation of the EM61 data is described below.

1. Collected data is downloaded from the data logger and input into a data handling program. The data is checked for validity by checking data statistics and then entered into a data processing program which can construct profiles or contour maps. The preliminary maps are constructed on the computer monitor and visually checked for validity. If data errors are noted, they are corrected at this time in the handling program, or the data may be repeated in the field if necessary. Correction of errors is documented in the field notebook.

2. If necessary, apply decorrugation filters to remove corrugation effects caused by alternating direction of line survey.

3. Construct final data maps, usually contour maps. If necessary, produce individual detailed maps of each identified anomalous area. RP 10/28/93

4. Identify lateral extent of each anomalous area on a base interpretation map.

5. If algorithms are developed, construct depth to top of object maps of anomalous areas.

6. Develop report detailing the following:

   - field procedures
   - interpretation techniques
   - result and location of anomalous areas.

INFORMATION ONLY

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	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
SURFACE GEOPHYSICAL SURVEYS

Approved By: _____ 5/12/92
(Name of Approver) (Date)

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for conducting surface geophysical surveys. In general, surface geophysical surveys will be conducted to aid characterization of the subsurface. Geophysical techniques measure variations in the physical properties of the subsurface. Thus, they are useful in identifying interfaces indicated by changes in seismic velocity, density, resistivity or conductivity, fluid content, degree of fracturing, soil or rock thicknesses, or linear features such as faults or dikes. Since they measure physical property variations, geophysical techniques can aid the delineation of man-made subsurface features (pipelines or buried tanks, drums, and trenches) as well as subsurface contamination. This SOP specifically addresses shallow electromagnetic (EM), ground penetrating radar (GPR), and self-potential (SP) techniques.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Oversight and supervision of the geophysical surveys will be conducted by EG&G personnel. The subcontractor project manager or task leader is responsible for assigning project staff to perform the geophysical surveys. Project staff performing these surveys will be trained geophysicists or trained personnel with a significant amount of geophysical field experience. The task leader is also responsible for assuring that these and any other appropriate procedures are followed by all project personnel.

Only qualified personnel shall be allowed to perform geophysical surveys. Qualifications are based on education, previous experience, or on-the-job training with supervision by another qualified person. All staff involved with the geophysical surveys shall have previous experience with data collection and interpretation procedures for the methods used. The subcontractor Project Manager shall document personnel qualifications related to this procedure in the project QA files.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Corwin, R.F. 1990. Applications of the Self-Potential Method for Engineering and Environmental Investigations, in proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems. Golden, CO. 1990.

Corwin, R.F., and Butler, D.K. Geotechnical Applications of the Self-Potential Method; Report 3; Development of Self-Potential Interpretation Techniques for Seepage Detection: Technical Report REMR-GT-6, U.S. Army Corps of Engineers, Washington, D.C. 1989.

Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA. Interim Final. EPA/540/G-89/004. October 1988.

McNeill, J.D. 1980. Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers, Technical Note TN-6, Geonics Ltd., Canada.

RCRA Facility Investigation Guidance. Interim Final. May 1989.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP GT.10, Borehole Clearing

5.0 PROCEDURES

The use of geophysical techniques will be discussed in the project work plans. Given the project-specific objectives and the subsurface information required, an appropriate geophysical program will be proposed and agreed upon between EG&G personnel and the subcontractor. The purpose of the subsurface investigation and result expectations must be outlined. Prior to the collection of geophysical data, several preliminary considerations must be made. These include as a minimum:

- Review existing and appropriate site, area, and regional subsurface geologic and hydrogeologic information including soil characteristics.
- Define any known hazards that pose a threat to the safety of field personnel.
- Review site utility plans and obtain the locations of electrical and telephone utilities and address their potential influence on survey results.

Subsequent sections describe specific procedures for each technique.

5.1 ELECTROMAGNETICS

5.1.1 Introduction

Electromagnetic (EM) methods provide a rapid means of measuring the electrical conductivity of subsurface soil, rock, and groundwater. Thus, it can be useful for assessing subsurface conditions such as depth and orientation of bedrock; lateral variations in soil and rock and extent of

paleochannels; lateral, and in some instances, vertical extent of contaminants; and the presence of ferrous and nonferrous metals.

The method involves the induction of electrical current into the subsurface. A small alternating current passing through a transmitter coil produces a primary, time-varying magnetic field into the ground. Through inductive coupling, the primary magnetic field produces small eddy currents in the subsurface which, in turn, create their own secondary magnetic field. The receiver coil senses both the primary and secondary fields. Changes in magnitude and phase of the individual currents are linearly related to the terrain conductivity. These changes in the individual currents are converted to voltages and output as ground conductivity values, which can be recorded manually, by a strip recorder, or a digital logger. Depth of investigation is related to the separation between the transmitter and receiver coils. By using multiple coil spacings, several penetration depths can be achieved. All conductivity values are subsequently plotted on a map so that their variation over the site can be analyzed.

Terrain conductivity is a function of the soil or rock composition, the porosity and permeability of the subsurface units, and the conductivity of the fluids filling the pore spaces. The possible sources of an EM anomaly must be kept in mind when collecting the data and during interpretation.

This SOP specifies procedures for EM surveys utilizing shallow penetration systems including the EM-31, EM-38, and EM 34-3. These instruments can be utilized with two different coil orientations, the horizontal dipole mode (coils vertical coplanar) and the vertical dipole mode (coils horizontal coplanar). The two modes allow different penetration depths to be achieved.

5.1.2 Survey Design

5.1.2.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete an EM survey:

- Geonics EM-31, EM-38, or EM 34-3 terrain conductivity system or equivalent (choice based on depth penetration required)
- Digital logger and/or analog strip recorder (when data collection is over large grid area)
- Wood stakes or lath
- Flagging
- Field notebook
- Black waterproof (permanent) pens

5.1.2.2 Field Procedures

A standard field procedure for conducting an EM survey is described below. Prior to EM data collection, two preliminary procedures must be conducted. These are:

- Design the appropriate field parameters given the purpose of the survey, (e.g., depth of investigation, whether EM-31, EM-38, or EM 34-3 is used, coil spacing, coil orientation, station spacing, etc.).

- Survey the locations of line endpoints along each line and denote these locations in the field with lath or wood stakes. Mark stations with coordinate designation based on the coordinate system used for the survey of the end points. Transfer line and station locations to the appropriate base map.

Design of appropriate field parameters must consider the following:

- The coil spacing should be 0.75 to 1.5 times the required depth of penetration depending on whether the instrument will be used in the vertical or horizontal dipole mode. Instrumentation must be chosen so that the objective penetration depths can be achieved. Table GT.18-1 summarizes instrument modes and approximate penetration depths.

- Spacing between stations determines the degree of resolution achievable; a spacing of 10 to 100 feet is commonly used; however, spacing as small as 2 feet may be required for extremely shallow targets or to aid resolution in very complex environments. Actual chosen station spacing must be determined by resolution and maximum depth required, and overall survey objectives.

- For grid areas, intraline spacing affects resolution; a spacing of 10 to 400 feet is commonly used. However, smaller spacing may be required depending on the resolution required and overall survey objectives.

- Definition of an EM anomaly requires three or more anomalous readings.

- Background conductivity noise caused by cultural interference, such as overhead or buried powerlines and steel-cased monitor wells, must be evaluated and/or estimated to assess their potential effect on an EM survey. High noise levels can make interpretation difficult and can cause significant anomalies to be overlooked and, in some instances, can make data collection and interpretation impossible. Actual background noise must be considered when collecting and interpreting the EM data.

- Background conductivities for the investigated materials or groundwater should be estimated to aid anomaly interpretation. Where possible, conductivities for site-specific groundwater should be determined by analyzing samples from monitoring wells adjacent to the survey area. This should be done as close as possible to the actual survey date to ensure that the pore water conductivity determined is representative at the time of the survey.

TABLE GT.18-1

EM INSTRUMENT MODE AND PENETRATION DEPTHS

Instrument	Coil Spacing	Mode	Approximate Depth of Penetration (ft)
EM-38	Fixed - 1 meter (3.28 feet)	HDM	2.5
		VDM	5
EM-31	Fixed - 3.66 meters (12 feet)	HDM	9
		VDM	18
EM-34-3	Variable - 10 meters (32.8 feet)	HDM	25
		VDM	49
	20 meters (65.6 feet)	HDM	49
		VDM	98
	40 meters (131.2 feet)	HDM	98
		VDM	197

Note: HDM = Horizontal Dipole Mode
VDM = Vertical Dipole Mode

A standard field procedure for conducting an EM survey is described below.

1. Perform a visual survey along the proposed lines. The visual survey will include a review of site utility plans; check for overhead wires; check for manhole covers, buried cables, buried gas line indications, and steel-cased monitoring wells; and have site locators confirm the presence of any possible telephone and utility features. Note any features in the field notebook.

2. Note in the field notebook excessive amounts or large pieces of metal on the ground surface.

3. Note in the field notebook large nearby variations in topography or buildings (within 50 feet).

4. Check the instrument battery for sufficient charge and test the instrument using manufacturer's procedures.

5. Initiate a site survey traverse with EM instrument. Instrument operation must follow manufacturer's operating procedures for horizontal and vertical dipole mode operation.

6. Record the obtained conductivity value in the data logger or field notebook. Note station number and coordinates.

7. Continue the above procedure for each station along the line. For two or more coil spacings or orientations at each station, multiple passes along each line will be made, ensuring that occupied stations are repeated with each coil orientation.

8. If hard copies of each line of data from the strip recorder are made, label and/or number all notations made on the record to correspond to notes made in the field notebook.

9. When a data logger is utilized, download data from the data logger to a computer on a daily basis for further analysis.

5.1.3 Data Processing and Interpretation

A standard procedure for processing and interpreting the EM data is described below.

1. Collected data is downloaded from the data logger or input to the main computer from recorded field notes and processed. Data is then plotted and may be contoured.

2. Comparing the results of all plots, variations in conductivity may indicate the presence of subsurface anomalies.

3. Using available borehole information and any other existing geophysical data as a reference, develop a subsurface conductivity model that is consistent with all available data.

5.2 GROUND PENETRATING RADAR

5.2.1 Introduction

Ground penetrating radar (GPR) has been used for mapping shallow geologic interfaces, delineating shallow bedrock, locating voids in concrete or limestone, and finding buried pipeline or reinforcement bars.

GPR involves a system that transmits electromagnetic pulses into the ground from an antenna near the surface. These pulses are reflected from a variety of subsurface interfaces back to a receiver. As the antenna is towed along a survey line, the GPR signals are processed and displayed on a graphic recorder. The displayed data is a two-dimensional continuous profile along the surveyed line, depicting time versus distance. The display is very similar to a geologic section, except that the record is a time section rather than a depth section.

GPR has excellent resolution of subsurface features when favorable conditions exist. However, actual depth penetration is highly site-specific and depends on the near-surface soil conductivity. Highly conductive soils, such as clays, can reduce penetration to less than three feet. Less conductive materials, such as clean, well-sorted sandstone, will allow depth penetration of 30 feet.

5.2.2 Survey Design

5.2.2.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete a GPR survey:

- GSSI SIR System-3 or equivalent radar system (more advanced models can be used)

- Flagging
- Lath or wooden stakes
- Field notebook
- Black waterproof (permanent) pens
- Tape measure (200 feet minimum) (Note: for relatively smooth surfaces, a measuring wheel can be substituted)
- Extra paper for profile recorder
- Extra stylus(s) for profile recorder

5.2.2.2 Field Procedures

A standard field procedure for collecting GPR data is described below. Prior to GPR data collection, two preliminary procedures must be conducted. These are:

- Design the appropriate field parameters, given the purpose of the survey (e.g., orientation of lines or grid, grid spacing, frequency of antenna, necessity of antenna shielding, etc.)
- Survey line endpoints and mark these locations in the field with lath or wooden stakes. Transfer line locations to the correct position on the base maps.

Design of appropriate field parameters must consider the following:

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- The antenna and associated transmitter frequency used must optimize the penetration depth and required resolution given the survey purpose. Typical frequencies are 80 Mhz, 100 Mhz, 120 Mhz, 300 Mhz, 500 Mhz, and 1000 Mhz. Higher frequency antennas allow greater subsurface resolution, but penetration is reduced over that of lower frequencies. To optimize results, surveys should be designed to have a minimum of two antenna frequencies available.

- For grid areas, intraline spacing affects resolution; a spacing of 3 to 50 feet is commonly used. Actual spacing must take required resolution into account.

- Method of antenna towing must be evaluated given the site conditions. For smooth surfaces or terrain, the antenna can be towed directly on the surface. For areas with significant vegetation or surface stones and rocks, the antenna may need to be suspended 6-18 inches above the ground or carried in a plastic non-conductive wagon to prevent antenna damage and potentially dubious GPR data collection.

- Antenna shielding should be considered and designed to handle the field conditions. Surface features such as fences, powerlines, trees, etc. can appear as prominent reflections on the GPR record.

A standard field procedure for conducting a GPR survey is described below.

1. Perform a visual survey along the proposed lines. The visual survey will include a review of site utility plans; check for overhead wires; check for manhole covers, buried cables, buried gas line indicators, and cased monitor wells; and have site locators confirm the presence of any possible telephone and utility features. Note the features in the field notebook.

2. Note in the field notebook excessive amounts or large pieces of metal on the ground surface.

3. Note in the field notebook large nearby variations in topography or buildings (within 50 feet).

4. Note the moisture content of soil, alluvium, or investigated media, as well as relative clay content, as these could significantly affect the penetration depths.

5. Conduct a test line using manufacturer's procedures. Instrument settings must be optimized to obtain appropriate data given project goals. Specific recording parameters that must be optimized include, but are not limited to, the following:

   - Radar scan speed
   - Signal range gain
   - High and low pass filter settings
   - Time range for recording
   - Transmitter pulse rate
   - Recording printer speed
   - Antenna towing speed

   Instrument settings should be varied during the test line to determine the optimum recording parameters. When possible, the test line should be conducted over a known buried feature in the survey area to help instrument setting optimization and calibrate penetration depths.

