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INTERIM FINAL RCRA FACILITY INVESTIGATION (RFI) GUIDANCE - VOLUME I AND II

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INTERIM FINAL

RCRA FACILITY INVESTIGATION (RFI) GUIDANCE

VOLUME I OF IV

DEVELOPMENT OF AN RFI WORK PLAN AND GENERAL CONSIDERATIONS FOR RCRA FACILITY INVESTIGATIONS

EPA 530/SW-89-031

MAY 1989

WASTE MANAGEMENT DIVISION
OFFICE OF SOLID WASTE
U.S. ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

On November 8, 1984, Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are §3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and §3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility Investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under §3008(h), §7003, and/or §3013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures Study may be necessary.

DISCLAIMER

This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.

Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.

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RCRA FACILITY INVESTIATION (RFI) GUIDANCE

VOLUME I

DEVELOPMENT OF AN RFI WORK PLAN AND GENERAL CONSIDERATIONS FOR RCRA FACILITY INVESTIGATIONS

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LIST OF ACRONYMS

AA	-	Atomic Absorption
AI	-	Soil Adsorption Isotherm Test
ASCS	-	Agricultural Stabilization and Conservation Service
ASTM	-	American Society for Testing and Materials
BCF	-	Bioconcentration Factor
BOD	-	Biological Oxygen Demand
CAG	-	EPA Carcinogen Assessment Group
CPF	-	Carcinogen Potency Factor
CBI	-	Confidential Business Information
CEC	-	Cation Exchange Capacity
CERCLA	-	Comprehensive Environmental Response, Compensation, and Lability Act
CFR	-	Code of Federal Regulations
CIR	-	Color Infrared
CM	-	Corrective Measures
CMI	-	Corrective Measures Implementation
CMS	-	Corrective Measures Study
COD	-	Chemical Oxygen Demand
COLIWASA	-	Composite Liquid Waste Sampler
DNPH	-	Dinitrophenyl Hydrazine
DO	-	Dissolved Oxygen
DOT	-	Department of Transportation
ECD	-	Electron Capture Detector
EM	-	Electromagnetic
EP	-	Extraction Procedure
EPA	-	Environmental Protection Agency
FEMA	-	Federal Emergency Management Agency
FID	-	Flame Ionization Detector
Foc	-	Fraction organic carbon in soil
FWS	-	U.S. Fish and Wildlife Service
GC	-	Gas Chromatography
GC/MS	-	Gas Chromatography/Mass Spectroscopy
GPR	-	Ground Penetrating Radar
HEA	-	Health and Environmental Assessment
HEEP	-	Health and Environmental Effects Profile
HPLC	-	High Pressure Liquid Chromatography
HSWA	-	Hazardous and Solid Waste Amendments (to RCRA)
HWM	-	Hazardous Waste Management
ICP	-	Inductively Coupled (Argon) Plasma
ID	-	Infrared Detector
Kd	-	Soil/Water Partition Coefficient
Koc	-	Organic Carbon Absorption Coefficient
Kow	-	Octanol/Water Partition Coefficient
LEL	-	Lower Explosive Limit
MCL	-	Maximum Contaminant Level
MM5	-	Modified Method 5
MS/MS	-	Mass Spectroscopy/Mass Spectroscopy
NFIP	-	National Flood Insurance Program

LIST OF ACRONYMS (Continued)

NIOSH	-	National Institute for Occupational Safety and Health
NPDES	-	National Pollutant Discharge Elimination System
OSHA	-	Occupational Safety and Health Administration
OVA	-	Organic Vapor Analyzer
PID	-	Photo Ionization Detector
pKa	-	Acid Dissociation Constant
ppb	-	parts per billion
ppm	-	parts per million
PUF	-	Polyurethane Foam
PVC	-	Polyvinyl Chloride
QA/QC	-	Quality Assurance/Quality Control
RCRA	-	Resource Conservation and Recovery Act
RFA	-	RCRA Facility Assessment
RfD	-	Reference Dose
RFI	-	RCRA Facility Investigation
RMCL	-	Recommended Maximum Contaminant Level
RSD	-	Risk Specific Dose
SASS	-	Source Assessment Sampling System
SCBA	-	Self Contained Breathing Apparatus
SCS	-	Soil Conservation Service
SOP	-	Standard Operating Procedure
SWMU	-	Solid Waste Management Unit
TCLP	-	Toxicity Characteristic Leaching Procedure
TEGD	-	Technical Enforcement Guidance Document (EPA, 1986)
TOC	-	Total Organic Carbon
TOT	-	Time of travel
TOX	-	Total Organic Halogen
USGS	-	United States Geologic Survey
USLE	-	Universal Soil Loss Equation
UV	-	Ultraviolet
VOST	-	Volatile Organic Sampling Train
VSP	-	Verticle Seismic Profiling
WQC	-	Water Quality Criteria

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SUMMARY

The Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) were enacted into law on November 8, 1984. One of the major provisions (Section 3004(u)) of these amendments requires corrective action for releases of hazardous waste or constituents from solid waste management units (SWMUs) at hazardous waste treatment, storage, or disposal facilities. Under this provision, any facility applying for a RCRA hazardous waste management facility permit will be subject to a RCRA Facility Assessment (RFA). The RFA is conducted by the regulatory agency and is designed to identify SWMUs which are, or are suspected to be, the source of a release to the environment. If any such units are identified, the owner or operator of the facility will be directed to perform a RCRA Facility Investigation (RFI) to obtain information on the nature and extent of the release so that the need for interim corrective measures or a Corrective Measures Study can be determined. Information collected during the RFI can also be used by the owner or operator to aid in formulating and implementing appropriate corrective measures. Such corrective measures may range from stopping the release through the application of a source control technique to a full-scale cleanup of the affected area. In cases where releases are sufficiently characterized, the regulatory agency may require the owner or operator to collect specific information needed to implement corrective measures during the RFI.

This document provides the owner or operator with guidance on conducting a RCRA Facility Investigation. Based on release determinations made by the regulatory agency (generally resulting from the RFA), the owner or operator of a facility will be notified, through an enforcement order or permit conditions, of those unit(s) and releases (known or suspected) which must be further investigated.

This guidance is divided into fifteen sections presented in four volumes. Volume I presents recommended procedures to follow in developing a work plan for conducting the investigation. It also describes the criteria that the Agency will use to interpret the data collected during the RFI. This interpretation is an integral part of the RFI and is discussed in Section 8, which describes the Health and Environmental Assessment (HEA) that is conducted by the Agency. The primary element of the HEA is a set of criteria (chemical concentrations), against which concentrations of hazardous constituents identified during the release

characterization are compared. The health and environmental assessment is used in determining the need for a Corrective Measures Study (CMS) or Interim Corrective Measures (ICM), and is based primarily on EPA-established chronic-exposure limits.

Volumes II and III describe specific methods for characterizing the nature, extent, and rate of contaminant release to soil, ground water, subsurface gas, air, and surface water. Each medium-specific section contains an example strategy for characterizing releases, which includes characterizing the source and environmental setting of the release, and conducting a monitoring program that will characterize the release. Also, each section provides a checklist of information that may be needed for release characterization, formats for data presentation, and field methods that may be used in the investigation. Highlights of the medium-specific sections are provided below.

Section 9 (SOIL)

- Gives specific emphasis to the potential for inter-media transfer of releases from the soil medium to other media;
- Explains the significance of surficial soil and deep soil contamination; and
- Highlights the role of leaching tests.

Section 10 (GROUND WATER)

- References the RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) to characterize site hydrology;
- Encourages the use of flow nets for interactive/verifiable site characterization; and
- Focuses on basement seepage as an important pathway for contaminant migration and exposure.

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Section 11 (SUBSURACE GAS)

- Focuses on methane gas from refuse landfills because of its explosive properties, as well as volatiles from underground tanks;

- Emphasizes the importance of subsurface gas as a pathway for inter-media transport (e.g., transfer of contamination from subsurface gas to soil and air); and

- Presents a subsurface gas migration model, detailed in in Appendix D.

Section 12 (AIR)

- Addresses monitoring and modeling of unit emissions and dispersion modeling for off-site receptors at or beyond the facility property boundary; and

- Provides an air release screening assessment methodology that may be used as a transition between the general quality determinations made in the RCRA Facility Assessment (RFA), regarding air emissions that warrant the actual performance of an RFI.

Section 13 (SURFACE WATER)

- Emphasizes the importance of understanding the form and frequency of releases to surface water and the role of biomonitoring; and

- Explains when sampling bottom sediments is important.

Volume IV presents a number of case studies selected to illustrate various concepts and procedures presented in Volume I, II and III. Most of the case studies are based on actual sites. In some cases, existing data have been supplemented with hypothetical data to illustrate a particular point.

Prior to conducting the investigation, the owner or operator will in most cases be directed, through a permit or enforcement order, to submit a written plan (the RFI Work Plan) that should propose, in detail, the manner in which the investigation will be conducted. Specific components of this plan are defined in Volume I of this guidance.

In planning the investigation, the owner or operator should consider a logical progression of tasks that will be followed in investigating the release. Generally, these tasks will consist of:

- Gathering information on the source of the release to the environment (e.g., gathering information on the unit and the waste in the unit);

- Gathering physical information on the environment surrounding the unit that will affect the migration and fate of the release (e.g., ground-water flow direction, average windspeeds, soil types); and

- Using the above information along with any existing monitoring or modeling information, to develop a conceptual model of the release, which will be used to plan and conduct a monitoring program to define the nature, rate and extent of the release.

The owner or operator should use existing sources of information when these sources can supply data of the quality and type needed. Information on waste constituents, for instance, may be available from operational records kept at the facility. In other instances, the owner or operator may propose a waste sampling and analysis effort to characterize the waste in the unit of concern, thereby producing new data on the waste. In either case, the owner or operator should ensure that the data is of the quality necessary to adequately define the release because such data will be used in determining the need for corrective measures.

Characterizing the release source and the environmental setting of the release will allow the owner or operator to design a monitoring program which will lead to adequate characterization of the release. This effort may be conducted in phases, if necessary, with each monitoring phase building on the findings and conclusions of the previous phase. For example, in those cases where the regulatory agency has

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identified a suspected release, the first phase of the monitoring program may be directed toward release verification. The level of effort required in an initial monitoring phase will thus be dictated by the level of knowledge on the release. The hypothetical examples of this approach given below illustrate that RFIs can vary widely in complexity and, thus, will not always involve elaborate studies.

- A facility contains both active and inactive landfills. All active landfills at the facility are regulated for ground-water releases under 40 CFR Part 264, Subpart F; however, an inactive unit was identified by the regulatory agency as being the source of a release to ground water. The waste in the unit was identified by the owner or operator as being supplied solely by a single, well-characterized process.

  Hydrogeologic information, such as identification of the uppermost aquifer and ground-water flow direction and rate, were defined in the RCRA Part B permit application for the active units required for compliance with Subpart B of 40 CFR Part 270. Environmental characterization data relevant to the inactive landfill, such as flow direction and hydraulic gradient, was readily derived from monitoring wells already installed to comply with the monitoring requirements of 40 CFR Part 264, Subpart F.

  In this case, the owner or operator was able to use existing information to characterize both the environmental setting and the source of the release and conduct a limited sampling program, starting with wells near the inactive unit, to define the release. After installation and sampling of these initial wells, the owner or operator determined the need for further well installation and sampling. In this case, the level of effort required to characterize the release, especially in characterizing the contaminant source and environmental setting, was minimal due to the detailed information already available.

- In another case, the owner or operator of a commercial facility with an inactive surface impoundment that had received waste from several generators was directed to conduct an investigation of a suspected release to a nearby stream. The suspicion of a release was based on

several fishkills noted in the stream during periods of heavy rains and reported observations of impoundment overflow during these periods. The owner or operator's knowledge of the impoundment's contents was limited due to the varying wastes managed, and a survey of drainage patterns around the impoundment had not been performed. Also, monitoring of the receiving stream itself had not been conducted at the time of the notification.

In this case, a rather extensive level of effort was required to characterize the release. Because the waste could not be readily characterized by direct sampling due to its varying nature over time, the owner or operator proposed to forego a direct waste characterization effort and conduct monitoring of the receiving stream for the constituents of concern. The owner or operator conducted a survey of drainage patterns around the site, developed a conceptual model of the release, and established a network of monitoring stations. Initial sampling was conducted in drains and swales around the unit, with subsequent monitoring taking place in drainage ditches and eventually the stream itself, with the design of each sampling effort based on knowledge gained from the previous effort. In addition, because contamination of the surface water column coincided with periods of heavy rains, sampling of the water column was conducted during such periods. The owner or operator also determined, through analysis of samples collected in the initial phases, that the waste constituents being released were highly water soluble and not likely to adhere to bottom sediments. In addition, the owner or operator determined that these constituents had a low potential to bioaccumulate. Stream sampling, therefore, was limited to water column samples; bottom sediment and biota sampling were not performed.

- During a visual site inspection conducted by the regulatory agency as part of the RCRA Facility Assessment, evidence was found that ten drums, placed in an unrestricted storage area, were releasing their contents to soils surrounding the area. Evidence observed by the investigative team included discolored soils and stressed vegetation. The regulatory agency issued a compliance order requiring the owner or operator to

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immediately remove the drums (as an interim corrective measure) and to conduct an investigation of the nature and extent of the contamination. The owner or operator complied with the order for removal and conducted sampling to characterize the waste in the drums. After identifying the constituents of the waste, the owner or operator proposed a work plan to characterize the release, starting with a screening survey of the area using an organic vapor analyzer (OVA), followed by the collection of samples in the immediate vicinity of the drum storage area, then additional sampling at progressively further distances from the area, if necessary. After collection of three rounds of sampling, sufficient data had been gathered to adequately define the extent of the release.

The above three examples illustrate general concepts that may vary on a site-specific basis.

The owner or operator should understand that the regulatory agency has a significant oversight responsibility to ensure the protection of human health and the environment. Accordingly, the regulatory agency may often choose to be present to observe RFI-related operations, especially field and sampling operations. Regulatory agency oversight of RFI field work is very important for ensuring a quality study. In planning and conducting the RFI, therefore, the owner or operator is encouraged to interact closely with the regulatory agency to assure that the data supplied during the investigation and, thus, the interpretation of the data, will be acceptable. The compliance order or permit conditions requiring the investigation will specify a schedule for conducting the investigation, including the reporting of data. The owner or operator should keep the regulatory agency advised of the progress of the investigation, including any delays, and changes to, or deletions of specific investigation activities.

This document presents guidance specific to the RFI and the RFI process. General subject areas which are common to many types of hazardous waste management activities (e.g., quality assurance and control, sampling, analytical methods, health and safety procedures), which are also important to the RFI, are addressed in a summary fashion. More detailed references on these subject areas are provided.

This RFI Guidance is tailored to the structure and goals of the RCRA Corrective Action Program. The RFI process described in this document parallels the technical components of the Remedial Investigation (RI) and removal guidance issued under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The RFI Guidance has been developed to address releases from operating as well as inactive and closing units. When such releases have been adequately characterized, the next step in the RCRA corrective action process can be initiated (i.e., determination of the need for corrective measures).

In order to assess the effectiveness of this Guidance Document an "RFI Feedback Questionnaire," is provided at the end of Volume I. This feedback will also help EPA determine the need for additional guidance.

SECTION 1

OVERVIEW OF THE RCRA CORRECTIVE ACTION PROGRAM

1.1 Introduction

The primary objective of the RCRA corrective action program is to clean up releases of hazardous waste or hazardous constituents at treatment, storage, or disposal facilities subject to Subtitle C of RCRA. "Release" means any spilling, leaking, pouring, emitting, emptying, discharging, injecting, pumping, escaping, leaching, dumping, or disposing of hazardous wastes (including hazardous constituents) into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing hazardous wastes or hazardous constituents).

The 1984 Hazardous and Solid Waste Amendments (HSWA) provided EPA with broad and expanded authorities for ensuring corrective action at facilities subject to RCRA. Authorities that may be used by EPA to ensure corrective action include:

- Section 3004(u) - Corrective Action for Continuing Releases

  Section 3004(u) of HSWA requires that permits issued after the date of enactment of HSWA (November 8, 1984) require corrective action for releases of hazardous waste or constituents from any solid waste management unit (SWMU) at any hazardous waste treatment, storage, or disposal facility seeking a permit, regardless of the time at which waste was placed in the unit.

- Section 3008(h) - Interim Status Corrective Action Orders

  Section 3008(h) of HSWA authorizes EPA to issue orders requiring corrective action or to take other appropriate response measures to protect human health and the environment based on any information

that there is or has been a release of hazardous waste into the environment from a facility authorized to operate under Section 3005(e).

- Section 3004(v) - Corrective Action Beyond the Facility Boundary

  Section 3004(v) authorizes EPA to require that corrective action be taken by the facility owner or operator beyond the facility property boundary where necessary to protect human health and the environment, unless the owner or operator demonstrates that he was unable to obtain permission to undertake such action.

Section 3005(c)(3) of HSWA (commonly known as the "Omnibus" provision) gives EPA authority to add to RCRA permits any conditions deemed necessary to protect human health and the environment.

In addition, Section 3004(n) of HSWA directs EPA to set standards for the control and monitoring of air emissions at hazardous waste treatment, storage, and disposal facilities as necessary to protect human health and the environment. These standards are presently being developed and will form the overall basis for regulating air emissions at these facilities. These standards may be used by EPA in evaluating corrective measures associated with air releases at solid waste management units. However, until these standards are sufficiently developed, EPA will use this RFI Guidance to address air releases that may require corrective measures.

EPA may also apply RCRA authorities existing prior to the passage of HSWA to implement the corrective action program. These authorities include RCRA Sections 3013 and 7003. Section 3013 may be used to order an owner or operator to conduct monitoring, testing, analysis, and reporting at a facility which is or may be releasing hazardous waste that may present a substantial hazard to human health or the environment. Section 7003 can be applied where hazardous waste management activities may present an imminent and substantial endangerment to health or the environment. Under this provision, the EPA Administrator may bring suit against an owner or operator to cease activities causing such endangerment or to take other appropriate action as may be necessary.

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Section 3004(u) has been codified as 40 CFR §264.101. A companion to EPA's July 15, 1985 (see 50 FR 28702), codification rule specifies additional information and data requirements for owners or operators of solid waste management units to support the conduct of RCRA Facility Assessments by the regulatory agency (see 52 FR 45788 - December 1, 1987). These authorities broaden the scope of the RCRA corrective action program from detecting and correcting releases to the uppermost aquifer from regulated units, to cleaning up continuing releases to any media resulting from other waste management units and practices at RCRA facilities. Prior to passage of HSWA, EPA exercised its authority under Section 3004 to require corrective action for releases of hazardous constituents to ground water from only certain land-based waste management units; 40 CFR Part 264, Subpart F contains requirements for corrective action at these "regulated units." Regulated units include surface impoundments, landfills, waste piles, and land treatment units that received hazardous waste on or after July 26, 1982. Also, EPA applied Sections 3013 and 7003, as appropriate, toward meeting corrective action program objectives. HSWA expanded RCRA authority to correct releases of hazardous waste or hazardous constituents to all media at RCRA facilities, and encourages the use of other authorities, as needed or appropriate, to help achieve corrective action objectives at these facilities.

Section 3004(u) of the HSWA corrective action provisions focuses on investigating releases from solid waste management units (SWMUs). A SWMU is any discernible unit at which solid or hazardous wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous wastes. Such units include any area at a facility at which hazardous wastes or hazardous constituents have been routinely and systematically released. A SWMU does not include an accidental spill from production areas and units in which wastes have not been managed (e.g., product storage areas).

This RFI Guidance addresses investigations of all releases from SWMUs (hereafter also referred to as units) to all media, including soil, ground water, subsurface gas, air, and surface water. Ground-water releases from regulated units will continue to be regulated under 40 CFR Part 264, Subpart F.

1.2 Overall RCRA Corrective Action Process

The RCRA Corrective Action Process consists primarily of the following four steps: the RCRA Facility Assessment (RFA), the RCRA Facility Investigation (RFI), the Corrective Measures Study (CMS), and Corrective Measures Implementation (CMI). A summary of the overall Corrective Action Process for identifying, characterizing, and correcting releases is presented in Figure 1-1. This process is discussed below.

RCRA Facility Assessment (RFA)

Release determinations for all environmental media (i.e., soil, ground water, subsurface gas, air, or surface water) will be made by the regulatory agency primarily through the RFA process. The regulatory agency will perform the RFA for each facility seeking a RCRA permit to determine if there are releases of concern. The major objectives of the RFA are to:

- Identify SWMUs and collect existing information on contaminant releases; and
- Identify releases or suspected releases needing further investigation.

The RFA begins with a preliminary but fairly comprehensive review of pertinent existing information on the facility. If necessary, the review is followed by a visual site inspection to verify information obtained in the preliminary review and to gather information needed to develop a sampling plan. A sampling visit is performed subsequently, if necessary, to obtain appropriate samples for making release determinations.

The findings of the RFA will result in one or more of the following actions:

- No further action under the RCRA corrective action program is required at that time, because no evidence of release(s) or of suspected release(s) was identified;

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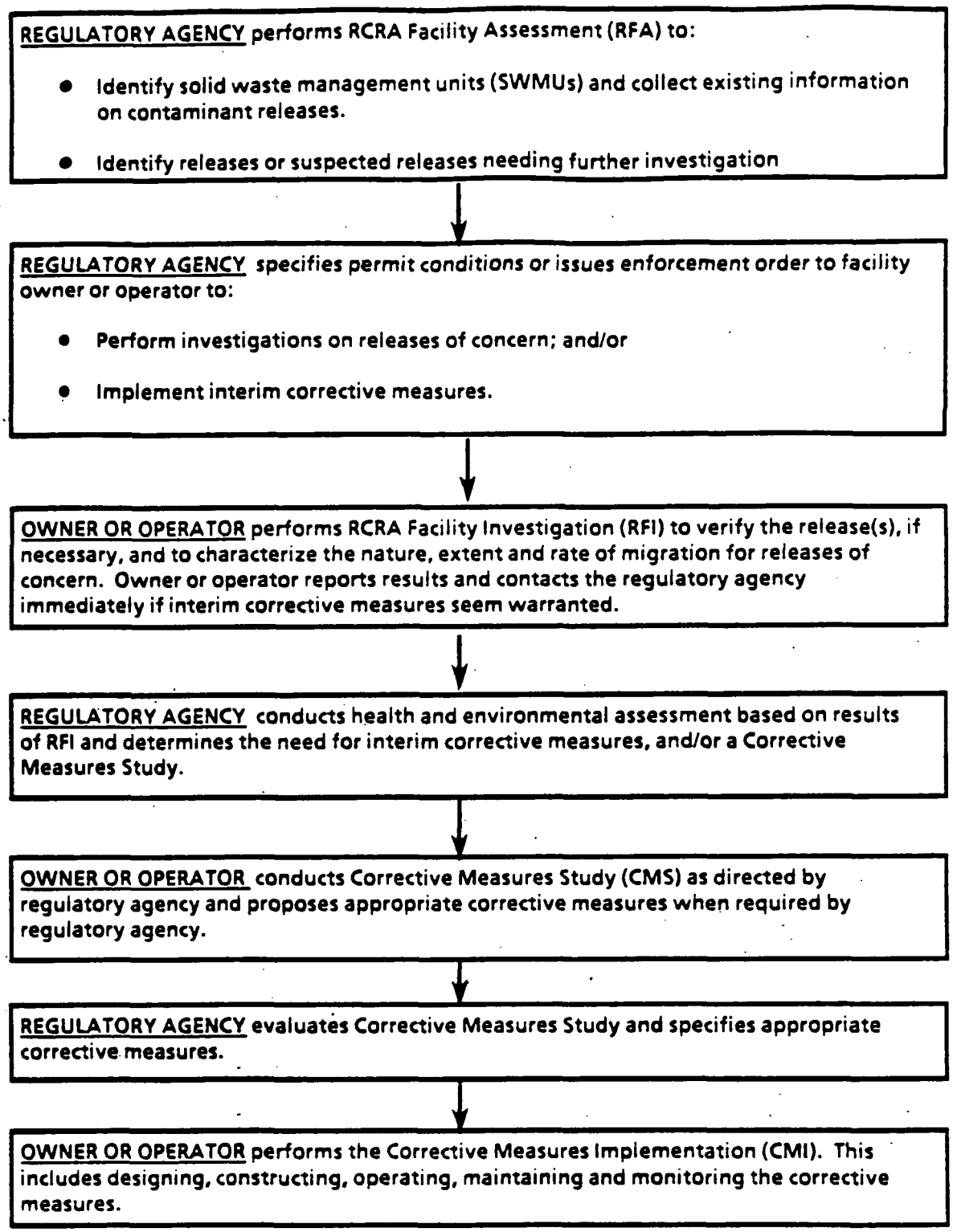

Figure 1-1: RCRA Corrective Action Process. Note that although certain aspects of the Corrective Action Process are the responsibility of either the regulatory agency or the owner or operator, close coordination between the regulatory agency and the owner or operator is essential throughout the process.

- An RFI by the facility owner or operator is required where the information collected indicates a release(s) or suspected release(s) that warrant(s) further investigation;

- Interim corrective measures by the owner or operator are required where the regulatory agency believes that expedited action should be taken to protect human health or the environment; and

- In cases where problems associated with permitted releases are found, the regulatory agency will refer such releases to the appropriate permitting authorities.

Guidance for conducting the RFA is presented in the following reference:

U.S. EPA. October, 1986. RCRA Facility Assessment Guidance. NTIS PB 87-107769. Office of Solid Waste. Washington, D.C. 20460.

RCRA Facility Investigation (RFI)

If the regulatory agency determines that an RFI is necessary, this investigation will be required of the owner or operator either under a permit schedule of compliance or under an enforcement order. The regulatory agency will apply the appropriate regulatory authority and develop specific conditions in permits or enforcement orders. These conditions will generally be based on results of the RFA and will identify specific units or releases needing further investigation. The RFI can range widely from a small specific activity to a complex multi-media study. In any case, through these conditions, the regulatory agency will direct the owner or operator to investigate releases of concern. The investigation may initially involve verification of suspected releases. If confirmed, further characterization of such releases will be necessary. This characterization includes identification of the type and concentration of hazardous waste or hazardous constituents released, the rate and direction at which the releases are migrating, and the distance over which releases have migrated. Inter-media transfer of releases (e.g., volatilization of hazardous constituents from contaminated soils to the air medium) should also be addressed during the RFI, as appropriate.

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The RFI also includes interpretation by the regulatory agency of release characterization data to established health and environmental criteria to determine whether a CMS is necessary. This evaluation is crucial to the RCRA Corrective Action Process. The regulatory agency will ensure that data and information collected during the RFI adequately describe the release and can be used with a high degree of confidence to make decisions regarding the need for a CMS.

Identifying and implementing interim corrective measures may also be conducted during the RFI. If, in the process of conducting the investigation, a condition is identified that indicates that adverse exposure to hazardous constituents is presently occurring or is imminent, interim corrective measures may be needed. Both the owner or operator and the regulatory agency have a continuing responsibility to identify and respond to emergency situations and to define priority situations that warrant interim corrective measures. The need for consideration of interim corrective measures, if identified by the owner or operator, should be communicated to the regulatory agency at the earliest possible time. As indicated earlier, the need for interacting closely with the regulatory agency is very important, not only for situations discussed above, but also to ensure the adequacy of the data collected during the RFI and the appropriate interpretation of those data.

Corrective Measures Study (CMS)

If the potential need for corrective measures is identified during the RFI process, the owner or operator is then responsible for performing a CMS. During this step of the Corrective Action Process, the owner or operator will identify, and recommend as appropriate, specific measures to correct the release.

Information generated during the RFI will be used not only to determine the potential need for corrective measures, but also to aid in the selection and implementation of these measures. For releases that have been adequately characterized, the owner or operator may be required to collect such information (e.g., engineering data such as soil compaction properties or aquifer pumping tests) during the RFI. Selection and implementation of corrective measures will be

addressed in future regulations and in separate guidance to be developed by EPA. In the interim, guidance for corrective measures selection and implementation is provided in several references, including the following:

U.S. EPA. September, 1986. Data Requirements for Remedial Action Technology Selection. Final Report. NTIS PB87-110813. Office of Emergency and Remedial Response and Office of Research and Development. Washington, D.C. 20460.

U.S. EPA. October, 1985. Handbook of Remedial Action at Waste Disposal Sites. EPA/625-6-85-006. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. June, 1985. Guidance on Feasibility Studies Under CERCLA. NTIS PB85-238590. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. June, 1987. RCRA Corrective Action Interim Measures. Interim Final. OSWER Directive No. 9902.4. Office of Waste Programs Enforcement. Washington, D.C. 20460.

U.S. EPA. May, 1985. Guidance Document for Cleanup of Surface Tanks and Drum Sites. OSWER Directive 9380.0-03. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. June, 1986. Guidance Document for Cleanup of Surface Impoundment Sites. OSWER Directive No. 9380-0.06. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. November, 1986. EPA/540/2-85/004. OSWER Directive No. 9380.0-05.

U.S. EPA. December, 1988. Guidance on Remedial Actions for Contaminated Ground Water at Superfund Sites. OSWER Directive No. 9283.1-2. Office of Emergency and Remedial Response. Washington, D.C. 20460.

EPA has developed a draft of a guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that are applicable to several EPA programs such as RCRA and CERCLA. The reference for this guide and a general discussion of its content are provided below.

U.S. EPA. 1989. Draft Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

This document is intended as a practical guide and reference source for EPA, state and industry personnel that are involved with assessing and remediating contaminated sites. Special emphasis is placed on technical support, potential data requirements and technologies related to assessing and remediating point-source contamination (e.g., problems associated with landfills, surface impoundments, and underground storage tanks). The guide is designed to address, in a general manner, releases to ground water, soil, surface water and air.

The principal objective of the guide is to facilitate technology transfer regarding the assessment and remediation of contaminated sites. It is anticipated that the guide will be available in two forms: (1) as a hard copy, i.e., in three-ring binder form and (2) stored on computer files within the OSWER Electronic Bulletin Board System (BBS). (Note: The OSWER Technology Transfer Bulletin Board Users Guide is available from OSWER headquarters.) This dual format will provide maximum flexibility to users and allow timely revision of existing text or the inclusion of supplemental material as appropriate. The primary function of the guide is to direct the user toward references and technical support for detailed information on program requirements, technical methods, data requirements and technologies.

The guide is divided into five sections: (I) Collection and Evaluation of Site Information, (II) Remedial Technologies, (III) Technical Assistance Directory, (IV) Annotated Bibliography, and (V) Compendium of Courses, Symposia, Conferences, and Workshops.

Section I is subdivided into Overview, Preliminary Site Assessment, Characterization of Contaminant Sources(s) and Environmental Setting, Assessment of Contaminant Fate and Transport, Selection, Design and Implementation of Remedial Technologies, and Performance Evaluation of Remedial Technologies. Brief discussions and tables are provided under these and other subdivisions to clarify how each phase of assessment/remediation fits into the overall, iterative process of collecting and evaluating site information. The tables, designed as screening tools, relate site information with technologies or methods, or vice versa. Guidance documents, references and other technical support are listed after the preliminary discussions and tables.

Section II contains descriptions of specific remedial technologies that are grouped under four categories: (1) source control, (2) withdrawal, injection and flow control, (3) water treatment, and (4) restoration of contaminated water supplies and utility/sewer lines. Each technology description includes a general description, application/availability, design and construction considerations, costs, and references. In addition, an overview of general references precedes the four categories of remedial technologies.

Section III is a technical assistance directory of EPA program, regional, and research staff that may be contacted to answer specific questions regarding the assessment and remediation of contaminated sites. The directory includes the individual's name, organization within EPA, area of expertise, mailing address, and phone number. The directory is intended to foster communication among scientists and engineers within EPA, other Federal agencies, industry, and state and local governments. Improved access to current scientific advances and data on the application and performance of technologies will likely enhance the effectiveness and efficiency of assessment and remediation programs.

Section IV is an annotated bibliography of guidance documents and references listed under Sections I and II. Brief summaries of each document are provided to assist the reader in selecting the appropriate technical guidance.

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Section V is a compendium of existing courses, symposia, conferences, and workshops. Each course, symposium, conference or workshop description includes the title, content, contact, and cost.

Corrective Measures Implementation (CMI)

CMI includes designing, constructing, operating, maintaining, and monitoring selected corrective measures. As indicated above, selection and implementation of corrective measures will be addressed in future regulations and in separate guidance to be developed by EPA.

1.3 Purpose of the RCRA Facility Investigation (RFI) Guidance

This document provides guidance to regulatory agency personnel for overseeing facility owners or operators who are required to conduct a RFI to characterize the nature, extent, and rate of migration of contaminant releases to soils, ground water, subsurface gas, air, and surface water. It also provides guidance on the interpretation of results by the regulatory agency to determine if interim corrective measures and/or a CMS may be necessary.

This RFI Guidance is not intended to describe all activities that may be undertaken during the RFI. For example, consideration of community relations and development of a community relations plan are addressed in other EPA guidances. This and other items that may be undertaken during the RFI are outlined in the following document:

U.S. EPA. November 1986. RCRA Corrective Action Plan. Interim Final. OSWER Directive No. 9902.4 Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

This document provides as much procedural specificity as possible to clearly define the owner or operator's responsibilities in the RFI. Each situation, however, is likely to be unique. Site-specific conditions, including the amount and quality of information available at the start of the RFI process, the existence of or potential for actual exposure, and the nature and extent of the release call for a flexible

approach to the release investigation. This RFI Guidance is written in this context. However, some situations may be so complicated and unique that further technical guidance may be necessary. If this is the case, the owner or operator should contact the responsible regulatory agency for assistance. If necessary, the responsible regulatory agency will contact EPA Headquarters.

1.4 Organization of this Document

This guidance is organized into four volumes containing 15 sections and 8 appendices. Volume I contains eight sections: Section 2 provides direction for preparation of the RFI Work Plan and procedures for submitting this Plan to the regulatory agency for review. Section 3 provides guidance on the general strategy to be employed in performing release investigations. Sections 4, 5, and 6 discuss Quality Assurance/Quality Control (QA/QC), Data Management and Reporting, and Health and Safety Procedures, respectively. Section 7 discusses how information from source (waste and unit) characterization can be used in the RFI process. Section 8 presents guidance on the interpretation of data collected during the RFI process, using health and environmental criteria. Guidance for situations that may require the application of interim corrective measures is also provided in Section 8.