6. Initiate a site survey traverse. Beginning at the GPR line endpoint, tow the antenna along the line with appropriate speed determined from the test line, and

using optimum instrument settings determined from the test line. Continue the above procedure for the entire line and subsequent grid lines.

7. If hard copies of each line of data from the printer are made, label all notations on the record to correspond to notes made in the field notebook, including recording parameters.

8. Permanent copies of this GPR data must be retained digitally on tape or disk, or on hard copy plots.

5.2.3 Data Reduction and Interpretation

Data reduction of GPR data is limited. Most GPR data processing occurs with the various instrument settings during recording.

Interpretation must consider all potential sources of a GPR anomaly, including interfering reflections from both surface and subsurface cultural features, and draw upon the interpreter's GPR experience. Using site surface data, available borehole information (should it exist), or any other existing geophysical data, develop a subsurface model that is consistent with all available data.

5.3 SELF-POTENTIAL

5.3.1 Introduction

Self-potential (SP) surveys allow the measurement of ambient voltages and voltage variations within the ground. These small voltages are generated by subsurface fluid, heat, or ion flow. For engineering or environmental applications, recording these voltage variations and resulting SP anomalies allows delineation of fluid flow in the vicinity of dams, reservoirs, wells, faults, or lined

ponds, and in some cases subsurface contamination. Thus, SP methods are useful in evaluating the integrity of engineered structures with regard to potential leakage of fluids.

The method involves recording the ambient voltage generated by subsurface currents between two electrode locations connected by a wire to a millivoltmeter. In practice, there are restrictions on the types of electrodes and voltmeter used, which are critical to the survey's success. Electrodes used must be nonpolarizing to reduce or eliminate spurious potentials generated at the electrode-ground contact. This is achieved by using a metal electrode immersed in a saturated solution of its own salt, such as a copper electrode immersed in a copper-sulfate solution. The millivoltmeter must have an input impedance sufficiently large to prevent significant current to be drawn from the ground during measurement. This is achieved by using a D. C. millivoltmeter with input impedance greater than 10^8 ohms.

Although the equipment and field procedures used for SP surveys are relatively simple, considerable care and effort are required for high-quality results. Data must be reproducible, sources of noise must be recognized, and appropriate data reduction methods are necessary to correct for electrode drift and polarization. Interpretation of SP data must be carried out by experienced personnel who are cognizant of all potential anomaly sources.

In engineering applications, SP anomalies of interest are usually generated by flows of fluid or ions through a porous medium such as rock or soil. The fields generated by fluid are electrokinetic (or streaming) potentials, and those generated by ionic flow are electrochemical potentials. The amplitude of SP fields generated by fluid flow in engineering targets may exceed 500 millivolts (mV), although magnitudes of tens to hundreds of mV are more common. SP fields generated by ionic flow related to artificial sources, such as buried metal or pipelines, tend to be relatively large and easy to detect. Fields generated by ionic flow due to contaminant plumes tend to be small in amplitude and may be difficult to detect. SP anomaly interpretation must consider all potential anomalies natural and manmade, which are usually superimposed on the target anomaly. The use

of magnetic and/or electromagnetic measurements in conjunction with SP data can be very helpful in recognizing sources of SP noise due to buried metallic objects.

The procedures outlined below are for SP surveys being conducted along the ground or a engineered structure surface. It does not specifically address procedures that may be employed for conducting SP surveys in ponds or fluid containment structures. Although the basic principles and procedures are the same, some survey logistical features must be designed on a project-specific basis for conducting SP surveys in a body of fluid.

5.3.2 Survey Design

5.3.2.1 List of Necessary Equipment

The following is a list of equipment that will be necessary to complete an SP survey;

- High impedance (10^8 ohms or greater) D.C. millivoltmeter (e.g., fluke model 8020A)

- Minimum of five SP electrodes. Copper-copper sulfate electrodes have been documented as the most stable for engineering applications. Use Tinker and Rasor Model 6B electrodes (or equivalent). Use of electrodes with different metal components will be discussed and approved by EG&G personnel before they are used.

- Two reels with connector plugs and a minimum of 500 linear feet of small diameter (20 gauge) solid wire (required wire length is dependent on survey grid size; for some surveys, more wire per reel may be necessary).

- One quart saturated copper-sulfate solution (or appropriate solution for the type of electrode used)
- Wood stakes or lath
- Garden tool sufficient to produce a 3-10 inch deep small hole for electrode emplacement.
- Tape measure (200 feet minimum) (Note: for relatively smooth surfaces, a measuring wheel can be substituted)
- Field notebook
- Black waterproof (permanent) pens
- Form GT.18A, Self-Potential Survey Data Form (see Section 7.0, Documentation)

5.3.2.2 **Field Procedures**

A standard field procedure for conducting an SP survey is described below. Prior to SP data collection, two preliminary procedures must be conducted. These are:

- Design the appropriate field parameters, given the purpose of the survey (e.g., coverage of survey area, station spacing, surface soil conditions, position of base electrode, etc.).

- Survey the line endpoints and mark these locations in the field with lath or wooden stakes. Mark all remaining station locations based on the predetermined grid with an identifiable marker (such as lath or wooden stakes).

Design of appropriate field parameters must consider the following:

- The SP survey is conducted in a series of short loops from a fixed base station. Each loop is initiated with a base station reading, followed by SP readings at a number of stations along a predetermined grid, and concluded by a final base reading. Duration of each SP loop should be no more than 35 - 50 minutes. Loops of this duration reduce uncertainties in drift corrections (see below).

- The base station location must be chosen at a site where conditions are unlikely to change during the survey period, and where background noise is a minimum.

- Spacing between stations determines the degree of resolution achievable; a spacing of 5 to 50 feet is commonly used. However, for small near-surface targets, spacing may be as small as 2 feet. The actual chosen station spacing must be determined by resolution required and overall survey objectives.

- Definition of an SP anomaly requires three or more anomalous readings.

- Topography effects can produce SP anomalies which are superimposed on target anomalies. The survey must be designed to allow determination of the topographical effects.

- SP readings are affected by the natural fluctuation of the earth's magnetic field and telluric currents. Design must consider their potential effect. Effects of these

fluctuations are removed by making electrode drift corrections relative to a fixed base location. On occasion, large solar magnetic storms will make SP data collection difficult or impossible.

- Background noise caused by cultural interference, such as overhead or buried powerlines and/or steel-cased monitor wells, must be evaluated and/or estimated to assess their possible effect on an SP survey. High noise levels can make interpretation difficult, can cause significant anomalies to be overlooked and, in some instances, can make data collection and interpretation impossible. Actual background noise must be considered when collecting and interpreting the SP data.

A standard field procedure for conducting an SP survey is described below.

1. Record the initial site information on Form GT.18A.

2. Perform a visual survey along the proposed lines. The visual survey will include a review of site utility plans; check for overhead wires; check for manhole covers, buried cables, buried gas line indicators, and cased monitor wells; and have site locators confirm the presence of any possible telephone and utility features. Note the features on Form GT.18A.

3. Note on Form GT.18A excessive amounts or large pieces of metal on the ground surface.

4. Note on Form GT.18A large nearby variations in topography or buildings (within 50 feet).

5. Note the moisture content of soil, alluvium, or investigated media, as well as relative clay content, as these could affect the electrode contact resistance.

6. Ensure that all electrodes are filled with saturated metal solution (for copper electrodes, use copper-sulfate solution).

7. Measure and record the reel wire resistance (infinite reading indicates open wire).

8. Measure resistance between reel frame and end of wire to check for short circuits. If a short is present, repair or do not allow reel to contact the ground during readings.

9. Put two electrodes in a solution bath (copper sulfate for copper electrodes) and measure and record the voltage between the electrode pairs. This measurement will be used to check the initial electrode polarization. Measurements should be made on the millivoltmeter range with a minimum of 1.0 mV resolution.

10. Install the base electrode at the base location. Dig a small hole into the moist soil underlying the surface soil. Do not add water to the hole. Ensure a good coupling between the ground and the porous electrode tip by tamping the soil around the electrode. Tie off the end of the reel wire and attach it to the base electrode terminal. Place a sun shade over the base electrode.

11. Install the measuring electrode next to the base station (within 1-2 inches) ensuring a good ground coupling. Connect the positive lead of the meter to the measuring electrode and the negative lead to the connection on the reel, and read the SP measurement for the initial polarization of the base and measuring

electrode. This measurement will be used as a basis for electrode drift correction for SP loops.

12. At a SP station, dig a small hole into the moist soil below the surface layer. Insert the measuring electrode ensuring good soil contact by tamping the soil around the electrode. Connect the positive lead of the meter to the measuring electrode and the negative lead to the connector on the reel. Shade the electrode from the sun.

13. Read the SP measurement on the millivoltmeter for 10-20 seconds to check for drift or telluric fluctuations. Obtain a stable average. Record the final value in mV with the proper polarity. Briefly measure and record the contact resistance between the electrodes using the appropriate kilo-ohms range of the multimeter.

14. Move to the next station and repeat steps 10-12.

15. After completing the survey loop, or after an elapsed time of 35-50 minutes, return to the base station and read the SP measurement at the base location in order to correct for electrode drift. Periodically throughout the day (approximately four times), remeasure the polarization between the electrodes in the solution bath when making a base tie.

16. Record all measurements and comments on Form GT.18A.

5.3.3 Data Processing and Interpretation

SP data reduction must eliminate all electrode drifts associated with telluric currents, polarization effects, temperature effects, and background noise. Drift corrections are made to the measuring electrode relative to the base electrode, which is assumed fixed. If a value has been predetermined

for the base, this "tie-in" correction must be included in the final corrected SP value for each measured station.

Most interpretations of SP data are performed qualitatively, involving preparation of data profiles and contour maps, and assessing the resulting anomalies. Experienced interpretation considers all potential sources of a given SP anomaly and assesses whether the anomaly is characteristic of the suspected target anomaly.

More sophisticated interpretation techniques can be employed, particularly when corroborative information exists, such as boring data or data from other geophysical methods. These other techniques include geometric and analytical modeling. The use of these techniques must be evaluated on a project-specific basis, with discussion and approval of their merit by EG&G personnel.

6.0 DECONTAMINATION

Personnel involved with surface geophysical surveys will follow all decontamination procedures as outlined in the Health and Safety Plan. Geophysical equipment which has been in contact with potentially contaminated ground surfaces will be decontaminated according to procedures outlined in SOP FO.3, General Equipment Decontamination, as well as any appropriate procedures specified in the Health and Safety Plan.

7.0 DOCUMENTATION

A permanent record of the implementation of this SOP will be kept by documenting field observations and data. The date of the manufacturer's most recent calibration and certification will be documented, if this information is available. Observations and data will be recorded with black waterproof (permanent) ink in a bound, weatherproof field notebook with consecutively numbered

pages. Documentation of completed decontamination activities will similarly be noted. When conducting SP surveys, data and observations will be documented on the Self-Potential Survey Data Form (Form GT.18A).

SELF-POTENTIAL SURVEY DATA

Date: _____
Location: _____
Line: _____
Base Electrode Location: _____
_____
_____
_____
Operator: _____

Project Name: _____
Voltmeter: _____
Base Electrode: _____
Portable Reference Electrode: _____
Measuring Electrode: _____
Reel Checks: Resistance: _____
Short Circuits: _____
General Site Conditions: _____
_____

Time	Station	ΔV Measured (mV)	Resistance (Kilo-OHMS)	Electrode Correction (mV)	Tie-In Correction (mV)	ΔV Corrected (mV)	Comments

Completed By: _____
Print Name Signature Date

Subcontractor: _____

INFORMATION ONLY

FIELD GAS CHROMATOGRAPHS

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.19, Rev. 2
	Page:	1 of 9
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
FIELD GAS CHROMATOGRAPHS

Approved By: _____ 5/12/92
(Name of Approver) (Date)

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REVIEWED FOR CLASSIFICATION/UCNI
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Date March 4 1992

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to use field gas chromatographs (GCs). These instruments are used in the identification and quantification of volatile organic compounds.

Level I and Level II analyses are defined as field screening/analytical methods which utilize equipment amenable to the rigors of field conditions, and are located at or near the sampling site.

Level I analytical support is typically defined as field screening, with the objective of generating data which will generally be used (for example during Phase 1 investigations), in refining sampling plans and determining the extent of contamination. A second objective of Level I analyses is to conserve other analytical support resources.

Level I analyses are generally effective for total Volatile Organic Compound (VOC) vapor readings using portable photoionization or flame ionization detectors (PID or FID). Detection is typically limited to volatile compounds. These types of analyses provide data for on-site, real-time total vapor measurements, evaluation of existing conditions, sample location optimization, extent of contamination, and health and safety evaluations. Data generated from Level I analyses are considered qualitative in nature although semi-quantitative and/or quantitative data can be generated (for example, by using the GC option of an FID, with sufficient calibration). Data generated from Level I analyses provide the following:

- Identification of soil, water, air and waste locations which have a high likelihood of showing contamination through subsequent analysis
- Real-time data to be used for health and safety considerations during site investigations

- Qualitative data relative to a primary calibration standard if the contaminants being measured are unknown

- Quantitative data if a contaminant is known and the instrument is calibrated to that substance

- Presence or absence of contamination

Level II analytical support is designed to provide real-time data for ongoing field activities or is used when initial data will provide the basis for seeking laboratory analytical support. As such, Level II analytical methods can be effectively utilized when a phased approach is used for field sampling. There have also been a significant number of instances where data derived from Level II support have been used to make decisions about site disposition.

Level II analyses are used for on-site, real-time baseline data development, extent of contamination and remedial activities. They generally provide rapidly available data for a variety of activities including hydrological investigations (establish depth/concentration profiles); extent of contaminant determination including special activities such as vadose zone sampling; cleanup operations (determine extent of contaminated soil excavation), and health and safety considerations.

Typically, a gas chromatograph and more sophisticated instruments operated in the field provide the bulk of the analytical support at this level. The ability to assess the data quality (accuracy and precision) is dependent upon the QA/QC steps taken in the process, including documentation of blank injections, calibration standard runs, and runs of standards between samples, sample duplicates, and performance evaluation standards.

The level of precision and accuracy that can be achieved by a specific Level I or II analysis varies as a function of numerous factors including the matrix and contaminant(s) being sampled, and the skill of the analyst doing the work.

3.0 QUALIFICATIONS

Only qualified personnel will be allowed to operate gas chromatographs (GCs). Required qualifications vary depending on the activity to be performed. In general, qualifications will be based on education, previous experience, and supervision by qualified personnel. The subcontractor's project manager will document personnel qualifications related to this procedure in the subcontractor's project QA files.

Operation of the gas chromatograph will be performed in accordance with the manufacturer's instructions. Personnel performing gas chromatography will receive training from a factory representative or a local area instructor certified by the manufacturer to administer training.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

Field Screening Methods Catalog: User's Guide. EPA/540/2-88/005. September 1988.

Chapman, H. and Clay, P., Field Investigation Team (FIT) Screening Methods and Mobile Laboratories Complementary to Contract Laboratory Program (CLP), TDD HQ-8507-01. October 17, 1986. (Draft).

Clark, A.E., Lataille, M. and Taylor, E.L., The Use of a Portable PID Gas Chromatograph for Rapid Screening of Samples for Purgeable Organic Compounds in the Field and in the Lab, U.S. EPA Region I Laboratory. June 29, 1983.

Morin, S.O., Development and Application of an Analytical Screening Program to Superfund Activities, Management of Uncontrolled Hazardous Waste Sites. Washington, D.C. November 4-6, 1985.

4.2 INTERNAL REFERENCES

A related SOP cross-referenced by this SOP is:

- SOP FO.3, General Equipment Decontamination

5.0 PROCEDURES AND EQUIPMENT

Equipment List

- Portable gas chromatograph with appropriate detector and accessories
- Chromatographic column(s) (project specific)[1]
- Vendor-supplied calibration standards (certified) and appropriate internal standards
- Glassware (project specific), including proper syringes
- Microprocessor and/or strip chart recorder with appropriate accessories and supplies (project specific)
- High purity specialty gases (project specific)

[1] Second column confirmation (dissimilar columns) if specified in Data Quality Objectives (DQOs).

- Field log book
- Instrument manufacturer's operation manual

All analyses shall be performed utilizing a field-area portable gas chromatograph (GC). A chromatographic column which separates target compounds shall be utilized. An internal standard will be added to each sample being analyzed on the GC (including calibration standards) to ensure proper instrument performance.

Prior to the start of analysis on each day, the GC shall be calibrated through the injection of commercially-available stock standards and/or appropriate dilution of traceable stock standards. This calibration (initial calibration) will, at a minimum, consist of the analysis of three standards with known concentrations. The lowest concentration standard shall be at the required quantification limit, the highest concentration standard shall be within the linear response of the instrument, and the middle concentration standard shall be approximately midway between these two. A linear regression of the concentration of the standard against the chromatographic peak area shall be performed. The correlation coefficient must be greater than 0.995.

The GC calibration must be verified after every 10 sample analyses throughout the day or after a highly-contaminated sample to ensure the proper purge time of the chromatograph column. Verification will be accomplished through analysis of the mid-range concentration standard. If the measured concentration differs from the concentration in the standard by more than 15%, the GC must be recalibrated using the initial calibration procedures above.

Samples are analyzed by injecting the same volume of sample into the gas chromatograph as was utilized during the calibration analyses. Target compound concentrations in the sample will be quantified using the average response factor calculated from the initial calibration. All sample analysis values must be less than the highest concentration calibration standard. If a sample is

analyzed containing a higher concentration than the highest standard, this sample must be rerun after dilution (alternatively, a smaller sample may be injected).

Specific analytical methods and calibration procedures, standards concentrations, detectors, temperature programs, etc. are dependent on the method of analysis and analytes of interest. Specific analytical methods and procedures will be detailed in applicable project work plans.

Data Verification and Reporting

Data obtained from the use of the portable GC will be verified by qualified EG&G or subcontractor personnel. Verification will include a review of the following specific parameters:

- GC performance and calibration, including initial and continuing calibrations
- Qualitative and quantitative identification of analytes including recalculation from raw data of at least 15 percent of all sample data
- Analysis of field duplicates, field and method blanks, and spikes
- Referee laboratory (outside) duplicate analyses (if required)
- Duplicate analysis of field samples by on-site GC operator

A checklist used for data verification is included as Form GT.19A.

6.0 DECONTAMINATION

Field gas chromatographs will be set up in the field site support zone in order to avoid contamination. Field sample containers will be decontaminated in accordance with SOP FO.3, General Equipment Decontamination, prior to being used. Additional equipment used during sample analysis will also be decontaminated in accordance with SOP FO.3, General Equipment Decontamination.

7.0 QUALITY ASSURANCE/QUALITY CONTROL

Quality Assurance (QA) and Quality Control (QC) activities will be accomplished according to the Quality Assurance Project Plan (QAPjP) and the project specific Quality Assurance Addendum (QAA).

In addition to adhering to the requirements of the site-specific Field Sampling Plan (FSP) and any supplementary site-specific procedures, the minimum QA/QC requirements for this sampling activity are the following:

- QC Samples -- The number and types of QC samples including duplicate samples, field blanks, equipment blanks, trip blanks, and other samples will be collected or prepared as specified in the QAA.

- Verification -- Verification activities are required for the above practices including surveillance and periodic record audits. These activities will be documented and become part of the completed project records.

7.1 QA/QC SAMPLES FOR FIELD GC ANALYSIS

Frequency of calibration, method blanks, replicates, etc., are dependent upon project Data Quality Objectives (DQOs), and must be addressed in the project-specific Quality Assurance Addendum (QAA).

Daily calibration and operational checks are required to ensure that the instrument is functioning properly. Manufacturer's calibration instructions will be followed prior to daily use, and calibration will be confirmed at the end of each day. The manufacturer's instrument operation manual will be present on site at all times.

8.0 DOCUMENTATION

The field documentation requirements for the field sampler will include recording all observations made during the analysis that could affect the quality of the analysis. The documentation for this analysis should be entered in a field notebook with consecutively numbered pages with locations identified on a sample location map.

Field documentation will include at a minimum:

- Date of sample collection
- Time of sample collection
- Location of the sample collected
- Sample number
- Unusual sampling conditions
- Problems encountered while obtaining the sample
- Each entry (or page) in the field notebook should be dated and initialed by the individual making the entry

DATA VERIFICATION CHECKLIST FOR GAS CHROMATOGRAPHIC ANALYSES

DATE _____

SAMPLES ANALYZED THIS DATE _____

_____

_____

ANALYST _____

DATA VERIFIED BY _____

_____

Answer Y = Yes; N = No where appropriate Y/N

I. Calibration

A. Was a 3-point calibration made at the start of the day? _____

B. Was the correlation coefficient greater than 0.995? _____

C. Was the GC calibration verified every 10 samples? _____

What standard was utilized for calibration verification? _____

Did the measured concentration differ by more than 15%? _____

If yes, was GC re-calibrated? _____

II. Blanks

A. Was a method blank run immediately following the initial calibration and prior to any samples? _____

B. Was any blank contamination present? _____

If yes, what was source of contamination and how was problem rectified? _____

_____

C. Were any field blanks run? _____

Any contamination present? _____

III. Sample Documentation

A. Were samples received in good condition? _____

If no, explain _____

_____

B. Were sample labels properly filled out? _____

If no, explain _____

_____

IV. Sample Analysis

A. Were samples analyzed WITHIN required holding time? _____
If no, explain _____

B. Were any problems encountered during analysis? _____
If yes, explain _____

C. Were target analytes detected above action level specified in DQOs? _____
If yes, was identification & quantification confirmed or second GC column if specified in DQOs? _____
Reference _____

D. Were duplicates analyzed? _____
If yes, what types _____

What was the relative percent difference (%RPD) between duplicates? _____

E. Were any spike samples analyzed? _____
What was result versus "true" concentration? _____

F. Were any computation/transcription errors noted? _____
If yes, explain _____

G. Overall assessment? _____

H. Notes _____

Completed By: _____
Print Name Signature Date

Subcontractor: _____

Data Verified By: _____
Print Name Signature Date

INFORMATION ONLY

PROCEDURES FOR SOIL INTERSTITIAL WATER SAMPLING AND SAMPLER INSTALLATION

EG&G ROCKY FLATS PLANT	Manual:	5-21000-OPS
EMD MANUAL OPERATION SOP	Procedure No.:	GT.20, Rev. 2
	Page:	1 of 25
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
PROCEDURES FOR SOIL
INTERSTITIAL WATER SAMPLING
AND SAMPLER INSTALLATION

Approved By:

(Name of Approver) 5/12/92 (Date)

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94-DMR-000297

LIST OF EFFECTIVE PAGES

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2A	2/28/94	94-DMR-000297
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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to install and sample soil interstitial water samplers, to set up telemetry equipment, and to construct and operate a rain simulator. The SOP is divided into five primary sections: Installation of Tension Soil Solution Samplers and Installation of Zero-Tension Samplers, Construction and Operation of a Rain Simulator, Installation of Data Acquisition and Telemetry Equipment, and Collection of Interstitial Waters.

The soil moisture samplers will be installed into the side wall of soil pits excavated by a backhoe (see SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Excavations, for excavation, sampling, backfilling, and decontamination procedures). All activities will be conducted in accordance with the Health and Safety Plan (HSP) that will be developed for these activities.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel installing equipment and performing sampling will be geologists, geotechnical engineers, or field technicians with an appropriate amount of applicable field experience or on-the-job training under the supervision of a qualified person.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

Ghodrati, M., F.F. Ernest Wajury. "Automated Spray System for Application of Solutes to Small Field Plots". Soil Science Society of Am Journal. Vol. 54. 1990. pp. 287-290.

Litaor, M.I. "Review of Soil Solution Samplers". Water Resources Research. Volume 24. 1988. pp. 728-733.

Rhoades, J.D. and J.D. Oster. Solute Content. A. Klute, ed. "Methods of Soil Analysis Agronomy". Vol. 9, Part 1. Soil Sci. Soc. of Am. 2nd ed. Madison, Wisconsin. 1986. pp. 985-1004.990.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples
- SOP FO.14, Field Data Management
- SOP GW.5, Field Measurement of Groundwater Field Parameters
- SOP GW.6, Groundwater Sampling
- SOP GT.7, Logging and Sampling of Test Pits, Trenches, and Construction Excavations

94-DMR-000297

5.0 INSTALLATION OF TENSION SOIL SOLUTION SAMPLERS

Tension soil solution samplers consist of a hollow, porous section made of PTFE (Teflon®) embedded with a silica which is attached to a sample vessel. Water samples are obtained by applying suction to the sampler that draws interstitial waters into the sample vessel. There are no maintenance requirements for the soil water samplers except protecting the access tubes from physical damage.

5.1 MATERIALS AND EQUIPMENT

- Teflon® soil water sampler
- Portable pump
- Collecting bottles
- Polyethylene tube (50 m)
- Thermo box
- Relay (200 VDC 20 amps; 3-30 VDC)
- Time domain reflectometry probes
- Plastic bags
- Stainless steel trowel
- 2-mm sieve and bottom pan
- Stainless steel mixing rod
- Mixing bowl
- Distilled water
- Stainless steel trowel

5.2 PROCEDURES

5.2.1 Preinstallation

The following steps will be performed prior to the installation of the tension soil solution samplers:

- The soil solution samplers, collection bottles, and connecting tubes have to be cleaned before installation. The cleaning procedure is performed in acid and distilled water baths. Connect the soil solution samplers to a pump and pass approximately 200 mL of 0.1 HCl through the porous section of the sampler.

- Flush distilled water through the porous section to clean the sampler from acid residue. The flushing process will continue until the specific conductance of the outflowing water is within 2 percent of the inflowing water.

- During the cleaning operation, the porous section and fitting of individual samplers will be checked for leaks and faulty seals. This will be accomplished by setting a vacuum in each sampler and observing if the vacuum is maintained over a 30-minute interval.

- After cleaning, the samplers will be placed in a clean plastic bag to prevent contamination during transport to the field.

- Upon arrival at the installation location, and immediately prior to installation, the porous section of the sampler will be placed in distilled water for about 30 minutes to saturate the sampler.

5.2.2 Installation

The goals of installation are to ensure good hydraulic contact between the sampler and the soil, and to minimize leakage of waters along the outside of the sampler. The following steps will be performed to correctly install the tension soil solution samplers and the time domain reflectometry (TDR) probes:

- Excavate a soil pit to the desired depth of the sampling interval.

- Install the soil solution samplers into the side wall of the soil pits.

- Using a stainless steel trowel, excavate a tunnel into the side wall of the soil pit at the location where the soil solution sampler will be installed. The tunnel will be approximately 10 cm in length and 5 cm in width.

- Sieve the soil from the excavated tunnel with a 2-mm sieve.

- After the tunnel has been excavated, mix a portion of the sieved excavated soil from the tunnel with water to make a slurry that has the consistency of cement mortar.

- Pour the slurry into the tunnel and push the soil water sampler into the tunnel so that the porous segment of the soil solution sampler is completely embedded in the soil slurry.

- Backfill the remaining area of the tunnel around the soil solution sampler with the same soil material that was originally excavated from the tunnel.

- Bring the free end of the recovery tube to the ground surface. Place the free end into a collection vessel, which resides inside a thermo box.