Volumes II and III provide detailed technical guidance on how to perform media-specific investigations. Volume II presents Sections 9, 10 and 11, which discuss the soil, ground water, and subsurface gas media, respectively. Volume III presents Sections 12 and 13, which discuss the air and surface-water media, respectively. Representative case study illustrations of various investigative approaches and techniques described in Volumes I through III are presented in Sections 14 and 15 of Volume IV.

1.5 Reference Information

This document provides guidance on characterizing known releases and on verification of suspected releases. Applicable field methods (e.g., sampling techniques) and equipment are described or referenced, as appropriate. This document uses, to the extent possible, existing guidances and information developed in various EPA programs (e.g., Office of Emergency and Remedial

Response, Office of Waste Programs Enforcement, Office of Air Quality Planning and Standards, and Office of Water), as well as State material to assist in performing release characterizations for the various environmental media. As such, many references are provided which refer the owner or operator to more complete or detailed information. Where available, identification or ordering numbers have been supplied with these citations. The following describes these identification numbers and provides information on how these documents may be obtained.

NTIS: NTIS stands for the National Technical Information Service. NTIS documents may be obtained by calling (703) 487-4650 or by writing to NTIS at the following address:

NTIS
U.S. Department of Commerce
Springfield, VA 22161

EPA: Environmental Protection Agency (EPA) Reports are available through EPA's Headquarters or Regional libraries, or by writing to EPA at the following address:

U.S. EPA
Public Information Center
401 M. Street, S.W.
Washington, D.C. 20460

Many EPA reports are also available through NTIS. NTIS should be contacted for availability information. The indicated EPA office may also be contacted for information by writing to the above address.

OSWER: OSWER stands for EPA's Office of Solid Waste and Emergency Response. Availability information on documents identified by an OSWER Directive Number can be obtained by calling EPA's RCRA/Superfund Hotline, at (800) 424-9346 (toll-free) or (202) 382-3000.

GPO: GPO stands for the U.S. Government Printing Office. Documents available through GPO may be obtained by calling GPO at (202) 275-3648.

1.6 Guidance Changes Description

The RFI Guidance has undergone a number of revisions since publication of the initial October 1986 draft. Draft documents were released to the public in July 1987, December 1987 (updated Section 8 - Health and Environmental Assessment only), and of course the current version, May 1989. These revisions were necessitated by both the need to remain consistent with evolving EPA policy with respect to corrective action, and the desire to provide facility owners and operators with sufficient information and guidance to ensure that investigations provide adequate information for confident decisionmaking. Further revision of the RFI Guidance is not anticipated. Following is a brief discussion of how the RFI Guidance has changed since its original release.

October 1986 Draft - This was the first draft of the RFI Guidance. It contained basic information on the conduct of RFIs, but did not go into great detail on media specific investigations, particularly with respect to the air and surface water media. In addition, this first draft contained little guidance pertaining to health and environmental assessment. This draft was circulated mainly to the EPA Regions, in an attempt to obtain comment before further development of the Guidance was initiated. As a result of this activity, the need for major revision was identified.

July 1987 Draft - This version of the RFI Guidance represented the first major revision made to the Guidance. Virtually all sections were restructured for consistency and new sections were added as well. The major changes were as follows:

- Revision of much of the regulatory and procedural aspects of the Guidance (contained in Volume I) to reflect the final RCRA Facility Assessment (RFA) Guidance.

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- Introduction of a new, more efficient means of selecting hazardous constituents and parameters to monitor for, based on available information on the unit(s) involved, the waste managed, the media being investigated and any previous data collected.

- Addition of guidance relating to the selection of methods for sampling and analysis, and incorporation of references to available information regarding acceptable methods already published by EPA's Superfund Program.

- Addition of new section on health and environmental assessment (Section 8), including tables of action levels for specific constituents in specific media.

- Major editing of all medium specific sections for consistency in structure and overall content.

- Expansion of all medium specific sections to address the importance of inter-media transport of contamination.

- Expansion of the Soil Section (Section 9) to emphasize the importance of recognizing soil as a key medium for inter-media transfer of contamination, both as a source and as a recipient of contamination.

- Expansion of the Ground Water Section (Section 10) to provide guidance on the use of flow nets and flow cells in defining site hydrogeology and contamination migration pathways.

- Complete rewrite of the Air Section (Section 12) to reflect the special considerations inherent in investigations of releases to air, and evolving Agency policy regarding renewed emphasis on monitoring vs modeling.

- Complete rewrite of Surface Water Section (Section 13) to reflect the importance of understanding the release mechanism (i.e., past vs

intermittent vs continual release), and the type of release (i.e., point source vs area source).

- Addition of new Volume IV - Case Studies.

December 1987 Draft - This revision of the RFI Guidance involved only Section 8 on Health and Environmental Assessment. Hence, only Section 8 was reissued. The major revisions made to Section 8 are summarized as follows:

- Clarification of the hierarchy in which the health and environmental criteria (i.e., action levels) are applied.

- Revision of the criteria tables to reflect new exposure assumptions for the soil medium.

- Revision of the criteria tables to reflect the latest additions and revisions made by EPA to health based exposure levels.

- Addition of new guidance pertaining to evaluation of deep soil and sediment contamination.

- Update in accordance with new MCLs promulgated for volatile organic constituents.

May 1989 Final Draft - The current final draft of the RFI Guidance constitutes significant revision over the previous drafts. Major changes from previous drafts include the following:

- Incorporation of improved graphics and tabular presentations throughout all four volumes of the Guidance.

- Incorporation of an RFI Guidance Feedback Form (at the end of Volume 1) to determine the utility of the Guidance as well as the need for further guidance.

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- General revision, where appropriate, to ensure consistency with the forthcoming regulations dealing with RCRA corrective action.

- Revision of the Section 8 criteria tables to reflect revised exposure assumptions for the soil medium.

- Revision of the Section 8 criteria tables to reflect the latest additions and revisions made by EPA to health based exposure levels.

- Incorporation of the concept of using leaching tests (Section 9 - Soil) to predict when soil contamination may affect underlying ground water, including a new appendix (Appendix F) presenting a draft EPA method developed specifically for contaminated soil.

- Addition of a new appendix (Appendix E) illustrating the calculation of basement air contaminant concentrations due to basement seepage of volatile organic contaminants.

- Addition of a new section (Section 8.6.3) pertaining to newly promulgated methods for evaluating ground-water contamination in a statistical manner, and reference to additional guidances and other documents available from EPA for conducting ground-water remediation (Section 10.7).

- Revision of the Air Section of the Guidance (Section 12) to reflect a new phased approach, involving an initial screening assessment, and the incorporation of a new appendix (Appendix G) containing draft Guidance on the screening assessment.

- Revision of the Air Section (Section 12) to reflect a balance between the application of modeling and monitoring approaches, depending on site-specific circumstances.

- Incorporation of the concept of using soil loss equations for determining contaminated soil loading to surface waters (Section 13), including a new appendix (Appendix H) illustrating the soil loss calculation.

- Rearrangement of the Volume IV Case Studies to reflect the order in which the specific points illustrated are presented in Volumes I through III.

- Incorporation of a new Volume IV case study illustrating the use of leaching tests to predict the potential for contaminated soil to contaminate underlying ground water.

1.7 Corrective Action Regulations

EPA is in the process of promulgating comprehensive corrective action regulations pursuant to HSWA Section 3004 (u) and (v). These regulations, which will appear primarily in Subpart S of 40 CFR Part 264, will establish requirements for all aspects of RCRA corrective action. Because the RFI Guidance is being released prior to the proposal and promulgation of Subpart S, the potential for differences is significant. Therefore, users of this guidance are advised to review the final Subpart S rule carefully when published. Potential differences are identified below:

- Identification of health and environmental criteria or "action levels" - The RFI Guidance includes tables of the most recent action levels in Section 8, Health and Environmental Assessment. However, these levels are continually being updated by EPA, and the levels presented in the Subpart S rule may differ.

- Development of health and environmental criteria - The RFI Guidance provides information on how action levels are developed (e.g., use of exposure assumptions, risk levels for carcinogens). The Subpart S rule may propose alternate methods for developing actions levels.

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- Definition of constituent - The RFI Guidance refers to constituents as those listed in 40 CFR Part 261, Appendix VIII. Use of the term "constituent" in the Subpart S rule is being reviewed.

- Action levels for surface water - The RFI Guidance identifies action levels for surface water to include various Agency-developed criteria (such as MCLs), but indicates that State-developed standards may also be considered. The Subpart S rule may propose a different scheme for establishing action levels for surface water.

- Action levels for soil - The RFI Guidance attempts to differentiate deep from surficial soil contamination, and provide methods (e.g., leaching tests) and action levels for determining the need for corrective action. Surficial soil and deep soil contamination may be addressed differently in the Subpart S rule.

- Influence of detection/quantitation limits on action levels - The RFI Guidance indicates that the detection limit will serve as the action level, where action levels are lower than detection limits. The issue of detection/quantitation limits is under Agency review, and may be changed in the Subpart S rule.

- Evaluation of chemical mixtures - The RFI Guidance provides the rationale and equations for computing adjusted action levels, assuming additive toxicity, when more than one constituent is present in a contaminated medium. The issue of evaluation of chemical mixtures is under Agency review and may be addressed differently in the Subpart S rule.

- Definition of Solid Waste Management Unit (SWMU) - The RFI Guidance definition of SWMU is currently under Agency review and may be changed in the Subpart S rule.

- Notification and Reporting - The RFI Guidance identifies specific reports that may be required throughout the performance of an RFI, and also

identifies specific situations in which the owner or operator is required to submit notifications to the regulatory agency. Notification and reporting requirements are being reviewed by EPA and may be changed in the Subpart S rule.

- Use of specific language - The specific language used in various sections of the RFI Guidance, for example when referring to factors the regulatory agency may consider in determining the need for interim corrective measures, may be changed in the Subpart S rule.

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SECTION 2

THE RFI WORK PLAN

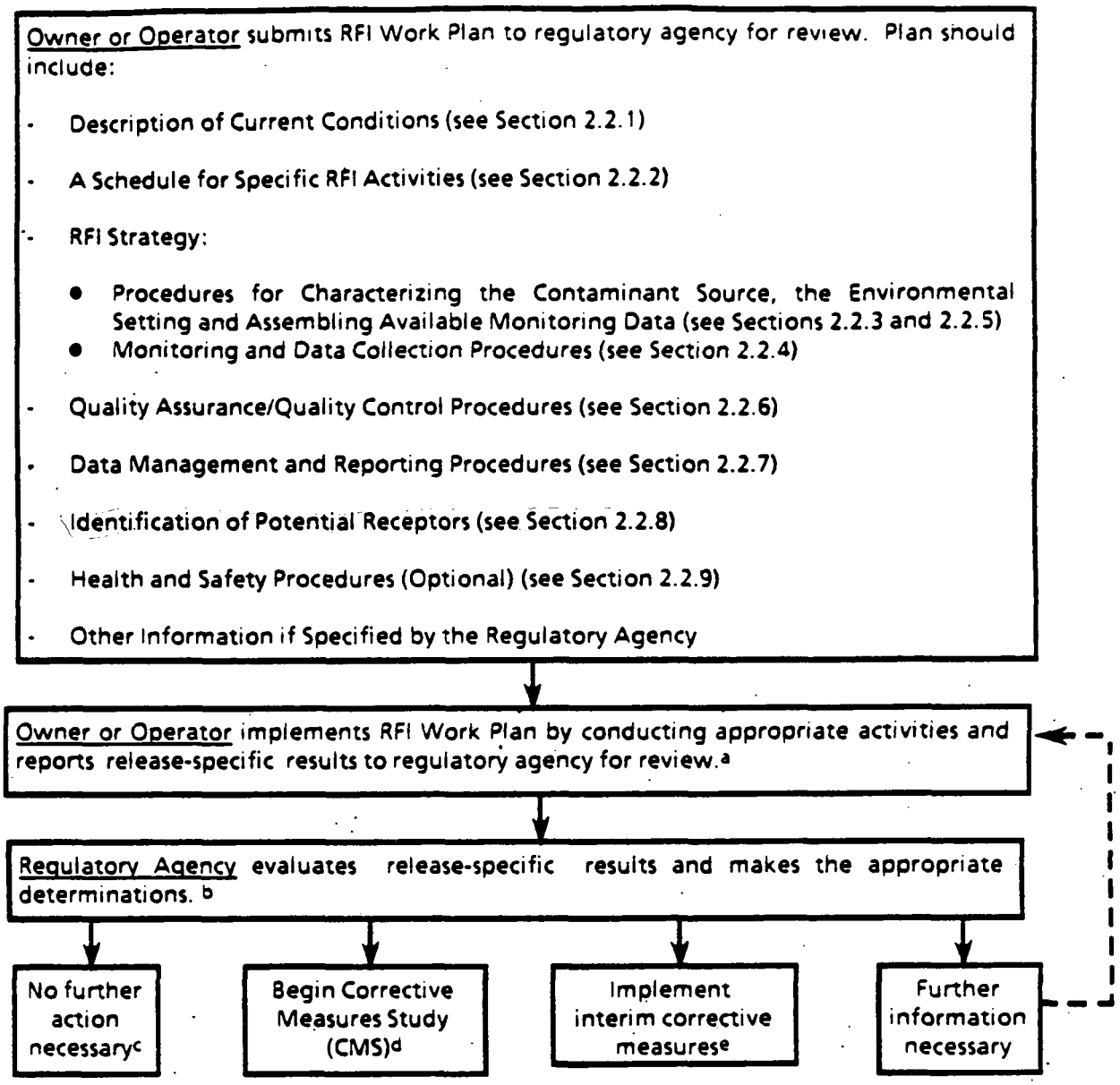
2.1 Introduction

If notified by the regulatory agency that an RFI must be conducted, the owner or operator should initiate a series of activities aimed at supplying specific information on the identified, suspected, or known releases of concern. Such activities can include release verification and characterization. Conducting the RFI should follow a logical sequence of actions involving the preparation and submittal of an RFI Work Plan, including development of a monitoring approach, performance of investigatory tasks, submission of results, and interactions with the regulatory agency on courses of further action. The overall RFI process is shown in Figure 2-1.

As indicated previously, each RFI situation is likely to be unique in various respects, including the unit or units releasing, the media affected, the extent of the release, the potential for inter-media impacts, the amount and quality of existing information, and other factors. The amount of work that may be involved in the RFI, and therefore the content of the RFI Work Plan, is also likely to vary. This section provides guidance concerning the general content of the RFI Work Plan.

2.2 Preparation of an RFI Work Plan

The RFI Work Plan is a detailed plan that the facility owner or operator should develop and follow throughout the RFI that will lead to characterization of the nature, extent, and rate of migration of a release of hazardous waste or hazardous constituents. This plan consists of a number of components that may be developed and submitted either concurrently or sequentially in accordance with the schedule specified in the permit or compliance order. These components are shown in the top box of Figure 2-1. Development and, therefore, submittal of specific plan components (e.g., detailed monitoring procedures) may not be required



a In some cases, existing information may be adequate to characterize specific releases.

b The owner or operator also has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures.

c No further action will be necessary where a suspected release is shown to not be an actual release based on an adequate amount of monitoring data or where release concentrations are shown to be below levels of concern for a sufficient period of time.

d Implies release concentrations were observed to be equal to or above health and environmental assessment criteria, or that there was a reasonable likelihood of this occurring.

e Interim corrective measures may also be implemented prior to or during the RFI, as necessary.

50 FIGURE 2-1. RCRA FACILITY INVESTIGATION (RFI) PROCESS.

until adequate information on the contaminant source and environmental setting is gathered and evaluated. Discussion on RFI reporting and schedules between the owner or operator and regulatory agency is encouraged.

The owner or operator should be guided by the information contained in the RFA Report and the conditions specified in the permit or compliance order in developing the RFI Work Plan. These conditions will usually indicate which units and releases are to be addressed in the RFI (based on the findings of the regulatory agency during the RFA), as well as which media are of concern. In most cases, the information contained in the RFA Report and the conditions specified in the order or permit will enable the owner or operator to develop a sufficiently focused RFI Work Plan. However, if additional guidance is needed by the owner or operator, consultation with the regulatory agency is advised.

2.2.1 Description of Current Conditions

As part of the RFI Work Plan, the owner or operator should provide background information pertinent to the facility, contamination, and interim corrective measures as described below. Data gathered during any previous investigations or inspections and other relevant data should be included. The owner or operator should consult with the regulatory agency to determine if any of these information items are irrelevant or have already been submitted in an appropriate format for other purposes (e.g., contained in a RCRA permit application).

2.2.1.1 Facility Background

The owner or operator should summarize the regional location, pertinent boundary features, general physiography, hydrogeology, and historical use of the facility for the treatment, storage or disposal of solid and hazardous waste. This information should include the following:

- Map(s) depicting:
  - General geographic location;

- Property lines, with the owners of all adjacent property clearly indicated;

- Topography and surface drainage (with an appropriate contour interval and a scale of 1 inch = 100 feet) depicting all waterways, wetlands, floodplains, water features, drainage patterns, and surface-water containment areas;

- All tanks, buildings, utilities, paved areas, easements, rights-of-way, and other features;

- All solid or hazardous waste treatment, storage or disposal areas active after November 19, 1980;

- All known past solid or hazardous waste treatment, storage or disposal areas regardless of whether they were active on November 19, 1980;

- All known past and present product and waste underground tanks or piping;

- Surrounding land uses (residential, commercial, agricultural, recreational);

- The location of all production and ground-water monitoring wells. These wells shall be clearly labeled and ground and top of casing elevations and construction details included (these elevations and details may be included as an attachment); and

- Location of any injection wells onsite or near the facility.

All maps should be consistent with the requirements set forth in 40 CFR §270.14 and be of sufficient detail and accuracy to locate and report all current and future work performed at the site including

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- A history and description of ownership and operation, solid and hazardous waste generation, and treatment, storage and disposal activities at the facility;

- Approximate dates or periods of past product and waste spills, identification of the materials spilled, the amount spilled, the location where spilled, and a description of the response actions conducted (local, state, or Federal response units or private parties), including any inspection reports or technical reports generated as a result of the response; and

- A summary of past permits requested and/or received, any enforcement actions and their subsequent responses, and a list of documents and studies prepared for the facility.

2.2.1.2 Nature and Extent of Contamination

The owner or operator should describe any existing information on the nature and extent of releases, including

- A summary of all possible source areas of contamination. This, at a minimum, should include all regulated units, solid waste management units, spill areas, and other suspected source areas of contamination. For each area, the owner or operator should identify the following:

  - Location of unit/area (which should be depicted on a facility map);

  - Quantities of solid and hazardous wastes;

  - Hazardous waste or constituents, to the extent known; and

  - Identification of areas where additional information is or may be necessary.

- A description of the degree and extent of contamination. This should include

- Available monitoring data and qualitative information on locations and levels of contamination at the facility;

- All potential migration pathways including information on geology, pedology, hydrogeology, physiography, hydrology, water quality, meteorology, and air quality; and

- The potential impact(s) on human health and the environment, including demography, ground-water and surface-water use, and land use.

The surface configuration of contaminant sources both on and off the site may impact assessment and remediation by contributing to the complexity of contamination. Technical factors such as contaminant migration potential, the ability to withdraw or treat contaminants, and the effectiveness of treatment trains can be significantly altered by the interaction of releases from different contaminant sources. Well-developed maps showing the number, spacing, and relative positions of contaminant sources are essential to the planning and implementation of assessment and remediation activities. In addition to map and field inspections, remote sensing, surface geophysical methods, and Geographic Information Systems are useful site evaluation tools. Information obtained from these site screening methods will help direct subsequent, more intensive activities to the major areas of concern.

Assessment activities may be subtly affected by the surface configuration of contaminant sources at the site. Figure 2-2 shows an example of overlapping ground-water contamination plumes from adjacent sources that contain different wastes. Organic solvents from Source A may facilitate the movement of otherwise low-mobility constituents from Source B. Contaminants from Source B, that are fairly insoluble in water, dissolve readily when in contact with solvents from Source A. This process is described as co-solvation. Examples of other potential complications in the ground water medium include heavy metal transport by complexation, particle transport, biotransformation, clogging of media pores or filtering devices by particulates, and changes in subsurface adsorptive properties. These and other factors suggest that an approach that focuses only on individual

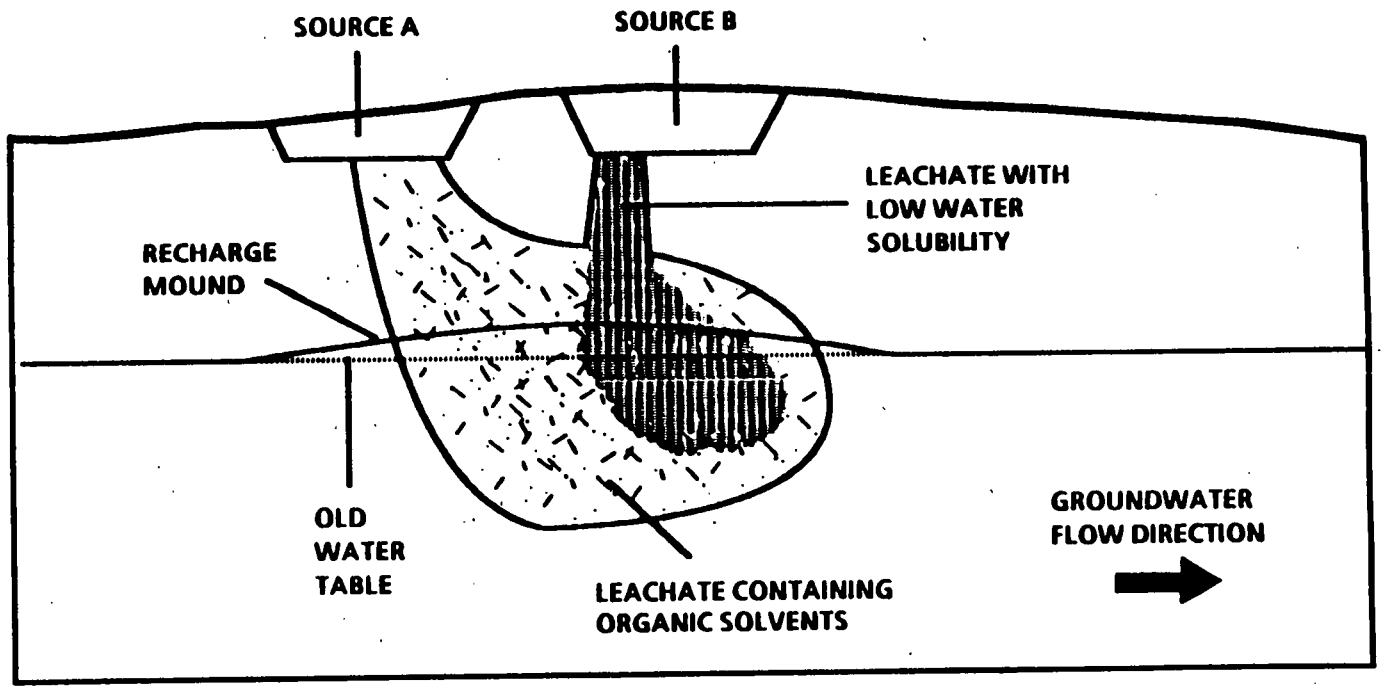

FIGURE 2-2. Overlapping Plumes From Adjacent Sources That Contain Different Wastes

contaminant sources without considering potential interactions between sources may lead to improper assessment and remediation. Additional information on this subject is provided in the following reference:

Keely, J.F. January, 1987. The Use of Models In Managing Ground-Water Protection Programs. EPA/600/8-87/003. EPA Office of Research and Development. Washington, D.C. 20460.

The extent of contamination at a site can be viewed in two ways. First the extent can be examined from a spatial perspective, i.e., where is the contamination located and what are its approximate dimensions? Second, the extent of contamination can be viewed from a toxicity or concentration level perspective, i.e., to what degree is the medium (e.g., soil, aquifer) "damaged" or contaminated? Chemical isopleth maps (discussed in Section 5) can be used to represent both components of contamination over a given area. Each perspective should be considered because both can influence ground-water remedy selection, and on a larger scale, future land use.

Data on the extent of contamination are gathered through a variety of analytical devices and methods, such as monitoring wells, soil gas monitoring, ambient air monitoring, modeling and geophysical techniques. As in all cases, a more extensive monitoring system allows for better delineation of the contaminant release. Economic considerations force investigators to obtain a maximum amount of information from assessment activities. With this in mind, areal photographs, color infrared imagery and other more sophisitcated remote sensing imagery may be useful in defining vegetation stress or other environmental indicators that aid in delineating the extent of contamination.

The vertical extent of contamination should also be considered in defining a release. For ground water, the vadose zone, uppermost aquifer, and if affected, other proximal interconnected aquifers and surface-water bodies, should be considered as an integral part of every ground-water decontamination process. The importance of controlling and cleaning up contamination within the vadose zone is well documented. Often, ground-water pollution abatement efforts are inhibited by percolating waters that collect leachate or products in a contaminated vadose zone and advance down to the water table. At this point, the initial ground-water

clean up attempt must be repeated causing additional problems and costs. To prevent continued loss of ground-water quality, vadose zone decontamination should be initiated and regarded as an important component of the ground-water remediation process.

Cross media effects also play an important role in defining the extent of contamination. Air, soil, surface-water, and ground-water quality are all potentially threatened by any contaminant release within the environment. Contaminants transported inconspicuously from a seemingly confined media to another may harm ecosystems or humans simply because the migration was not anticipated. Both natural pathways between media and those created by anthropogenic features (e.g., improperly constructed monitoring wells) may increase the extent of contamination. For these reasons the complex interactions between environmental media should not be overlooked.

2.2.1.3 Implementation of Interim Corrective Measures

The owner or operator should document interim corrective measures that were or are being undertaken at the facility. This should include

- Objectives of the interim measures, including how the measure is mitigating a potential threat to human health and the environment and/or is consistent with and integrated into any long-term solution at the facility;

- Design, construction, operation, and maintenance requirements;

- Schedules for design, construction and monitoring; and

- Schedule for progress reports.

2.2.2 Schedule for Specific RFI Activities

In the RFI Work Plan, the owner or operator should propose a schedule for completing the RFI within the time frame of the order or permit schedule of compliance. The schedule should be as specific as possible and should indicate dates

for submittal of the various components of the RFI Work Plan, dates for starting and accomplishing specific tasks associated with the RFI, and dates for reporting information from specific tasks to the regulatory agency.

2.2.3 Procedures for Characterizing the Contaminant Source and the Environmental Setting

Prior to establishing monitoring procedures to provide data on the release, certain information should be acquired to determine constituents of concern and appropriate sampling locations. Two key areas should be addressed: characterization of the source (i.e., waste and unit), and characterization of the environmental setting. These areas are described in general terms below. They are also described in detail in each of the media-specific sections.

2.2.3.1 Contaminant Source Characterization

Characterization of the unit(s) and associated waste may be necessary to identify applicable monitoring constituents or useful indicator parameters for the release characterization. Design and operational information on the unit, such as unit size and amount of waste managed therein, may be necessary to determine release rates.

In some cases, adequate characterization of the waste in the unit can be made by evaluating existing waste management records or data on the process generating the waste. In other cases, a sampling and analysis effort may be necessary. If so, the owner or operator should define the sampling and analysis effort in regard to:

- Constituents, analytical methods, detection limits, and the rationale for their selection;
- Sampling methods, sampling locations, equipment, and schedule; and
- Pertinent QA/QC procedures to ensure valid waste characterization.

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Identification of monitoring constituents and use of indicator parameters are discussed further in Section 3 and supported by Appendix B. Waste and unit characterization methods, including sampling, are described in Section 7. QA/QC procedures are described in Section 4.

Unit characterization should include information such as construction procedures and materials, and liner specifications, if applicable. Such information may be important in evaluating the probable degree of contamination from the unit, and consequently, the probable type and severity of the release.

Waste characterization will not always provide complete information for use in identifying monitoring constituents. This may be especially true for old units, where significant degradation of constituents may have occurred, and for those units that have received many different types of waste, where it is difficult to be sure that all wastes in the unit were sampled and analyzed. The owner or operator should be aware of these possibilities. Further guidance on appropriate procedures in these cases is provided in Sections 3 and 7.

Important data on individual sources also includes the condition of the source, the spatial distribution of the source, and waste management practices. The condition of a source may significantly affect its capacity to contaminate the surrounding environment. Evaluating and controlling contaminant sources early on may significantly reduce the costs of assessment and remediation.

Waste treatment, storage and disposal units (e.g., landfills, surface impoundments, and waste piles, etc.) that do not have containment systems are, of course, more susceptible to the release of contaminants. If there is no cover or liner present, the release of constituents from a unit will largely depend on site characteristics (e.g., infiltration, hydrogeology) and contaminant characteristics (e.g., solubility, specific gravity), which are discussed in later sections. Source control technologies such as cover installation, waste removal, in situ waste treatment, or subsurface barrier construction may be appropriate when no containment system is present.

When a containment system is present, it is appropriate to evaluate the condition of the system to determine if modifications could significantly reduce or

prevent further releases. Table 2-1 presents an outline describing some of the important characteristics of waste treatment, storage and disposal unit containment systems that should be evaluated. The degree of modification to a source will largely depend on contaminant migration potential, exposure potential, and the feasibility of implementing remedial measures, which in turn are affected by site hydrogeology, land use, waste characteristics, and other factors.

The three-dimensional distribution of each source should also be carefully delineated to focus remedial activities on the site's "hot spots" (i.e., those regions with the highest concentrations of contaminants). Cleaning up contaminated sites without identifying, defining and characterizing these hot spots may lead to ineffective, inefficient remediation attempts. Innovative technologies such as specialized coring methods (see Section 9), geophysical methods (see Section 10 and Appendix C), and soil gas sampling devices (see Section 11) may provide better resolution of these hot spots than more conventional methods and devices (e.g., monitoring wells, and split-spoon samplers).

The manner in which wastes are managed may significantly affect the nature and extent of contamination by influencing the spatial and temporal variability of contaminant releases. Important factors to consider when characterizing contaminant sources include the total quantity of wastes, the location and timing of waste management, waste and constituent characteristics, and general waste management practices.

As indicated previously, the total quantity of contaminants within a source is an obvious yet important consideration when assessing or remediating contamination. In general, the potential extent of contamination is proportional to the volume of wastes managed in the source, taking into account other factors such as hydrogeologic setting, exposure potential, and the condition of the source.

In addition, the location of waste treatment, storage, and disposal units may affect the type and degree of remedial measures. In addition to the surface configuration of sources, the location of different quantities and types of waste within a source may affect the potential for release. For instance, low pH liquid waste placed near wastes containing heavy metals may promote the migration of the metal cations by increasing their solubility.

TABLE 2-1. CONTAINMENT SYSTEM EVALUATION

I. Cover[1]
   A. Characteristics of the soil to be used in the cover
   B. Cover and surrounding land topography
   C. Climate characteristics
   D. Composition of the cover
      1. Component type
      2. Component thickness
   E. Cover design and construction practices
   F. Cover configuration
   G. Cover drainage characteristics
      1. Material used in drainage system
      2. Thickness of drainage system
      3. Slope of the drainage system
   H. Vegetative cover
   I. Post-closure maintenance
      1. Cap system
         a. Adequate vegetative cover
         b. Erosion
         c. Settlement/subsidence
      2. Run-on and run-off control system
         a. Adequate vegetative cover
         b. Erosion
         c. Flow obstructions
II. Liner and Leachate Collection/Detection System
   A. The number of liners

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[1] Information in this section was in part obtained from EPA's technical resource document, Evaluating Cover Systems for Solid and Hazardous Waste, SW-867, 1982.

TABLE 2-1. CONTAINMENT SYSTEM EVALUATION (Continued)

B. The type and thickness of the liners
   1. The compatibility of the liners with the waste type
   2. The structural strength of the liners
   3. The liner foundation
C. The age and installation methods of the liners
D. Description of leachate collection system
   1. Thickness of drainage layer
   2. Material used in the drainage system
   3. Slope of the collection system
   4. Method of leachate collection
   5. Method of leachate withdrawal
E. Description of leak detection system
   1. Thickness of detection system
   2. Material used in the system
   3. Slope of the detection system
   4. Method of leak detection
   5. Ability to withdraw leachate from the system

III. Other Factors
   A. Compatibility of bottom-most liner with the underlying geology
   B. Relationship of the ground-water table to the bottom liner
   C. Water content (percent solids and free liquids content)
   D. Compatibility of waste with containment system (or underlying soil, if no containment system is present)
   E. Waste load on the containment system

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Transportation of wastes on and off site is an equally important consideration. For instance, a buried transmission line may rupture and release contaminants to the subsurface. Vehicles conveying wastes to, from, or within a site may spill or leak substances onto the ground and eventually cause subsurface contamination. Carefully maintained records of waste transportation or field inspections may reveal such potential leaks or spills.

The timing of waste management also is important in assessing and remediating site contamination. Two aspects of timing are important to recognize here: the age of the source and the history of waste management. Both aspects may affect the timing, nature, and degree of assessment and remediation.

Due to the generally slow movement of some types of contamination (e.g., ground water plumes), releases covering a large area are more likely to originate from older sources (i.e., sources that have managed wastes for long periods or at previous times). Older sources are generally harder to define and characterize due the paucity of waste management data and little, if any, containment features. Newer units, on the other hand, are more likely to have accurate management records and improved design features for containment. Remediation for an older source contaminating the ground water, for example, may involve substantial plume control, aquifer restoration, and capping of large areas of contaminated soil. On the other hand, a recently detected leak from a new source may be abated by minor containment system repair, with little or no aquifer restoration and plume control required.

The history of waste management for a specific source affects assessment and remediation by influencing the source's capacity to contaminate over time. In addition to the spatial variability of wastes, the temporal variability of waste management should be considered. Sources may form discrete or continuous plumes, depending on the history of waste management. As shown in Figure 2-3, the configuration of ground-water contamination may be profoundly affected by the timing of releases. Assessment and remediation of contamination are consequently aided by understanding the history of waste management for individual sources.