- The soil moisture content will be measured by TDR. The application of an automated TDR system in the soil environment has been recently tested by Campbell Scientific, Inc. This system consists of a Tektronix 1502B cable tester that is coupled with a CR10 data logger and multiplexers to provide an automated, multiple-probe TDR soil moisture measurement. The installation of this TDR system will be performed following the manufacturer's instructions.

- Connect all the wires (e.g., data logger, pump, relay, and TDR) and test communication. Also see Section 8.0 for the telemetry layout.

- Backfill and compact the soil pit with the native soil.

6.0 INSTALLATION OF ZERO-TENSION SAMPLERS

Soil interstitial waters, in excess of field capacity, are free to drain through soil (mostly through macropores) under the influence of gravity. A zero-tension sampler consists of a collection trough that is placed at depth in the soil to collect interstitial water samples. The zero-tension sampler is made of plexiglass of varying dimensions which, depending on field conditions (e.g., varying clay or cobble content), will be driven into the side of the soil pits. If excessive coarse grain soils are encountered, the zero-tension sampler may not be able to be installed at a particular location. In each zero tension sampler, the water drains from the collection trough to a collection bottle, which sits on a load cell. This water will be brought to the surface periodically through a suction line by the use of a hand-held vacuum pump. The suction line is made of polyethylene tubing.

6.1 MATERIALS AND EQUIPMENT

MATERIALS	DIMENSIONS	QUANTITY PER SAMPLER
Plexiglass of varying dimensions (for constructing zero-tension samplers and sample bottle enclosures)	25 cm x 45 cm 25 cm x 35 cm 25 cm x 25 cm 25 cm x 5 cm	4 1 1 3
Plexiglass clear thickened cement	# 33	
Epoxy glue	ounce	1
Vacuum hand-held pump		1
Wooden pad	10 cm x 10 cm x 3 cm	1
Mallet		

MATERIALS	DIMENSIONS	QUANTITY PER SAMPLER
Bottles and caps for collection of water (1 & 2 liters)		1*
Bottle base made of PVC		1*
Load cell SPI-3		1*
Polyethylene tubes	40 cm long	
Access tubes of various sizes (PVC) with caps		1
Temperature probes		10

* May require less than one if several samplers are connected to one load cell.

6.2 PROCEDURES

6.2.1 Installation

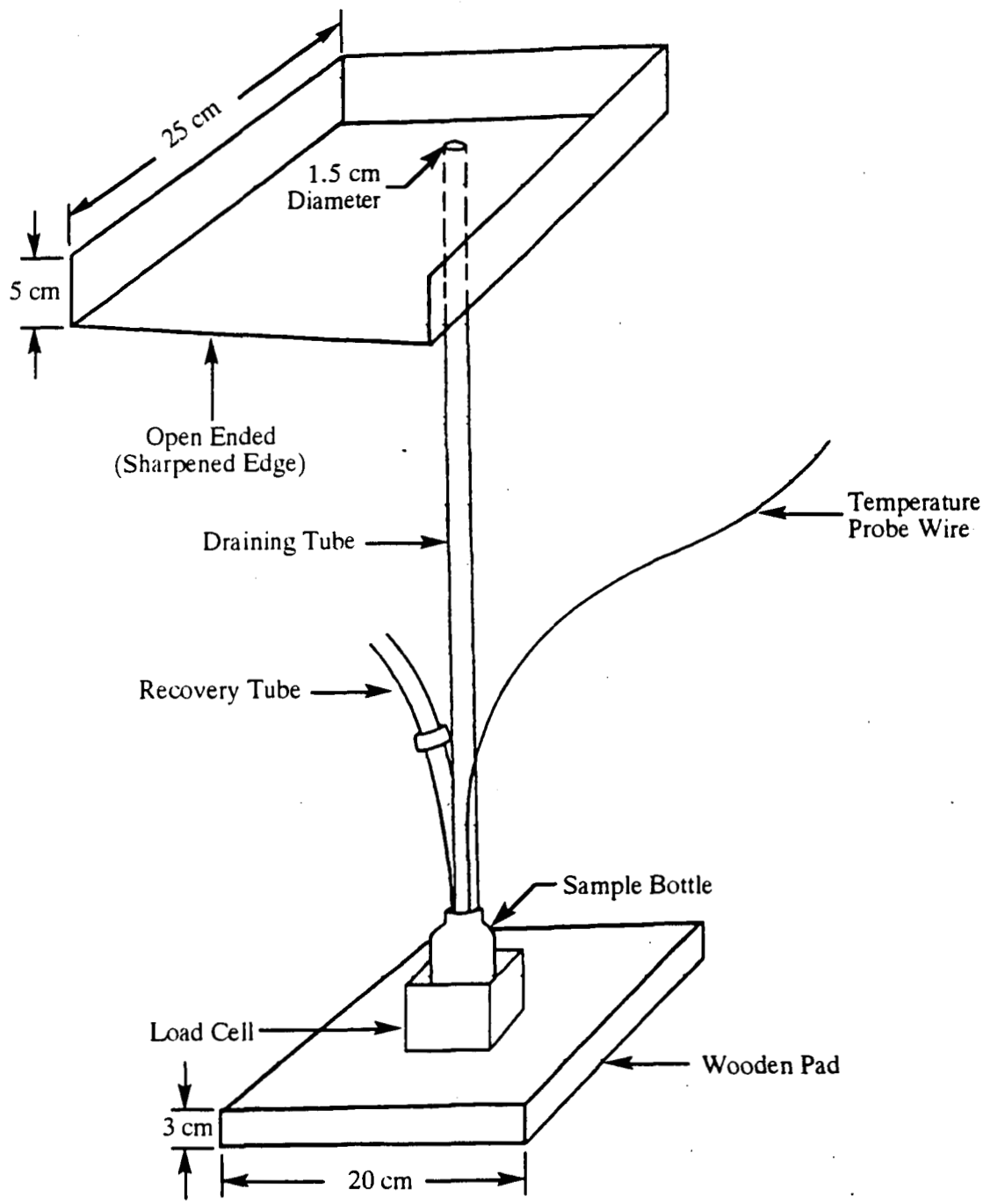
The following steps will be performed to ensure proper installation of the zero-tension samplers:

- The zero-tension sampler will be made of four segments of plexiglass: a base unit (25 cm width x 25 cm length) and three side units (25 cm x 5 cm) (see Figure GT.20-1).

- Sharpen the open end of the zero-tension sampler with a file to facilitate easy installation.

- Drill a hole (1.5-cm inner diameter) in the base of the zero-tension sampler, approximately 2 cm from the exposed end of the trough.

FIGURE GT.20-1 ZERO-TENSION SAMPLER



Not To Scale

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- Insert one end of a polyethylene draining tube (approximately 40 cm long) inside the hole. Use an Epoxy superglue to make the attachment permanent. Make sure that the inserted end of the tube will be flush with the body of the sampler.

- Dig a test soil pit to the desired depth for the sampler installation.

- The zero-tension sampler will be placed in the side wall of the soil test pit at an angle so that the exposed end slopes gently (approximately 5°) toward the bottom of the soil pit.

- The sharp end of the sampler will be driven into the pit face with a mallet in a manner so that there is minimal structural and textural disturbance to the soil. Drive the sampler until the face of the pit is approximately 1 cm from the draining tube.

- Any voids above or below the zero-tension sampler should be filled with soil.

- The water sampled by each zero-tension sampler will be collected in a 1-liter sample bottle mounted on a load cell (A load cell is an electronic sensor).

- Place a sample bottle inside a threaded PVC base and screw the base into the loading surface of the load cell.

- Mount the load cell on a wooden pad (10 cm length x 10 cm width x 3 cm thick) with the bolt provided with the load cell.

- Construct an enclosure made of plexiglass (45 cm height x 25 cm width x 25 cm length) to house the load cell and mounted bottle. Drill a hole in the top of the enclosure to facilitate an entrance to the access tube.

- Drill three holes 3 cm apart in the bottle cap to accommodate the insertion of a draining tube, a recovery tube, and a temperature probe.

- Drill three holes 3 cm apart in the top of the plexiglass enclosure to accommodate the insertion of a draining tube, recovery tube, and temperature probe.

- Place a draining tube, a recovery tube, and a temperature probe through the cap and inside the sample bottle.

- Firmly close the caps.

- Place the draining tube, recovery tube, and temperature probe through the holes in the top at the enclosure. The free end of the recovery tubes will be brought to the ground surface prior to backfilling and will not be buried.

- Place the enclosure above the load cell and mounted bottle inside the soil pit. Connect all the wires (i.e., load cell, temperature probes, and data logger) and test communication.

- Calibrate the load cell reading with known amount of water added to the bottle via a graduated cylinder.

- The zero-tension soil solution samplers will be placed every 10-15 cm down the soil column to the depth of the caliche horizon or other semi-impermeable layer.

- All the enclosures will be covered with the soil removed during the excavation of the pit, and the pit will be compacted and backfilled.

7.0 OPERATION OF A RAIN SIMULATOR

A rain simulator will be used to verify that all the components of the soil solution sampler apparatus are interfacing and communicating with each other and the base station. Correction to the calibration of the load cells will be performed during the rain simulation experiment. Figure GT.20-2 is a schematic diagram of a rain simulator. The procedure for operating a rain simulator is as follows:

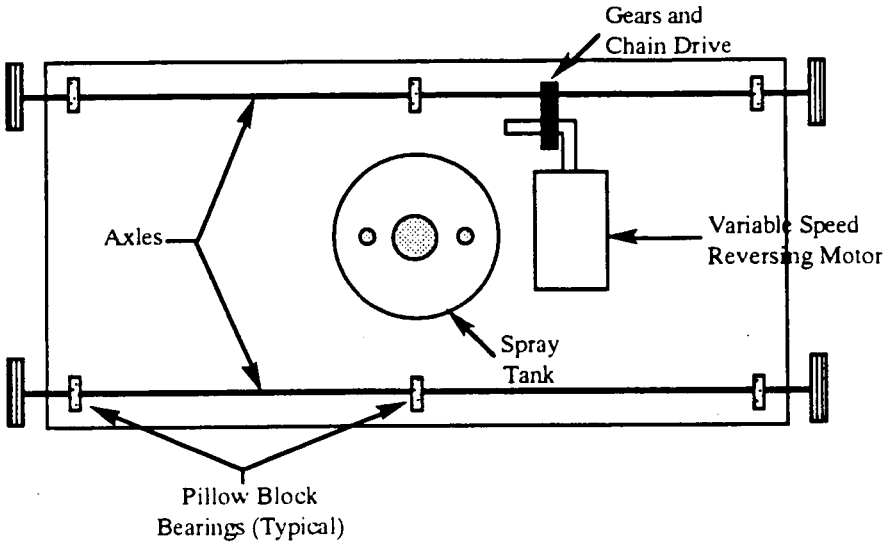
1. The rain simulator is designed to work only on a flat area.
2. The amount of water applied per experiment will vary according to the vadose-zone flow model simulation.
3. Different air pressures will be applied to accommodate various flow requirements.
4. The flow requirements will be determined by the vadose-zone modeling and recorded in the field notebook.
5. Prevent any surface flow by adjusting the air pressure and the chain drive of the reversible motor.

8.0 INSTALLATION OF DATA ACQUISITION AND TELEMETRY EQUIPMENT

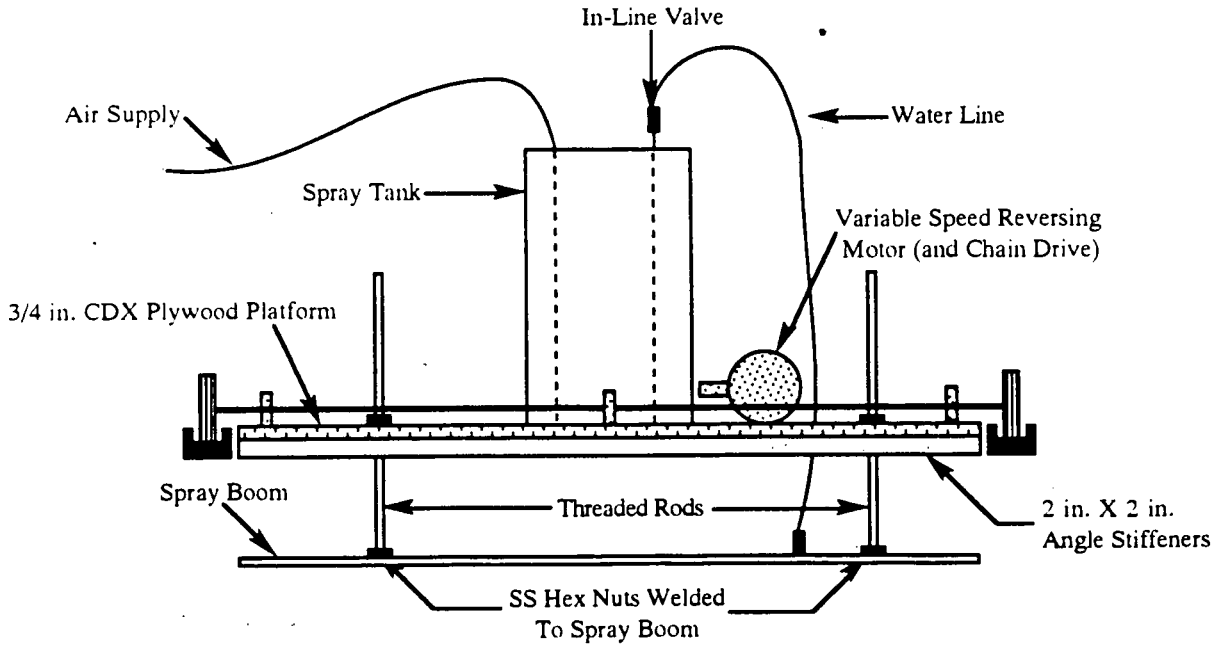
Installation of data logging and data collection equipment will consist of a remote station, a base station, and, if necessary, a repeater station. The attached equipment list contains the required equipment needed to interface the data logger to the soil sampling pumps via relay, to the sensors and precipitation gauge, and to the remote telemetry equipment. Since line of sight cannot be achieved from the soil sampling site to the telemetry base site, a telemetry repeater station is anticipated to be utilized to complete the data telemetry link.

RAIN SIMULATOR

Top View



Side View



Not To Scale

FIGURE GT.20-2

816

8.1 MATERIALS AND EQUIPMENT

8.1.1 Remote Station

CAMPBELL SCIENTIFIC EQUIPMENT LIST
REMOTE STATION

ITEM	PART NO.	QUANTITY
CR-10 Control Module w/64K RAM and CR-10 WP Wiring Panel	CR-10M	1 each
Modem (Radio Telemetry)	RF-95	1 each
5-watt UHF Transceiver, with frequency 403.00 MHz	P-50	1 each
Celwave Antenna w/mount, w/frequency 403.00 MHz *(or equivalent)	BA-6012-0	2 each
(RF Cable) Coax BNCNM, Radio to Antenna, w/type N female (Remote Station)	BNCNM	8 feet
Sealed Rechargeable Battery	PS12-LA	1 each
12-V Power. Supply w/regulator	PS-12	1 each
12" x 14" enclosure	ENC 12/14	1 each
P50/RF95 Bracket Kit	6228	1 each
Solar Panel, 18 watt w/mounts	MSX-18R	1 each
16 Channel, Multiplexer	AM-416	1 each
Multiplexer Enclosure	AM-ENC	1 each
Instrument Tripod & Grounding Kit (10 ft.)	CM-10	1 each

8.1.2 Base Station

BASE STATION

ITEM	PART NO.	QUANTITY
RF Base Station	RF-232	1 each
5-watt UHF Transceiver, with frequency 403.00 MHz	P-50	1 each
Celwave Antenna w/mount, w/frequency 403.00 MHz * (or equivalent)	BA-6012-0	1 each
(RF Cable) Coax BNCNM	BNCNM	as req.
IBM Computer PC, XT, PS, or equivalent, for operating telemetry system, and data collection.		1 each
Data Logger Support Software	PC-208	1 each

8.1.3 Repeater Site

If line of sight cannot be achieved from the remote station to base station, a repeater station will have to be utilized. The following lists the equipment for one complete repeater station.

REPEATER SITE

ITEM	PART NO.	QUANTITY
RF Modem	RF-95	1 each
5-watt UHF Transceiver, with frequency 403.00 MHz	P-50	1 each
Celwave Antenna w/mount, w/frequency 403.00 MHz * (or equivalent)	BA-6012-0	1 each

ITEM	PART NO.	QUANTITY
(RF Cable) Coax BNCNM	BNCNM	as req.
12-V Power Supply w/regulator, battery and ports	PS-512M	1 each
P50/RF95 Bracket Kit	6228	1 each
Solar Panel, 10 watt w/mounts	MSX-10	1 each
12" x 14" Enclosure	ENC 12/14	1 each
Instrument Tripod & Grounding Kit (10 ft.) IF REQUIRED	CM-10	1 each

* Antenna Equivalent: If an alternate antenna is employed for this system, it is recommended that a YAGI, directional-type antenna be used.

8.2 PROCEDURES

8.2.1 Remote Site Installation

The following steps will be performed to ensure proper remote site installation:

- Assemble the instrument tripod, attaching grounding system, and secure.
- Attach the data logger/telemetry enclosure to the instrument tripod.
- Place the data logger, power supply, and telemetry equipment inside the enclosure.
- Attach the solar panel to the instrument tripod, orienting the face of the panel to the south.

- Attach the telemetry antenna to the instrument tripod, and secure the antenna coaxial cable to the tripod mast with tape or cable ties. Route the antenna cable into equipment enclosure, but do not connect to P-50 radio.

- Connect all wires (pump relays, sensors, solar panel, telemetry, and TDR) to the data logger.

- Ensure RF Modem has a "station ID" configured as per manufacturer's instructions.

- Connect VSWR meter between the P-50 radio antenna connector and the antenna coaxial cable. Set the VSWR meter to measure reflected power.

- Turn on P-50 radio and manually key the radio, checking reflected and forward power to check the equipment setup. Refer to manufacturer's specifications for forward and reflected power.

- Remove the VSWR meter and connect the antenna coaxial cable to the P-50 radio.

8.2.2 Repeater Installation

If a telemetry repeater site is required for the data telemetry link, the following installation steps will be followed:

- Assemble the instrument tripod, attaching the grounding system, and secure.

- Attach the telemetry enclosure to the instrument tripod.

- Place the power supply and telemetry equipment inside the enclosure.

- Attach the solar panel to the instrument tripod, orienting the face of the panel to the south.

- Attach the telemetry antenna to the instrument tripod, and secure the antenna coaxial cable to the tripod mast with tape. Route the antenna cable into the equipment enclosure, but do not connect to the P-50 radio.

- Ensure that the RF Modem has a station ID configured as per manufacturer's instructions.

- Connect VSWR meter between the P-50 radio antenna connector and the antenna coaxial cable. Set the VSWR meter to measure reflected power.

- Turn on the P-50 radio and manually key the radio, checking reflected and forward power. Refer to manufacturer's specifications for forward and reflected power.

- Remove the VSWR meter and connect the antenna coaxial cable to the P-50 radio.

8.2.3 Base Station Installation

The following steps will be performed to ensure proper base station installation:

- Install antenna on the roof of T-130B (to be installed by RFP Communications Dept.) and route the antenna coaxial cable into the office space.

- Remove the cover from RF Base Station.

- Connect the VSWR Meter to the P-50 radio and antenna coaxial cable.

- Turn on the base station and the P-50 radio and manually key the radio, testing forward and reflected power.

- Remove the VSWR meter, connect the antenna coaxial cable to the antenna connecter on the P-50 radio, and replace the base station cover.

- Connect the serial cable from the base station to the serial port on an IBM computer.

- Load the Campbell support software and soil sampling data logger program (to be written by user) into the IBM computer.

- Set up the station file as per manufacturer's instructions. Before proceeding to telemetry testing, the following information must be clearly understood by the base station operator. Due to the schedule of the soil sampling project, an independent operating frequency could not be allocated in time, and, therefore, a "time sharing" method of operating the telemetry will be used. The frequency being "time shared" is the operating frequency for the Emergency Response Meteorological Monitoring System. The times of operation for the monitoring system (actual telemetry communication) occur once every 15 minutes, i.e., 0801, 0816, 0831, 0846, etc., and the duration of "on-the-air" communications is approximately 30-45 seconds. This communication system has first priority over the system sharing the same frequency, and under no circumstances should attempts be made to establish

a telemetry link during the scheduled communication times of the Meteorological Monitoring System.

- Telemeter soil sampling program to the remote site and test the data logger function using the Campbell support software.

8.2.4 Soil Moisture Data

The soil moisture data obtained by the TDR will be transferred daily to a dedicated computer using the radio telemetry system. These data will be processed and tabulated daily. The soil moisture data will be transferred periodically to the RFEDS.

9.0 COLLECTION OF INTERSTITIAL WATERS

The frequency of soil interstitial water sampling will be estimated daily via remote control system See Section 8.0 and the project-specific field sampling plan/work plan or the Quality Assurance Addendum (QAA) for more information.

9.1 MATERIALS AND EQUIPMENT

- Vacuum hand-held pump
- Filters (0.45, 0.22, and 0.1 μm)
- Filtration device
- Distilled water
- Polyethylene tubes
- Collection bottles precleaned to EPA specifications
- Plastic sheeting
- Logbook

- Sample labels
- HACH portable laboratory equipment for measuring pH, temperature, and specific conductance

9.2 PROCEDURES

9.2.1 Zero-Tension Sampler

The following are the procedures for using the zero-tension sampler:

- Rinse the collection vessel and the draining tubes with distilled water, following the procedures in SOP GW.6.
- Connect the recovery tube of the zero-tension sampler to a polyethylene access tube about 40 cm long (see Figure GT.20-3).
- Connect the polyethylene tube to the draining inlet of the collection vessel.
- Attach a polyethylene tube about 25 cm long to the evacuation tube in the collection vessel.
- Connect the portable vacuum pump to the polyethylene tube and hand pump the system to approximately 50 kPa. The water from the zero-tension sampler will flow from the zero-tension sampler collection bottle to the collection vessel.
- Measure the pH, temperature, and specific conductance, following the procedure in SOP GW.5.

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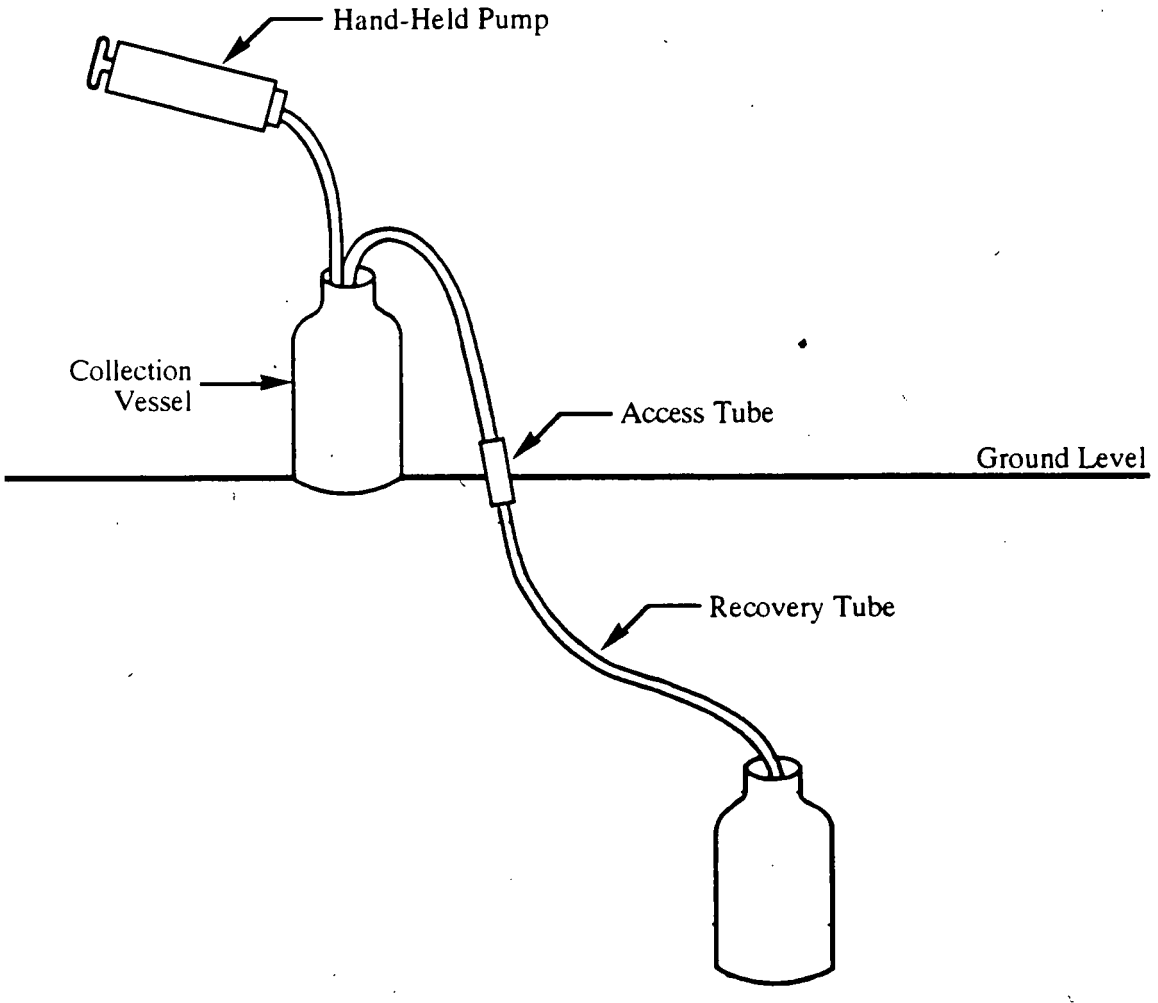
FIGURE GT.20-3
COLLECTING A SAMPLE FROM THE ZERO-TENSION SAMPLER



Not To Scale

(4011-930-0149-930)(Figure GT.20-3)(03/01/92)

- Filter the soil interstitial water by using a sequential filtration mode (0.45, 0.22, and 0.1 μm) described in SOP GW.6.

- Pour the sample into the appropriate sampling bottle. Label and submit the sample bottle to the designated lab according to SOP FO.13.

9.2.2 Tension Sampler

The following are the procedures for using the tension sampler:

- Rinse the collection vessel and the draining tubes with distilled water, following the procedure in SOP GW.6.

- Pour the soil interstitial waters that are accumulated in the collection vessels housed inside the thermo box into a collection vessel.

- Measure the pH, temperature, and specific conductance, following the procedure in SOP GW.5.

- Filter the soil interstitial water by using a sequential filtration mode (0.45, 0.22, and 0.1 μm) described in SOP GW.6.

- Pour the sample into the appropriate sampling bottle. Label and submit the sample bottle to the designated lab, according to SOP FO.13.

10.0 DECONTAMINATION

Excavation equipment will be decontaminated prior to excavating each trench or pit and at the conclusion of the operation. Sampling and peeling equipment will be decontaminated prior to collecting each sample. Care should be taken to inspect and monitor all excavation equipment, especially the backhoe, to ensure that no hydraulic and/or fuel leaks add contaminants to the site.

Specific decontamination procedures are described in SOP FO.3, General Equipment Decontamination and SOP FO.4, Heavy Equipment Decontamination.