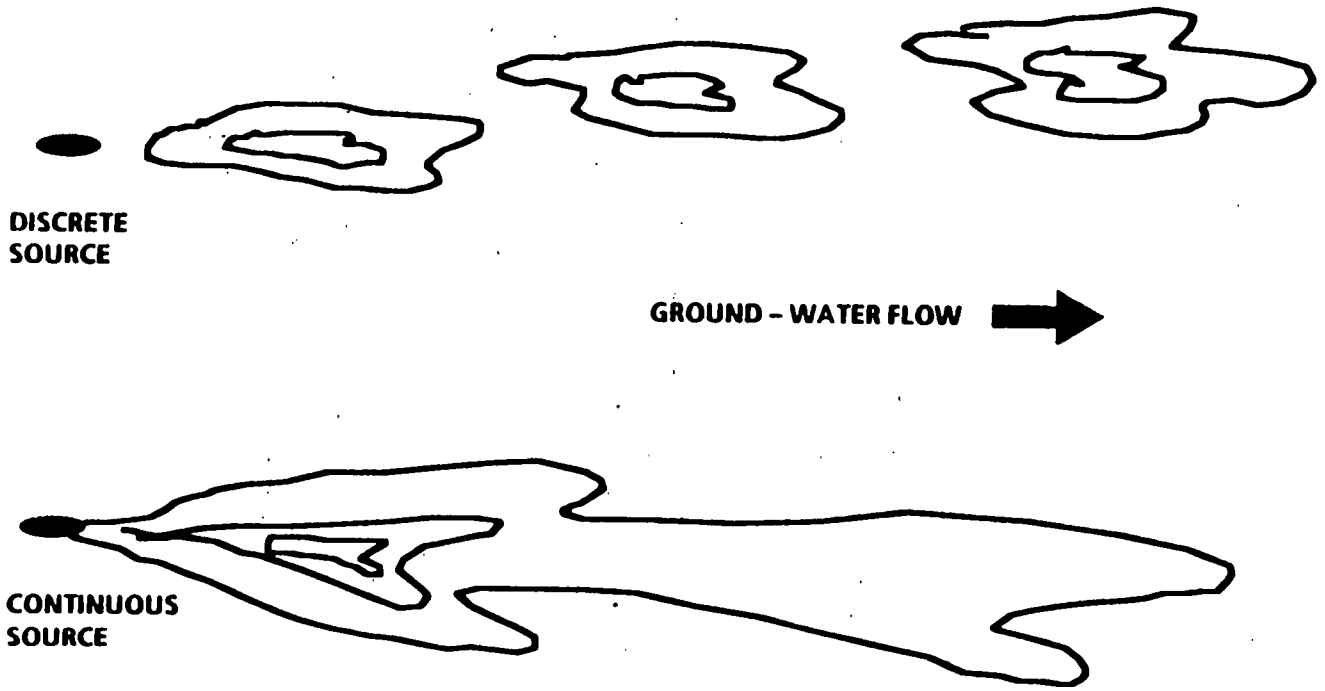

FIGURE 2-3. Discrete versus Continuous Contaminant Sorces.

In some cases, altering the timing of waste management may be an effective source control measure. For instance, placement of wastes in landfill cells without covers may be limited to anticipated dry periods. By doing so, the amount of moisture in contact with wastes may be significantly reduced, thus minimizing the potential for contaminant migration.

Specific characteristics of waste and constituents affecting the assessment and remediation of contamination in specific media are discussed in the media specific sections of this guidance. These characteristics include the compatibility of wastes with the unit, the containment system (if any), the underlying geology, and interactions between different wastes and constituents. Assessing the characteristics of wastes and constituents in conjunction with data on the condition of the source and site hydrogeology may aid assessment and remediation by identifying problems related to waste containment or complicated fate and transport mechanisms. If waste/containment system compatibility problems are discovered during a site evaluation, source modification such as liner replacement may be necessary to reduce or prevent further releases. In some cases, modifying waste treatment, storage, and disposal practices (e.g., restricting certain wastes from operating landfills) may be the most appropriate source control measure.

Interactions between wastes and constituents and underlying geology may alter contaminant migration potential and complicate control, recovery and treatment operations. For example, acidic leachate may cause or exacerbate solution cavity development in areas underlain by karst geology, thus promoting the migration of contaminants. In other instances, interactions between contaminants and subsurface materials may reduce the effectiveness and efficiency of remediation technologies; for example, by changing the chemistry of contaminated ground water or by inhibiting fluid flow to and from heavily contaminated areas.

Predicting the interactions between different wastes and constituents is among the most difficult tasks performed during site investigations. Such interactions may affect contaminant migration potential and complicate recovery and treatment operations. One example is the clogging of pore spaces or well screens by precipitates which form by chemical interactions between wastes or constituents. Other examples include co-solvation, particle transport and mobile

transformation products (see Table 2-2). It should be noted that laboratory testing of waste, or constituent interactions may not accurately depict subsurface processes. For this reason, ground-water chemistry and waste treatment, storage, and disposal conditions at the site should be considered when predicting the behavior of certain combinations of wastes or constituents. In some instances, this may mean additional sampling, monitoring, and field testing.

Reviewing waste management records to assess the quality of waste management practices may aid assessment and remediation activities by providing insight into the release potential of a source, and consequently, facilitate remedy selection. For instance, factors such as waste packaging, handling and placement, freeboard maintenance, and waste characterization may indicate how well a waste management unit is operated and maintained. Improvements in such waste management practices may reduce contaminant migration potential and therefore should be considered viable source control measures.

2.2.3.2 Environmental Setting Characterization

Characterization of the environmental setting may be necessary to determine monitoring locations (i.e., contaminant pathways) and to aid in defining the boundaries of the contaminated area. Techniques for characterizing the environmental setting are media-specific and are described in Volumes II and III of this Guidance. Examples of environmental information that may be required are wind speed and direction, subsurface stratigraphy, and surface-water body volumes and flow rates.

2.2.4 Monitoring and Data Collection Procedures

Specific monitoring procedures should be identified in the RFI Work Plan to characterize each release of concern. These procedures should indicate the proposed approach for conducting the investigation and should account for the following:

- Historical information and/or information gathered during the characterization of the contaminant source and the environmental setting;

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TABLE 2-2. PHYSICAL, CHEMICAL AND BIOLOGICAL PROCESSES AFFECTING CONTAMINANT FATE AND TRANSPORT (Keely, 1987)

PHYSICAL PROCESSES

Advection (porous media velocity)
Hydrodynamic Dispersion
Molecular Diffusion
Density Stratification
Immiscible Phase Flow
Fractured Media Flow

CHEMICAL PROCESSES

Oxidation-Reduction Reactions
Radionuclide Decay
Ion-Exchange
Complexation
Co-Solvation
Immiscible Phase Partitioning
Sorption

BIOLOGICAL PROCESSES

Microbial Population Dynamics
Substrate Utilization
Biotransformation
Adaptation
Co-metabolism

- An approach for implementation, including the type of information to be collected;

- Description of the monitoring network; and

- Description of monitoring activities (e.g., sampling, meteorological monitoring).

Monitoring procedures may include a phased approach for release characterization as described in the media-specific sections of this Guidance. The initial phase may include a limited monitoring effort followed by subsequent phases, if necessary. The design of subsequent monitoring phases may be based on information gathered during a prior phase; therefore, revisions to the monitoring procedures may become necessary as the RFI progresses. A phased approach may be particularly useful in cases where a suspected release was identified by the regulatory agency as a result of the RFA process. In this case, the first monitoring phase may be designed to provide for release verification as well as the first step for release characterizaton. If revisions to a proposed monitoring approach become necessary, documentation should be submitted to the regulatory agency to support such changes.

2.2.5 Assembling Existing Data to Characterize the Contaminant Release

The owner or operator should assemble and review existing analytical and monitoring data pertinent to the release(s) and media of concern. This information can be used to determine the need for and to plan the extent of additional monitoring. Only data that have been collected using reliable methods and documented QA/QC procedures should be used as the basis for planning additional efforts. The amount and quality of existing data will determine the need for additional monitoring information on the release. Sources of such data include

- Information supplied by the regulatory agency with the permit conditions or compliance order;

- The RFA report;

- Facility records;
- The facility's RCRA permit application;
- State and local government agency files, and
- CERCLA site reports (e.g., Records of Decisions).

2.2.6 Quality Assurance/Quality Control (QA/QC) Procedures

The use of properly documented and implemented QA/QC procedures for monitoring activities (including sampling and analysis) is an essential part of the RFI Work Plan. It is important to ensure that data generated during the investigation are valid (i.e., supported by documented procedures) such that they can be used with confidence to support determinations regarding the need for and design of subsequent monitoring, the need for interim corrective measures, and the need for a Corrective Measures Study. These procedures are used to describe and document data quality and include such activities as

- Defining sampling and analytical techniques;
- Confirming and documenting correct sample identity;
- Establishing precision and accuracy of reported data;
- Documenting all analytical steps in determining sample identity and constituent concentrations;
- Establishing detection limits for constituents of concern; and
- Establishing any bias arising from field sampling or laboratory analytical activities.

Another important aspect of QA/QC is to ensure the use of qualified personnel (e.g., licensed or certified) to conduct or oversee various parts of the investigation. QA/QC procedures are described in Section 4.

2.2.7 Data Management and Reporting Procedures

Data management procedures should be included as part of the RFI Work Plan for organizing and reporting investigation data and results. Satisfactory presentation of investigation results to the regulatory agency is essential in characterizing and interpreting contaminant releases. Guidance on these procedures is presented in Section 5.

2.2.8 Identification of Potential Receptors

As specified by the regulatory agency in the permit or order, the owner or operator should provide in the RFI Work Plan information describing the human populations and environmental systems that may be susceptible to contaminant releases from the facility. Such information may include

- Existing and possible future use of ground water, including type of use (e.g., municipal and/or residential drinking water, agricultural, domestic/non-potable, and industrial);

- Location of ground-water users, including wells and discharge areas;

- Existing and possible future uses of surface waters draining the facility, including domestic and municipal uses (e.g., potable and lawn/gardening watering), recreational (e.g., fishing and swimming), agricultural, and industrial and environmental (e.g., fish and wildlife populations) uses;

- Human use of or access to the facility and adjacent lands, including recreational, hunting, residential, commercial, zoning, and the relationship between population locations and prevailing wind direction;

- A description of the biota in surface-water bodies on, adjacent to, or which can be potentially affected by the release;

- A description of the ecology on and adjacent to the facility;

- A demographic profile of the human population who use or have access to the facility and adjacent land, including age, sex, sensitive subgroups (e.g., schools, nursing homes), and other factors as appropriate; and

- A description of any endangered or threatened species near the facility.

This information can be used to determine whether any interim corrective measures may be necessary at the facility. If populations are currently being adversely exposed or such exposure seems imminent, interim corrective measures may be necessary. Further information regarding interim corrective measures is provided in Section 8 (Health and Environmental Assessment).

Receptors can be affected by the transfer of a release from one medium to another. Apparent or suspected inter-media transfers of contamination, as identified in the permit or order, should be addressed in the RFI Work Plan. Table 2-3 illustrates some potential inter-media contaminant transfers and pathways. In examining the extent of a release, the owner or operator may be directed to collect sufficient information to allow the identification of potential inter-media transfers.

Situations where inter-media contaminant transfer may be important may arise through common usage of the contaminated medium. For example, drinking of ground or surface waters contaminated with volatile constituents poses an obvious hazard. Less obvious is the inhalation hazard posed by showering with such contaminated waters. Situations such as this should also be considered when determining the need for interim corrective measures.

The guidance presented in the media-specific sections (Volumes II and III) addresses potential areas for inter-media transfer. The guidance also identifies situations in which contamination of more than one media can be characterized, to some extent, using common procedures. For example, soil-gas analyses, such as those conducted using an organic vapor analyzer (OVA), can be used to monitor for subsurface gas (e.g., methane), as well as to indicate the overall extent of certain types of contaminant releases to ground water.

TABLE 2-3. SOME POTENTIAL INTER-MEDIA CONTAMINANT TRANSFER PATHWAYS

Release Media	Potential Receiving Media	Transfer Pathways
Air	• Soil • Surface Water	- Deposition of particles - Atmospheric washout
Soil	• Ground Water • Subsurface Gas • Surface Water	- Migration through the unsaturated zone - Migration through the soil - Overland runoff
Ground Water	• Surface Water • Subsurface Gas	- Ground-water discharge - Volatilization
Surface Water	• Ground water • Air • Soil	- Ground-water recharge - Volatilization - Deposition of floodplain sediments
Subsurface Gas	• Air • Soil	- Venting through soil - Migration through soil

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2.2.9 Health and Safety Procedures

Health and safety procedures may be included as part of the RFI Work Plan. The owner or operator is advised to understand, use, and document health and safety procedures describing efforts that will be taken to ensure the health and safety of the investigative team and others (e.g., the general public) during the RFI. The owner or operator should also be aware that on December 19, 1986, the Occupational Safety and Health Administration (OSHA) issued an interim final rule on hazardous waste site operations (29 CFR 1910.120) which specifically requires certain minimum standards concerning health and safety for anyone performing activities at CERCLA sites, RCRA sites, or emergency response operations. Further discussion on this topic is provided in Section 6.

2.3 Implementation of the RFI Work Plan

After review of the RFI Work Plan by the regulatory agency, the owner or operator should implement the plan as directed. In some cases, adequate information may exist to characterize specific releases, and an extensive monitoring effort may not be necessary. The extent of monitoring will depend on the amount and quality of existing information and the nature of the release. Results of investigative activities should be submitted to the regulatory agency according to the RFI Work Plan schedule. Further guidance on specific reports that may be required is provided in Section 5.

The owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. Interim corrective measures may be necessary if receptors are currently being exposed to release constituents or if such exposure seems imminent. These situations may become evident at any point in the RFI process. The owner or operator should contact the regulatory agency immediately if any such situation becomes apparent. Further information regarding the evaluation of the results of release characterization is presented in Section 8.

2.4 Evaluation by the Regulatory Agency

The regulatory agency will evaluate reports of release-specific results of the RFI submitted by the owner or operator to make determinations for further action. Such determinations may include

- No further action is necessary at that time;
- Further information on a release is necessary. The owner or operator will be advised to initiate additional monitoring activities;
- Interim corrective measures are necessary; or
- Adequate information is available to conclude that a CMS is necessary.

The regulatory agency may elect to be present at the facility to observe any phase of the release investigation. As indicated previously, close coordination between the owner or operator and the regulatory agency is essential throughout the RFI process. Also, as shown in Figure 2-1, interim corrective measures may be implemented prior to or during the RFI, as necessary.

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SECTION 3

GENERAL STRATEGY FOR RELEASE INVESTIGATION

3.1 INTRODUCTION

An investigation of releases from solid waste management units requires various types of information. This information is specific to the waste managed, unit type, design, and operation, the environment surrounding the unit or facility, and the medium to which contamination is being released. Although each medium will require specific data and methodologies to investigate a release, a general strategy for this investigation, consisting of two elements, can be described:

- Collection and review of data to be used in developing a conceptual model of the release that can be used to plan and develop monitoring procedures. These data may include existing information on the facility/unit or related monitoring data, data which can be gathered from outside sources of information on parameters affecting the release, or the gathering of new information through such mechanisms as aerial photography or waste characterization.

- Formulation and implementation of field investigations, sampling and analysis, and/or monitoring procedures designed to verify suspected releases (if necessary), and to evaluate the nature, extent, and rate of migration of verified releases.

As stated in Section 2, two components of the RFI Work Plan will address these elements. These are

- Procedures to characterize the contaminant source and the environmental setting; and

- Monitoring procedures.

Sections 3.4 and 3.5 provide general guidance on these procedures. Section 3.2 outlines the general strategy suggested for all release investigations, and Section 3.3 briefly discusses concepts concerning data quality that are designed to ensure that data collected during the investigation will adequately support decisions that will eventually be made regarding the need for corrective measures. Section 3.6 provides guidance for formulating methods and monitoring procedures, and addresses monitoring constituents and indicator parameters, use of EPA and other methods, sampling considerations, and analytical methods and detection limits. Section 3.7 provides information concerning various decisions that may be made based on monitoring data and other information collected during the RFI process.

3.2 Phased Strategy for Release Investigations

At the start of the RFI process, varying amounts of information will exist on specific releases and units. In some instances, suspected releases may have been identified based on strong evidence that releases have occurred, but with little or no direct data confirming their presence. On the other end of the spectrum, there may be enough existing data at the start of the RFI to begin considering whether some form of corrective measure may be necessary.

This potentially broad spectrum of situations that may exist at the beginning of the RFI may call for a flexible, phased approach for the release investigation, beginning with an evaluation of existing data and collecting additional data, as necessary to characterize the release source and the environmental setting. From such data, a conceptual model of the release can be formulated in order to design a monitoring program capable of release verification and/or characterization.

The release characterization may be conducted in phases, if appropriate, with each monitoring phase building on the findings and conclusions of the previous phase. The overall level of effort and the number of phases for any given characterization effort depend on various factors including

- The level of data and information available on the site;

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- The complexity of the release (e.g., number of units, release pathways, affected media); and

- The overall extent of the release.

As many situations are likely to be unique with respect to the above factors, the number and intensity of each of the phases of the RFI process leading to eventual characterization and to assessment against health and environmental criteria are also likely to be unique. Even though some RFIs may have several phases, it is important to make sure that the establishment of a phased approach does not result in undue delay of the RFI process.

Case Study No. 18 in Volume IV (Case Study Examples) provides an illustration of a phased characterization.

3.3 Data Quality and Use

Throughout the RFI process, it should be kept in mind that the data will be used in making comparisons to health and environmental criteria to determine whether a CMS or interim corrective measures may be necessary. Therefore, the data collected during the investigation must be of sufficient quality to support decisions as to the need for corrective measures. The data can also be used to help establish the scope and types of corrective measures to be considered in the CMS.

Qualitative or quantitative statements that outline the decision-making process and specify the quality and quantity of data required to support decisions should be made early in the planning stages of the RFI. These "data quality objectives" are then used to design sampling and analytical plans, and to determine the appropriate level of quality assurance and control (QA/QC). As this subject is normally considered a QA/QC function, it is presented in more detail in the QA/QC Section (Section 4) of this document. It is briefly discussed here to stress the importance of defining the objectives of the investigation, and of designing data-gathering efforts to meet these objectives throughout the investigation.

3.4 Procedures for Characterizing the Contaminant Source and the Environmental Setting

Before monitoring procedures are established, information on the contaminant source (i.e., waste and unit) and environmental setting may be required. The owner or operator should identify necessary data and formulate procedures to gather these data.

Unit-specific data that may be required for release investigation include such parameters as the physical size of the unit, the amount of waste in the unit, operational schedules, age, operational lifetime, and release controls. Data concerning the environmental setting that may be necessary are specific to the medium affected, and may include such information as climate, hydrogeologic setting, vegetation, and topography. These and other important elements are described below, starting with a discussion of the importance of existing information.

Case Study Numbers 8, 10, 12, 13, 14, and 30 in Volume IV (Case Study Examples) provide examples of the techniques discussed below.

3.4.1 Sources of Existing Information

Useful existing data may be found in the following sources:

- The RCRA Facility Assessment report. This report should provide information on the unit(s) known to be causing or suspected of causing a release to the environment and the affected media. It may also include data supporting the regulatory agency's release determinations. The owner or operator may wish to obtain the RFA report from the regulatory agency for use in scoping the RFI.

- Facility records and files. Other useful information may be available in facility records and files. This information may include data from required ground-water monitoring activities, results of required waste analyses, and other analytical results (e.g., tests run on wastes to determine such parameters as liner compatibility or free liquid

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composition). The owner or operator may have information on the characteristics of the waste in the units of concern from other in-house sources, such as waste reduction and engineering studies on the process(es) feeding the units, or from analyses performed in conjunction with other regulatory programs, such as the National Pollutant Discharge Elimination System (NPDES) permitting process or Clean Air Act Standards. Design and construction information may also be contained within facility files. For example, design and construction information for advanced wastewater treatment systems may contain information on inactive units.

- RCRA Permit Application. Under current requirements, a RCRA permit application should include a description of the waste being managed at the facility (although not necessarily for all the units of concern), descriptions of the units relevant to the permit, descriptions of the general environment within and surrounding the facility (including descriptions of the subsurface stratigraphy), and design and operating information such as runon/runoff controls. A companion rule (promulgated December 1, 1987) to the July 15, 1985, codification rule for Section 3004(u) expands the information requirements under §270.14(d) for all solid waste management units to be located on the facility topographic map, and to contain information on unit type, dimensions and design, dates operated, and waste managed, to the extent available.

- State Construction Permit (e.g., industrial wastewater) files.

- Environmental or other studies conducted in conjunction with ownership changes.

- Interviews with facility personnel (current or retired).

- Environmental audit reports.

- Investigations for environmental insurance policies.

3.4.2 Waste and Unit Characterization

In addition to obtaining waste data on general parameters such as pH, density, and viscosity, which may be needed to characterize a release to specific media (and which may also be useful in evaluating corrective-measure technologies), the owner or operator should characterize the unit's waste to the compound-specific level. This characterization may serve as a basis for identifying monitoring constituents and indicator parameters for the media of concern. It should be noted that the owner or operator may be required to characterize all potential constituents of concern for a given medium, unless it can be shown that only certain constituents could be released from the waste source. A detailed waste characterization, through the use of facility records and/or additional waste sampling and analysis, can be utilized to limit the number of constituents for which release monitoring must be performed during the RFI. (See also Section 3.6.1.)

Waste and unit characterization procedures should address the following:

- Existing sources of information on the unit and waste and their utility in characterizing the waste source; and

- Methods for gathering data on the waste and unit that are not presently available.

In some cases the location of disposal areas (units) may not be obvious. Some of these disposal areas or units may have been buried, overgrown by trees, or covered by structures such as buildings or parking lots. In such cases, use of geophysical techniques (e.g., ground-penetrating radar - see Appendix C) may be useful in locating former disposal areas containing materials such as discarded drums or buried tanks.

After evaluating existing data, the owner or operator may propose to collect additional waste and unit characterization information. In such cases, the owner or operator should propose procedures in the RFI Work Plan for

- Sampling--This should include sampling locations, schedules, numbers of samples to be taken, and methods for collecting and storing samples.

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- Analysis--This should include a listing of analytical constituents or parameters and the rationale for their selection, analytical methods, and identification of detection limits.

- QA/QC--This should include specific steps to be taken to ensure the viability and validity of data produced during a waste sampling effort.

- Data management--The owner or operator should describe data management procedures, including the format(s) by which data on the contaminant source will be presented to the regulatory agency and the various reports that will be submitted.

Further guidance on the types of information and methods to be used in gathering waste and unit data is given in Section 7. Case Study Numbers 3, 4, 7, 8, 9, and 10 in Volume IV (Case Study Examples) illustrate some of the activities discussed above.

3.4.3 Characterization of the Environmental Setting

Data on the environmental setting will generally be necessary for characterizing the release, and may also be helpful for evaluating various corrective-measure technologies. The information necessary is specific to the site and medium receiving the release and is described in the media-specific sections (Sections 9 through 13). Some examples of the methods and techniques that may be used are as follows:

- Direct media measurements--Direct media measurements can provide important information that can be used to determine the rate and extent of contaminant release. For example, hydraulic conductivity measurements are essential in determining ground-water flow rates. Wind roses and patterns can be used in determining how far air contamination may migrate and are essential input for air dispersion models. Specific measurements helpful for investigating the rate and extent of releases are discussed in the media-specific sections (Sections 9 through 13) of this Guidance.

- Aerial photography--Aerial photography can provide information that can be helpful in determining the extent of contamination at a site. Interpretation of aerial photographs can aid in describing past and present contaminant sources, pathways, and effects. Information obtained can include ecological impacts (e.g., decaying vegetation), topography, drainage patterns, fracture traces, and other erosional features. The usefulness of aerial photography is discussed further in Appendix A.

- Geophysical techniques--Geophysical techniques can aid in characterizing subsurface conditions fairly rapidly with minimal disturbance of the site. Such characterization can provide information on physical (e.g., stratigraphic) and chemical (e.g., contaminant extent) conditions and can also be used to locate buried drums, tanks, and other wastes. Geophysical techniques include electromagnetic induction, seismic refraction, electrical resistivity, ground-penetrating radar, magnetic borehole methods, and other methods. These techniques can be particularly useful in determining appropriate sampling locations. However, these geophysical techniques are not always applicable at a particular site and do not provide detailed contaminant concentration data. Therefore, sampling will generally be necessary to provide data needed for adequately characterizing the release. Further details on these techniques are available in Section 10 on Ground Water, and in Appendix C (Geophysical Techniques).

- Surveying and mapping--According to the 40 CFR Part 270 requirements for RCRA permit applications, the owner or operator must provide a topographic map and associated information regarding the site. If an adequate topographic map does not exist, a survey may be necessary to measure and plot land elevations. Site-specific surveying and mapping can provide an effective means of expressing topographic features (e.g., subtle elevation changes and site drainage patterns) of an area useful in characterizing releases. Surveying and mapping are discussed in further detail in Appendix A.

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The owner or operator should describe the following in the RFI Work Plan:

- Specific techniques to be used in defining the environmental setting for the releases of concern at the facility;
- A rationale for the use of these techniques;
- Specific QA/QC procedures applicable to the proposed techniques;
- Procedures for managing and presenting the data; and
- Potential uses of the information obtained from this characterization.

3.4.4 Assembling Available Monitoring Data

The owner or operator should compile and assess available media-specific monitoring data as a means of determining additional data needs. It is conceivable, in certain instances, that available data will be sufficient to characterize a release and provide the basis for making a determination on the need for corrective measures. However, this conclusion would be valid only if available data are current, comprehensive, accurate, and supported by reliable QA/QC methods. Otherwise, the use of available data should be limited to planning additional monitoring efforts.

3.5 Use of Models

3.5.1 General Applications

Mathematical and/or computer modeling may provide information useful to the owner or operator during the RFI and in the design of corrective measures. The information may prove useful in refining conceptualizations of the environmental setting, defining likely contaminant release pathways, and designing corrective measures (e.g., pumping and treating contaminated ground water).

Because a model is a mathematical representation of an often-complex physical system, simplified assumptions must be made about the physical system, so

that it may fit into the more simplistic mathematical framework of the model. Such assumptions are especially appropriate because the model assumes a detailed knowledge of the relevant input parameters (e.g., permeability, porosity, etc.) everywhere in the area being modeled.

Because a model uses assumptions as to both the physical processes involved and the spatial and temporal variations in field data, the results produced by the model may provide only a qualitative assessment of the nature, extent, and rate of migration of a contaminant release. Because of the assumptions made, a large degree of uncertainty may arise from some modeling simulations. Such modeling results should not be unduly relied on in selecting precise monitoring locations or in designing corrective measures.

Use of predictive models during the RFI may be appropriate for guiding the general development of monitoring networks. Each of the media-specific sections identify where and how such predictive models may be used, and identify references containing specific models. For example, models are identified in the Surface Water Section (Section 13) for use in determining the extent of a monitoring system which may be necessary in a stream. Modeling results are generally not acceptable for expressing release concentrations in an RFI. An exception to this is the air medium (Section 12). Atmospheric dispersion models are suggested for use (especially when downwind monitoring is not feasible) in conjunction with emission-rate monitoring or modeling in order to predict downwind release concentrations and to define the overall extent of a release.

Where a model is to be used, site-specific measurements should be collected and verified. The nature of the parameters required by a model varies from model to model and is a function of the physical processes being simulated (e.g., ground-water flow and/or contaminant transport), as well as the complexity of the model. In simulating ground-water flow, for example, hydrogeologic parameters that are usually required include hydraulic conductivity (vertical and horizontal); hydraulic gradient; specific yield (unconfined aquifer) or specific storage (confined aquifer); water levels in wells and nearby surface-water bodies; and estimates of infiltration or recharge. In simulating contaminant transport in ground water, physical and chemical parameters that are usually required include ground-water velocity; dispersivity of the aquifer; adsorptive characteristics of the aquifer (retardation);

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degradation characteristics of the contaminants; and the amount of each contaminant entering the aquifer (source definition).

Model input parameters that can be determined directly should be measured, with consideration given to selecting representative samples. Because the parameters cannot be measured continuously over the entire region but only at discrete locations, care should be taken when extrapolating over regions where there are no data. These considerations are especially important where the parameters vary significantly in space or time. The sensitivity of the model output both to the measured and assumed input parameters should be determined when evaluating modeling results. In addition, the ability of the model to be adequately calibrated (i.e., the ability of the model to reproduce current conditions), and to reproduce past conditions should be carefully evaluated in assessing the reliability of model predictions. Model calibration with observed physical conditions is critical to any successful modeling exercise.

Many models exist that may be applicable for use in the RFI. Because EPA is a public agency and models used by or for EPA may become part of a judicial action, EPA approval of model use should be restricted to those models that are publicly available (i.e., those models that are available to the public for no charge or for a small fee). The subset of models that are publicly available is quite large and should be sufficient for many applications. Publicly available models include those models developed by or for government agencies (e.g., EPA, U.S. Geological Survey, U.S. Department of Energy, U.S. Nuclear Regulatory Commission, etc.) and national laboratories (e.g., Sandia, Oak Ridge, Lawrence Berkeley, etc.), as well as models made publicly available by private contractors. Any publicly available model chosen should, however, be widely used, well-documented, have its theory published in peer-reviewed journals, or have some other characteristics reasonably ensuring its credibility. For situations where publicly available models are not appropriate, proprietary models (i.e., models not reasonably accessible for use or scrutiny by the public) should be used only where the models have been well-documented and have undergone substantial peer review. If these minimal requirements have not been met, the model will not be considered reliable.

The Graphical Exposure Modeling System (GEMS) may be particularly useful for various aspects of the RFI. GEMS is an interactive computer system, developed

by EPA's Office of Pesticides and Toxic Substances, which provides a simple interface to environmental modeling, physiochemical property estimation, statistical analysis, and graphic display capabilities, with data manipulation which supports all these functions. Fate and transport models are provided for soil, ground water, air, and surface water, and are supported by various data sets, including demographic, hydrologic, pedologic, geologic, climatic, economic, amoung others. Further information on GEMS may be obtained by calling EPA at (202) 382-3397 or (202) 382-3928 or by writing to EPA at the following address:

U.S. EPA
Office of Pesticides and Toxic Substances
Exposure Evaluation Division (TS-798)
401 M Street, S.W.
Washington, D.C. 20460

If the use of a model is proposed to guide the development of a monitoring network, the owner or operator should describe how the model works, and explain all assumptions used in calibrating and applying the model to the site in question. In addition, the model and all related documentation should be made available to the regulatory agency for review.

Case Study Numbers 20, 24, 25, and 31 in Volume IV (Case Study Examples) illustrate the use of various models that may be applied during the RFI.

3.5.2 Ground-Water Modeling

Ground-water modeling is often used for site characterization, remedy selection and design, and prediction of site-specific cleanup levels and time requirements. As with other models, a ground-water model is a simplified representation of reality, usually expressed with mathematics, that aids in understanding and predicting subsurface contaminant fate and transport. As such, models may include flow nets, ground-water flow models, simple analytical solute transport models, method of characteristics models, or complex multi-phase finite element models.

Perhaps the most important role of ground-water models for assessment and remediation programs is their application in selecting, collecting and analyzing field data on subsurface contaminant fate and transport. Model development and site characterization should be combined in an iterative process of fate and transport simulation and data collection. For instance, after examining several cross-sections and water level data sets, the investigator may develop several flow nets to better understand the ground-water flow regime beneath a site. Following this, a series of simulations using a simple analytical solute transport model can roughly estimate the range of concentrations with respect to distance and time for various contaminants. These results could then be compared with actual concentrations of samples collected from monitoring wells. Discrepancies between observed and predicted concentrations may suggest that additional site characterization is required or that the model does not adequately simulate actual field conditions.

Ground-water models may be used to some extent in predicting contaminant migration, selecting and designing remedial systems, evaluating the performance of technologies, and projecting cleanup levels. For instance, assuming a pump and treat alternative is appropriate, analytical or numerical ground-water flow models could be used to estimate the placement of recovery wells and plume control wells. Such models could also be used in planning the timing of ground-water withdrawals. However, these types of applications should only be used in concert with actual data collection (e.g., collecting ground-water samples) and field demonstrations (e.g., pilot studies). Exclusive model use for the above applications without adequate data collection and field demonstration may lead to incorrect and inefficient remedy selection.

The following documents provide information on the uses of models and point out many of their limitations and underlying assumptions:

Keely, J.F. January 1987. The Use of Models in Managing Ground Water Protection Programs. EPA/600/8-87/003. EPA Office of Research and Development. Washington, D.C. 20460.

U.S. EPA. January 1989. Resolution on Use of Mathematical Models by EPA for Regulatory Assessment and Decision-Making. Report of the Environmental

Engineering. Committee, Science Advisory Board. EPA-SAB-EEC-89-012. Washington, D.C. 20460.

These documents emphasize the importance of using ground-water models that are commensurate with the extent and quality of collected field data. Matching the model with the type of contamination problem is equally important. Certain instances may arise where more sophisticated models may be appropriate. For example, a finite element model simulating multi-phase flow of a hydrocarbon release in a well-characterized area may contribute to both defining the problem and selecting the remedy. The key rule to follow is to match the model with the type of contamination problem and the level and quality of data. In addition, every modeling exercise should include a sensitivity analysis to determine the relative impact of different variables on modeling results. The following presents excerpts from the above identified EPA Science Advisory Board report on mathematical models which are particularly relevant for regulatory assessment and decision-making:

- The use of mathematical models for environmental decision-making has increased significantly in recent years. The reasons for this are many, including scientific advances in the understanding of certain environmental processes, the wide availability of computational resources, the increased number of scientists and engineers trained in mathematical formulation and solution techniques, and a general recognition of the power and potential benefits of quantitative assessment methods. Within the U.S. Environmental Protection Agency (EPA) environmental models which integrate release, transport, fate, ecological effects and human exposure are being used for rule making decisions and regulatory impact assessments.

- The realistic characterization of an environmental problem requires the collection of laboratory and field data - the more complex the problem, the more extensive and in-depth are the required studies. In some cases involving more complex issues, future projections of environmental effects, larger geophysical regimes, inter-media transfers, or subtle ecological effects, mathematical models of the phenomena provide an essential element of the analysis and understanding. However, the

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models cannot stand alone; adequate data are required. Indeed, a major function of mathematical models is as a tool to design field studies, interpret the data and generalize the results.

- Mathematical models should ideally be based on a fundamental representation of the physical, chemical and biological processes affecting environmental systems.

- An improperly formulated model can lead to serious misjudgements concerning environmental impacts and the effectiveness of proposed regulations. In this regard, a bad model can be worse than no model at all.

- There are a number of steps needed to confirm the accuracy and utility of an environmental model. As a preliminary step, the elements of the basic equations and the computational procedures employed to solve them should be tested to ensure that the model generates results consistent with its underlying theory. The confirmed model should then be calibrated with field data and subsequently validated with additional data collected under varying environmental conditions.

- The stepwise procedure of checking the numerical consistency of a model, followed by field calibration, validation and *a posteriori* evaluation should be an established protocol for environmental quality models in all media, recognizing that the particular implementation of this may differ for surface water, air and ground water quality models.

- A number of methods have been developed in recent years for quantifying and interpreting the sensitivity and uncertainty of models. These methods require careful application, as experience with uncertainty analysis techniques is somewhat limited, and there is a significant potential for misuse of the procedures and misinterpretation of the results. Potential problems include the tendency to confuse model uncertainty with temporal or spatial variation in environmental systems, the tendency to rely on model uncertainty analysis as a low-cost substitute for actual scientific research, and the tendency to ignore

important uncertainties in model structure when evaluating uncertainties in model parameters.

- Peer review is an essential element of all scientific studies, including modeling applications. Peer review is appropriate in varying degrees and forms at different stages of the model development and application process. The basic scientific representation incorporated in the model should be based on formulations which have been presented in the peer reviewed scientific literature. Ideally, the model itself and initial test applications should also be presented in peer-reviewed papers.

3.6 Formulating Methods and Monitoring Procedures

The RFI Work Plan should describe monitoring procedures that address the following items on a release-specific basis:

- Monitoring constituents of concern and other monitoring parameters (e.g., indicators);
- Sampling locations and frequency;
- Sampling methods;
- Types of samples to be collected;
- Analytical methods; and
- Detection limits.

These items are discussed below.

3.6.1 Monitoring Constituents and Indicator Parameters

Selection and use of reliable and useful monitoring constituents and indicator parameters is a site-specific process and depends on several factors, including the following:

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- The phase of the release investigation (e.g., verification, characterization);
- The medium or media being investigated;
- The degree to which verifiable historical information exists on the unit or release being investigated;
- The degree to which the waste in the unit(s) has been characterized through sampling and analysis;
- The extent of the release;
- The concentration of constituents within the contaminated media; and
- The potential for physical, chemical, or biological transformations (e.g., degradation) of waste or release constituents.

The general strategy for the selection of specific monitoring constituents starts with a large universe list of constituents (i.e., 40 CFR Part 261, Appendix VIII). (It should be noted that the definition of constituent may also include components of 40 CFR Part 264, Appendix IX that are not also on Appendix VIII, but are normally monitored for during ground-water investigations.) Based on site-specific considerations (e.g., the contaminated media, sampling and analysis of waste from the unit, or industry-specific information), this list may be shortened to an appropriate set of monitoring constituents. Constituents initially deleted as a result of this process may have to be analyzed at selected locations during and/or following the RFI, especially if a CMS is found necessary. The discussion below explains the use of the four lists presented in Appendix B for selecting monitoring constituents and supplemental indicator parameters.

List 1 in Appendix B identifies indicator parameters recommended for release verification or characterization for the five environmental media discussed in this Guidance. This list was developed based on a review of RCRA and CERCLA guidances, as well as on information obtained during RCRA and CERCLA site

investigations. These indicator parameters should be used in the RFI unless the owner or operator can show that their use will not be helpful. For example, although total organic carbon and total organic halogen are listed as indicator parameters for ground water, their use may not be warranted for releases consisting primarily of inorganic (e.g., heavy-metal) contamination. In addition, as indicated in the footnote in List 1, although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that use of these parameters may not provide an adequate indication of contamination, primarily due to precision and accuracy problems.

At most sites, however, the use of indicator parameters will be appropriate, especially for ground-water monitoring. In general, any constituent not expected to be contained in or derived from the waste or the contaminated area may not serve as a reliable or practical indicator of a release. Studies have examined the frequency of occurrence of analytes in ground-water at hazardous waste sites throughout the country (Garman, Jerry, Tom Freund and Ed Lawless. 1987. Testing for Ground-water Contamination at Hazardous Waste Sites: Journal of Chromatographic Science, Vol. 25, pp. 328-337). These studies indicate that metals and volatile organic compounds (VOCs) are two sets of analytes that generally provide a reliable and practical way of detecting and monitoring a release to ground water.

In addition, investigations by EPA's Environmental Monitoring Systems Laboratory in Las Vegas, Nevada, and others have shown that most of the compounds being released from hazardous waste facilities (as high as 70%) are volatile organics. These compounds have a low molecular weight and are fairly water soluble, which accounts for their high mobility in ground water. Furthermore, volatiles are produced in relatively large quantities in the United States and wastes containing them are managed in significant quantities at most permitted hazardous waste facilities.

Metals, particularly those that are amenable to the ICP (Inductively Coupled Plasma) scan, are the second most common set of contaminants that are released at hazardous waste management facilities, and therefore are also expected to be excellent indicators of releases to ground water, as alluded to earlier.

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A list of those 40 CFR 264 Appendix IX constituents commonly found in contaminated ground water and amenable to analysis by volatile organics and ICP (metals) methods is provided in List 2.

List 3 in Appendix B is a master list of potential hazardous constituents that may, at one time or another, have to be monitored during an RFI. It contains the 40 CFR Part 261, Appendix VIII list of hazardous constituents in the left-hand column. The five environmental media columns contain X's where there is a reasonable probability, based on physical or chemical characteristics, of a particular constituent being present in the given medium. However, constituents not containing an X for a particular medium may still be present in that medium, despite a relatively low probability of their presence. Therefore, the regulatory agency may add such constituents for monitoring when appropriate. List 3 was derived through consultation with various EPA program offices and through examination of existing regulations. The rationale for identifying specific Appendix VIII constituents for the various media is explained below:

- Reactivity with water. Those constituents that react with or decompose in water were not marked with an X in the water-related columns.

- Existence of viable analytical techniques for a constituent in a specific medium. In many cases, constituents were not included for a specific medium because valid analytical methodologies are not currently available for that particular constituent/medium combination. In some cases, standard reference materials are not available for the analysis.

[Note that the above two criteria describe the primary rationale used to develop the 40 CFR Part 264, Appendix IX list of ground-water monitoring constituents. Hence, the ground-water and surface-water columns in List 3 are based on the final Appendix IX constituent list.]

- Recommendations from other EPA program offices. Offices concerned with the release of hazardous constituents to various media were consulted for recommendations on the analytes of primary concern. Appendix VIII hazardous constituents regarded by EPA's Office of Air

Quality Planning and Standards (OAQPS) as being of primary concern for release to air are identified in the air column in List 3.

- Background information. Analytes recommended for subsurface gas releases were chosen due to their predominance in past studies of this problem. The primary sources used for the subsurface gas medium are:

  U.S. EPA. Technical Guidance for Corrective Measures -Subsurface Gas. Prepared by SCS Engineers for U.S. EPA, Office of Solid Waste. Washington, D.C. 20460.

  South Coast Air Quality Management District. December 1986. Hazardous Pollutants in Class II Landfills. U.S. EPA, Region IX. San Francisco, CA 94105.

- The soil column includes constituents that may be present in both saturated and unsaturated soil. The column generally identifies constituents that are also identified for the ground-water and surface-water media, but contains additional constituents that are normally analyzed during soil contamination investigations (e.g., hydrogen sulfide and other gases), and certain other compounds that can be highly attenuated in soil (e.g., polyaromatic hydrocarbons).

An RFI may involve the investigation of waste which is hazardous by characteristic, as well as containing specific hazardous constituents. For example, methane, which is not an Appendix VIII hazardous constituent, is shown as an indicator parameter in List 1 for releases of subsurface gas. Because methane at sufficient concentrations possesses explosive or reactive properties, it can be hazardous based on the reactivity characteristic (40 CFR 261.23). Hence, subsurface gas may be the subject of an RFI even if specific hazardous constituents are not identified in the release.

List 4 in Appendix B is an industry-specific list. This list identifies categories of constituents, based on the classification presented in the 3rd Edition of EPA's Test Methods for Evaluating Solid Waste (EPA/SW-846), that may be present if wastes from a given industry are contained in the releasing unit. The EPA/SW-846 chemical

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classifications for these categories are reprinted as a supplement to List 4. List 4 applies to all media and may be used in conjunction with List 3 to identify industry-specific constituents that have a reasonable probability of being present in a particular medium. List 4 was derived from a review of the Development Documents for Effluent Guidelines Limitations prepared for various industries under EPA's NPDES program, information received from several EPA Regional Office Hazardous Waste Programs, and other references, as indicated in Appendix B. It does not cover all industries that may be subject to an RFI. The Development Documents for Effluent Guidelines Limitations are available for the 30 industries identified in List 4, and may be obtained from the National Technical Information Service (NTIS).

[Note that the chemical categories upon which List 4 are based are not mutually exclusive. If a category is identified as being appropriate for an industry, all constituents within the category should be monitored regardless of whether the constituent is contained in other categories.]

The use of the Appendix B lists in developing and implementing the general investigation strategy is described below.

The phase of the release investigation is a very important consideration. For example, the use of indicator parameters (List 1) along with specific hazardous constituents, can be helpful in verifying the presence of a suspected release. However, indicators alone are not adequate in showing the absence of a release, partially because of their relatively high detection limits (i.e., generally 1000 µg/l versus 10 to 20 µg/l for specific constituent analyses), and because indicator parameters do not account for all classes of constituents that may be present. Verification of the absence of a release should therefore always be supported by specific hazardous constituent analyses.

For the same reasons, indicator parameters should not form the sole basis for release characterization, especially at locations in the release where indicator concentrations are close to detection limits. Indicator parameters may be particularly useful in mapping large releases, but should always be used in conjunction with specific monitoring constituents.

Specific monitoring constituents and indicator parameters may also need to be modified as the investigation progresses, because physical, chemical, and biological degradation may transform constituents as the release ages or advances. When chemicals degrade, they usually degrade into less toxic, more stable species. However, this is not always the case. For example, one of the degradation products of trichloroethylene is vinyl chloride. Both of these chemicals are carcinogens. Information on degradation can be found in the environmental literature. Particular references include:

> U.S. EPA. 1985. Atmospheric Reaction Products from Hazardous Air Pollutant Degradation. NTIS PB85-185841. Washington, D.C. 20460.
>
> U.S. EPA. 1984. Fate of Selected Toxic Compounds Under Controlled Redox Potential and pH Conditions in Soil and Sediment Water Systems. NTIS PB84-140169. Washington, D.C. 20460.

This topic is discussed in more detail later in this section and in each of the media-specific sections.

After a release is adequately characterized in terms of concentrations of hazardous constituents (or hazardous characteristics), a comparison of these concentrations to EPA health and environmental-based criteria will be made (see Section 8). Although this comparison may involve a shortened list at this stage the RFI, all potential monitoring constituents (even those deleted earlier in th process) may need to be analyzed at selected monitoring locations to verify their presence or absence.

The use of ICP spectroscopy (for metals) and gas chromatography/mass spectrometry for volatile organic compounds (List 2) can be particularly helpful in delineating releases where little or no information is available on the source. These methods are relatively cost-effective because they address a number of constituents in a single analysis.

The medium or media being investigated is also an important consideration in identifying monitoring constituents. For example, non-volatile constituents may be poor candidates for monitoring of an air release, unless wind-blown particulates are

of concern. List 3 in Appendix B has been developed to aid in identifying constituents most likely to be measurable in each medium of concern.

Historical information (e.g., records indicating the industry from which wastes originated) may be useful in selecting monitoring constituents. List 4 in Appendix B may be helpful in identifying classes of constituents that may be of concern if a particular industry can be identified.

Waste sampling and analysis (see Section 7) may be performed to tailor the initial list of monitoring constituents. Although complete waste characterization is recommended in most cases, this may not always be possible or desirable (e.g., for a large unit in which many different wastes were managed over a long period or in cases where wastes have undergone physical and/or chemical changes over a long period). A complete historical waste characterization in such cases would not be possible. Other cases where waste sampling and analysis would generally be inadvisable are those where the waste is highly toxic (e.g., nerve gas) or explosive (e.g., disposed munitions). In these cases, it may be more appropriate to sample the environmental medium of concern at locations expected to indicate the highest release concentrations. Such sampling activities should be performed following appropriate health and safety procedures (see Section 6).

The extent of the release may also dictate, to some degree, the selection of monitoring constituents. For apparently small releases (e.g., 5 square yards of contaminated soil), it may be reasonable to base all analyses on specific monitoring constituents. For larger releases, the use of indicator parameters along with specific monitoring constituents may be a better approach. In this case, an appropriate balance between indicator parameters and monitoring constituents is advisable.

In addition, the potential for physical, chemical, or biological transformations (e.g., degradation) of constituents should also be considered in identifying monitoring constituents. Biodegradation may be of particular importance for the soil and surface-water media. For example, trichloroethylene in a waste unit or medium can degrade over time to vinyl chloride and other products. Such products may be present at higher concentrations than the parent trichloroethylene and may also be more toxic. Therefore, the selection of monitoring constituents should consider the potential for constituents to be transformed over time. Each of the media-specific

sections contains a discussion of physical, chemical, and biological transformation mechanisms.

Another approach that may be taken in selecting monitoring constituents for a particular medium is to use physical and chemical property data, such as the octanol/water partition coefficient or solubility, to predict which constituents may be present in a given medium. Further guidance on the use of this approach, including tables presenting data on relevant physical and chemical properties of various constituents, is presented in the following reference:

U.S. EPA. October, 1986. Superfund Public Health Evaluation Manual. EPA 540/1-86/060. NTIS PB87-183125. Office of Emergency and Remedial Response. Washington, D.C. 20460.

Case Study Numbers 1, 2, 4, 9, and 10 in Volume IV (Case Study Examples) illustrate application of the concepts discussed above.

3.6.2 Use of EPA and Other Methods

As described in the preceding sections, and in the media-specific sections (Sections 9 through 13), many different types of methods may be employed in conducting the RFI. These include methods for sampling, QA/QC, and field operations, as well as methods for physical, biological, and chemical analyses. These methods were developed by various organizations, including EPA, other Federal and State agencies, and by "standard-setting" organizations [e.g., ASTM, (American Society for Testing and Materials)]. Some of these methods are final, while others are in draft or proposed status. As discussed previously, the RFI Work Plan should propose methods that best suit the needs of the situation under investigation. Guidance in the following sections, and in the media-specific sections, is given on methods recommended in certain situations, including appropriate references. The following discussion highlights some general guidelines to follow in the selection of methods:

- Use of EPA Methods:

EPA recently published the 3rd Edition of its testing manual for solid waste (U.S. EPA. 1986. Test Methods for Evaluating Solid Waste. EPA/SW-846, GPO No. 955-001-00000-1), generally known as SW-846. This manual provides QA/QC methods, analytical methods, physical and chemical property test methods, and sampling and monitoring methods. These methods are acceptable for the RFI and contain guidance on unique problems that may be encountered during solid and hazardous waste investigations. Where possible, it is recommended that SW-846 (or equivalent) methods be used over other available methods. SW-846, however, may not provide all methods applicable in certain situations. In such cases, other EPA methods manuals (including EPA Regional Office methods manuals) may be used. One such document that should be particularly useful is EPA's Compendium of Field Operations Methods, developed by the Office of Emergency and Remedial Response (OSWER Directive No. 9355.0-14, EPA 540/P-87/001A, August 1987). This document provides discussions of various methods that can be applied in field investigations, and includes general considerations for project planning, QA/QC, and sampling design. Specific methods presented include:

- Rapid field screening procedures (e.g., soil gas surveys using portable field instruments);
- Drilling in soils;
- Test pits and excavation;
- Geological reconnaissance;
- Geophysics;
- Ground-water monitoring;
- Physical and chemical properties;
- Surface hydrology;

- Meteorology;

- Biology and Ecology/Bioassay and Biomonitoring; and

- Surveying, Photography, and Mapping.

- Use of Other Federal or State Methods:

  The Occupational Safety and Health Administration (OSHA), the Food and Drug Administration (FDA), and several other Federal agencies have developed methods and methods manuals for specific applications. In addition, State and EPA Regional Offices have also developed methods and methods manuals. These methods may also be used during release investigations, if appropriate. The media-specific sections of this Guidance identify where such methods may be particularly applicable.

- Use of Other Methods:

  Several "standard-setting" organizations are involved in the development of test methods for various applications. One such organization, the ASTM, publishes test methods and other standards in its Annual Book of ASTM Standards, which is updated yearly. Many of ASTM's methods may be applicable for use in the RFI; however, if comparable EPA methods exist, they are preferred because they often contain important information necessary for regulatory purposes.

Many ASTM and EPA methods are similar and some are identical. The primary reason for this is that many EPA methods are derived from ASTM methods. Some of ASTM's methods are adopted by EPA in toto. EPA's Compendium of Field Operations Methods, for example, contains many ASTM methods that can be used during an RFI.

Although ASTM's Committee D-34 on Waste Disposal has only published several final methods (ASTM. 1986 Annual Book of ASTM Standards. Volume 11:04), it has many other methods currently in various stages of development.

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Several methods under development that may be applicable to the RFI process are expected to be finalized and available soon.

Other organizations are also involved in the development and standardization of test methods. Many industrial and environmental association methods can also be used during an RFI. EPA's Compendium of Field Operations Methods identifies several of these.

All methods proposed for use by the owner or operator should be clearly described and adequately referenced.

3.6.3 Sampling Considerations

This section discusses several considerations important in designing a sampling plan, including sample types, and pertains to sampling of the waste source and the affected environmental media. Section 7 contains additional guidance on waste source sampling. A general discussion of sampling equipment and procedures is presented in EPA's SW-846. Other guidances containing general information that can be used in designing a sampling plan include the following:

U.S. EPA. August, 1987. Compendium of Field Operations Methods. Office of Emergency and Remedial Response. OSWER Directive No. 9335.0-14. EPA 540/P-87/001A. Washington, D.C. 20460.

U.S. EPA. 1985. Practical Guide for Ground-Water Sampling. Robert S. Kerr Environmental Research Laboratory. EPA/600/2-85/104. Ada Oklahoma.

U.S. EPA. 1986. RCRA Ground-Waster Monitoring Technical Enforcement Guidance Document. OSWER Directive No. 9950.1. Office of Waste Programs Enforcement. Washington, D.C. 20460.

U.S. EPA. July 24, 1981. RCRA Inspection Manual. Section V. Office of Solid Waste. Washington, D.C. 20460.

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U.S. EPA. June, 1985. Guidance on Remedial Investigations Under CERCLA. Office of Emergency and Remedial Response. NTIS PB85-238616. Washington, D.C. 20460.

U.S. EPA. May, 1984. Soil Sampling Quality Assurance Users Guide. CR810550-01. NTIS PB84-198621. Washington, D.C. 20460.

3.6.3.1 General Sampling Considerations

Various methods exist for obtaining acceptable samples of waste and for each medium described in this document. Each of the media-specific sections (Sections 9 through 13) describes appropriate methods. The RFI Work Plan should propose methods that best suit the needs of the sampling effort. The following criteria should be considered in choosing such methods:

- Representativeness--The selected methods should be capable of providing a true representation of the situation under investigation.

- Compatibility with Analytical Considerations--Sample integrity must be maintained to the maximum extent possible. Errors induced by poorly selected sampling techniques or equipment can result in poor data quality. Special consideration should be given to the selection of sampling methods and equipment to prevent adverse effects during analysis. Materials of construction, sample or species loss, and chemical reactivity are some of the factors that should receive attention.

- Practicality--The selected methods should stress the use of simple, practical, proven procedures capable of being used in or easily adapted to a variety of situations.

- Simplicity and Ease of Operation--Because of the nature of the material to be sampled, the physical hazards that may be encountered during sampling, and the wearing of safety equipment, the proposed sampling procedures should be relatively easy to follow and equipment simple to operate. Ideally, equipment should be portable, lightweight, and rugged.

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- Safety--The risk to sampling personnel and others, intrinsic safety of instrumentation, and safety equipment required for conducting the sampling should be carefully evaluated.

3.6.3.2 Sample Locations and Frequency

Because conditions in the unit or in the contaminant release will change both temporally and spatially, the design of the monitoring network should be developed accordingly. Spatially, sufficient samples should be collected to adequately define the extent of the contamination. Temporally, the plan should address spreading of the release with time and variation of concentrations due to factors such as changes in background concentrations, waste management practices, unit operations, the composition of the waste, and climatic and environmental factors. For example, sampling and supplemental measurements (e.g., wind speed) should be conducted when releases are most likely to be observed, when possible.

Selection of specific sampling locations and times will be site- and release-dependent. Three general approaches can be used in selecting specific sampling locations. Selection of a particular approach depends on the level of knowledge regarding the release. Judgmental sampling generally involves selection of sampling locations based on existing knowledge of the release configuration (e.g., visual evidence or geophysical data). A systematic approach involves taking samples from locations established by a predetermined scheme, such as a line or grid. Such samples can help to establish the boundaries of a contaminated area. Random sampling involves use of a "randomizing scheme," such as a random number table, to select locations within the study area. Random sampling can be useful when contaminant spatial distribution is expected to be highly variable. Regardless of the sampling approach taken, it is recommended that a coordinate (grid) system be established at the site to describe and record sampling locations accurately. As a release investigation progresses, and as more information regarding a release is gathered, the sampling approach may be varied as appropriate. Application of judgmental, systematic, and random sampling is discussed below.

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3.6.3.3 Judgmental Sampling

Judgmental sampling is appropriate when specific information exists on the potential configuration of a release. Many releases are likely to fall into this category, because site layout or unit characteristics will often indicate areas of potential contamination. Examples of judgmental sampling include:

- Taking air samples at areas generally downwind of a unit;
- Taking grab samples of surface soils from a drainage channel that receives surface runoff from a known contaminated area; and
- Obtaining soil cores downslope from a known waste burial site.

Judgmental sampling will generally bias the data obtained toward higher contaminant concentrations. For example, samples taken only from areas of suspected contamination would generally be biased toward higher concentrations. In many cases, this approach will suit the needs of the RFI.

3.6.3.4 Systematic or Random Grid Sampling

Systematic or random grid sampling allows the collection of a set of unbiased samples at the area of concern. These samples can be used for detection of contamination, for calculation of averages (e.g., for characterizing the contents of a surface impoundment when it is expected to be fairly homogeneous), and for modeling purposes. The size and shape of the grid should consider site-specific factors. However, some general recommendations can be made for effective grid planning. The following steps are recommended in establishing a grid system:

(1) Choose the study area to be included in the grid. To define the full extent of the contaminated area, this area should be larger than the suspected extent of contamination.

(2) Select the shape and spacing of the grid. The shape may vary (e.g., rectangular, triangular, or radial), depending on the needs of the investigation. The grid spacing should be based on consideration of the

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appropriate density of sampling points. For example, an initial sampling effort in an area of widespread, homogeneous contamination may use a 200-foot grid, whereas a search for "hot spots" in a poorly defined contaminated area might require a 50-foot or smaller spacing.

(3) Draw (or overlie) the sampling grid on a plan of the site. To minimize sampling bias, a random number table may be used to choose sampling cells.

(4) Transfer the grid onto the study area by marking grid line intersections with wooden stakes. The exact location of the sample within each grid cell may be chosen systematically (e.g., at each node) or randomly (i.e., anywhere within each cell).

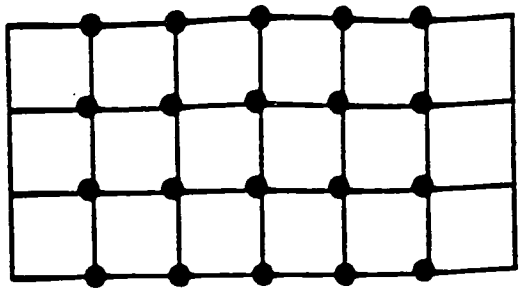
Figure 3-1a shows a systematic grid with samples taken at each node. Random grid sampling produces a sampling distribution such as that shown in Figure 3-1b. A possible limitation of systematic grid sampling is that if contaminants are distributed in a regular pattern, the sampling points could all lie within the "clean" areas (Figure 3-1c). This possibility should be considered when proposing a sampling approach.

3.6.3.5 Types of Samples

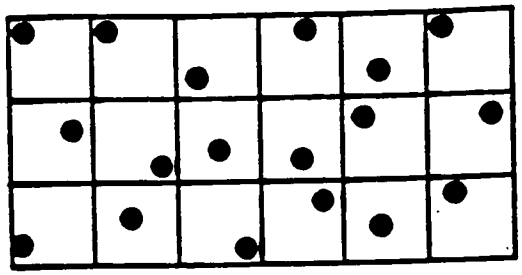
The owner or operator should propose the types of samples to be collected with the monitoring procedures. In general, there are three basic sample types: grab, composite, and integrated, as discussed below.

- Grab sampling--A grab sample is an individual sample taken at a specific location at a specific time. If a contaminant source or release is known to be fairly constant in composition over a considerable period of time or over substantial distances in all directions, then the sample may serve to represent a longer time period or a larger volume (or both) than the specific point and time at which it was collected.

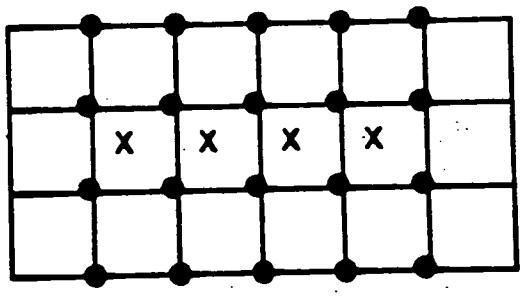
  When a contaminant source or release is known to vary with time, grab samples collected at suitable intervals and analyzed separately can



a) SYSTEMATIC GRID SAMPLING



b) RANDOM GRID SAMPLING



X = BURIED WASTE

c) CASE IN WHICH SYSTEMATIC GRID SAMPLING MISSES WASTES BURIED IN A REGULAR PATTERN

FIGURE 3-1. GRID SAMPLING.

indicate the magnitude and duration of variations. Sampling intervals should be chosen on the basis of the frequency with which variations may be expected. It may not always be desirable to take samples at equal intervals (e.g., subsurface gas releases are sensitive to seasonal influences). If sample composition is likely to show significant variation with time and space, grab samples from appropriate locations are recommended.

- Composite samples--Composites are combinations of more than one sample collected at various sampling locations and/or different times. Analysis of composites generally yields average values which may not accurately describe the distribution of release concentrations or identify hot spots. Compositing does not reflect actual concentrations and can reduce some concentrations to below detection limits. Composites may, in limited instances, be used to reduce the number of individual grab samples (e.g., when calculating an average value is appropriate). For example, compositing waste samples from a surface impoundment may be performed to determine an average value over several different locations. Compositing may also be useful in determining the overall extent of a contaminated area, but should not be used as a substitute for characterizing individual constituent concentrations. Therefore, compositing should be limited and should always be done in conjunction with an adequate number of grab samples.

- Integrated samples--An integrated sample is typically a continuously collected single sample taken to describe a population in which one or more parameters vary with either time or space. An integrated sampling technique can account for such variations by collecting one sample over an extended time period, such that variations can be averaged over that period. The most common parameter over which sampling periods are integrated is time. Time-integrated samples can provide an average of varying concentrations over the period sampled.

  Integrated sampling may be appropriate under limited circumstances. For example, process stream flows often change with variations in the process itself or with environmental conditions, such as wind speed. A

flow-integrated sampling device can collect a sample over a period of time as the sampling rate increases or decreases with the rise and fall of the stream flow. The device automatically biases sample collection toward those periods of high flow, with sampling rates decreasing during low-flow periods.

Integrated samples can be particularly useful for air and surface-water investigations where continuous changes in environmental conditions can affect constituent concentrations. See Sections 12 and 13 (air and surface water, respectively) for more information.

3.6.4 Analytical Methods and Use of Detection Limits

Analytical methods should be appropriate for the constituents and matrices being sampled. As indicated previously, the EPA publication Test Methods for Evaluating Solid Waste (EPA/SW-846), should be used as the primary reference for analytical methods. This document contains analytical methods that can be applied to solid, liquid, and gaseous matrices, and also presents detection limits generally associated with these methods. It is important to understand that detection limits can vary significantly depending on the medium (e.g., air, water, or soil) and other matrix-specific factors (e.g., presence of multiple contaminants). In addition to SW-846, the following reference provides detection limit information for water and soil matrices:

U.S. EPA. March, 1987. Data Quality Objectives for Remedial Response Activities. Volume 1 (Development Process) and Volume 2 (Example Scenario). Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. EPA 540/G-78/003a. OSWER Directive No. 9335.0-7b. Washington, D.C. 20460.

Detection limits should be stated along with the proposed analytical methods in the RFI Work Plan. Analytical values determined to be at or below the detection limit should be reported numerically (e.g., $\leq$0.1 mg/l).

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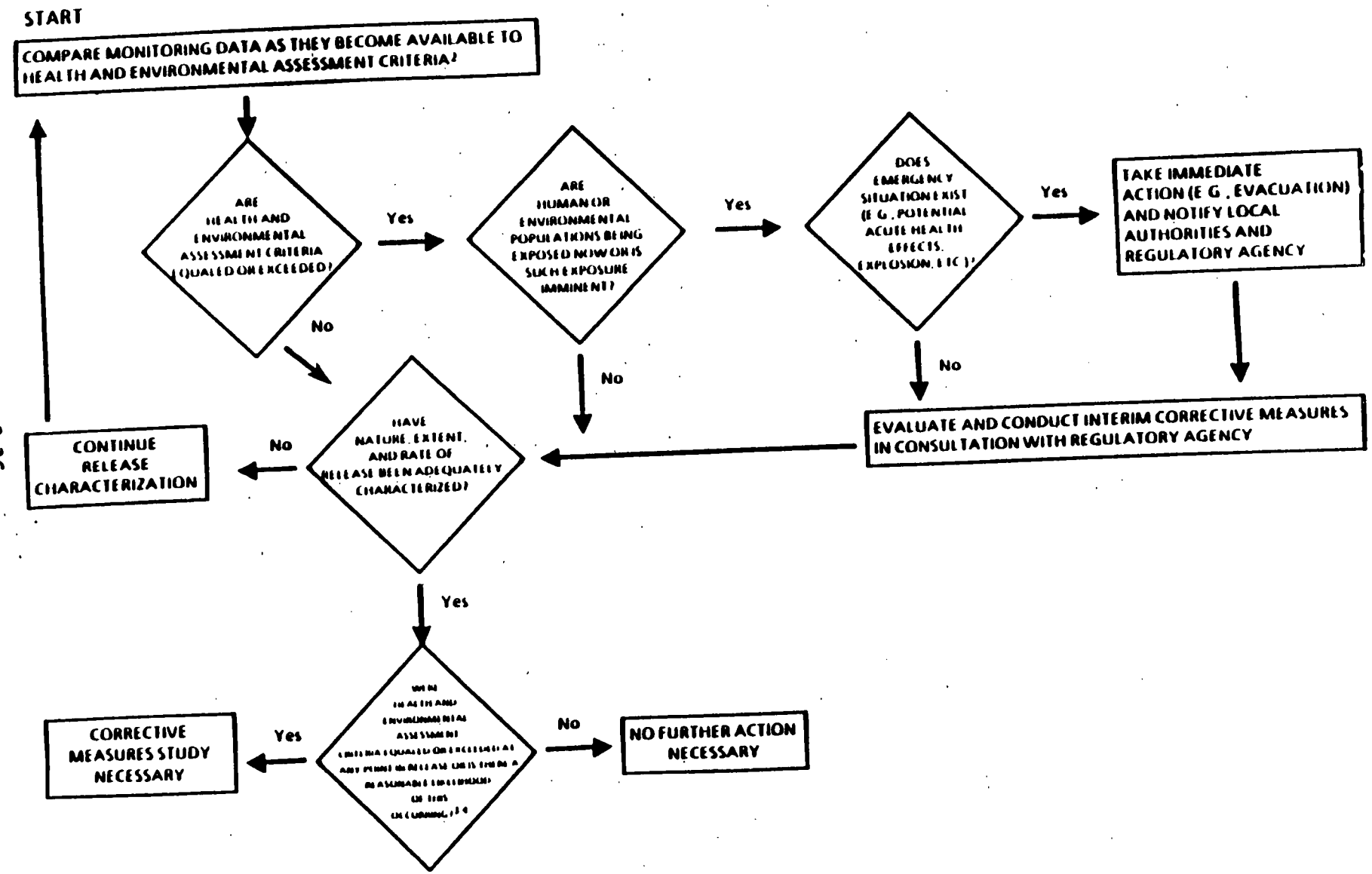
As monitoring data become available, both within and at the conclusion of discrete investigative phases, they should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and (2) a CMS. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Figure 3-2.

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D.

FIGURE 3-2
RFI DECISION POINTS[1]

(See Following Page for Footnotes)



FOOTNOTES FOR FIGURE 3-2

1 Although the health and environmental assessment is conducted by the regulatory agency, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures.

2 If sufficient monitoring data indicate that a release identified as "suspected" by the RFA has actually not occurred, no further action is necessary unless the regulatory agency determines that the occurrence of a release is or may be imminent.

3 For the air medium, the health and environmental assessment criteria are applied at actual receptor locations. For all other media, these criteria are applied at the unit or waste management area boundary and beyond.

4 A Corrective Measures Study or interim corrective measures may still be required based on qualitative criteria. (See Section 8 for discussion).

SECTION 4

QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES

4.1 Overview

Quality assurance (QA) is a management system for ensuring that all information, data, and decisions resulting from the RFI are technically sound and properly documented. Quality control (QC) is the functional mechanism through which quality assurance achieves its goals. Quality control programs, for example, define the frequency and methods of checks, audits, and reviews necessary to identify problems and dictate corrective action to resolve these problems, thus ensuring data of high quality. Thus, a QA/QC program pertains to all data collection, evaluation, and review activities that are part of the RFI.