11.0 DOCUMENTATION

All field information required by this SOP will be documented on Forms GT.7A and GT.20A~~, B,~~ and C. Form GT.~~20~~7A will be used to record data during excavation of the test pit and soil sampling. Form GT.20~~B~~A will be used for recording data collected during soil interstitial water sampling. Form GT.20C will be used to record data during filtering of the soil interstitial water sampling. Field observations and data will be recorded with black waterproof (permanent) ink on the field data forms.

Information from the Pit Soil Profile Description (Form GT.7A) and Soil Water Sampling Field Data Form (Form GT.20A) shall be entered into the field data capture program (Datacap) when released (see procedure FO.14, Field Data Management).

94-OMR-000297

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT FORM GT.20A (REV. 3)

SOIL WATER SAMPLING FIELD DATA FORM

PROJECT NAME: _____ PROJECT CHARGED: _____

SUBCONTRACTOR: _____ LOCATION CODE: _____ DATE: _____

CREW MEMBERS: _____

Sample Number	Sample ID	QC Code	Temp (C)	pH	Alkal.	Turbid.	Specific Cond.	Comments

Completed By: _____ **Date:** _____
Print Name Signature

Checked By: _____ **Date:** _____
Print Name Signature

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SAMPLE FILTERING FORM

Project Name _____

Sample Number	Pit Number	Date Sampled	Filtering (μm)			Analysis
			0.45	0.22	0.1	

Completed By: _____

Print Name Signature Date

Subcontractor: _____

(4011-930-0077-930)(GT20REV.2)(03/02/92)

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DOCUMENT MODIFICATION REQUEST (DMR)

PAGE 1 of 1

Refer to 1-A01-PPG-001 for Processing Instructions.
Printor Type All Information (Except Signatures).

1. Date	25.
12-6-93	DMR No. 94-DMR-000297

SERD 2229

2. Originating Document Number/Revision: 5-21000-OPS-GT.20

INFORMATION ONLY

3. New Document Number or Document Number if it is to be changed with this Revision: N/A

4. Originator's Name/Phone/Pager/Location: P. A. Kiefer, X8698, 080

5. Document Title: Procedures for Soil Interstitial Water Sampling and Sampler Installation

6. Document Type: ☒ Procedure ☐ Other _____

7. Document Modification Type (Check only one): ☐ New ☐ Revision ☒ Intent Change ☒ Nonintent Change ☐ Editorial Correction ☐ Cancellation

RR 2/22/94

8. Item	9. Page	10. Step	11. Proposed Modifications
1	4	4.2	Add reference as identified on attached.
2	25	11.0	Make changes as identified on attached
3	GT.20A (rev.2)		Eliminate this form from the procedure
4	GT.20B (rev.2)		Eliminate this form from the procedure
5	GT.20A (rev.3)		Insert this form into the procedure (ATTACHED)

12. Justification (Reason for Modification, EJO #, TP #, etc.)

Form GT.20A (rev.2) was combined with GT.7A (rev.2) into the new, all including, form GT.7A (rev.3). This procedure directs the user to use GT.7A (rev.3), this DMR eliminates GT.20A (rev.2). The existing form GT.20B was revised and renamed to GT.20A.

If modification is for a new procedure or a revision, list concurring disciplines in Block 13, and enter N/A in Blocks 14 and 15. If modification is for any type of change or a cancellation, organizations are listed in Block 13, then Concurror prints, and signs in Block 14, and dates in Block 15.

13. Organization	14. Print, Sign (if applicable)	15. Date (if applicable)
SME	M. Z. Litaor	12-6-93
SM	P. A. Kiefer	12-6-93
EQS	(RR) Mark Brooks	02-23-94

Originator's Supervisor (print/sign/date): D. Stagg 2/4/94

17. Assigned SME/Phone/Pager/Location	18. Cost Center	19. Charge Number	20. Requested Completion Date	21. Effective Date
M. Z. Litaor/8583/NA/080	3003	ENV-GT	02/25/94	FEB 28 1994

22. Accelerated Review? Yes ☐ No ☒

23. ORC Review: ORC Review Not Required

24. Responsible Manager (print,sign,date): ~~Bruce Peterman~~ Mark Levin

RR 2/23/94

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REVIEWED FOR CLASSIFICATION / UCNI

BY NA

INFORMATION ONLY

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	Page:	1 of 13
	Effective Date:	March 1, 1992
Category 2	Organization:	Environmental Management

TITLE:
CONE PENETROMETER
TESTING

Approved By:
(Name of Approver) 5/21/92 (Date)

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REVIEWED FOR CLASSIFICATION/UCNI
By
Date March 4, 1992

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) to conduct cone penetrometer testing (CPT). This SOP describes personnel responsibilities and qualifications, testing equipment and procedures, and documentation requirements.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

All personnel performing these procedures are required to have the appropriate health and safety training as specified in the site-specific Health and Safety Plan. In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures before CPT begins.

Personnel performing CPT must be highly trained individuals who understand the test characteristics and geology in which they are testing. Field managers will have had previous field experience performing CPT.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a list of references reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

Guidelines For Cone Penetration Test. U. S. Department of Transportation. July 1978.

Meigh, A. C. Cone Penetration Testing (Methods and Interpretation) . Construction Industry Research and Information Association (CIRIA). 1987.

Penetration Testing. Institution of Civil Engineers. 1989.

Robertson, P. K. and Campanella, R. G. Guidelines For Use & Interpretation of the Electric Cone Penetration Test. Hogentogler & Company, Inc. September 1984.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination.
- SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)
- SOP GT.17, Land Surveying
- SOP GT.22, In-Situ Sampling With BAT System

5.0 TESTING PROCEDURES

5.1 GENERAL

CPT provides a way to rapidly measure soil parameters such as bearing, friction, and pore pressure (if a piezometric CPT is used). Electric cone penetrometers have built-in sensors (usually strain gauges) at the tip and sides (sleeve) of the probe that measure penetration resistance and side friction of soils. Typically, tip penetration resistance and sleeve friction are different for clayey soils when compared to granular soils. This makes CPT useful for

identifying sands and gravels versus clays and silts. See Figure GT.21-1 for an example of a CPT log. Four important uses of the CPT data are:

- To identify soils and evaluate subsurface soil profiles
- To interpolate subsurface conditions between control boreholes
- To evaluate soil parameters (i.e., shear strength, etc.)
- To measure soil moisture content

A special rig is used to hydraulically push the CPT tool into the subsurface. Segments of rod are added as the probe is advanced at a constant rate of 0.6-1.0 inches (1.5-2.5 cm) per second. Continuous measurements of the penetration tip resistance and sleeve friction are recorded. These data are transferred through an electrical cable, connected to the CPT probe, to a computerized data acquisition system in the rig. Typically, data is recorded at approximately every 0.4-0.8 inches (1-2 cm) of penetration. The collected data can then be interpreted to provide information on the engineering characterization of the subsurface soils.

CPT may not be successful in soil that contains cobbles, boulders, rock, or other debris. These materials may damage the cone penetrometer (CP) probe or make it impossible for it to penetrate into the material. Sites will be evaluated for these conditions before testing begins to determine if CPT is appropriate. In addition, many projects require conventional borings to supplement CPT.

The following sections give details on equipment and procedures for CPT along with documentation requirements. During CPT, the appropriate personal protective equipment (PPE) as specified in the site-specific Health and Safety Plan will be worn at all times.

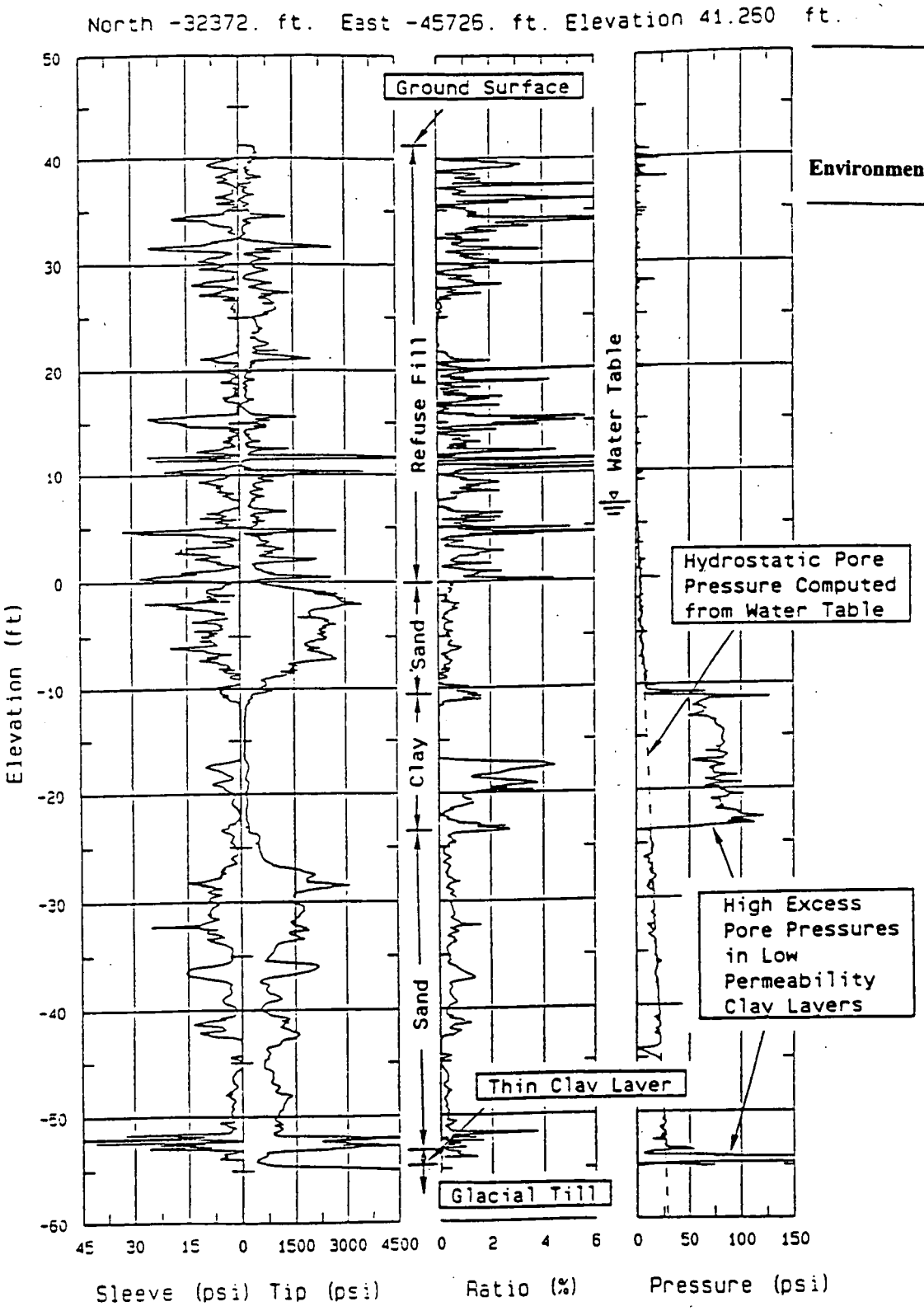


FIGURE GT.21-1 TYPICAL DATA FROM THE CONE PENETROMETER

FROM: Applied Research Associates, Inc.

5.2 EQUIPMENT

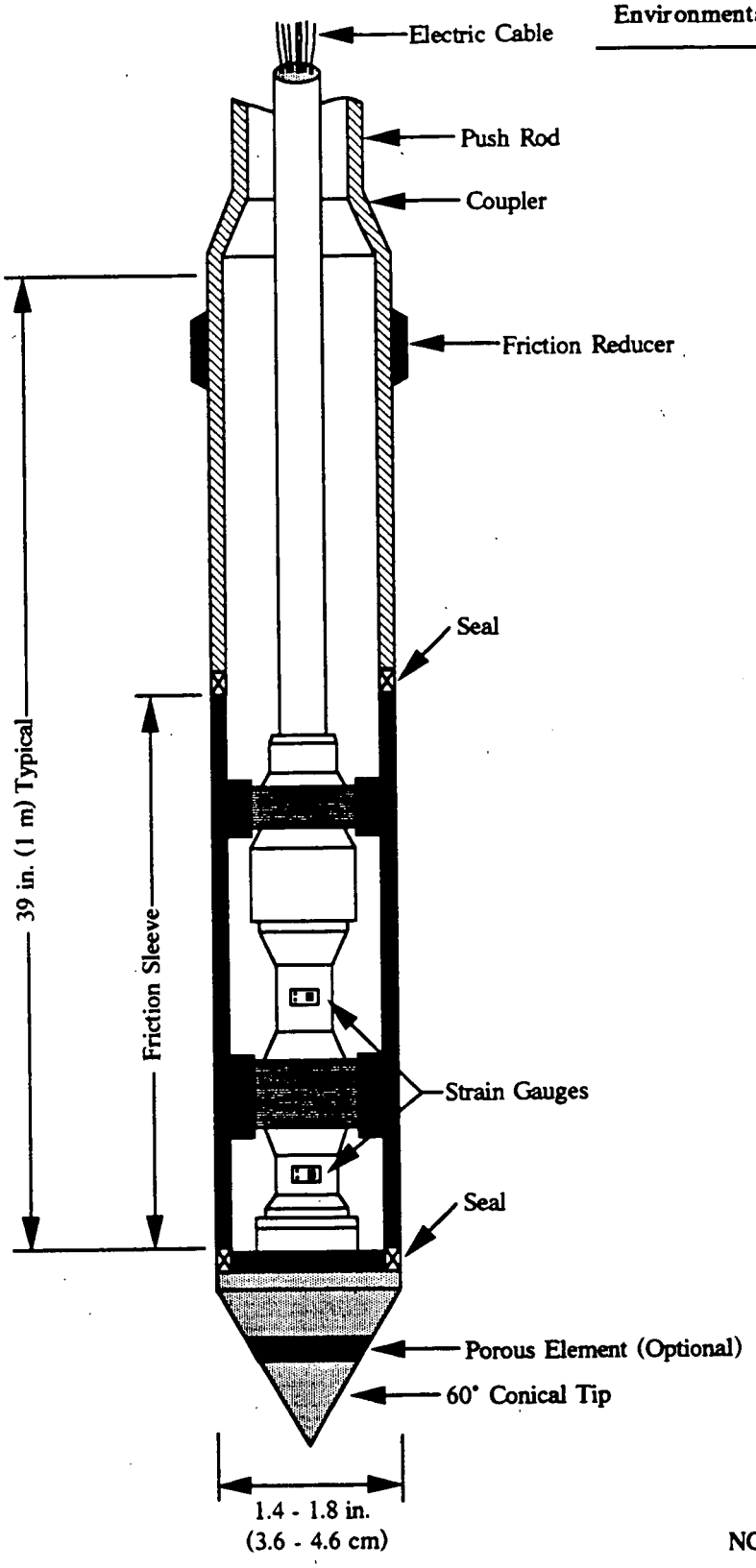
The following is a list of equipment that will be needed for cone penetrometer testing:

- Rig equipped for CPT
- CPT rods
- CPT electric probe
- High-pressure steamer/sprayer
- Long-handled bristle brushes
- Wash and rinse tubs
- Phosphate-free, lab-grade detergent (e.g., Liquinox)
- Distilled water
- Plastic sheeting
- Sample locations (map and/or list)
- Appropriate health and safety equipment
- Log book

5.3 CPT PROBE AND RIG

The CPT probe is composed of a 1.4 inch-1.8 inch (3.6 cm-4.6 cm) diameter probe with a conical point. Most CP probes are 1.4 inches (3.6 cm) in diameter. Typically, electric cone penetrometers have strain gauges that measure penetration resistance and side friction of soils. The continuous data from the strain gauges is transferred electronically through a cable, connected to the probe, to a computerized data acquisition system in the CPT rig. See Figure GT.21-2 for a schematic diagram of an electric CP.