Data generated during the RFI will provide the basis for decisions on corrective measures; therefore, the data should present a valid characterization of the situation. Utilization of erroneous or poor-quality data in reporting RFI results may lead to unnecessary repetition of sampling and analysis or, more importantly, to faulty decisions based on poor results. The owner or operator should develop adequate QA/QC procedures for the RFI. Implementation of these procedures will allow the owner or operator to monitor and document the quality of the data gathered.

The next portion of this section (4.2) describes the general design of a QA/QC program. The following portions of this section (Sections 4.3 and 4.4) outline and describe important QA/QC considerations that should be accounted for in the performance of sampling and analysis.

Section 4 is not intended to constitute a complete guide to constructing QA project plans or QC programs. EPA has established, through the issuance of various documents, guidance describing the development and implementation of QA/QC programs that can be used to design effective QA/QC procedures for the RFI. The

final portion of this section (Section 4.5) presents references that provide additional guidance in constructing appropriate QA/QC procedures for the RFI.

When selecting field personnel and analytical services to perform any RFI activity, the owner or operator is encouraged to evaluate available QA/QC programs and procedures in light of the information and references provided in this section. Participation in internal and/or external (e.g., Federal or State) laboratory validation/certification programs may be particularly important in selecting laboratory services.

Case Study No. 5 in Volume IV (Case Study Examples) provides an example of an effective QA/QC program.

4.2 QA/QC Program Design

The initial step for any sampling or analytical work should be to strictly define the program goals. Once these goals have been defined, a program can be designed to meet them. QA and QC measures are used to monitor the program and to ensure that all data generated are suitable for their intended uses. The responsibility of ensuring that the QA/QC measures are properly employed should be assigned to a knowledgeable person (i.e., a QA/QC specialist) who is not directly involved in the sampling or analysis.

One approach found to provide a useful structure for a QA/QC program is preparing both program and project-specific QA/QC plans. The program plan sets up basic policies, including QA/QC, and may include standard operating procedures (SOPs) for specific methods. The program plan serves as an operational charter for defining purposes, organizations, and operating principles. Thus, it is an orderly assemblage of management policies, objectives, principles, and general procedures describing a plan for producing data of known and acceptable quality. The elements of a program plan and its preparation are described in the following reference:

U.S. EPA. September 20, 1980. Guidelines and Specifications for Preparing Quality Assurance Program Plans. Office of Monitoring Systems and Quality Assurance. EPA/QAMS-004/80. NTIS P883-219667. Washington, D.C. 20460.

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Project-specific QA/QC plans differ from program plans in that specific details of a particular sampling/analysis program are addressed. For example, a program plan might state that all equipment will be calibrated according to a specific protocol given in written SOPs, while a project plan would state that a particular protocol will be used to calibrate the equipment for a specific set of analyses that have been defined in the plan. The project plan draws on the program plan for its basic structure and applies this management approach to specific determinations. An organization or laboratory would have only one QA program plan, but would have a QA project plan for each of its projects. The elements of a project plan and its preparation, presented in Table 4-1, are described in detail in the following reference:

U.S. EPA. December 29, 1980. Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. Office of Monitoring Systems and Quality Assurance. EPA/QAMS-005/80. NTIS PB83-170514. Washington, D.C. 20460.

4.3 Important Considerations for a QA/QC Program

The use of qualified personnel for conducting various portions of the RFI is of paramount importance to an effective QA/QC program. This pertains not only to qualified QA/QC specialists, but also to specialists in other fields, including hydrogeologists, air quality specialists, soil scientists, analytical chemists and other scientific and technical disciplines. The owner or operator should ensure that qualified specialists, primarily individuals with the proper education, training, and experience, including licensed or certified professionals, are directing and performing the various RFI activities. The same general principles apply to selection of contractors and/or outside laboratories.

4.3.1 Selection of Field Investigation Teams

The owner or operator should consider the following factors when selecting any field investigation team:

- Level of expertise and/or training required (e.g., experience, references);

TABLE 4-1
ESSENTIAL ELEMENTS OF A QA PROJECT PLAN

1. Title Page
2. Table of Contents
3. Project Description
4. Project Organization and Responsibility
5. QA Objectives
6. Sampling Procedures
7. Sample Custody
8. Calibration Procedures and Frequency
9. Analytical Procedures
10. Data Reduction, Validation, and Reporting
11. Internal Quality Control Checks
12. Performance and System Audits
13. Preventive Maintenance
14. Specific Routine Procedures Used to Assess Data Precision, Accuracy, and Completeness
15. Corrective Action
16. Quality Assurance Reports to Management

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- Available workforce; and
- Time and equipment constraints.

4.3.2 Laboratory Selection

The owner or operator should consider the following factors when selecting a laboratory:

- Capabilities (facilities, personnel, instrumentation), including:
  - Participation in interlaboratory studies (e.g., EPA or other Federal or State agency sponsored analytical programs);
  - Certifications (e.g., Federal or State);
  - References (e.g., other clients); and
  - Experience (RCRA and other environmentally related projects).
- Service:
  - Turnaround time; and
  - Technical input (e.g., recommendations on analytical procedures).

The owner or operator is encouraged to gather pertinent laboratory-selection information prior to extensively defining analytical requirements under the RFI. A request may be made to a laboratory to provide a qualifications package that should address the points listed above. Once the owner or operator has reviewed the various laboratory qualifications, further specific discussions with the laboratory or laboratories should take place. In addition, more than one laboratory should be considered. For large-scale investigations, selection of one laboratory as a primary candidate and one or two laboratories as fall-back candidates should be considered.

The quality of the laboratory service provided is dependent on various factors. The owner or operator should be able to control the quality of the information (e.g., samples) provided to the laboratory. It is extremely important that the owner or operator communicate to the laboratory all the requirements attendant to the RFI. This includes the identification of the number of samples and their matrices, sampling schedule, parameters and constituents (analytes) of interest, required analytical methodologies, detection limits, holding times, deliverables, level of QA/QC, and required turnaround of analytical results.

4.3.3 Important Factors to Address

A major element in release characterization is to define the QA/QC measures that will be followed to ensure the validity of data generated during the investigation. These measures should ensure that data generated are suitable for their intended uses. QA/QC procedures should address the following factors:

(1) Intended use(s) for the data, and the necessary level of precision and accuracy for these intended uses (See Section 4.4.1).

(2) Procedures for representative sampling, including:

- Selecting appropriate sampling locations, depths, etc.;
- Providing a sufficient number of samples and sampling sites;
- Obtaining all necessary ancillary data;
- Determining conditions (e.g., weather) under which sampling should be conducted;
- Determining which media are to be sampled (e.g., ground water, air, soil, sediment, etc.);
- Determining which constituents are to be measured;
- Selecting appropriate sample containers;

- Selecting the frequency of sampling and duration of the sampling period;
- Selecting the types of samples (e.g., composites and grabs) to be collected;
- Detailing methods of sample preservation; and
- Detailing methods of sample chain-of-custody.

(3) Documentation of field sampling operations and procedures, including:

- Documentation of procedures for preparation of reagents or supplies that become an integral part of the sample (e.g., filters and adsorbing reagents);
- Documentation of procedures and forms for recording the exact location and specific considerations associated with sample acquisition;
- Documentation of specific sample preservation methods;
- Calibration of field devices;
- Collection of replicate samples;
- Submission of field blanks, where appropriate;
- Detailing of potential interferences present at the facility;
- Listing of construction materials and techniques associated with monitoring wells, piezometers, and other monitoring equipment;
- Listing of field equipment and sample containers;
- Copy of sampling order; and

- Documentation of decontamination procedures.

(4) Analytical procedures, including:

- Appropriate analytical methods;
- Appropriate sample storage;
- Appropriate sample preparation methods;
- Appropriate calibration procedures; and
- Data management (e.g., review, reporting, and recordkeeping) procedures.

(5) Planning for the inclusion of proper and sufficient QA/QC activities, including the use of QC samples, throughout the study is necessary to ensure that the quality of the sampling and analytical data will meet the objectives of the RFI.

The factors and considerations described above are important for any environmental monitoring and measurement project. If these factors are adequately addressed (i.e., appropriate procedures are developed, tasks are assigned to qualified personnel; and sufficient QA/QC steps are employed), the goals of the RFI should be met. If the QA/QC procedures are sound, problems will be detected early, enabling the appropriate corrective actions to be taken.

[Note that the term "corrective action," in the context of a QA/QC program pertains to actions taken as a result of problems (e.g., sample contamination) uncovered by an effective QA/QC program. This should not be confused with the corrective measures that may be applied as a result of the RFI. Corrective actions as a result of QA/QC are discussed in Section 4.4.10.]

4.4 QA/QC Objectives and Procedures

The following describes the general components of QA/QC objectives and procedures. Specific references regarding recommended procedures are presented in Section 4.5.

4.4.1 Data Quality and Use

Throughout the RFI process, it is important that the owner or operator keep in mind the eventual use to which data will be put; that is, comparison of data to health and environmental criteria to determine whether some form of corrective measure may be necessary to correct the release. Therefore, data collected during the investigation needs to be of sufficient quality to support decisions regarding whether interim corrective measures and/or a CMS may be necessary.

Qualitative or quantitative statements that outline the decision-making process and specify the quality and quantity of data required to support decisions should be made early in the planning stages of the RFI. These data quality objectives (DQOs) are then used to design sampling and analysis plans and to determine the appropriate level of QA/QC.

The following discussion concerning DQOs is summarized from the following document:

U.S. EPA. March, 1987. Data Quality Objectives for Remedial Response Activities. Volume 1: Development Process. Volume 2: Example Scenario. EPA 540/G-87/003a. OSWER Directive No. 9335.0-7B. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. Washington, D.C. 20460.

This document may be reviewed for more detailed information. The Example Scenario (Volume 2) may be particularly helpful in understanding the overall DQO process.

The first step in the process of developing DQOs involves defining the decisions to be made based on the data and the objectives of the investigation. The

second step is defining a set of objectives (DQOs) that can be used to design the sampling and analysis plan and determining the appropriate level of QA/QC. Ultimately, these DQOs are also used to determine the adequacy of the data in terms of whether their quality and quantity are sufficient to enable confident decision-making. This process of defining the objectives of the investigation and designing data-gathering efforts to meet these objectives, should be initiated prior to starting the investigation. Refinements or revisions to these objectives may also be necessary as the investigation progresses.

The criteria most commonly used to specify DQOs and to evaluate available sampling, analytical, and QA/QC options are known collectively as the Precision, Accuracy, Representativeness, Completeness, and Comparability (PARCC) parameters. A brief description of these follows:

- Precision - a measure of the reproducibility of analyses under a given set of conditions.

- Accuracy - a measure of the bias in a measurement system.

- Representativeness - the degree to which sampling data accurately and precisely represent selected characteristics.

- Completeness - a measure of the amount of valid data obtained from a measurement system compared to the amount that could be expected to be obtained under "normal" conditions.

- Comparability - the degree of confidence with which one data set can be compared to another.

When using these parameters to assess data quality, only precision and accuracy can be expressed in purely quantitative terms. The other parameters are best expressed using a mixture of quantitative and qualitative terms. All these parameters are interrelated in terms of overall data quality and may be difficult to evaluate separately due to these interrelationships. The relative significance of each parameter depends on the type and intended use of the data being collected. Each parameter is addressed in further detail below.

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Precision is a measure of the scatter of a group of measurements made at the same specified conditions around their average. Values calculated should demonstrate the reproducibility of the measurement process. Determination of precision in relation to the RFI deals primarily with sampling and analytical procedures. The sample standard deviation and sample coefficient of variation are commonly used as indices of precision. The smaller the standard deviation and coefficient of variation, the better the precision.

Precision is stated in units of measurement or as a percentage of the measurement average, as a plus and minus spread around the average measured value. There are many sources of variation or error within any measurement system. Depending on the nature of the investigation, variation or error may be introduced at various stages. Examples of these are sample collection, handling, shipping, storage, preparation, and analysis. When summarizing precision determinations, the component or components of the measurement system that are included should be noted. The stage at which a replicate is placed within the measurement system, for example, generally dictates the components that affect the precision determination.

Accuracy is defined as the agreement of a measurement with an accepted reference or true value. This is normally expressed as the difference between measured and reference or true values or the difference as a percentage of the reference or true value. It may also be expressed as a ratio of the measurement to the true value. Accuracy is a measurement of system bias.

The determination of accuracy or bias within the measurement system is generally accomplished through the analysis of the neat sample (e.g., distilled water as opposed to pond or local water) and the analysis of the sample spiked at a known concentration utilizing a standard reference material. As in the case of the precision determination, the point at which the sample is spiked determines which components of the measurement system have an effect on the accuracy of the analysis. The three sample spiking points are sample acquisition (field matrix spike); preparation (lab matrix spike); and analysis (analysis matrix spike). The field matrix spike provides a best-case estimate of bias based on recovery. It includes matrix effects associated with sample preservation, shipping, preparation, and analysis.

The lab matrix spike provides an estimate of recovery incorporating matrix effects associated with sample preparation and analysis only. The analysis matrix spike provides an indication of matrix effects associated with the analysis process only. In addition to the above sample spiking points, the analysis of a known concentration of a standard reference material into the appropriate method solvent (e.g., deionized water, methanol, 2 percent nitric acid, etc.) provides an indication of the accuracy of the analytical system calibration.

Completeness is defined as the measure of the amount of valid data obtained from a measurement system compared to the amount that could be expected to be obtained under "normal" conditions. The completeness goals should be identified, to the extent possible, at the beginning of the RFI to ensure that sufficient valid data are collected to meet the RFI objectives and to provide a measurement whereby the progress of the RFI may be monitored during data collection.

QA/QC procedures may benefit through tabular presentations of the precision, accuracy, and completeness goals for the work performed under the RFI.

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. QA/QC procedures should address all data gathering with regard to representativeness. All RFI data compilation should reflect as precisely and as accurately as possible the conditions that existed at the time of measurement. Examples of factors that should be considered include:

- Environmental conditions at the time of sampling;
- Fit of the modeling or other estimation techniques to the event(s);
- Appropriateness of site file information versus release conditions;
- Appropriateness of sampling and analytical methodologies;
- Number of sampling points;

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- Representativeness of selected media; and

- Representativeness of selected analytical parameters.

Comparability is defined as an expression of the confidence with which one data set can be compared to another. In terms of the RFI, comparability may be applied to:

- RFI data generated by the owner or operator over a specific time period;

- Data generated by an outside laboratory over a specific time period;

- RFI data generated by an outside laboratory versus data generated by the owner or operator; and

- Data generated by more than one outside laboratory.

The utilization of standard methodologies for the various data generation categories (e.g., sampling, analysis, geological, and meteorological) should ensure data comparability. The owner or operator should take the appropriate measures to ensure the comparability of data compiled under the RFI.

The PARCC parameters are indicators of data quality. Ideally, the end use of the measurement data should define the PARCC parameters necessary to satisfy that end use. Ideally, numerical precision, accuracy, and completeness goals should be established to aid in selecting measurement methods to be used. However, RFI work may not fit this ideal situation. RFI sites are likely to differ substantially from one another, and information on overall measurements (e.g., sampling and analysis) may be limited such that it may not be practical to initially set meaningful PARCC goals. In such cases, the historical precision and accuracy achieved by different sampling and analytical techniques should be reviewed to aid in selecting the most appropriate technique. Only those techniques that have been adequately evaluated (e.g., precision and accuracy studies), and which therefore have a documented history of acceptable performance, should be proposed for use.

Precision and accuracy statements and detection limit information for analytical methods can be found in the DQO document referenced earlier in this section, as well as the following reference:

U.S. EPA. November, 1986. Test Methods for Evaluating Solid Wastes. EPA/SW-846. GPO No. 955-001-00000-1. Office of Solid Waste. Washington, D.C. 20460.

Each of the PARCC parameters should be considered in evaluating sampling and analysis options. To the extent possible, they should be defined as goals to be achieved by the data collection program. It should be recognized, however, that DQOs can be developed for RFI work without strictly defined PARCC goals.

Whenever measurement data are reviewed, the PARCC parameters should be included in the review. Precision and accuracy data may be expressed in several ways and are best evaluated by an analytical chemist or a statistician. The data reviewer should keep the action levels (health and environmental criteria) and the end use of the data in mind when reviewing precision and accuracy information. In some cases, even data of poor precision and/or accuracy may be useful. For example, if all the results are far above an action level, the precision and accuracy are less important. However, close to the action level, precision and accuracy are much more important and should be carefully reviewed. If results have very good precision but poor accuracy, correcting the reported results using the percent recovery or percent bias data may be acceptable.

4.4.2 Sampling Procedures

To ensure that sample collection will provide high quality and representative data, the owner or operator is advised to carefully select appropriate sampling procedures that will meet the objectives of the investigation. Some factors to consider in choosing the best sampling methodologies include the following:

- Physical and chemical properties of the medium to be sampled;
- Relative and absolute concentrations of analytes of concern;

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- Relative importance of various analytes to RFI objectives;
- Method performance characteristics;
- Potential interferences at the site; and
- Time resolution requirements.

QA/QC procedures relevant to sampling activities should also be formulated and followed during any site environmental characterization. These procedures should include a description of the techniques to be utilized in performing tasks such as well drilling, stratigraphic analysis, meteorological measurements, and surface water flow measurements. More information can be found in the references identified in Section 4.5, and in the media-specific sections (Sections 9 through 13).

4.4.3 Sample Custody

An essential part of any program that requires sampling and analysis is ensuring sample integrity from collection to data reporting. This includes the ability to trace the possession and handling of samples from collection through analysis and final disposition. The documentation of the history of the sample is referred to as chain-of-custody.

Chain-of-custody procedures should identify the components that will be utilized for all sampling and analysis under the RFI, including a transfer in custody and how the chain-of-custody procedures and documents will effectively record that transfer. The following sample custody procedures should be addressed:

(1) Field sampling operations:

- Documentation of procedures for preparation of reagents or supplies that become an integral part of the sample (e.g., filters and adsorbing reagents);

- Provision of procedures and forms for recording the exact location and specific considerations associated with sample acquisition;

- Documentation of specific sample preservation methods;

- Provision of pre-prepared sample labels containing all information necessary for effective sample tracking; and

- Establishment of standardized field tracking reporting forms to establish sample custody in the field prior to shipment.

(2) Laboratory operations:

- Identification of a responsible party to act as sample custodian at the laboratory facility authorized to sign for incoming field samples, obtain documents of shipment, and verify the data entered onto the sample custody records;

- Provision for a laboratory sample custody log consisting of serially numbered standard lab-tracking report sheets; and

- Specification of laboratory sample custody procedures for sample handling, storage, and dispersement for analysis.

4.4.4 Calibration Procedures

Another important consideration in any environmental measurement is the calibration of the measurement system. An improperly and/or infrequently calibrated system may have a serious negative impact on the precision and accuracy of the determinations. The result will be erroneous data and the need to repeat the measurements. The calibration procedures utilized should therefore be defined. Points that should be addressed include:

- For each measurement parameter, including all contaminant measurement systems, reference the applicable SOP or provide a written description of the calibration procedure(s) to be used;

- List the frequency planned for recalibration and/or the criteria utilized to dictate the frequency of recalibration; and

- List the calibration standards to be used and their source(s), including traceability procedures.

4.4.5 Analytical Procedures

The owner or operator should select analytical procedures that will meet the objectives of the RFI. Factors to consider in choosing appropriate analytical methodologies include:

- Scope and application of the procedure;

- Sample matrix;

- Potential interferences;

- Precision and accuracy of the methodology; and

- Method detection limits.

EPA-approved methodologies, such as those identified in the 3rd edition of Test Methods for Evaluating Solid Wastes (EPA/SW-846) or equivalent, should be utilized when available.

For each measurement parameter, including all contaminant measurement systems, the owner or operator should reference the SOP or provide a written description of the analytical procedure(s) to be used in support of the RFI. If any method modifications are anticipated due to the nature of the sample(s) being investigated, these modifications should be explicitly defined.

An important factor to consider in any analytical procedure is holding time. Samples have a limited shelf life. Analysis should occur within the time specified by the method. This is especially important for organic contaminants. For example,

volatile organic compound (VOC) analysis should occur within 2 weeks of sampling. Acceptable sample holding times for all classes of Appendix VIII constituents are discussed in Test Methods for Evaluating Solid Waste (EPA/SW-846).

4.4.6 Data Reduction, Validation, and Reporting

This portion of the QA/QC procedures applies to all measurements performed in support of the RFI. The owner or operator should identify the data reduction scheme planned for collected data and include all equations and reporting units used to calculate the concentration or value of the measured parameter.

Data validation is the process of reviewing data and accepting or rejecting it on the basis of sound criteria. Validation methods may differ for various measurements but the chosen validation criteria must be appropriate to each type of data and the purpose of the measurement. Records of all data should be maintained, even those judged to be "outlying" or spurious values. Personnel assigned the responsibility of data validation should have sufficient knowledge of the particular measurement system to identify questionable values.

The owner or operator should identify the principal criteria that will be applied to validate data integrity during collection and reporting. In addition, the methods that will be utilized to identify and treat outliers should be addressed. The validation process should include mechanisms whereby data reduction is verified. In the case of computerized data reduction, this may include subjecting a surrogate data set to reduction by the software to ensure that valid results are produced.

4.4.7 Internal Quality Control Checks

Quality control checks are performed to ensure that the data collected is representative and valid data. Internal QC refers to all data compilation and contaminant measurements. Quality control checks are the mechanisms whereby the components of QA objectives are monitored. Examples of items to be considered are as follows:

(1) Field Activities:

- Use of standardized checklists and field notebooks;
- Verification of checklist information by an independent person;
- Strict adherence to chain-of-custody procedures;
- Calibration of field devices;
- Collection of replicate samples; and
- Submission of field blanks, where appropriate.

(2) Analytical Activities:

- Method blank(s);
- Laboratory control sample(s);
- Calibration check sample(s);
- Replicate sample(s);
- Matrix-spiked sample(s);
- "Blind" quality control sample(s);
- Control charts;
- Surrogate samples;
- Zero and span gases; and
- Reagent quality control checks.

The owner or operator should consider those checks that will meet the QA objectives of the RFI. In addition, the owner or operator should present, in tabular format, the frequency with which each control check will be used.

4.4.8 Performance and Systems Audits

A systems audit is a qualitative evaluation of all components of the measurement systems to determine their proper selection and use. This audit includes a careful review of all data-gathering activities and their attendant QC procedures. Systems audits are normally performed before or shortly after systems are operational. However, such audits should be performed at sufficiently regular intervals during the lifetime of the RFI or continuing operation. Systems audits should be conducted by an individual who is technically knowledgeable about the operation(s) under review and who is independent of any other contribution to the RFI. The primary objective of the systems audit is to ensure that the QA/QC procedures are being adhered to.

After systems are operational and generating data, performance audits are conducted periodically to determine the accuracy of the total measurement system(s) or component parts thereof. Performance audits are quantitative evaluations of the measurement system(s). QA/QC procedures should include a schedule for conducting performance audits for each measurement parameter where all measurement systems are included. Examples of performance auditing mechanisms for analytical activities would be the inclusion of "blind" samples into the normal sample flow, an analyst performing the analysis of a sample previously analyzed by another analyst, and the results of any appropriate interlaboratory study samples analyzed during the term of the RFI. Performance audit checks relative to data handling operations might be the insertion of erroneous parameters into field records. This should trigger the validation procedures by entering unreasonable combinations of responses.

4.4.9 Preventive Maintenance

Preventive maintenance schedules ensure the maximum amount of active time for analytical instrumentation, field devices and instrumentation, and computer

hardware over the course of the RFI program. The following types of preventive maintenance should be considered:

- A schedule of important preventive maintenance tasks that must be carried out to minimize downtime of all measurement systems; and

- A list of any critical spare parts that should be on hand to minimize downtime.

4.4.10 Corrective Action for QA/QC Problems

Corrective actions are those measures taken to rectify a measurement system that is out of control. [Note that the term "Corrective Action," as used in this section, is a common QA/QC term applied to problem-solving activities. It should not be confused with the RCRA Corrective Action Program.] Corrective action may be initiated by any person performing work in support of the RFI at any time. For example, an analyst should be familiar with the precision and accuracy of the analysis that is being performed. If the results of the analysis are not within the anticipated limits, there are appropriate corrective actions that should be initiated by the analyst. There are, however, other checks within the measurement system that only the person assigned QA/QC responsibilities would be in a suitable position to evaluate and take action upon if required. A "blind" sample inserted in the normal sample flow would be an example of such a check.

The corrective action procedures to be utilized in the accomplishment of the RFI objectives should be contained in the QA/QC procedures and should include the following elements:

- The predetermined limits for data acceptability beyond which corrective action is required; and

- For each measurement system, the identity of the individual responsible for initiating the corrective action and also the individual responsible for approving the corrective action, if necessary.

In addition to routine corrective actions taken by all personnel contributing to the RFI, performance and systems audits may result in the necessity of more formal corrective action.

4.4.11 Quality Assurance Reports to Management

Another important aspect of the QA/QC program is the communication between the QA/QC organization and the management organization. Regular appraisal by management of the quality aspects related to the ongoing RFI data-gathering efforts provides the mechanism whereby the established objectives may be met.

QA/QC procedures should provide details relating to the schedule, information to be provided, and the mechanism for reporting to management. Reports to management should include:

- Periodic assessment of measurement data accuracy, precision, and completeness;
- Results of performance audits;
- Results of system audits;
- Significant QA/QC problems and recommended solutions; and
- Resolutions of previously stated problems.

The individual(s) responsible for preparing the periodic reports should be identified. These reports should contain a separate QA/QC section that summarizes data quality information.

4.5 References

Following is a list of the major references, including EPA guidances, recommended for use in designing effective QA/QC programs for RFIs:

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U.S. EPA. September 20, 1980. Guidelines and Specifications for Preparing Quality Assurance Program Plans. Office of Monitoring Systems and Quality Assurance. QAMS-004/80. NTIS PB83-219667. Washington, D.C. 20460.

U.S. EPA. December 29, 1980. Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans. Office of Monitoring Systems and Quality Assurance. QAMS-005/80. NTIS PB83-170514. Washington, D.C. 20460.

U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes. 3rd Edition. Office of Solid Waste. EPA/SW-846. GPO No. 955-001-00000-1. Washington, D.C. 20460.

U.S. EPA. August, 1987. Compendium of Field Operations Methods. OSWER Directive No. 9355.0-14. EPA/540/P-87/001A. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. July, 1981. RCRA Inspection Manual. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. June, 1985. Guidance on Remedial Investigations Under CERCLA. Office of Emergency and Remedial Response. NTIS PB 85-238616. Washington, D.C. 20460.

U.S. EPA. May, 1984. Soil Sampling Quality Assurance Users Guide. EPA 600/4-84-043. NTIS PB84-198621. Washington, D.C. 20460.

U.S. EPA. 1985. Sediment Quality Assurance Users Guide. EPA 600/4-85-048. NTIS PB85-233542. Washington, D.C. 20460.

U.S. EPA. March, 1987. Data Quality Objectives for Remedial Response Activities. Volume 1: Development Process. Volume 2: Example Scenario. EPA 540/G-87/003a. OSWER Directive No. 9335.0-7B. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. Washington, D.C. 20460.

SECTION 5

DATA MANAGEMENT AND REPORTING

5.1 Data Management

Release characterization studies may result in significant amounts of data, including results of chemical, physical, or biological analyses. This may involve analyses of many constituents, in different media, at various sampling locations, and at different times. Data management procedures should be established to effectively process these data such that relevant data descriptions (e.g., sample numbers, locations, procedures, methods, and analysts) are readily accessible and accurately maintained.

In order to ensure effective data management, the owner or operator should develop and implement a data management plan to document and track investigation data and results. This plan should address data and report processing procedures, project file requirements and all project-related progress reporting procedures and documents. The plan should also provide the format(s) to be used to present the data, including data reduction.

Data presentation, reduction and reporting are discussed in Sections 5.2, 5.3, and 5.4, respectively.

5.2 Data Presentation

RFI data should be arranged and presented in a clear and logical format. Tabular, graphical, and other visual displays (e.g., contaminant isopleth maps) are essential for organizing and evaluating such data. Tables and graphs are not only useful for expressing results, but are also necessary for decision-making during the investigation. For example, a display of analytical results for each sampling location superimposed on a map of the site is helpful in identifying data gaps and in selecting future sampling locations. Graphs of concentrations of individual constituents plotted against the distance from the source can help to identify patterns, which can be used to design further monitoring efforts.

Various tabular and graphic methods are available for data presentation, as illustrated in Table 5-1. Particular methods most applicable to the RFI may vary with the type of unit, the type of data, the medium under consideration, and other factors. The owner or operator should propose methods in the RFI Work Plan that best illustrate the patterns in the data.

Often, certain types of data, such as stratigraphy and sampling location coordinates, are more effectively displayed in graphic form. Such data may be presented in tabular form but should also be transformed into graphic presentations. For example, stratigraphy might be effectively illustrated on a two-dimensional (or possibly three-dimensional) cross-sectional map. Three-dimensional data presentation is particularly relevant to the RFI, as three-dimensional characterization is generally required to adequately characterize the nature, extent, and rate of release migration.

Sampling locations may be effectively illustrated on a topographic map, as shown in Figure 5-1. Topographic maps and the regulatory requirements for their preparation (40 CFR Part 270.14(b)) are also discussed in Appendix A. Table 5-2 provides some useful data presentation methods. In addition, many of the Case Studies presented in Volume IV illustrate effective data presentation techniques. Case Study No. 6 is of particular relevance to data presentation techniques. Specific data presentation techniques are discussed below.

5.2.1 Tables

Tabular presentations of both raw and sorted data are useful means of data presentation. These are discussed below.

5.2.1.1 Listed (Raw) Data

Simple lists of data alone are not adequate to illustrate trends or patterns resulting from a contaminant release. However, such lists serve as a good starting point for other presentation formats. These lists are also valuable for sample validation and auditing. Therefore, such lists are highly recommended for reporting results during the RFI. Each data record should provide the following information:

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TABLE 5-1

USES OF TABLES AND GRAPHICS IN AN RFI

Tabular Displays

1. Display site information and measurements
   - Water table elevations
   - Sampling location coordinates
   - Precipitation and temperature data
   - Lists of site fauna and flora

2. Display analytical data
   - List of constituents of concern and other monitoring parameters with associated analytical measurements
   - Display sorted results (e.g., by medium, sampling date, soil type)
   - Compare study and background area data
   - Report input data, boundary conditions, and output values from mathematical modeling

Graphic Displays

1. Display site features
   - Layout and topography (equivalent to the required RCRA permit application map)
   - Sampling locations and sampling grids
   - Boundaries of sampling area
   - Stratigraphy and water table elevations (profile, transect, or fence diagram)
   - Potentiometric contour map of ground water
   - Ground-water flow net
   - Population plot and/or local residential map
   - Features affecting inter-media transport

2. Illustrate the extent of contamination
   - Geographical (areal) extent of contamination
   - Vertical distribution of contaminant(s)
   - Contamination values, averages, or maxima at sampling locations

3. Demonstrate patterns and trends in the data
   - Change in concentration with distance from the source
   - Change in concentration with time
   - Display estimates of future contaminant transport derived from modeling

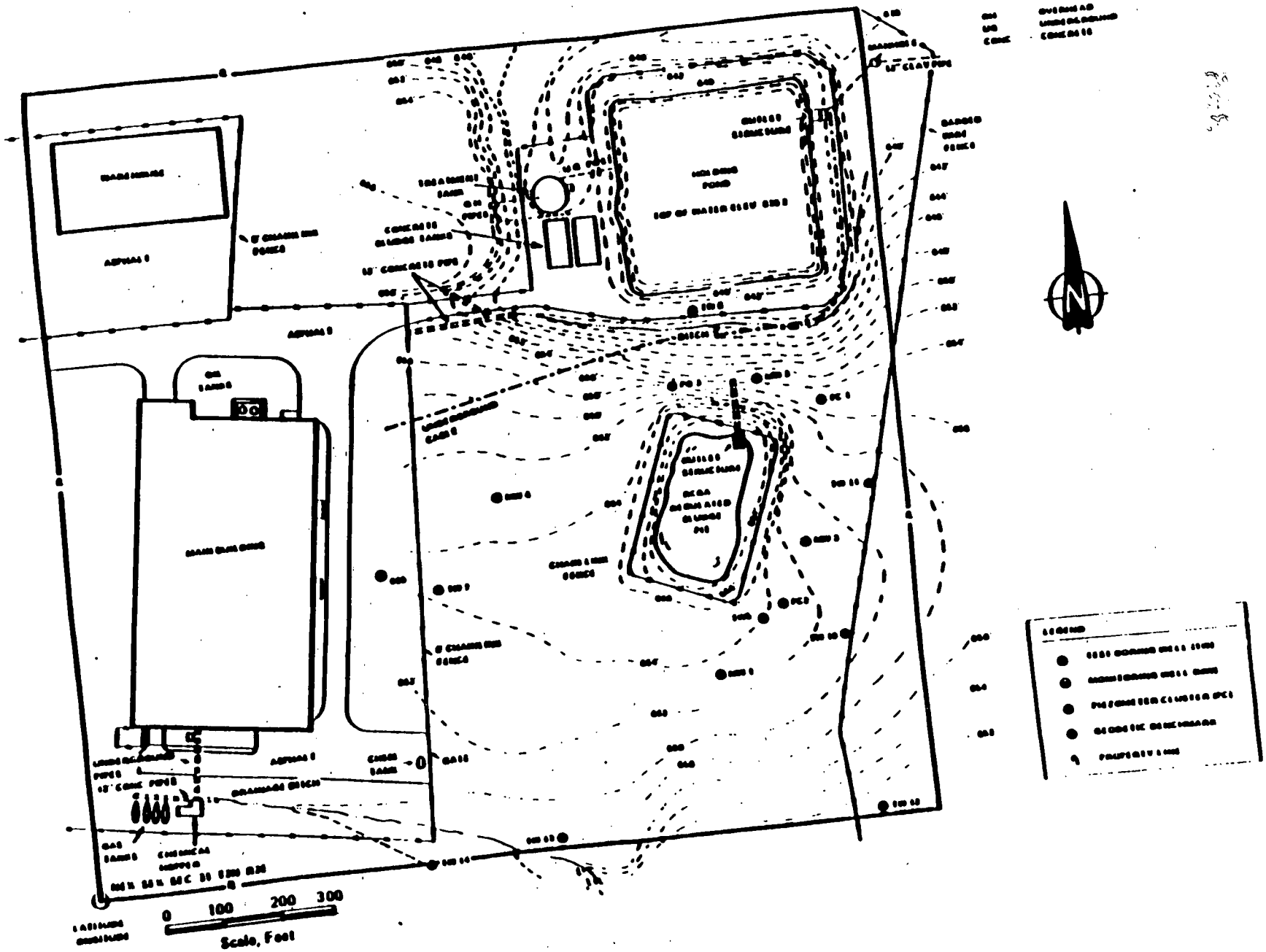

Figure 5-1. Topographic Map Showing Sampling Locations

Table 5-2

Useful Data Presentation Methods

Tables

Unsorted (raw) data

Sorted tables

Graphic Formats and Other Visual Displays

Bar graphs

Line graphs

Area or plan Maps

Isopleth (contour) plots

Ground-water flow nets

Cross-sectional plots, transects, or fence diagrams

Three-dimensional graphs

- Unique sample code;
- Sampling location and sample type;
- Sampling date;
- Laboratory analysis identification number;
- Property or component measured;
- Result of analysis (e.g., concentration);
- Detection limits; and
- Reporting units.

Analytical data will generally be reduced at the laboratory before they are reported (i.e., the owner or operator does not have to report instrument readings or intermediate calculations, although this information should be maintained for ready access if needed). The owner or operator should report all data to the regulatory agency, including suspected outliers or samples contaminated due to improper collection, preservation, or storage procedures. The rejected data should be marked as such in the data tables, and explanations of rejected data should be presented in footnotes.

In addition to analytical data, the owner or operator may be required to provide sampling logs for all samples obtained during the investigation. Sampling logs are records of procedures used in taking environmental samples, and of conditions prevailing at the site during sampling. Information in the log should include:

- Name and address of sampler;
- Purpose of sampling;
- Date and time of sampling;

- Sample type (e.g., soil) and suspected contaminants;
- Sampling location, description, and grid coordinates (including photos);
- Sampling method, sample containers, and preservation (if any);
- Sample weight or volume;
- Number of samples taken;
- Sample identification number(s);
- Amount purged (for ground water);
- Field observations;
- Field measurements made (e.g., pH, temperature);
- Weather conditions; and
- Name and signature of person responsible for observation.

The owner or operator should also describe any unusual conditions encountered during sampling (e.g., difficulties with the sampling equipment, post-sampling contamination, or loss of samples).

5.2.1.2 Sorted Summary Tables

Presentation of results grouped according to data categories is one of the simplest formats used to display trends or patterns in data. Examples of categories of data include medium tested, sampling date, sampling location, and constituent or property measured. Table 5-3 shows an example of a sorted table; data are sorted by medium (ground water), sampling date, and constituent measured.

TABLE 5-3

SORTED DATA

(Concentration of Volatile Organic Compounds in Monitoring Well #32)

		Concentration (µg/l)			
Date	Sample Identification Number	Methylene Chloride	Acetone	Trichloroethylene	Benzene
1/3/82	MW-32-1/3A	20	120	20	30
2/12/82	MW-32-2/12A	≤10	220	NA	≤10
4/24/82	MW-32-4/24A	≤10	140	20	20

NA - Not analyzed.

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In Table 5-4, the data are sorted by medium, location, depth, and constituent analyzed. Inclusion of the sample identification number allows the reader to cross-reference the data and look up any information not listed in the table.

Preparation of data summary tables can be simplified by use of a computer spreadsheet program. These programs can perform sorting operations, perform simple calculations with the data, and display results in a number of tabular and graphical formats.

5.2.2 Graphic Presentation of Data

The graphic methods of data presentation will often illustrate trends and patterns better than tables. Some graphic formats useful for environmental data include bar graphs, line graphs, areal maps, and isopleth-plots. These graphic methods of data presentation are discussed below.

5.2.2.1 Bar Graphs and Line Graphs

Bar graphs and line graphs may be used to display changes in contaminant concentrations with time, distance from a source, or other variables. For example, Figure 5-2 compares two methods of displaying changes in concentrations over distance. Bar graphs are generally preferable to line graphs in instances where there is not enough information to assume continuity between data points. However, line graphs generally can display more information in a single graph.

Attention to the following principles of graphing should provide clear and effective line and bar graphs:

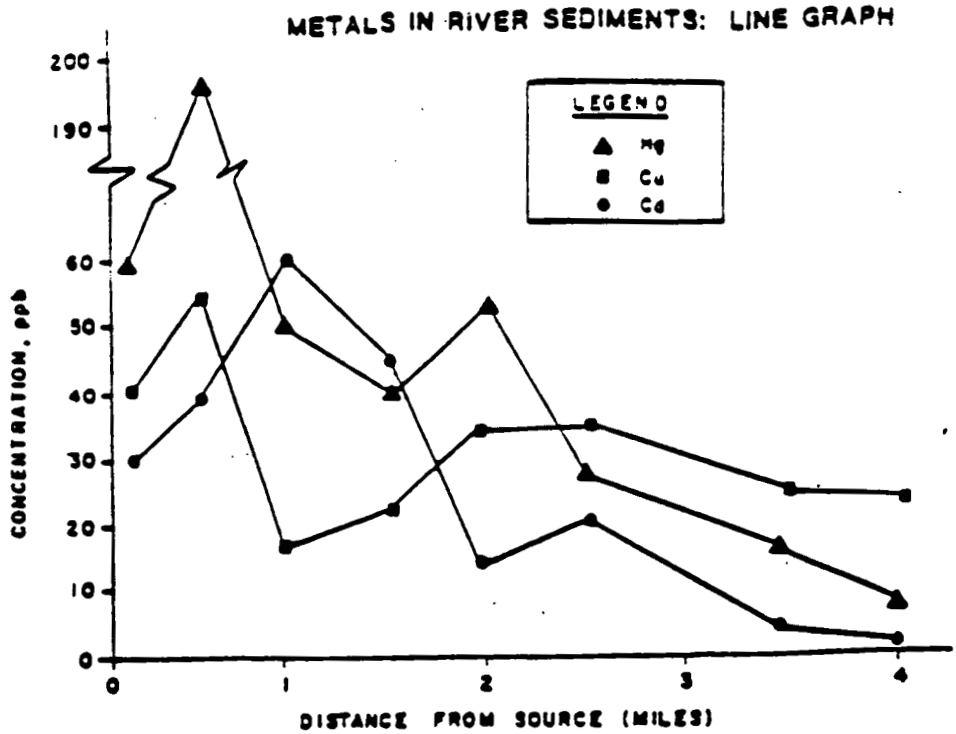
- Do not crowd data onto a graph. Plots with more than three or four lines or bar subdivisions become confusing. Different symbols or textures should be used to distinguish each line or bar;

- Choose the scale of the x and y axes so that data are spread out over the full range of the graph. If one or two data points are far outside the range of the rest of the data, a broken line or bar may be used to indicate

TABLE 5-4

SOIL ANALYSES: SAMPLING DATE 4/26/85

Sample Identification, Location, and Depth			Concentration (mg/kg)		
Sample ID Number	Location	Depth	Lead	Arsenic	Chromium
SB-1	N of lagoon	surface	240	55	1,200
SB-2	N of lagoon	6 inches	40	15	220
SB-3	N of lagoon	18 inches	15	15	36
SB-4	SE corner	surface	360	84	5,300
SB-5	SE corner	6 inches	170	29	430
SB-6	SE corner	18 inches	22	$\leq$1.0	47



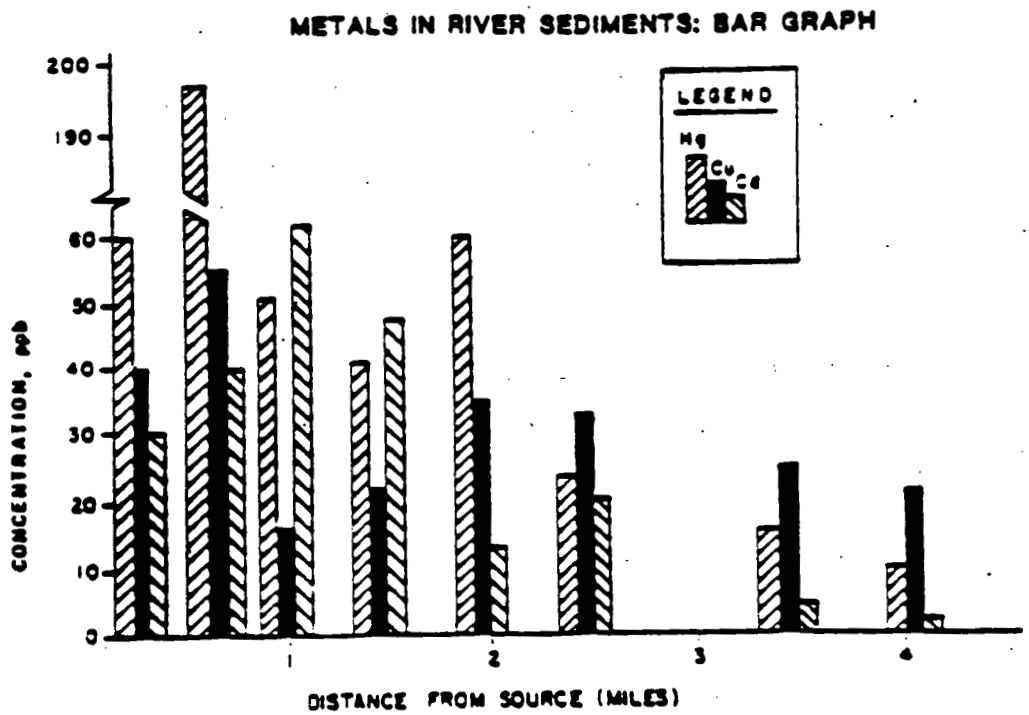


Figure 5-2. Comparison of line and bar graphs

a discontinuous scale. If the data range exceeds two orders of magnitude, the owner or operator may choose to plot the logarithms of the data;

- The x and y axes of the plot should be clearly labeled with the parameter measured and the units of measurement; and

- The x axis generally represents the independent variable and the y axis the dependent variable.

5.2.2.2 Area or Plan Views (Maps)

The distribution of hazardous constituents at a site may be represented superimposing contaminant concentrations over a map of the site. Distribut.. may be shown by listing individual measurements, or by contour plots of the contaminant concentrations. Individual techniques are discussed below:

Contamination shown at discrete points--In this format, no assumptions are made concerning contamination outside the immediate sampling area. For example, in Figure 5-3, soil phenol concentrations are shown by the height of the vertical bar at each sampling site. Soil samples indicated on this map were taken from approximately the same depths. Note that one bar is discontinuous so as to bring the lower values to a height that can be seen on the graph. Other possible representations of the same information could use symbols of different shapes, sizes, or colors to represent ranges of concentration. For example, a triangle might represent 0 to 10 ppm; a circle 10 to 100 ppm, etc.

Display of average concentrations--Shadings or textures can be used to represent average contamination concentrations within smaller areas at a site. Shading represents estimated areas of similar concentration only and should not be interpreted as implying concentration gradients between adjacent points.

Contaminant isopleth maps--Lines of equal concentration are called isopleths. Construction of a contaminant isopleth map generally requires a relatively large number of sampling locations spaced regularly across the study area. An isopleth map is prepared by marking the site map with the concentrations detected at each

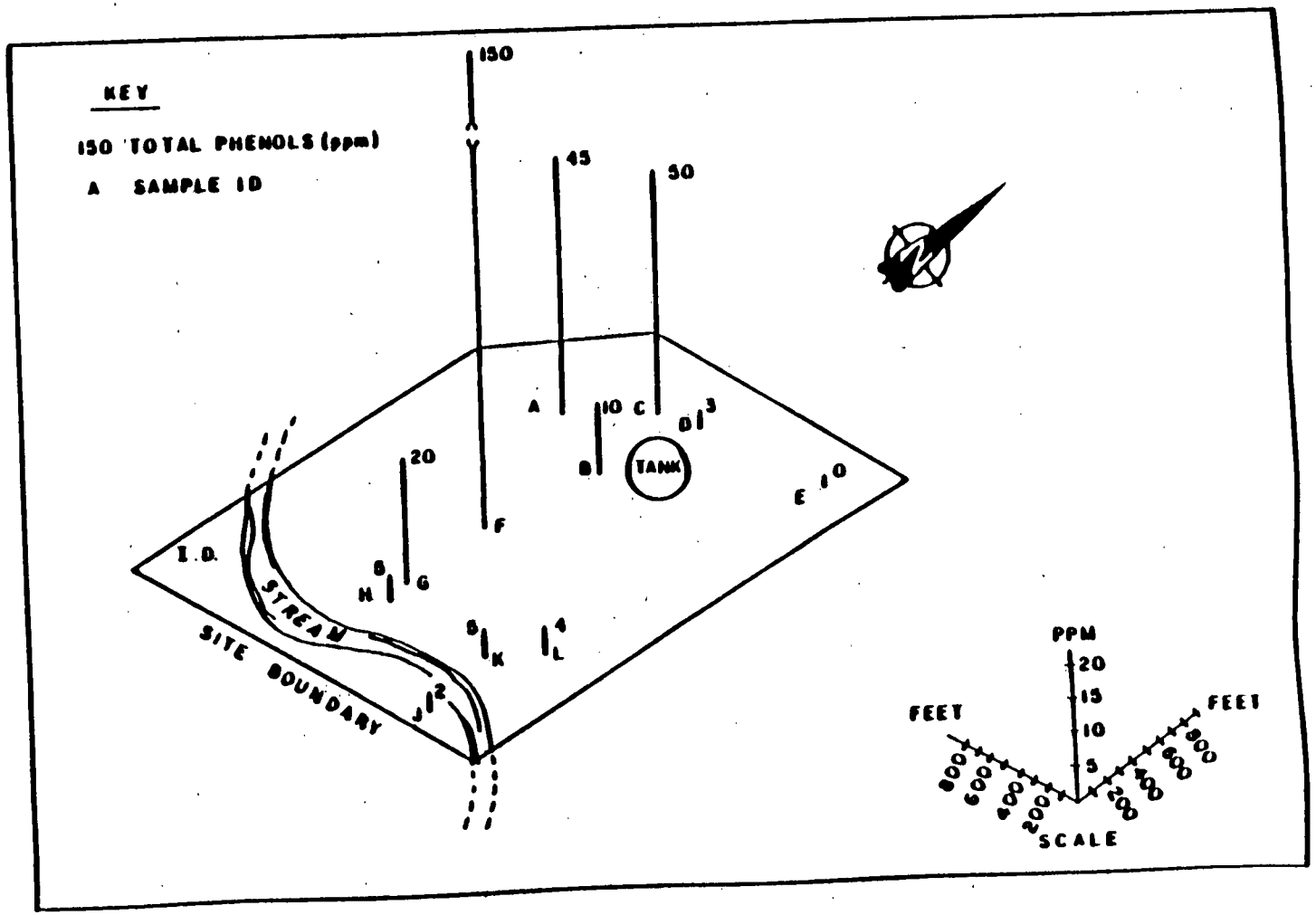


Figure 5-3. Phenol concentrations in surface soils (ppm = mg/kg)

sampling location. Lines are drawn to connect data points of the same concentration, similar to contours of elevation, as shown in Figure 5-4. Figure 5-5 demonstrates the use of an isopleth plot to show the distribution of an air release.

5.2.2.3 Isopach Maps

A technique that is useful for displaying certain types of geological data is the isopach map. Isopachs are contour maps in which each line represents a unit of thickness of a geologic material (e.g., the soil layer) as shown in Figure 5-6. This format would be useful if, for example, oil is known to be contained within a highly permeable sand layer of varying thickness, confined between low-permeability clay layers. The isopach map displays thickness only and does not provide information on absolute depth or slope.

5.2.2.4 Vertical Profiles or Cross-Sections

Vertical profiles are especially useful for displaying the distribution of a contaminant release in all media. For soil and ground water, the usual approach is to select several soil cores (or monitoring wells) that lie in approximately a straight line through the center of the contaminant release. This cross-section represents a transect of the site. A diagram of the soil (or ground water) profile should be prepared along the length of the transect, displaying subsurface stratigraphy, location of the waste source, and the location and depth of boreholes, as shown in Figure 5-7. Concentrations may also be indicated on the plot as discrete measurements or isopleths and may be drawn as in Figure 5-8. Figure 5-9 presents a plan view of Figure 5-7, showing the offset in cross-section. If the sampling points do not fall in a straight line, an alternate display called a fence diagram can be used. Figure 5-10 shows a fence diagram of subsurface stratigraphy, which also includes analytical data.

To characterize the three-dimensional distribution of a subsurface contaminant release, the owner or operator will generally need to prepare several transects crossing the plume in different directions.

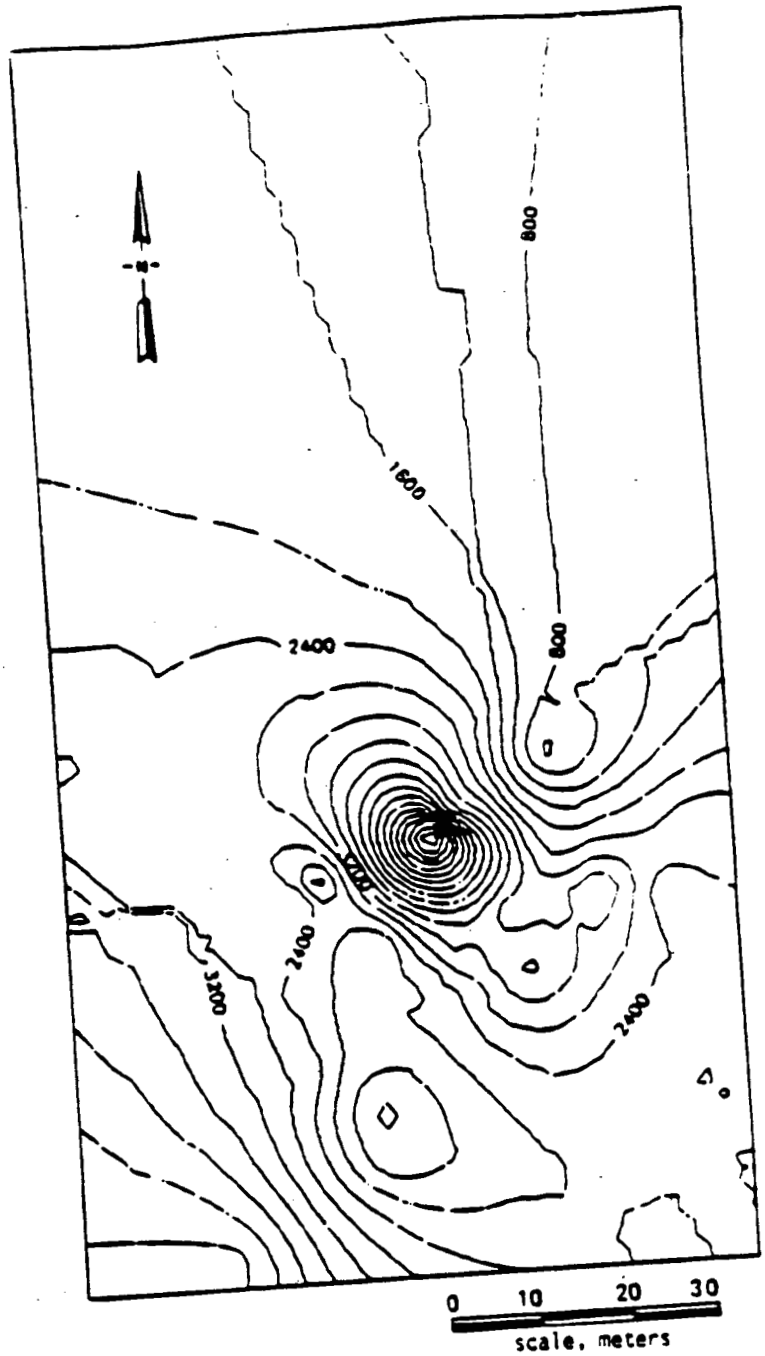
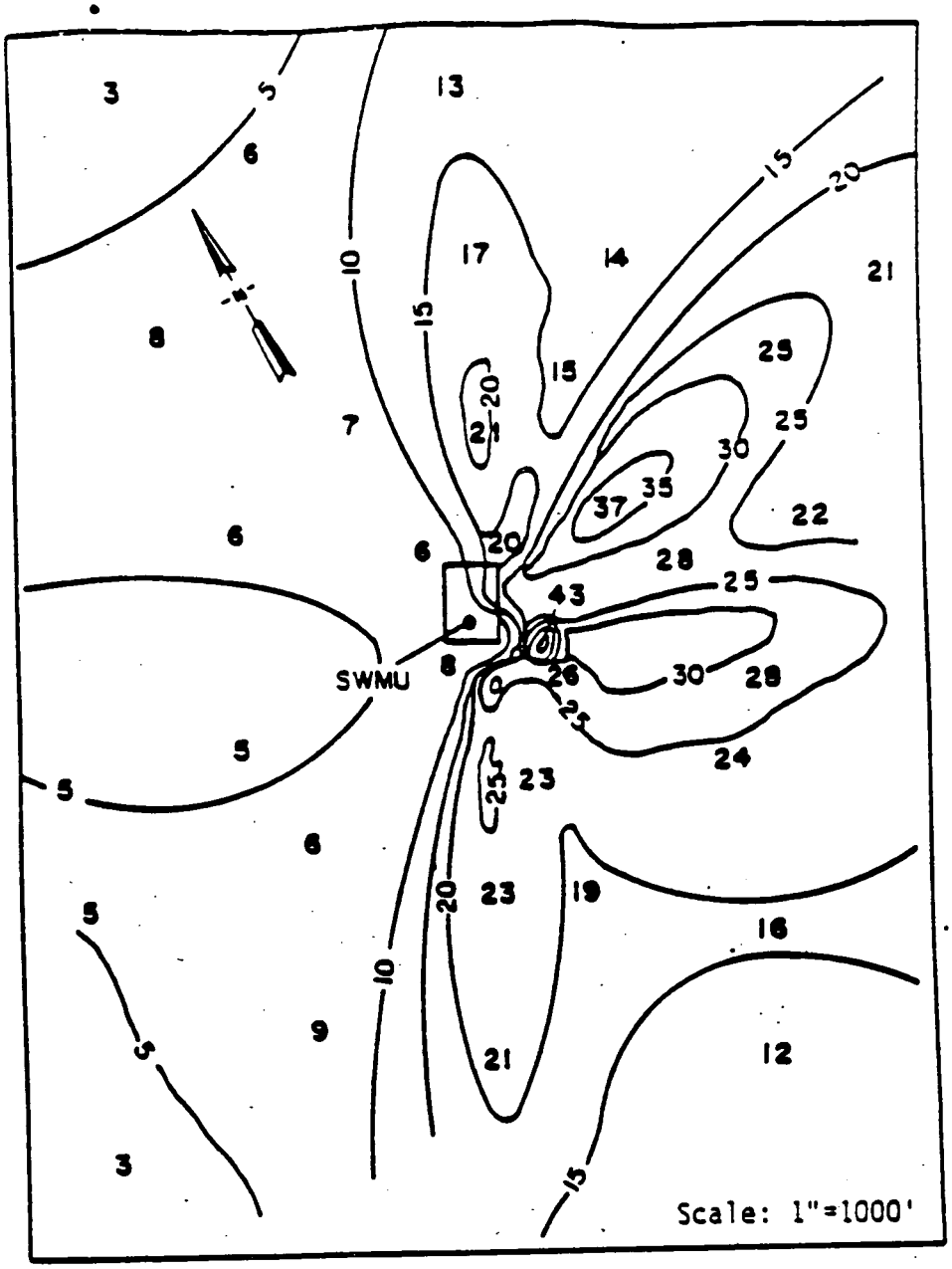


Figure 5-4. Isopleth Map of Soil PCB Concentrations (µg/kg)



ISOPLETHS ARE IN MICROGRAMS PER CUBIC METER

Figure 5-5. Isopleth Map of Diphenylamine Concentrations in Ambient Air in the vicinity of a SWMU.

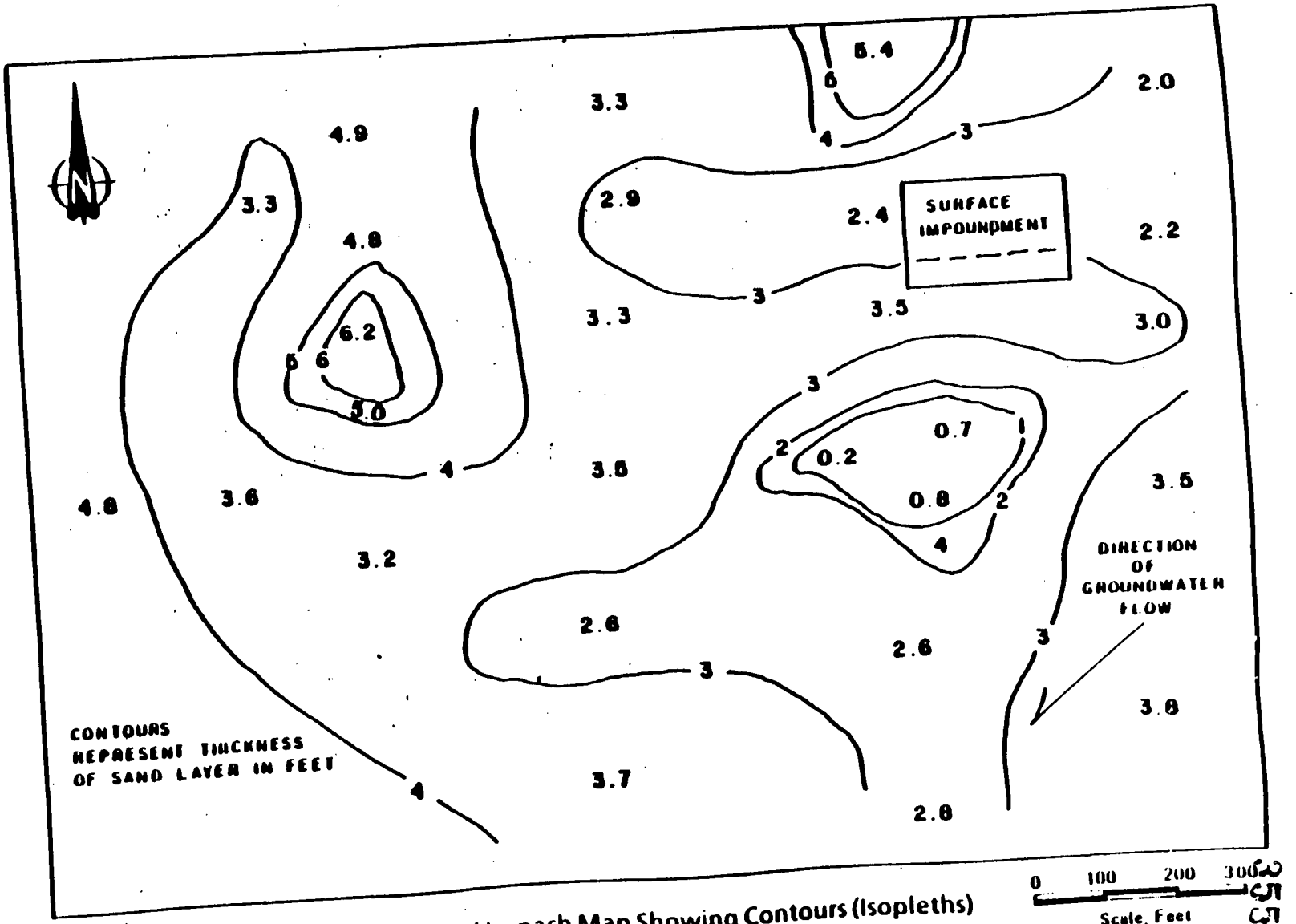


Figure 5-6. Sand Isopach Map Showing Contours (Isopleths)

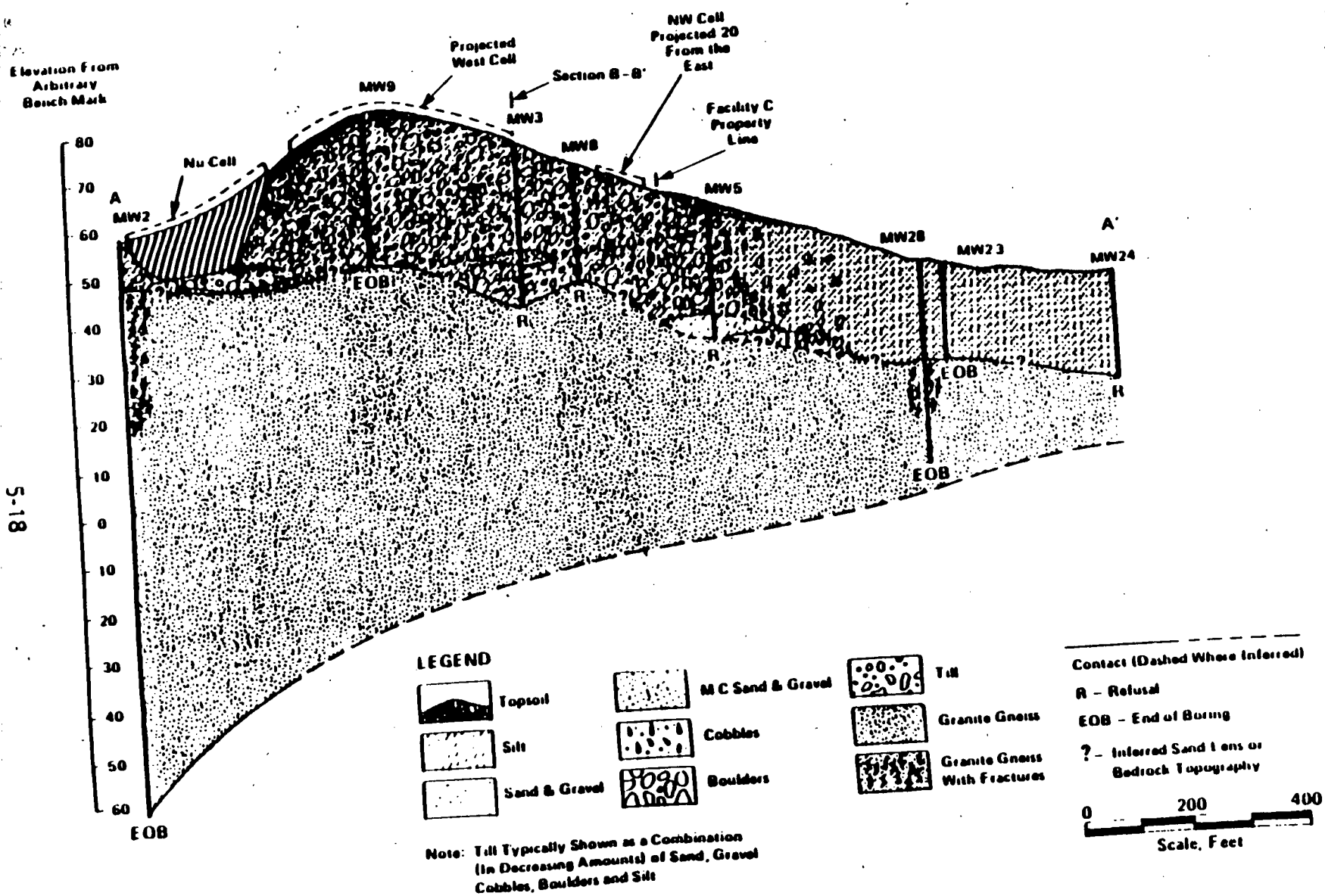


Figure 5-7. Cross Section A-A'-Site Subsurface Profile

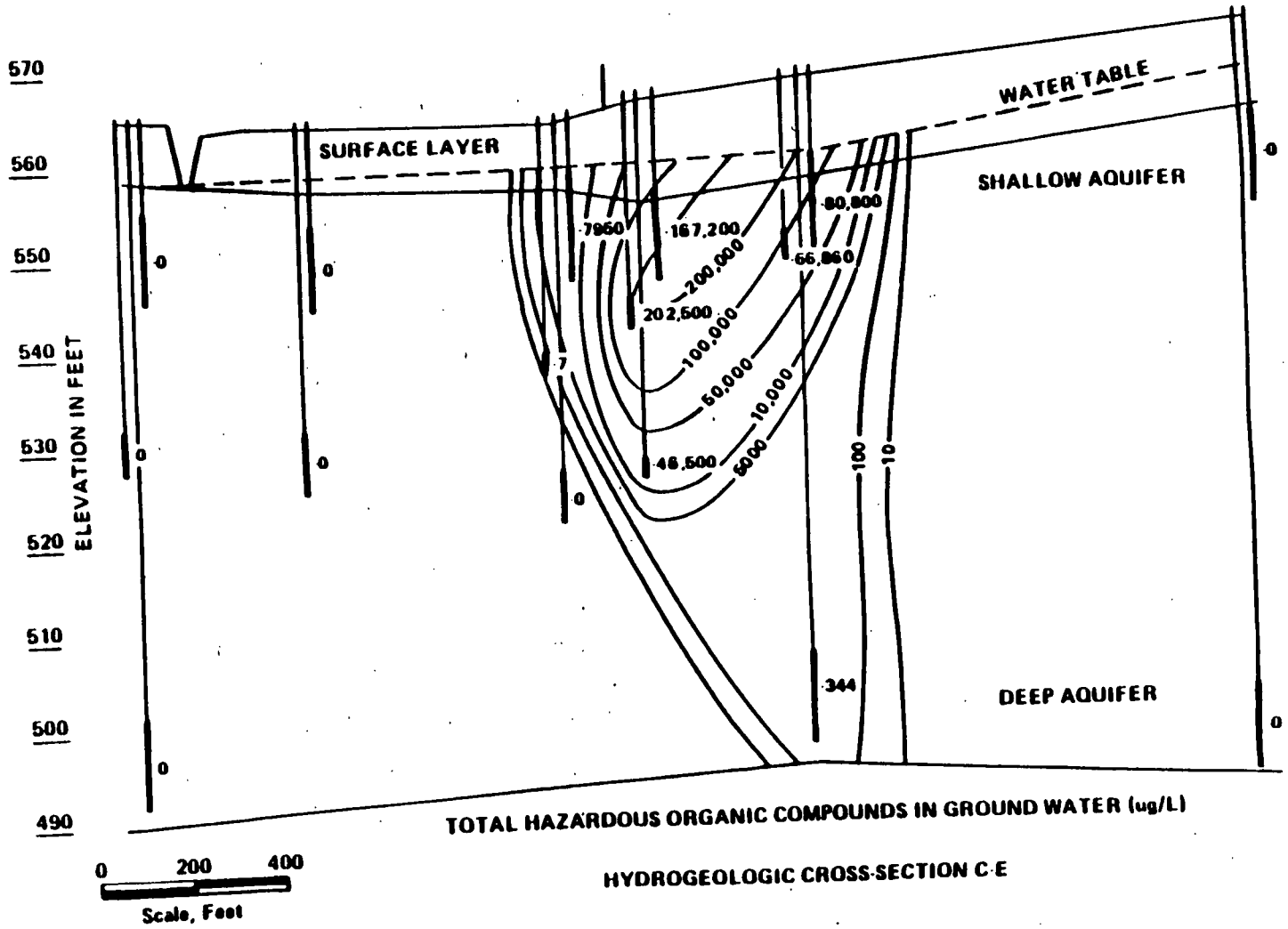


Figure 5-8. Transect Showing Concentration Isopleths (µg/l)