Electric Cone Penetrometer



NOT TO SCALE

Figure GT.21-2

A friction reducer or coupling is usually placed approximately 1.0 ft-3.3 ft (30 cm-100 cm) behind the cone tip (see Figure GT.21-2). The purpose of the friction reducer is to increase the hole diameter in order to reduce soil contact against the cone rods. This makes the CP easier to push into the subsurface. Typically, a 2-inch long steel tube is welded (and chamfered to 30°) over the cone rod as a friction reducer.

CPT rods used to hydraulically push the CPT probe into the subsurface are made of high-tensile steel with special tapered threads. They are usually 1.4 in (3.6 cm) outside diameter and 0.6 inches (1.6 cm) inside diameter. A standard push rod is 3.3 ft (1 m) in length. Rods smaller in diameter than the cone base may be used, but there must be a minimum length of 39 inches (1 m) of rod immediately above the cone that is the same diameter as the cone (see Figure GT.21-1).

Rigs outfitted with a hydraulic jacking system are utilized to push the cone penetrometer into the subsurface. The rigs are usually specially built, but an anchored drill rig or trailer-mounted setup can also be used. There are light, medium, and heavy rigs depending on the thrust required. This SOP addresses CPT with medium and heavy rigs. The CPT rigs are often mounted in heavy duty trucks that are ballasted to a total dead weight of approximately 15 metric tons (150 kN). Screw anchors are then utilized to develop the extra reaction to reach the maximum thrust of approximately 20 metric tons (200 kN), if needed. The rigs are usually separated into push and data acquisition workspaces.

5.4 PROCEDURE

Before testing, sites will be located, numbered, and identified using stakes (or paint sticks on paved surfaces). Refer to SOP GT.17, Land Surveying, for more information regarding site location procedures.

After test sites have been located, an exclusion zone will be established according to the project Health and Safety Plan, and the CPT rig will be set up. The procedure for conducting CPT at a specific location is as follows:

1. Decontaminate the rig and downhole equipment. See SOP FO.3, General Equipment Decontamination, and SOP FO.4, Heavy Equipment Decontamination for specific details regarding decontamination.

2. Set up the rig to obtain a thrust direction as close to vertical as possible. The maximum acceptable deviation from vertical is 2%.

3. Advance the CPT probe and add CPT rods connected hand-tight as the probe advances. The electrical cable used to transfer data to the surface will be continuous, and it will be prethreaded through the push rods before the test begins.

4. Monitor the breathing zone of the CPT rig for volatile organic compounds (VOCs) during testing. See SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs), for more information regarding the use of monitoring instruments.

5. Check the computer data acquisition system before CPT begins and also during testing to ensure that it is working properly.

6. Advance the hole at a continuous rate of 0.6-1.0 inches (1.5-2.5 cm) per second to the desired depth.

7. Record the appropriate readings/measurements at every 0.4-0.8 inches (1-2 cm) of penetration using the computer data acquisition system (Note: readings should be taken at regular intervals, and the interval between readings shall never exceed 7.9 inches or 20 cm).

8. Review and evaluate field plot(s) of tip/sleeve resistance to ensure data quality.

9. When the test is complete, pull the CPT out of the subsurface. If the rig is equipped for it, the hole will be grouted from the bottom as the rods are withdrawn.

10. If the rig is not equipped to grout up the hole, screen the open hole for volatile organic compounds (VOCs) after the CP has been pulled out of the ground. See SOP FO.15 for more information regarding the use of monitoring equipment.

11. Grout the hole up if it has not already been completed by the rig. PVC pipe may be used if the hole did not collapse. If the hole collapsed, hollow CPT rods and a sacrificial tip will be used. The PVC pipe or CPT rods will be pushed to the bottom of the hole. Grout will then be pumped to the bottom of the hole as the CPT rods or PVC pipe are withdrawn.

If CPT testing is used at landfill sites or other sites where heavy debris (i.e., concrete, wood, etc.) may be present, special care will be taken. Readings will be monitored closely as the CP is pushed into the ground in order to recognize debris. If debris is encountered, the CP will be pulled out of the ground, and the hole will be grouted up. The CP system will then be offset (see Section 5.5 for minimum offset distances), and a new site will be tested. This procedure will be repeated until the desired depth is reached.

If lubricants are required for downhole equipment, only pure vegetable oil will be used. If gas and/or liquid samples are to be taken, the sampling procedures will be carried out according to SOP GT.22, In Situ Sampling With BAT System.

The thrust used for CPT testing is approximately 10-20 metric tons (100 kN-200 kN). In soft soils, however, a thrust as low as 2 metric tons (20 kN) may be sufficient. The test rods may buckle if a thrust of greater than 20 metric tons (200 kN) is applied. Generally, in most uncemented soils, a thrust capacity of 10 metric tons (100 kN) will handle more than 90% of CPT to 98 feet (30 m) depth.

5.5 CALIBRATION AND CHECKS

The CPT probe will be checked before a test begins and between test holes to ensure that its dimensions and surface roughness are within acceptable limits. The test system will also be calibrated as needed, and the calibration will be documented. Specifically, the load cells will be calibrated according to manufacturer specifications and industry standards at least every three months.

Before performing CPT, the straightness of the push rods will be checked. The bottom five push rods will be particularly checked by rotating them to see if they wobble. If a wobble is noticeable, the push rod(s) will not be used.

CPT will not be performed within 3.3 ft (1 m) of an existing CPT site. In addition, CPT will not be performed within 10 ft (3 m) of an uncased or unfilled borehole.

6.0 DECONTAMINATION

All equipment including the rig, probe, rods, etc. will be decontaminated before arrival at the work site. Between test holes, all downhole equipment will be decontaminated. Decontaminated equipment will be placed on new plastic or racks until it is used. CPT rigs will be decontaminated when moved out of a work area or when they become unusually dirty as a result of site or testing conditions, at the discretion of the site or project manager. See SOP FO.3, General Equipment Decontamination, and SOP FO.4, Heavy Equipment Decontamination, for specific details regarding decontamination.

7.0 DOCUMENTATION

All information required by this SOP will be documented on the Cone Penetrometer Testing Form (Form GT.21A) and/or the CPT log. The Cone Penetrometer Testing Form will be filled out for each day of testing at a given location and, in situations where more than one test hole is completed per day per rig, at least one form will be completed per test hole. The Cone Penetrometer Testing Form will include the following information and have space for comments and documentation of general observations:

- Project name
- Date
- Site location/identification and coordinates
- Weather
- Testing company and personnel
- Equipment descriptions (i.e., rig, probes, etc.)
- Environmental monitoring results
- Grouting details
- End-of-day status (i.e., partially complete, complete, etc.)

- Comments/observations

Any additional comments and/or observations will be recorded with black waterproof (permanent) ink in a bound log book with consecutively numbered pages.

All final CPT logs should have headers. At a minimum, the header should include the following information:

- Project name
- Date
- Site location/identification
- Elevation and depth reference
- Testing company and operator
- Equipment information
- Total depth

CONE PENETROMETER TESTING FORM

Project Name: _____ Date: _____

Site Location/Identification: _____

Coordinates: _____ North (Y) _____ East (X)

Weather Conditions: _____

Testing Company: _____

Testing Team Leader: _____

Testing Team Member: _____

Testing Team Member: _____

Rig Type: _____

Cone Type and Size (In): _____

Total Depth (Ft): _____

Grouting Details: _____

End-of-Day Status: _____

HIGHEST ENVIRONMENTAL MONITORING RESULTS

Organic Vapors: _____ (Value) _____ (Units) _____ (Instrument Used)

Comments: _____

_____

_____

_____

_____

Completed By: _____ (Print Name) (Signature) (Date)

Subcontractor: _____

(4011-930-0078-930)(GT21REV.1)(03/03/92)

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INFORMATION ONLY

APPROVAL PROCESS FOR CONSTRUCTION ACTIVITIES ON OR NEAR INDIVIDUAL HAZARDOUS SUBSTANCE SITES (IHSSs)

EG&G ROCKY FLATS PLANT	**Manual:**	**5-21000-OPS**
EMD MANUAL OPERATION SOP	**Procedure No.:**	**GT.24, Rev. 0**
	Page:	**1 of 7**
	Effective Date:	**November 8, 1991**
Category 2	**Organization:**	**Environmental Management**

TITLE:
APPROVAL PROCESS FOR CONSTRUCTION ACTIVITIES ON OR NEAR INDIVIDUAL HAZARDOUS SUBSTANCE SITES (IHSSs)

Approved By:

[signature] 5/12/92
(Name of Approver) (Date)

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REVIEWED FOR CLASSIFICATION/UCNI
By [signature]
Date May 12, 1992

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2.0 PURPOSE AND SCOPE

This standard operating procedure (SOP) describes procedures that will be used at the Rocky Flats Plant (RFP) for obtaining appropriate approval for construction activities on or near Individual Hazardous Substance Sites (IHSSs). This SOP is applicable to all operations conducted at the Rocky Flats plant site involving any type of construction including excavation as defined in the plant H&S manual. This SOP describes personnel responsibilities and qualifications, and procedures for construction activities.

3.0 RESPONSIBILITIES AND QUALIFICATIONS

Personnel overseeing construction activities will be engineers or other trained construction coordination personnel with an appropriate amount of applicable field experience or on-the-job training under the supervision of another qualified person. In addition, all personnel are required to have a complete understanding of the procedures described within this SOP and receive specific training regarding these procedures.

Personnel using light or heavy equipment, scientific monitoring devices, or operating company vehicles must have appropriate training and/or licenses.

4.0 REFERENCES

4.1 SOURCE REFERENCES

The following is a reference reviewed prior to the writing of this procedure:

A Compendium of Superfund Field Operations Methods. EPA/540/P-87/001. December 1987.

EG&G. Rocky Flats Plant Environmental Restoration Health and Safety Program Plan. October 1990.

4.2 INTERNAL REFERENCES

Related SOPs cross-referenced by this SOP are as follows:

- SOP FO.1, Air Monitoring and Dust Control
- SOP FO.3, General Equipment Decontamination
- SOP FO.4, Heavy Equipment Decontamination
- SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)
- SOP FO.16, Field Radiological Measurements

5.0 CONSTRUCTION PROCEDURES

5.1 IHSS BOUNDARIES

IHSS boundaries are not legally defined, (i.e., boundaries cannot be staked to the nearest foot). Therefore, they are subject to interpretation. IHSS location maps that are presently in circulation are to be used for preliminary planning only. If a determination of a IHSS boundary is required in the field, this determination must be made by designated EM personnel in coordination with the Rocky Flats Plant excavation coordinator.

5.2 CONSTRUCTION AUTHORIZATION

All proposed construction and excavation plans on or near IHSSs must be presented to EM personnel for approval. Site drawings showing proposed construction and excavation locations, as well as an excavation plan showing the placement of excavated soils must be submitted to the RFP Excavation Coordinator in the Construction Management (CM) branch of Plant Facilities Program Management. The plans will be reviewed by a joint EM, H&S, and CM excavation committee (known as the Soil Disturbance Assessment Committee) for compliance with EPA and CDH guidelines, proper H&S procedures, and for interference with plant utilities.

Additionally, all projects will be reviewed by EM to determine whether a IHSS will be impacted by possible groundwater inflow. Approval of the joint excavation committee, must be obtained before excavation to proceed.

5.3 SAMPLING

If a proposed construction project has been deemed by Environmental Management to impact a IHSS, a sampling plan will be required and sampling will be done. At the completion of sampling, a risk assessment will be completed using analytical data from samples to get the disposition of the soils. The preparation of the sampling plan shall be at the direction of the EM department. Costs incurred to complete sampling, analysis, and risk assessment shall be assumed by the project user.

5.4 PROCEDURES

Construction activities that may generate dust will be carried out according to SOP FO.1, Air Monitoring and Dust Control. During construction activities that require excavation of soil,

monitoring for radionuclides and volatile organic compounds (VOCs) may be required by H&S. See SOP FO.15, Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs) SOP FO.16, Field Radiological Measurements, and the Site-Specific Health and Safety Plan for more information regarding the use of monitoring instruments.

All residual soils within a IHSS will remain within that specified unit. There are provisions for moving soils off of IHSSs in special circumstances where the soil can be characterized as non-hazardous material. This determination will only be made by EM after sampling and risk analysis is completed. Additional time should be planned for projects if this is to be considered. The soil to be left in the IHSS may be graded, mounded, and used as backfill, as long as it can be demonstrated that there will be no danger of distribution off of the IHSS by erosion, wind, or hydraulic (surface or subsurface) action. Removal of soils from the immediate area of the excavation must be outlined in the excavation plan.

Treatment of residual soils and redistribution back into a IHSS is prohibited. Soil brought into a IHSS will be considered potentially contaminated soil, and therefore cannot be removed from the unit once it is brought in. Transfer of soils between IHSSs is prohibited.

Excavation in or near IHSSs must consider possible encounters with contaminated groundwater. Pumping of groundwater off a IHSS into other areas is prohibited without proper authorization. This authorization can be obtained only after sampling and analysis (contact the Clean Water Act division of EM at plant extension 4368). Additionally, design of excavations that encounter potentially contaminated groundwater may require sampling points (sampling wells) that will remain after construction activities are complete. All incidental waters that interfere with construction will be tested before they can be removed. For excavations in or near IHSSs that may encounter contaminated groundwater, steps will be taken to ensure that future migration of groundwater out of the IHSS will not occur.

Residual soils that cannot be graded, mounded, or used as backfill will be placed in appropriate containers and stored at the IHSS.

6.0 DECONTAMINATION

All equipment will be decontaminated before arrival at the work site and again between construction sites. See SOP FO.3, General Equipment Decontamination, and SOP FO.4, Heavy Equipment Decontamination, for specific details regarding decontamination.

7.0 DOCUMENTATION

All information required by this SOP will be documented on the appropriate forms attached to this SOP.

IHSS construction will require an excavation package. The person proposing construction will submit a completed Soil Disturbance Assessment Committee Evaluation Form (see attached), accurate plans/drawings showing specific location of work, and scope of work to be performed to the Excavation Administrator. This request shall be made a minimum of two weeks prior to start of work.

The Excavation Specialist will prepare a Site Survey Determination for Environmental Impact and Worker Exposure form and a Soil Disturbance Assessment form (see attached). He will submit the Site Survey Determination for Environmental Impact and Worker Exposure form to Environmental Management (EM), Industrial Hygiene (IH), Facilities Engineering (FE), Radiological Engineering (RE), and Construction Safety (CS) for pre-job environmental and worker potential hazard(s) exposure assessment.

U.S. DEPARTMENT OF ENERGY ROCKY FLATS PLANT

LAND USE REQUEST

SOW or CA Title:	Authorization No:
	WC No:

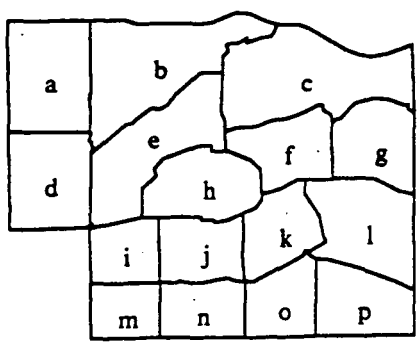
Work Manager:	Group:	Phone No.:

Check the Boxes That Apply:

- ☐ IAG Driven
- ☐ Routine Program
- ☐ Other — Describe _____
- ☐ Regulatory Driven
- ☐ Site Investigation
- ☐ RCRA
- ☐ CERCLA

Job Description/Objectives:

Location Description (Describe Below and Indicate on Locator Map to Right – Also Attach Detailed Plan and Location Map):



Emergency Contacts (Name and Number):
DOE/RFP Project Manager:
Subcontractor Manager:

Plant Support Required? If Yes, List/Describe (If No, List Contractor Support To Be Provided): ☐ Yes ☐ No

Duration of Project (Include Start/End Dates):

Is This Follow-Up To Existing Work? ☐ Yes ☐ No

Contract No. _____ Title _____ Manager _____

Describe:

Note: Upon Contract Award, Submit List of Subcontract Personnel Needing Access to Buffer Zone

AUTHORIZATION

	RECOMMEND REFERRAL TO RFP LONG RANGE PLANNING COMMITTEE			
	PERMISSION DENIED			
	REQUEST MORE INFORMATION AS SPECIFIED			
	PERMISSION GRANTED	LMC Signature:	Date:	Control No.

RF-46427

Revised 01/02/92

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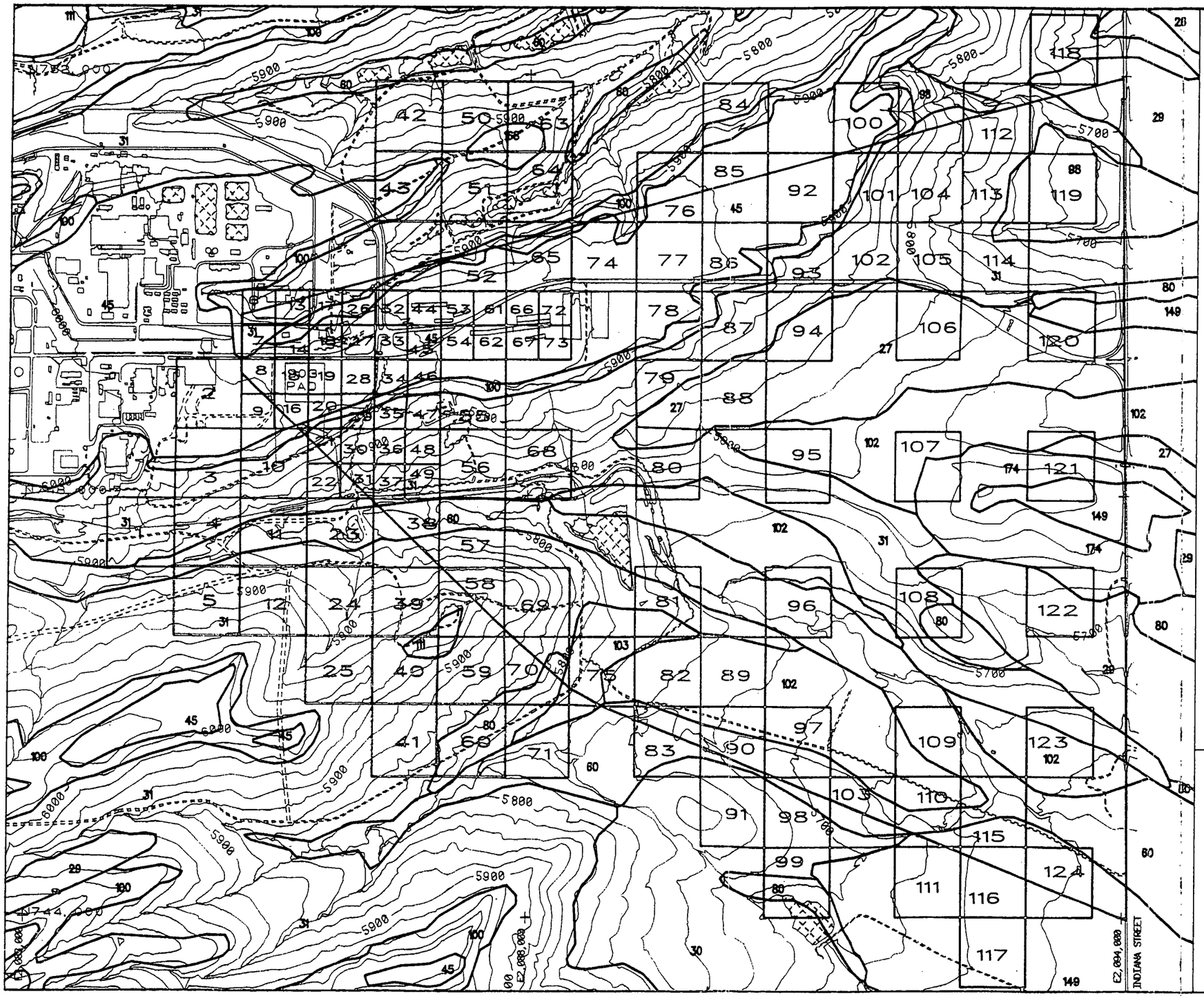

EXPLANATION

ESTIMATED MAXIMUM EXTENT OF SURFICIAL SOILS CONTAINING TWO dpm/g ACTIVITY BY CDH PROTOCOL

25 — 10 ACRE SAMPLING PLOT LOCATIONS

25 — 10 ACRE SAMPLING PLOT LOCATIONS NORTH AND SOUTH OF OPERABLE UNIT 2

25 — 2.5 ACRE SAMPLING PLOT LOCATIONS

NO. — SOIL TYPES

N

0 feet 1000 2000

CONTOUR INTERVAL = 20 FEET

U.S. DEPARTMENT of ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI WORK PLAN

PROPOSED SURFICIAL SOIL SAMPLING PLOT IDENTIFICATION NUMBERS

FIGURE 1 4/4/91

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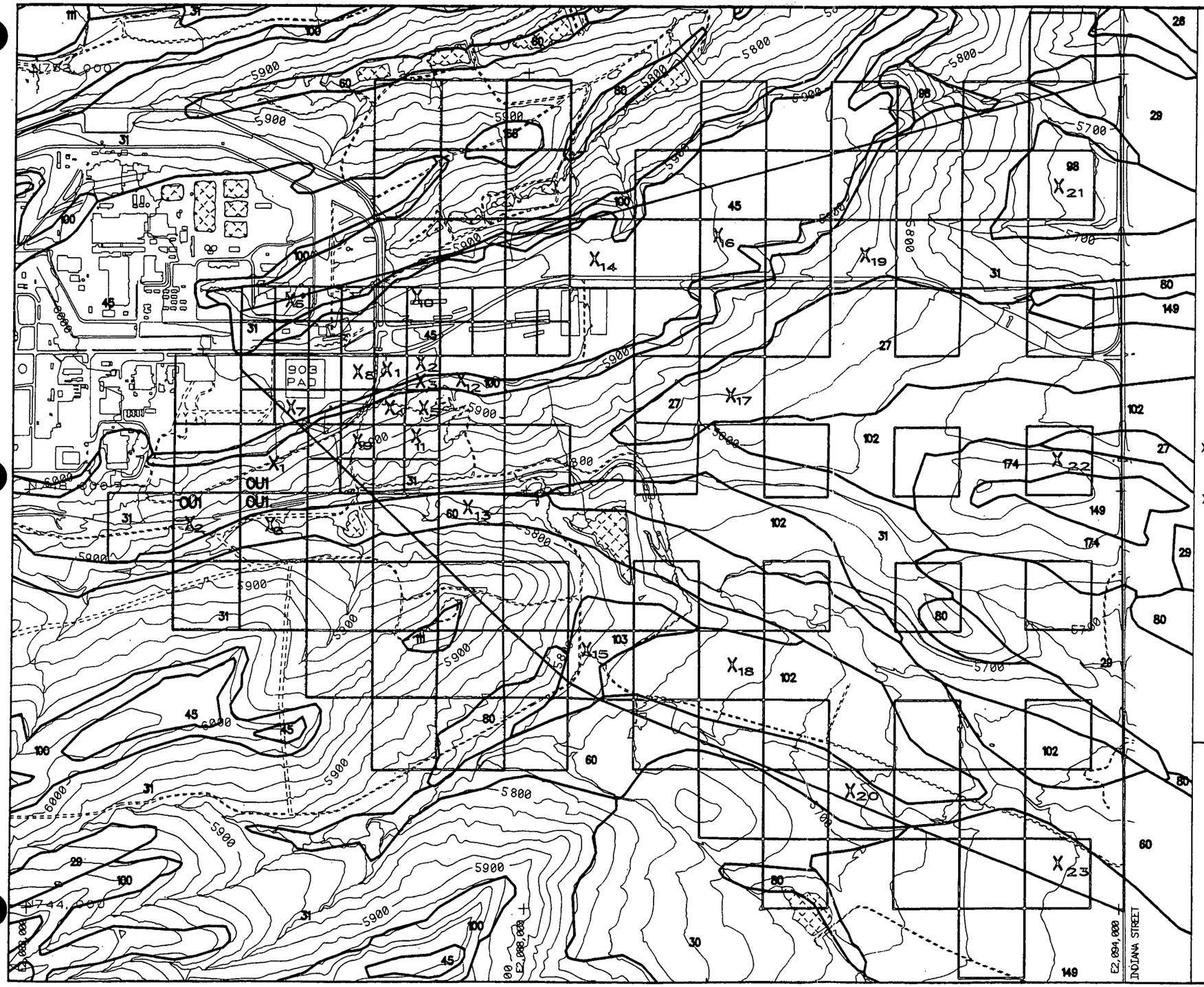

EXPLANATION

ESTIMATED MAXIMUM EXTENT OF SURFICIAL SOILS CONTAINING TWO dpm/g ACTIVITY BY CDH PROTOCOL

10 ACRE SAMPLING PLOT LOCATIONS

10 ACRE SAMPLING PLOT LOCATIONS NORTH AND SOUTH OF OPERABLE UNIT 2

2.5 ACRE SAMPLING PLOT LOCATIONS

NO. SOIL TYPES

X_1 to X_5 LOCATION OF SOIL SOLUTION SAMPLERS

X_6 TO X_{23} SOIL PROFILE SAMPLING LOCATIONS FOR OPERABLE UNIT 2

0 feet 1000 2000

CONTOUR INTERVAL = 20 FEET

U.S. DEPARTMENT of ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO. 2
PHASE II RFI/RI WORK PLAN

PROPOSED SURFICIAL SOIL SAMPLING LOCATIONS

FIGURE 2 4/4/91