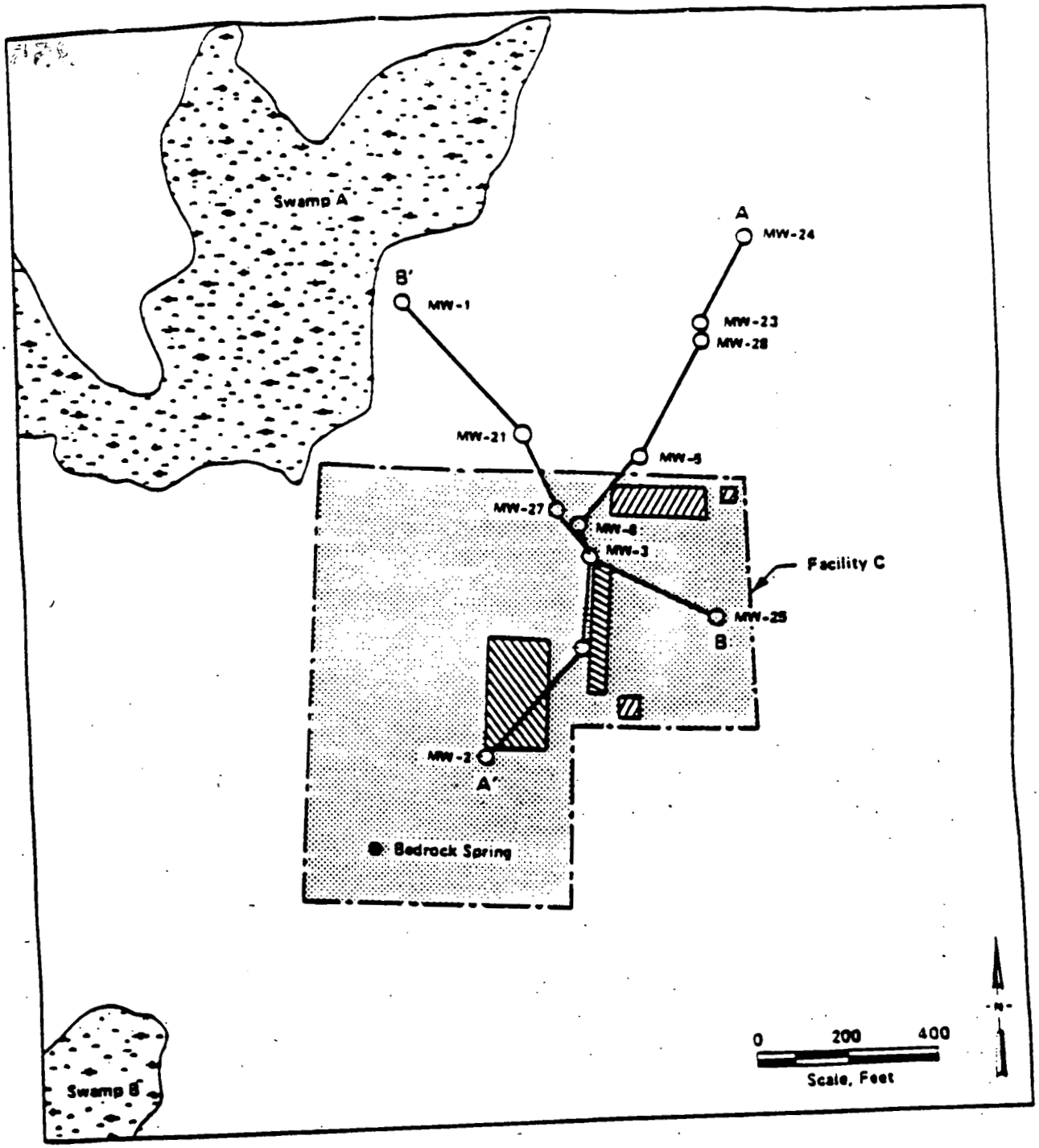


Figure 5-9. Plan View of Figure 5-7 Showing Offsets in Cross Section

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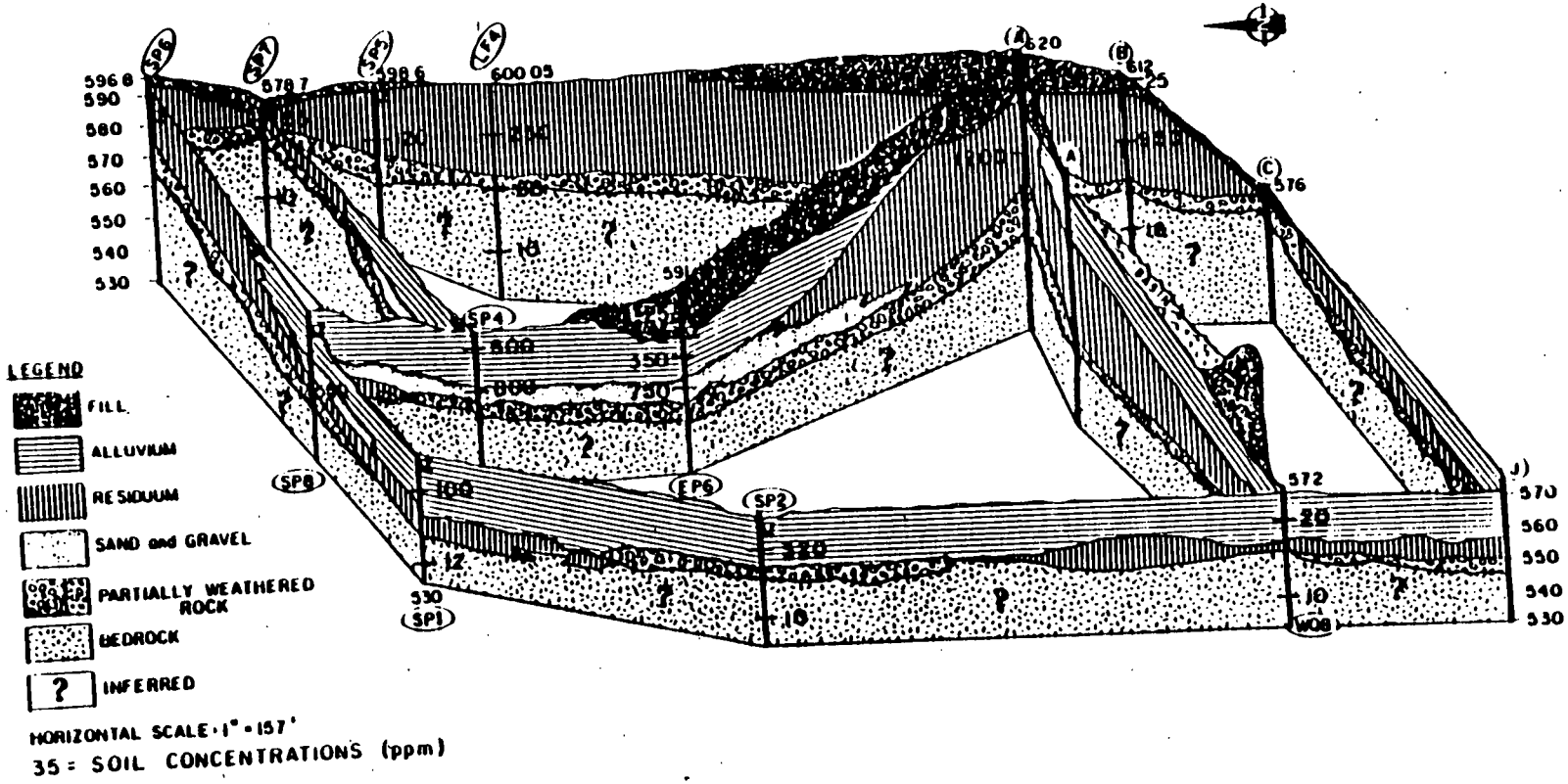

Figure 5-10. Fence Diagram of Stratigraphy Showing Lead (Pb) Concentrations (ppm = mg/kg)

5.2.2.5 Three-Dimensional Data Plots

Computer graphics packages are available from several commercial suppliers to produce three-dimensional data plots. A common use of this technique is to represent contaminant concentrations across the study area as a three-dimensional surface, as shown in Figure 5-11. The information provided by this approach does not differ greatly from that of Figure 5-4. The primary difference is that the smoothing of the concentration dissimilarities between adjacent sampling locations in Figure 5-11 makes patterns in the data easier to visualize. Precise concentrations, however, cannot be displayed in this format because the apparent heights of the contours change as the figure is rotated.

5.3 Data Reduction

Data should be reported according to accepted practices of QA and data validation. All data should be reported. Considerations, however, include treatment of replicate measurements, identification of outlier values, and reporting of results determined to be below detection limits.

5.3.1 Treatment of Replicates

Replicate measurements of a single sample should be averaged prior to further data reduction. For example, Table 5-5 shows how to calculate an overall mean when replicate analyses for a single sample have been performed. The three "B" values are averaged before the mean is calculated. This removes bias from the overall mean. The number of analyses is indicated by "n".

5.3.2 Reporting of Outliers

Any program of environmental measurement can produce numbers that lie outside the "expected" range of values. Because field variability of environmental measurements can be great, deciding whether an extreme (outlier) value is representative of actual contaminant levels may be difficult. Outlier values may be the result of:

- A catastrophic unnatural (but real) occurrence such as a spill;

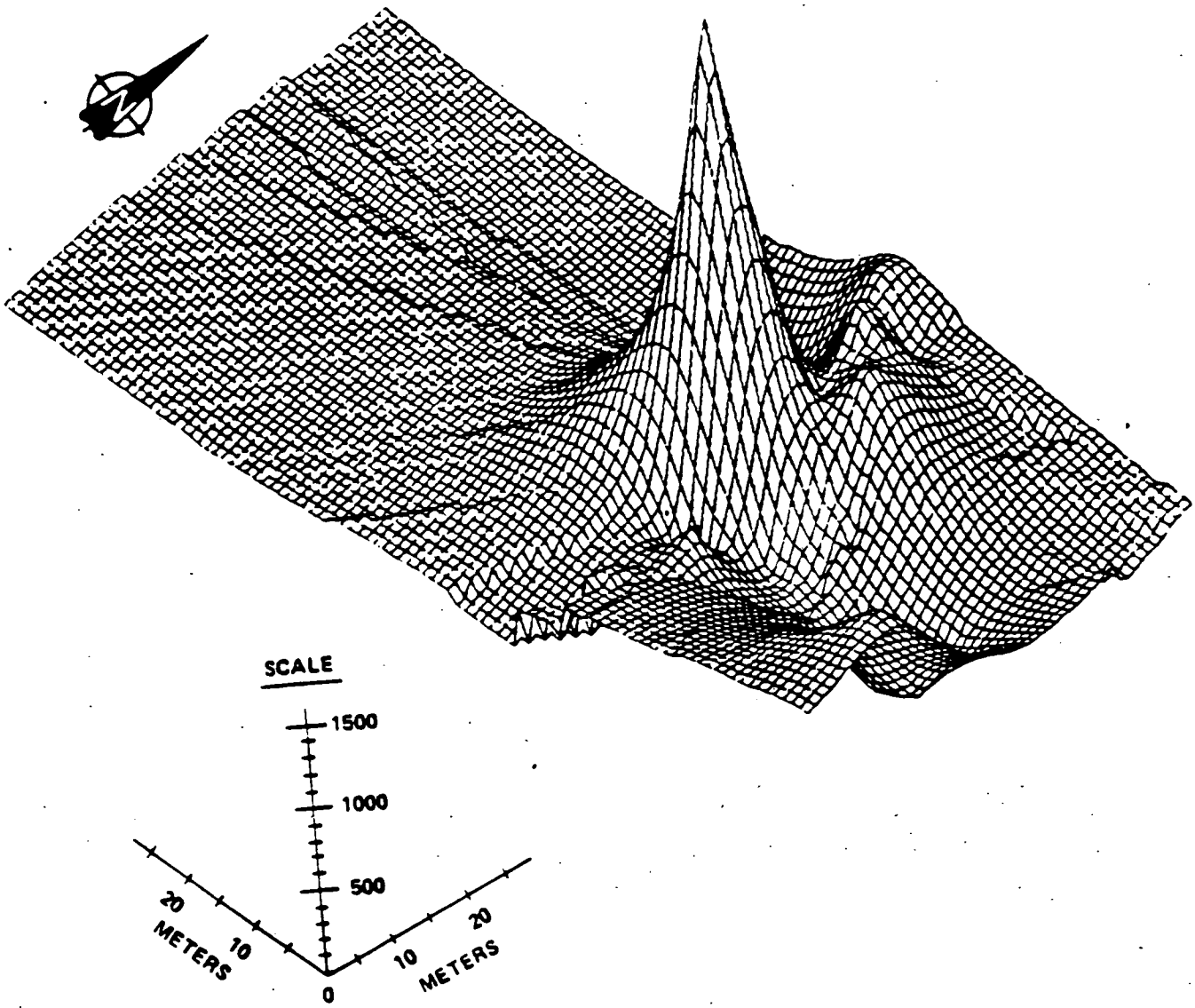

Figure 5-11. Three-Dimensional Data Plot of Soil PCB Concentrations (µg/kg)

TABLE 5-5

CALCULATION OF MEAN VALUES FOR REPLICATES

Raw Data		Data Summary		
Sample	Concentration	Sample	Concentration	n
A	4.3	A	4.3	1
B	1.8	B	1.8	3
B	2.0	C	7.6	1
B	1.6	D	6.3	1
C	7.6			
D	6.3	mean [(A + B + C + D)/4]	5.0	6

- Inconsistent sampling or analytical chemistry methodology;
- Errors in the transcription of data values or decimal points; and
- True but extreme concentration measurements.

The owner or operator should attempt to correct outlying values if the cause of the problem can be documented. The data should be corrected, for example, if outliers are caused by incorrect transcription and the correct values can be obtained and documented from valid records. Also, if a catastrophic event or a problem in methodology occurred that can be documented, data values should be reported with clear reference. Documentation and validation of the cause of outliers must accompany any attempt to correct or delete data values, because true but extreme values must not be altered. Statistical methods for identifying outliers require that the analytical laboratory have an ongoing program of QA, and that sufficient replicate samples be analyzed to account for field variability.

Outlier values should not be omitted from the raw data reported to the regulatory agency; however, these values should be identified within the summary tables.

5.3.3 Reporting of Values Below Detection Limits

Analytical values determined to be at or below the detection limit should be reported numerically (e.g., $\leq$0.1 mg/l). The data presentation procedures should cite analytical methods used including appropriate detection limits.

5.4 Reporting

As indicated in Section 3.7, the owner or operator should respond to emergency situations and identify to the regulatory agency priority situations that may require interim corrective measures. Such reporting should be done immediately. In addition, results of various activities conducted during the RFI should be reported to the regulatory agency, as required in the compliance order or by the permit conditions.

Various reports may be required. These may include interim, draft, and final reports. In addition, periodic progress reports (e.g., bimonthly) may also be required. Progress reports should generally include the following information:

- A description and estimate of the percentage of the RFI completed;
- Summaries of all findings;
- Summaries and rationale for all changes made in the RFI Work Plan during the reporting period;
- Summaries of all contacts with representatives of the local community, public interest groups, or government representatives during the reporting period;
- Summaries of all problems or potential problems encountered during the reporting period;
- Actions being taken to rectify problems;
- Changes in personnel during the reporting period;
- Projected work for the next reporting period; and
- Copies of daily reports, inspection reports, laboratory/monitoring data, etc.

Reports, including interim, progress, draft, and final reports may also be required for specific activities that may be performed during an RFI. Examples of specific reports or components that may be required include:

- RFI Work Plan;
- Description of Current Situation;
- Geophysical Techniques;

- Waste and Unit Characterization;
- Environmental Setting Characterization;
- Selection of Monitoring Constituents/Indicator Parameters;
- Results of "Phases" of the Investigation;
- QA/QC results;
- Interim Corrective Measures; and
- Identification of Potential Receptors.

In addition, a draft and final RFI report that incorporates the results of all previous reports will generally be required. This report should be comprehensive and should be sufficiently detailed to allow decisions to be made by the regulatory agency regarding the need for interim corrective measures and/or a CMS. It should be noted that these decisions may also be made by the regulatory agency on the basis of results of progress reports and/or other reports as described above.

SECTION 6

HEALTH AND SAFETY

6.1 Overview

Protecting the health and safety of the investigative team, as well as of the general public, is a major concern during hazardous waste RFIs. Hazards to which investigators may be exposed include known and suspected chemical substances, heat stress, physical stress, biological agents, equipment-related injuries, fire, and explosion. Many of these hazards are encountered in any type of field study, but exposure to chemical hazards is a major concern for the investigative team at hazardous waste facilities.

In addition to the protection of team members, the public's health and safety should also be considered. RFIs may attract the attention and presence of the news media, public officials, and the general public. Not only is the safety of these observers a concern, but their actions should not hinder the operations and safety of the investigative team. Other public health concerns include risks to the surrounding community from unanticipated chemical releases, and events such as fires and explosions.

The facility owner or operator should develop and update as necessary health and safety plans and procedures to address the needs of the RFI. The health and safety plan should, in particular, establish requirements for protecting the health and safety of the investigative team, facility workers, and the general public throughout the investigation.

Health and safety plans should be reviewed and approved by qualified (via education and work experience) safety and health professionals. While professional certifications such as Certified Industrial Hygienists or Certified Safety Professionals are highly regarded, such certifications are not required under the OSHA standard for plan review/approval, nor do they inherently guarantee proficiency in hazardous materials operations. In addition, health and safety plans should be

discussed thoroughly with the investigative team prior to initiating field activities. Other appropriate parties (e.g., local emergency services) should also be involved, as necessary.

Compliance with health and safety regulatory requirements is the ultimate responsibility of the employer, who, for purposes of the RFI, is the facility owner or operator. Development and implementation of health and safety procedures is therefore the responsibility of the owner or operator. Although these procedures may be presented as part of the RFI Work Plan and reviewed by the regulatory agency, ultimate responsibility and liability rest with the owner or operator. Section 6.2 presents general health and safety regulations and guidance that should be reviewed prior to developing health and safety procedures, Section 6.3 outlines basic elements of health and safety procedures which should be addressed, and Section 6.4 reviews application of zones of operation or work zones.

6.2 Applicable Health and Safety Regulations and Guidance

On December 19, 1986, the Occupational Safety and Health Administration (OSHA) issued, in the Federal Register (29 CFR 1910.120), an interim final rule on hazardous waste site operations and emergency response, which specifically requires certain minimum standards concerning health and safety for anyone performing activities at CERCLA sites, RCRA sites, emergency response operations, sites designated for remediation by a state or local agency, or any other operation where employees' operations involve dealing with hazardous waste. The following discussion provides details on the major requirements of the interim final rule.

<u>Development and implementation of a safety and health program:</u>

The development and implementation of a formal, written safety and health program has long been recognized as a foundation for successful occupational risk minimization. In recent years, this recognition has been receiving increased emphasis from the Occupational Safety and Health Administration (OSHA). For example, as stated in the July 15, 1988 Federal Register (53 FR 26791):

> . . . OSHA has become increasingly convinced of the relationship between superior management of safety and health programs - which address all safety

and health hazards, whether or not covered by OSHA standards - and low incidence and severity of employee injuries.

As a result, OSHA has intensified its focus on management practices in its evaluation of workplaces. One primary area of this focus has been on documented safety and health programs. This increased emphasis is evidenced in several other OSHA standards that have been promulgated (e.g., Respiratory Protection - 29 CFR 1910.134, Occupational Noise Exposure - 29 CFR 1910.95, Hazard Communication - 29 CFR 1910.1200, and Subpart C of the Construction Industry Standards - 29 CFR 1926).

In addition to these individual subject area requirements, OSHA has released for comment and information a proposed rule on General Safety and Health Programs (previously-referenced Federal Register - 53 FR 26791). In that proposal, suggested guidelines for establishing and implementing new safety and health programs - or evaluating/modifying existing programs - are provided. The proposed rule advises employers to "institute and maintain...a program which provides policies, procedures and practices that are adequate to recognize and protect their employees from occupational safety and health hazards."

Specific elements of the program proposed by OSHA are addressed under four subject headings. These headings include management commitment, worksite analysis, hazard prevention and control, and safety and health training.

It is of no small consequence that management commitment is the first issue addressed in this proposed rule. A strong commitment from top management representatives is critical to the success of any program. Additionally, this commitment needs to be highly visible to employees. Clear program goals and objectives need to be specified, as well as identification and assignation of appropriate levels of authority, responsibility and accountability. Finally, at least annual program reviews and evaluations are necessary to identify the effectiveness of the program, and incorporate any necessary program modifications.

The second program area recommended for inclusion is worksite analysis. The intent of this part of the program is to identify methods and practices to be utilized for recognizing potential hazards. Examples of methods that can be used to achieve

these objectives include: periodic, comprehensive worksite surveys; analysis of new processes, materials and equipment; and performance of routine job or phase hazard analyses. Other recommended methods include the conduct of regular site inspections, and accident (or near-accident) investigations.

The third program area addresses hazard prevention and control. These efforts should include identifying appropriate engineering, administrative, and/or personnel protective equipment and hazard controls. Additionally, emergency preparedness and a medical program should be elements of this portion of the overall program.

The final topic identified in the proposed rule addresses safety and health training. Employee education and training needs should be provided so that employees are fully aware and capable of handling potential hazards in the performance of their work. Additionally, safety and health training of supervisors and managers needs to be addressed and performed to ensure that they are aware of their responsibilities in regard to health and safety.

To summarize, a written, comprehensive health and safety program, that has visible top-management support, is an important element of a safe and healthful work environment. However, the written program itself must be effectively implemented, periodically evaluated - and modified as necessary, in order to achieve its objectives.

Performance of site characterization and analysis:

In addition to the general items of worksite analysis identified above, specific requirements for this type of analysis are presented under OSHA regulation 29 CFR 1910.120. Performance of site characterization and analysis is specifically addressed in paragraph (c) of this regulation.

A site characterization and analysis addressing each site task and operation planned to be performed needs to be conducted. This effort generally proceeds in three phases. Initially (prior to any actual site entry), a data-gathering phase is performed to collect any relevant information that may identify potential site hazards. This activity may include such items as obtaining shipping/disposal

manifests or other such records, including newspaper/media reports, and interviewing persons with potential knowledge of past operations (e.g., previous employees, nearby residents). This initial phase may also consist of the conduct of an offsite reconnaissance (e.g., around the perimeter of the site), and characterization based on all of the collected data. The second phase of this process is the conduct of an onsite survey. Finally, the third phase involves site entry, with a continuance of monitoring efforts to provide current information for evaluating potential site hazards.

In view of this phased approach, it is clearly intended that site characterization and analysis is a continuous process. It is initiated prior to any actual onsite involvement, and continues throughout the performance of onsite activities.

Development and implementation of a site control program:

Site control elements need to be established to minimize potential for employee contact with contamination, and the transfer of contaminants into non-contaminated areas. These program elements need to be clearly defined in the employer's site safety and health plan. As stated in the preamble of the rule establishing 29 CFR 1910.120, (December 19, 1986 Federal Register), the establishment of a site control program should be performed "in the planning stages of a project and modified based on new information and site assessments developed during site characterization." The preamble further states that the "appropriate sequence for implementing these measures should be determined on a site-specific basis."

The primary intent of this requirement is that the site control program must be addressed on a site-specific basis. However, employers should develop a general program that identifies minimum performance requirements in order to establish overall uniformity for all projects. For each specific project, the OSHA regulations specify that the site control program include - at a minimum - the following:

- A map of the site;
- Designation of site work zones;

- The practice of using what the regulation refers to as a "buddy system" (defined as a "system of organizing employees into work groups in such a manner that each employee of the group is designated to observe the activities of at least one other employee in the work group. The purpose of the buddy system is to provide quick assistance to those other employees in the event of an emergency.");

- Establishment and maintenance of site communications;

- Establishment and implementation of site standard operating procedures or safe work practices; and

- Identifying the nearest medical facility that would be contacted in the event of a site incident resulting in a need for such services.

Compliance with employee training requirements (specified in paragraph (e) of the standard) and the development and implementation of an employee training program:

An employee training program must be developed and implemented, meeting (at a minimum) the training requirements specified in paragraph (e) of the hazardous waste regulation. The program must include provisions for both initial and refresher training of employees on matters of health and safety. All involved employees must receive effective training prior to performing any operations that could result in their exposure to potential safety and health hazards.

The training requirements specified in this regulation are categorized into several subject areas. While the majority of the requirements address CERCLA (Superfund)-related operations, RCRA-related projects and emergency response operations, general training requirements are also specified. The intention of this categorization is to recognize that varying degrees of risk potential exit, thereby requiring different types of health and safety training.

Additionally, for CERCLA-type operations, the program must be further subdivided to address health and safety training program elements for employees and onsite management and supervisors. All individuals must receive introductory

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training (40 hours in duration) prior to their initial assignment. This is to be supplemented by 8-hours of annual refresher training, and the conduct of site-specific training for each assignment. Onsite managers and supervisors who will be assigned responsibility for direct, onsite supervision, must receive an additional 8-hours of specialized training for operations management upon job assignment.

Employees involved in normal RCRA operations are required to receive a lesser amount of initial training (24-hours) and 8-hours of annual refresher training. These requirements are applicable for employees who will be involved in hazardous waste operations involving storage, disposal and treatment. However, major corrective actions under RCRA would need to be addressed in a manner similar to the previously - identified CERCLA training requirements.

The final category specifying employee training requirements addresses individuals who participate in (offsite) emergency response operations (e.g., HAZMAP team personnel). Any employees involved in such operations are required to receive at least 24 hours of training annually.

The development and implementation of an employee training program must be initiated by first identifying which of the requirements are applicable, and identifying the employees who need to be included. The overall program also needs to address other types of required employee health and safety training applicable to the work site(s) and job tasks. Examples of other types of required training may include:

- Hazard Communication Training (29 CFR 1910.1200);
- Hearing Conservation Training (29 CFR 1910.95);
- Respiratory Protection Training (29 CFR 1910.134); and
- Others-based on types of equipment, processes, etc.

After all training needs have been identified and the program has been developed and implemented, it must be periodically reviewed and evaluated to determine its effectiveness, with appropriate modifications made where necessary.

Finally, appropriate records of employee training must be maintained to satisfy applicable recordkeeping requirements.

Development and implementation of a medical surveillance program:

A comprehensive medical surveillance program must be established for employees engaged in hazardous waste operations. Employees who have been, or are expected to be, exposed to hazardous substances or health hazards must be participants in such a program. Therefore, one of the first tasks in program development should be to define how many (and which) employees need to be covered.

A second critical element in the development of the program is the selection of a physician (or physicians) who will be utilized to perform the examinations. The selected physician must be licensed, should be knowledgeable in occupational medicine, and familiar with the nature of the work tasks that the employees that he/she will be examining will be performing.

The program needs to provide examinations to employees prior to their first hazardous materials job assignment, at least once every twelve months following the initial examination, upon job termination or reassignment, as soon as possible for any employee demonstrating symptoms of overexposure to hazardous substances, and at more frequent times - as determined to be necessary by the examining physician.

The extent of the examination is at the discretion of the examining physician. However, in order for the physician to appropriately determine the necessary parameters, protocols, tests, etc., he/she must be made very familiar with the nature of the patient's job duties. Therefore, the regulation requires that the physician be provided with a copy of the standard-in its entirety, a description of the employee's duties relative to potential exposures, a description of known or anticipated exposure levels that have been - or may be - encountered by the employee, a description of personal protective equipment that the employee has used or may use, and the employee's previous medical history.

The established medical program should be developed to address medical concerns specified by other regulations as well as hazardous waste operations (e.g., respiratory protection usage, audiometry, asbestos exposures, and other applicable regulations). Therefore, it should have a mechanism incorporated to provide for periodic program review and evaluation to determine effectiveness, and the need for modification as deemed necessary. Finally, medical surveillance recordkeeping must be performed and maintained in accordance with OSHA 29 CFR 1910.20.

Incorporation of engineering controls, administrative controls, and the development and implementation of a personal protective equipment program:

To protect employees from potential hazards that may be encountered in hazardous materials operations (e.g., chemical, physical, biological hazards), employers are required to implement appropriate control efforts. In order of preference, such approaches are to employ engineering and administrative controls where feasible, and (as a last resort), personal protective equipment. However, these control efforts are not mutually-exclusive. The regulation provides for the employer to utilize appropriate combinations of these three types of controls in protecting his/her employees. However, where items of personal protective equipment (PPE) are used, a PPE program must be developed and implemented.

In the developmental stages of the program, the employer must define the types of PPE that will or may be necessary for employee usage. Examples include respiratory protection (with considerations given to the types necessary - e.g., air-supplied vs air-purifying, half-face masks, full facemasks, etc.), hearing protection, head protection, foot protection, dermal protection, eye/face protection, etc. Many of these types of PPE are regulated under specific OSHA standards. Therefore, upon identification of the types of PPE to be used, the regulations must be consulted in developing and implementing the program to ensure overall compliance and program adequacy.

The program must also provide for proper selection of equipment on the basis of the known or suspected hazards to be encountered, proper maintenance, cleaning, servicing, storage of equipment, and, proper training of employees in the correct use and recognition of the limitations of the selected equipment. As with

other programs, provisions for review and evaluation for effectiveness must be incorporated, enabling necessary modifications to be made.

Development and implementation of an air monitoring program:

The establishment of an air monitoring program is essential. The purpose of the program is to gain accurate information on employee exposures in order to implement the correct PPE, engineering controls, and work practices. Airborne contaminants can present a significant threat to employee safety and health. Thus, identification and quantification of these contaminants through air monitoring is an essential component of a safety and health program.

The intent of this requirement is that the air monitoring program be addressed on a site-specific basis. After the site characterization and analysis phase has been completed, personnel should be cognizant of possible contaminants on each specific site. With this information, proper air sampling and analytical methods can be chosen.

Reliable measurements of airborne contaminants are useful in selecting proper personal protective equipment, determining whether engineering controls can achieve permissible exposure limits and which controls to use. Also, this information is used in delineating areas where protection is needed and in assessing potential health effects of exposure. Knowledge of potential health effects will further aid in determining the need for specific medical monitoring.

In view of this approach, air monitoring is a continuous process. It should be initiated prior to any actual onsite involvement, and should continue throughout the performance of onsite activities.

The developed program needs to contain elements identifying the types of monitoring equipment available for employee use, proper selection, maintenance and calibration procedures, employee training, and provisions for equipment cleaning and storage.

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Development and implementation of an employee informational program:

The Occupational Safety and Health Administration is requiring under 29 CFR 1910.120, that employers, as part of their safety and health program, develop and implement a site-specific health and safety plan (HASP) for each hazardous waste site operation.

The site health and safety plan must be developed by the employer, utilizing the other parts of the organizational plan and the employer's safety and health program. The HASP must address the anticipated health and safety hazards associated with each work operation or task, and the means to eliminate the hazards or to effectively control them to prevent injury or illness.

The minimum requirements that a HASP must include is the following:

- The names of those responsible for assuring that safe and healthful practices and procedures are followed throughout all work operations;
- Risk analysis or systems analysis for specific work tasks or operations on the site;
- Employee training assignments both offsite and on-the-job training onsite;
- A list of personal protective equipment needed for each work task and operation onsite;
- The employers medical surveillance program for the site;
- The methods for identification and characterization of safety and health hazards on the site including the air monitoring procedures that will be performed throughout the work onsite;
- Site control measures including those for establishing work zones on the site;

- The necessary decontamination procedures which are matched to the kinds of anticipated contaminants to be cleaned from personnel and equipment;

- The general safe work practices to be adhered to by personnel onsite;

- The contingency plan for emergencies and confined space entry procedures;

- Site-specific training and site inspections and procedures to be followed in changing or modifying the plan; and

- All emergency numbers of local authorities (e.g., ambulance, police), as well as directions to the nearest hospital and a map to the hospital.

As a separate section, an emergency response plan must also be included. This plan is discussed in greater detail in a latter section of this subsection of the guidance document.

Adherence to proper procedures for handling drums and containers:

The handling of drums and containers at hazardous waste sites poses one of the greatest dangers to hazardous waste site employees. Hazards include detonation, fire, explosion, vapor generation, and physical injury resulting from moving heavy containers by hand and working in the proximity of stacked drums, heavy equipment and deteriorated drums. The employer must implement procedures and provide proper work practices in order to minimize the risks to site personnel.

The appropriate procedures for handling drums depend primarily upon the drum contents. Thus, prior to handling, drums should be visually inspected to gain as much information as possible about their contents. The inspection crew should look for symbols, words, or other marks on the drum indicating that its contents are hazardous, e.g., radioactive, explosive, corrosive, toxic and/or flammable. The crew should also look for signs of deterioration (such as rust, corrosion, and leaks), and whether the drum is under pressure.

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Conditions in the immediate vicinity of the drums may also provide information about drum contents and their associated hazards. Monitoring should be conducted in the area around the drums using instruments such as a radiation survey meter, organic vapor monitors, and combustible gas indicators.

As a precautionary measure, personnel should assume that unlabeled drums contain hazardous materials until their contents are characterized. Also, they should bear in mind that drums are frequently mislabeled - particularly drums that are reused.

Employers must ensure that any personnel involved with handling drums are aware of all pertinent regulations. OSHA regulations (29 CFR Parts 1910 and 1926) include general requirements and standards for storing, containing, and handling chemicals and containers, and for maintaining equipment used for handling drums and containers. EPA regulations (40 CFR Part 265) stipulate requirements for types of containers, maintenance of containers, and design and maintenance of storage areas. DOT regulations (49 CFR Parts 171 through 178) also stipulate requirements for containers and procedures for shipment of hazardous wastes.

Development and implementation of a decontamination procedure:

Decontamination procedures must be developed on a site- and/or task-specific basis, and be implemented prior to performing any site entrance activities. These methods must be specifically matched to the hazardous substance(s) of concern at the site in order to be effective. Procedures for both personnel and equipment decontamination must be developed and implemented in order to minimize potential for:

- Employee exposure to substances of concern;
- Transferring contaminants offsite or to previously non-contaminated areas; and
- Exposing the environment and/or offsite receptors to hazard potential.

The standard requires that upon implementation of these procedures, the site safety and health officer must conduct monitoring for effectiveness on a continuous basis.

Decontamination procedures must be supplemented by incorporation of and adherence to standard operating procedures that are developed to minimize potential for personnel and equipment to come into contact with contaminated substances and surfaces. Additionally, the developed decontamination procedures must incorporate provisions for controlling, collecting, and disposing generated wastes in a proper manner. These materials will typically include items of personal protective equipment, decontamination (wash and rinse) fluids, as well as materials generated during site activities (e.g., drill cuttings, pumped monitoring well fluids, etc.).

Development and implementation of an Emergency Response Plan:

Prior to any onsite work, the employer must develop and implement an emergency response plan that is site-specific, and all involved employees must be made aware of the provisions of this plan. This is to be incorporated as a separate section of the site safety and health plan, and it must include provisions for: recognition of emergency situations; methods for alerting onsite personnel of emergency situations; site evacuation procedures; provisions for emergency medical treatment; lines of authority in emergency situations; emergency decontamination procedures; and methods for evaluating the effectiveness of the emergency response plan.

The regulations require that the role of individual employee's in emergency situations be reflected in the plan. Two categories of employee activities are also discussed. One is from the standpoint of onsite emergency response, while the other addresses offsite response activities. In addition, the greater the roles and responsibilities of the employee in a response situation, and the greater the risk potential that may be presented, the more detailed and comprehensive the emergency response plan will need to be. It is also common that both on- and offsite response efforts may be necessary, depending on the nature and extent of the specific situation. Therefore, the emergency response plan needs to address both onsite and offsite activities.

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The emergency response plan must include provisions for the following elements, at a minimum:

- Pre-emergency planning;
- Personnel roles, lines of authority, training, and communication;
- Emergency recognition and prevention;
- Safe distances and places of refuge;
- Site security and control;
- Evacuation routes and procedures;
- Decontamination;
- Emergency medical treatment and first aid;
- Emergency alerting and response procedures;
- Critique of response and follow-up;
- Personal protective equipment and emergency equipment;
- Establishment of an Incident Command System;
- Procedures for incident reporting to appropriate local, state, and/or Federal agencies;
- Regular rehearsal and employee training of the elements of the plan; and
- Periodic plan review, with necessary modifications, for plan effectiveness.

Compliance with the requirements for both illumination, and sanitation at temporary workplaces:

Minimum requirements for illumination and sanitation (potable and non-potable water supplies and toilet facilities) are specified in the regulation, incorporating the requirements of Subpart C of the Construction Industry standards (29 CFR Part 1926).

Illumination requirements are specified by site areas or operations. Generally, lower levels of illumination are necessary in areas where employee presence is incidental or nonfrequent, and where activities involve low risk potential. Greater amounts of illumination are required in general site areas, indoor site facilities, and in personnel facilities. The highest illumination intensity requirements are specified for areas including first aid stations, infirmaries, and offices.

Sanitation requirements address procedures for providing, identifying, and dispensing potable water and nonpotable water. Additionally, if appropriate, provisions must be made for toilet facilities, food handling, sleeping quarters, and washing facilities.

Compliance with the requirements specified under paragraph (o) of the standard for certain operations conducted under RCRA, including developing and implementing a hazard communication program (meeting the requirements of OSHA 29 CFR 1910.1200):

The OSHA regulation contains less extensive requirements for normal (e.g., non-corrective action type) RCRA operations (vs CERCLA operations) in recognition that, by comparison, hazards should be "better controlled and more routine and stable" (51 FR 45661, December 9, 1986). Employers conducting operations on RCRA facilities must develop and implement the following programs and procedures:

- Hazard Communication Program in conformance with the requirements of OSHA 29 CFR 1910.120;

- A medical surveillance program;
- A health and safety program;
- Decontamination procedures; and
- An employee training program.

Following is a list of other regulations that should be considered when developing health and safety programs and procedures:

Citation	Title
29 CFR 1910.134	Respiratory Protection
29 CFR 1910.95	Hearing Conservation
29 CFR 1903	Inspections, Citations, and Proposed Penalties
29 CFR 1904	Recording and Reporting of Occupational Injuries and Illnesses
29 CFR 1926	Safety and Health Regulations for Construction
29 CFR 1960	Federal Employee Safety and Health Programs
29 CFR 1975	Coverage of Employers Under the Occupational Safety and Health Act
29 CFR 1977	Regulations on Discrimination Against Employees Exercising Rights Under the Occupational Safety and Health Act

Other Federal and State regulations may also address the health and safety of the investigative team and the public. Department of Transportation (DOT) regulations (49 CFR 171-178), for example, specify containers, labeling, and transportation restrictions for hazardous materials. These regulations cover the transport of compressed-air cylinders, certain instruments, solvents, and samples. RCRA regulations (40 CFR 260-265) may apply to the storage, treatment, and disposal of investigation-derived materials, including disposable clothing, used respirator cartridges and canisters, and spent decontamination solutions.

Individual states may have occupational safety and health regulations more stringent than OSHA's. These should be consulted to determine their applicability and to ensure compliance. In addition, several guidance manuals exist that may be helpful in establishing health and safety procedures. These are listed below:

- Ford, P. J. and Turina, P. T. 1985. Characterization of Hazardous Waste Sites--A Methods Manual: Volume I--Site Investigations. EPA- 600/4-84/075. NTIS PB 85-215960. Washington, D.C. 20460.

- U.S. EPA. 1984. Standard Operating Safety Guides. Office of Emergency and Remedial Response. Washington, D.C. 20460.

- U.S. EPA. 1985. Basic Field Activities Safety Training. Office of Emergency and Remedial Response. Washington, D.C. 20460.

- NIOSH/OSHA/USCG/EPA. 1985. Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities. NIOSH 85-115. GPO No. 017-003-00419-6.

- Levine, S.P. and W.F. Martin. 1985. Protecting Personnel at Hazardous Waste Sites. Butterworth Publishers.

- U.S. EPA. 1985. Guidance on Remedial Investigations Under CERCLA. Office of Emergency and Remedial Response. NTIS PB 85-238616. Washington, D.C. 20460.

- U.S. EPA. 1986. Occupational Health and Safety Manual. EPA 1440.

- U.S. EPA. Order 1440.2 - Health and Safety Requirements for Employees Engaged in Field Activities.

- U.S. EPA. Order 1440.3 - Respiratory Protection.

Professional recommendations and standards have also been offered by organizations such as the American Conference of Governmental Industrial

Hygienists, the ASTM, the American National Standards Institute, and the National Fire Protection Association.

6.3 Elements of a Health and Safety Plan

RFI health and safety plans should address the following:

- Names of key personnel and alternates responsible for site safety and health, and the appointment of a site safety officer;
- A safety and health risk analysis for each site task and operation;
- Employee training assignments;
- Personal protective equipment (PPE) to be used by employees for each of the site tasks and operations being conducted;
- Medical surveillance requirements;
- Frequency and types of air monitoring, personnel monitoring, and environmental sampling techniques and instrumentation to be used - also, methods of maintenance and calibration of monitoring and sampling equipment to be used;
- Site control measures;
- Decontamination procedures;
- Site standard operating procedures;
- Confined space entry procedures; and
- A Contingency Plan addressing site emergency action procedures.

6.4 Use of Work Zones

Although this section of the RFI Guidance is intended to be only an introduction to the health and safety aspects of hazardous waste site investigations, the establishment of zones of operation or work zones deserves some attention. It should be recognized, however, that the health and safety aspects described below may not apply to all sites.

Hazardous waste sites should be controlled to reduce the possibility of (1) exposure to any contaminants present, and (2) transport of contaminants offsite by personnel and equipment. One recommended method to prevent or reduce the possibility of the transfer of contaminants offsite, and to maintain control at the site, is to establish work zones, or areas on the site where prescribed operations occur. It is also important to control access points (i.e., entrances or exists) for each designated work zone. The use of a three zone system might include:

- Zone 1: Exclusion Zone
- Zone 2: Contamination Reduction Zone
- Zone 3: Support Zone

Zone 1, the Exclusion Zone, would include all areas onsite where contamination is known or suspected to be present. The boundaries can be established based on results of previous investigations, visual observations, facility records, or similar information. Appropriate levels of personal protective equipment (PPE) in this zone are based on the types and concentrations of contaminants known or suspected to be present, and other hazards that may be present. In addition, only specifically authorized personnel should be allowed into this zone. Once the boundaries of Zone 1 have been determined, they should be physically secured and defined by barriers such as fences or barricades.

Zone 2, the Contamination Reduction Zone, would be set up to provide a buffer to separate contaminated areas from non-contaminated areas, and may actually surround Zone 1. Decontamination stations would generally be set up between Zone 1 and Zone 2, or within Zone 2. These stations would serve as areas

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for decontamination of both personnel and equipment. Some level of PPE may also be required in this zone, as some level of contamination or other hazard may be present. Access into Zone 2 from the Support Zone (Zone 3), is also controlled; only authorized personnel should be allowed access. Any worker entering Zone 2 should also be wearing the appropriate PPE.

The Support Zone, Zone 3, would be located in a clean or uncontaminated area, and would be directly outside of Zone 2. The support zone may have several functions, including use as a command post and first aid station, and would serve to house equipment sheds or trailers, mobile laboratory facilities, training and briefing areas, etc.

SECTION 7

WASTE AND UNIT CHARACTERIZATION

7.1 Objectives and Purposes of Waste and Unit Characterization

Because the waste managed or contained in a unit provides the source for a contaminant release, detailed knowledge of the source characteristics is valuable in identifying monitoring constituents and indicator parameters, possible release pathways, a conceptual model of the release, monitoring procedures, and also in linking releases to particular units. Waste and unit characteristics will also provide information for determining release rates and other release characteristics (e.g., continuous as opposed to intermittent). Waste and unit information is also important for determining the nature and scope of any corrective measures which may be applied.

Without adequate waste characterization, it is difficult to ensure that all constituents of concern will be monitored during the release investigation, unless all possible constituents are monitored. The extent of adequate waste characterization, however, will vary depending upon the nature of the facility and types of units studied. For example, waste characterization for a unit dedicated to a single steady-state process will be much less extensive than for a unit at an offsite facility that manages a variety of wastes that vary over time.

As indicated above, waste characterization may also be helpful in identifying constituents to discriminate among releases from different units. In some situations (e.g., more than one unit in a waste management area), it may be important to identify which unit is responsible for the release of concern. Accurate identification of the unit from which the release is occurring may hinge on the ability to link the released contaminants to the waste managed in a particular unit (or, in some cases, to "decouple" the contamination from a particular unit).

Sufficient characterization of the waste for the purpose of the RFI may not be possible due to the diversity of wastes managed in the unit over time or the relative

inaccessibility of the waste in the unit. Waste characterization may be of limited utility where:

- The waste managed in the unit varies over time such that adequate determination of the waste constituents cannot be made. An example of this is an offsite commercial facility receiving different wastes from different generators.

- The unit of concern is no longer active and the waste cannot be sampled through a reasonable effort. This situation may occur at closed landfills where sampling of buried drums may not be practical due to their inaccessibility.

In certain situations, waste characterization may also not be advisable. For example, the waste in question may be extremely toxic (e.g., nerve gas), or highly reactive or explosive (e.g., disposed munitions). In such cases, release characterization may be based on constituents (or parameters) identified in the affected medium (e.g., leachate) at the point where the medium becomes (or is suspected of becoming) contaminated. If it becomes necessary to conduct waste characterizations in these situations, or to remove the waste in question, a high level of health and safety protection (See Section 6) should be instituted.

Waste characterization should also be designed to provide sufficient information to support the implementation of interim measures and/or corrective measures. For example, if buried drums are identified during the RFI, the nature of the waste within these drums (e.g., ignitability, corosivity, reactivity, constituent concentrations), if accessible, should be ascertained to determine if they should be removed from the site and how they should be subsequently managed as well as to support the investigation of media-specific releases under the RFI.

Design and operational characteristics of the unit are factors that will affect the rate of release and location within the unit from which the contamination is being or has been released. Such factors as unit size, type, operational schedule, and treatment, storage, or disposal practices should be helpful.

Although 40 CFR Section 264.13 of the RCRA regulations (General Waste Analysis) contains waste analysis requirements, the information required may not always be sufficient for purposes of the RFI. Waste characterization to determine specific hazardous constituents, for instance, is not always required. In addition, little or no data on inactive units may be available. The RFI Work Plan should be consistent, as appropriate, with the items identified in the requirements of 40 CFR Section 264.13. Further guidance is given below.

7.2 Waste Characterization

In cases where a waste characterization is to be performed, the following approach is recommended:

- Identify data needs through review of existing information;
- Sample the waste; and
- Characterize the physical and chemical properties of the waste and waste constituents.

If the unit has a leachate collection system, the leachate should also be sampled and analyzed, as it may also provide useful information, particularly with respect to the leachable portions of wastes contained in the unit.

7.2.1 Identification of Relevant Information

In general, a waste characterization should produce the following types of information:

- Identification of specific hazardous constituents and parameters which can be used in release verification or characterization (See Section 3.6);
- Physical and/or chemical characteristics of the waste useful for identifying possible migration pathways through the environmental media of concern; and

- Physical and/or chemical characteristics of the waste, which may be necessary to evaluate treatment and/or management options.

Identifying specific constituents of the waste through a sampling and analysis program may require an extensive level of effort. The owner or operator is advised to use various informational sources on the specific waste in question in order to focus the analytical effort required. Such sources are described below.

7.2.1.1 EPA Waste Listing Background Document Information

The RCRA Hazardous Waste Listing Background Documents developed for the identification and listing of hazardous wastes under 40 CFR Part 261 contain information on waste-specific constituents and their physical and chemical characteristics. These documents contain information on the generation, composition, and management of listed waste streams from generic and industry-specific sources. In addition to identifying hazardous constituents in the wastes, the documents may also provide data on potential decomposition products. In some background documents, migratory potential is discussed and exposure pathways identified.

Appendix B of the Listing Documents provides detailed information on the fate and transport of hazardous constituents. Major physical and chemical properties of selected constituents are listed, including molecular weights, vapor pressures and solubilities, octanol-water partition coefficients, hydrolysis rates, biodegradation rates, volatilization rates, and air chemistry (e.g., reaction) rates. Another section of this appendix estimates the migratory potential and environmental persistence of selected constituents based on a conceptual model of disposal in an unconfined landfill or lagoon.

The appropriate uses and limitations of the Listing Documents are outlined in Table 7-1. In addition, Case Study No. 1 in Volume IV (Case Study Examples) illustrates the use of the Listing Documents.

A list of the available listing background documents may be obtained by reviewing 40 CFR Parts 261.31 and 261.32. These background documents are available in EPA's RCRA docket at the following location:

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Table 7-1

Uses and Limitations of EPA Listing Background Documents

Uses	Limitations
• Identifies the hazardous constituents for which a waste was listed. • In some cases, provides information on additional hazardous constituents that may be present in a listed waste. • In some cases, identifies decomposition products of hazardous constituents. • Provides overview of industry; gives perspective on range of waste generated (both quantity and general characteristics). • May provide waste-specific characteristic data such as density, pH, and leachability. • May provide useful information on the migratory potential, mobility, and environmental persistence of certain hazardous constituents. • May list physical and chemical properties of selected constituents.	• Applicable only for listed hazardous wastes. • Industry coverage may be limited in scope. For example, the Wood Preserving Industry Listing Document only covers organic preservatives. Inorganics such as inorganic arsenic salts, account for approximately 15 percent of the wood preserving industry. • Data may not be comprehensive. For example, not all potentially hazardous constituents may be identified. Generally, only the most toxic constituents common to the industry as a whole are identified. • Data may not be specific. Constituents and waste characteristics data often represent an industry average which encompasses many different types of production processes and waste treatment operations. • Some Listing Documents were developed from limited data/reports available to EPA at the time of promulgation, resulting in varying levels of detail for different documents. • Listing Documents for certain industries (e.g., the Pesticides Industry) may be subject to CBI (confidential business information) censorship. In such cases, constituent information may be expurgated from the document.

EPA RCRA Docket
U.S. Environmental Protection Agency (WH-562)
Room S-212
401 M St., S.W.
Washington, D.C. 20460

7.2.1.2 Facility Information

Identification of the constituents of a waste stream may be made through examination of records already existing in the facility. Engineering data on process raw materials or analytical data on the process effluents will also provide a good starting point for waste characterization. In some cases, generally where waste characteristics are well-defined, data on process raw materials or effluents will provide sufficient information for performing the RFI. More specifically, these sources may be:

- Hazardous waste characterization data used for a RCRA Permit Application;
- Waste Analysis Plan (as required by 40 CFR Part 264.13);
- State or local permit applications;
- Initial batch treatment results from an offsite hazardous waste disposal facility;
- Hazardous waste compatibility results for bulk shipments;
- Purchase orders and packing lists;
- Analyses conducted to provide data for shipping manifests;
- Facility records of past waste analyses;
- Process operational data;
- Product quality control analyses;

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- Data from past releases of hazardous waste into the environment;
- Compatibility results for containment liner studies;
- Past Federal, State, or local compliance and inspection results;
- OSHA industrial hygiene monitoring results;
- Facility health and safety monitoring data;
- Engineering design data from construction of plant processes;
- Performance specifications for process equipment;
- Related emissions data such as NPDES discharge results; and
- Information from past or present employees.

7.2.1.3 Information on Physical/Chemical Characteristics

Information on physical or chemical characteristics of the waste or waste constituents that may be useful in predicting movement of the contamination through the media of concern or in evaluating waste treatment or management options may be found in the following references:

Callahan, et al. 1979. Water-Related Environmental Fate of 129 Priority Pollutants, Volumes I and II. Office of Water Planning and Standards. NTIS PB 297606. Washington, D.C. 20460.

Dawson, et al. 1980. Physical/Chemical Properties of Hazardous Waste Constituents. Prepared by Southeast Environmental Research Laboratory for U.S. EPA. EPA RCRA Docket. Washington, D.C. 20460.

U.S. EPA. 1985. Health Effects Assessment for [Specific Chemical]. [Note: 58 individual documents available for specific chemicals or chemical groups].

Environmental Criteria and Assessment Office. Cincinnati, Ohio 45268. [See Section 8.4 for a list of these documents]

Jaber, et al. 1984. Data Acquisition for Environmental Transport and Fate Screening. Office of Health and Environmental Assessment, U.S. EPA. EPA 600/6-84-009. NTIS PB 84-140102. Washington, D.C. 20460.

Lyman, et al. 1982. Handbook of Chemical Property Estimation Methods. McGraw-Hill, New York.

Mabey, et al. 1982. Aquatic Fate Process Data for Organic Priority Pollutants. Prepared by SRI International, EPA Contract Nos. 68-01-3867 and 68-03-2981. Prepared for Office of Water Regulations and Standards. Washington, D.C. 20460.

U.S. EPA. 1980. Treatability Manual, Volume I. EPA 600/2-82-001a. Office of Research and Development. NTIS PB 80-223050. Washington, D.C. 20460.

U.S. EPA. 1984. Characterization of Constituents from Selected Waste Streams Listed in 40 CFR Section 261. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1984. Exposure Profiles for RCRA Risk-Cost Analysis Model. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1986. Ambient Water Quality Criteria. Office of Water Regulations and Standards. Washington, D.C. 20460.

Perry and Chilton. 1973. Chemical Engineers' Handbook. McGraw-Hill. 5th Ed. New York.

Verschueren. 1983. Handbook of Environmental Data for Organic Chemicals. Van Nostrand Reinhold Co. New York. 2nd ed.

Weast et al. 1979. CRC Handbook of Chemistry and Physics. CRC Press.

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Windholtz, et al. 1983. The Merck Index. Merck & Co. Rahway, NJ.

U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes. 3rd Edition. Office of Solid Waste. EPA/SW-846. GPO No. 955-001-00000-1. Washington, D.C. 20460.

U.S. EPA. 1984. Characterization of Hazardous Waste Sites--A Methods Manual. Volume III. Available Analytical methods. EPA 600/4-84-038. NTIS PB 84-191048. Washington, D.C. 20460.

Some commercially available computer information systems that contain chemical properties data and/or estimation methods may also be used. An example would be the Chemical Information System (CIS) (7215 York Road, Baltimore, MD 21212). Another example is the Graphical Exposure Modeling System (GEMS) data base discussed in Section 3.5. The owner or operator should consult with the regulatory agency prior to use of such systems.

7.2.1.4 Verification of Existing Information

If existing information is current and sufficient to completely identify the type, amount, and location of waste, then available information may be considered adequate. If existing information is used, constituents present should be verified by recent waste analysis or by dated analysis that is substantiated by recent facility records showing that no changes in process, manufacturing, or other practices that could alter waste composition have occurred. If existing information does not provide adequate waste characterization, or if the waste characteristics have changed, sampling may be required.

7.2.2 Waste Sampling

All sampling should be conducted in a manner that maintains sample integrity and encompasses adequate QA/AC. The characterization of waste in any unit must be representative. As wastes are often generated in bulk quantities from a large variety of processes, adequate determination of the waste profile requires that cyclical or random variations in waste composition be considered. The characterization should account for variation in waste content by collecting samples

that are representative of all potential waste variations. If a wide variation in waste composition is expected, it is preferable to document the range of this variation through the analysis of numerous samples. If little variation is anticipated, a lesser amount of sampling may be appropriate. If composite sampling is proposed, it must not mask unexpected or unanticipated compositional variations, and should always be complemented with an appropriate number of grab (non-composited) samples. Generally, compositing should not be used when evaluating variation in waste composition. Collection of representative samples will involve different procedures for different waste and unit types. This is discussed further in Section 7.4. Case Studies No. 3, 4, and 17 in Volume IV (Case Study Examples) provide illustrations of waste sampling uses, considerations, and techniques.

7.2.3 Physical/Chemical Waste Characterization

Compound-specific waste characterization should consider the constituents listed in 40 CFR Part 261, Appendix VIII, as the universe of overall constituents. Except for especially complex waste, many of the compounds on this list may be eliminated using the guidance presented previously in this section and in Section 3.6. As indicated in Section 3.6

- The owner or operator should provide a sound justification or analytical results of waste analyses as substantiation for the elimination of constituents from further consideration;

- The analysis of waste samples to determine their characteristics should be performed using standard methods, such as those described in the 3rd edition of EPA/SW-846 (Test Methods for Evaluating Solid Waste), or equivalent methods; and

- A detailed QA/QC Plan should clearly define the sample preparation techniques, analytical methodology, required analytical sensitivities and detection limits, and collection of blanks and duplicates.

In addition, for units that contain a mixture of solid, sludge, and/or liquid waste material, each phase should be analyzed and volume proportions measured.

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7.3 Unit Characterization

Information on unit characteristics may affect release properties and pathways. The owner or operator should obtain relevant information on the unit for use in developing the RFI strategy. Such information may include

- Unit dimensions (including depth below grade);
- Unit type;
- Unit purpose (e.g., biodegradation);
- Structural description, including materials and methods of construction, and any available drawings;
- Amounts of waste managed;
- Previous uses of area occupied by unit;
- Unit location;
- Description of liner or cap materials;
- Holding/retention time;
- Key operating parameters, such as waste management schedule;
- Waste treatment/application or loading rate;
- Biological activity present;
- Vent numbers and sizes; and
- Drainage areas.

7.4 Applicable Waste Sampling Methods

7.4.1 Sampling Approach

References for waste sampling methods discussed in this section are listed in Section 3.6.3. A summary of available waste sampling methods for various waste matrices is provided in Table 7-2.

Collection of waste samples requires methodology suited to the type of waste and unit sampled. In addition, waste sampling requires specialized equipment and protocols that may be designed especially for waste analysis or adapted from other sampling methods. Several important points to consider when developing a sampling approach are as follows:

- Compatibility of sampling methods and materials with the constituents being sampled.

- Ensuring the safety of personnel. Careful attention should be given to the level of protection and safe practices required for sampling activities. If the sampler is wearing protective gear that limits vision and mobility, or is fatiguing to wear, the collection procedures should be as simple as possible.

- Waste samples are generally not preserved and are considered hazardous for shipping purposes.

7.4.2 Sampling Solids

Sampling of solid materials should utilize readily available techniques. In general, the primary concern for the sampling of solid materials is effectively representing a large amount of possibly heterogeneous material in small samples. In order to address this concern, discrete samples should be collected from sufficient locations to characterize the waste with respect to location and time. Sampling methods vary depending on whether samples are to be collected at the surface, or

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TABLE 7-2. SAMPLING METHODS SUMMARY FOR WASTE CHARACTERIZATION

Waste Type/Unit Type	1 Scoops and Shovel	2 Triers	3 Thiefs	4 Augers	5 Core Samplers	6 Glass Tubes	7 Petite Ponar Grab	8 Dippers	9 Coliwasa	10 Pump and Tubing	11 Kemmerer Bottle	12 Bacon Bomb
Solid Wastes												
Waste Piles	X	X	X	X								
Land Treatment Units	X				X*							
Landfills				X	X							
Drum Handling	X		X									
Sacks and Bags	X	X	X									
Trucks	X	X	X		X							
Conveyor Belts	X											
Unloading/Loading/ Transfer Areas	X				X							
Sludge Wastes												
Waste Piles	X	X			X		X					
Drum Handling	X				X	X			X			
Tanks	X							X	X			
Surface Impoundments	X						X	X	X			
Trucks	X	X			X		X	X				
Conveyor Belts	X	X										
Unloading/Loading/ Transfer Areas					X	X		X				
Liquid Wastes												
Drum Handling						X		X	X	X		
Tanks									X	X	X	X
Surface Impoundments								X	X	X	X	X
Trucks								X		X	X	X
Unloading/Loading/ Transfer Areas								X		X		X

* Core Sampler modified to serve as air-tight container for retention of volatile fraction.

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below the surface. For a unit currently in operation, variation in waste stream composition over time should be considered in determining when samples should be taken.

For large amounts of solid materials, sample locations may be determined by applying a three-dimensional grid in combination with random sampling techniques as discussed in Section 3. In certain circumstances, compositing samples may be acceptable to minimize the number of sample analyses, as long as waste composition remains fairly constant over the sampling period. When composition waste is expected to vary (e.g., in complex wastes), grab samples should be taken. Compositing should be employed only when the representativeness of the waste characterization is uncompromised, and should always be accompanied by confirmational grab samples.

Bulk solid materials are generally homogeneous. They are likely to be found in waste piles, drums, bags, trucks or hoppers, or on conveyor belts. Bulk solid materials can be sampled using various methods. Surface soil or soil-like materials found at land treatment units, in landfills, and at waste transfer (e.g., loading and unloading) areas can also be sampled using the same basic methods. Deeper soil sampling will require other methods as described in Section 9 on soil.

Five basic solid sampling methods are discussed below:

- Scoops and shovels are useful for sampling dry or moist granular, powdered, or otherwise unconsolidated solids from piles as well as from other containers of solid material (e.g., bags, drums, hoppers, trucks, or shallow containers). Waste material transported to the unit by conveyor belt can be sampled using a scoop to collect samples from the belt. Scoops are applicable to solid waste materials that are within easy reach of sampling personnel. Scoops made of stainless steel or Teflon are preferable due to the inertness of these materials to most waste types. This sampling method is limited in utility to collection of samples near or on the surface of the waste. For collection of samples at greater depth, other methods are necessary. Shovels are used in the same manner as scoops when larger quantities of sample are needed or when an extended reach is required. Shovels are available in inert materials like

Teflon or stainless steel. Scoops and shovels will enable collection of land treatment unit samples from depths up to about 16 inches. Because most land treatment units manage organic waste streams, extreme care must be taken to retain the volatile organic components of the sample through rapid handling of the exposed sample during the collection process. Containers that have septum caps or air-tight lids should be used in conjunction with the scoop and shovel sampling method. Collection of soil samples from depths lower than the normal depths of tilling are described in Section 9. Contaminated surface soils at waste transfer areas are also easily sampled using scoops and shovels.

- Triers are used to withdraw a core of sample material. The trier is similar to a scoop in that it is inserted by hand into the material to be sampled; however, the design allows for the collection of a core of material. Triers are most useful for sampling waste piles, bags, hoppers, or other sources of loose solid waste material. Cores are most readily obtained with triers when the material being sampled is moist or sticky so that the core, which is cut by rotating the trier, stays together while the sample is removed from the waste material source. These samplers are useful only when they can be inserted horizontally into the material being sampled. Triers are readily available in lengths from 61 to 100 cm and are usually made of stainless steel with wooden handles.

- Thiefs are essentially long hollow tubes with evenly spaced openings along their lengths. An inner tube with similar openings is oriented so that the openings are not aligned and the entire dual-tube thief is inserted into the solid waste material. After insertion, the inner tube is rotated to align the openings, thus allowing the solid material to flow into the inner tube. The inner tube is then rotated back to the closed position, sealing the openings prior to withdrawal of the sampler. Thiefs can be inserted horizontally, vertically, or at various angles into the sample as long as the material will flow (by gravity) into the slots of the sampling tubes. This method is best suited for sampling of dry free-running solids. Thiefs are available in a range of sizes to allow for collection of materials of varying particle size, but are not generally useful for particles in excess of 0.6 cm. Thiefs, like triers, are available in a

variety of materials, usually brass or stainless steel, and are appropriate for sampling waste piles, drums, or hoppers.

- Augers can be used to sample solid material at varying depths. The use of augers is generally exclusive to the collection of soil samples at depth such as at landfills. However, for large waste piles which cannot be sampled in any other manner, it may be necessary to obtain samples from the inside portions of the pile in order to assess the overall characteristics of the material in the pile. Generally, augers are used in conjunction with a thin-wall tube sampler that is inserted into the borehole to collect an undisturbed sample from the depth at which the auger was stopped. The nature of the solid material and the physical size and accessibility of the unit will determine the applicability of augering and the most suitable type of auger. Augers are designed for general types of soil conditions and "disturb" samples to varying degrees. If possible, sampling of waste material should be conducted prior to or during waste placement because sampling by augers and thin-wall tubes can be difficult and time consuming. Backhoes may be required to gain access to the interior portions of the unit (e.g., a waste pile).

- Core samplers such as previously described in conjunction with augers are frequently used for soil sampling. Section 9 addresses soil sampling in greater detail. Core samplers can also be used to collect cores of land treatment unit samples and provide excellent samples for spanning the depth of treated soil. Thin-wall tube core samplers can be used to collect vertical cores at most desired locations. Sampling of top soil layers that contain the applied waste material can usually be accomplished using conventional hand coring techniques. As with the scoop and shovel method, extra consideration should be given to preventing losses of volatile organic components from the sample; the use of air-tight sample containers is recommended. Another technique is to utilize a core sampler which can itself be used as an air-tight sampling container. Recent designs include a coring device with Teflon-gasketed end caps that can be used to both collect and contain land treatment samples for soil and soil-gas analyses.

7.4.3 Sampling Sludges

Sludges are "semi-dry" materials ranging from dewatered solids to high-viscosity liquids. Due to their liquid content, sludge materials are not usually stored or handled as solids, and often require containment in drums, tanks, or impoundments, to prevent runoff of the liquid portion of the sludge. Sludges also include sediments with high liquid content under a liquid layer. Sampling must frequently include extended-reach equipment to gain access to the submerged sludge layer. For those cases where sludges are piled and have a sufficiently high solids content, methods previously discussed under "Solids" may be adequate. The equipment used in some of the solid material sampling methods is available with modifications to contain samples with a high liquid content.

Sediments can accumulate at the bottom of drums due to settling of suspended solids in liquid and sludge wastes. These sediments can be readily sampled using the previously discussed methodology. Glass-tube samplers, particularly those of larger bore, can be pressed into bottom sediments of drums to obtain samples. For bottom sediments or sludges that are too thick or resistive for glass tubes, corers with or without core catchers can be inserted into the drum for collection of sediments.

Basic methods for sampling sludges are discussed below:

- Scoops and shovels are useful for collecting sludge samples from the surface of a sludge pile, or at shallow depths in drums, tanks, or surface impoundments. Shovels will allow for the collection of larger volume samples. Extra care may be required to collect "representative" samples if the liquid fraction of the sludge tends to separate from the sample while being collected. The liquid fraction should be considered part of the sludge material and must be retained for adequate characterization. Long-sleeve gloves may be required for personnel protection.

- Triers may be useful for collection of cores of material from sludge piles. The nature of the waste will determine the utility of this method. Triers are not generally used for sludges; however, on a trial-and-error basis, their applicability may be determined.

- Core samplers modified to retain sludge material can be used to collect sludge from waste piles where samples are required from various depths. Core catchers, such as thin-wall tube samplers that prevent washout of the wet sludge during recovery of the sampler from the sludge source, are available for attachment to the tip of coring devices. Because sludges are most often formed through deposition of solids from a liquid mixture, the composition of the sludge may vary significantly with time and location. The use of a core sampler equipped with a core catcher can provide for collection of a sample profile. These types of corers are available with extension sections that allow for collection of samples from depths well below the surface of the waste. Corers are generally equipped with a cutting edge on the tip that greatly facilitates penetration of a thick bottom layer and can also be outfitted with core catchers to assist in retaining looser sediment materials that might be more readily lost from the bottom of a glass tube. The amount of sludge present can be easily estimated by measuring the depth to the apparent bottom and comparing it to the known interior depth.

- Glass tubes or a Composite Liquid Waste Sampler (COLIWASA) can be used to collect bottom sediments from drums or shallow tanks when they are gradually inserted into the solid layer at the bottom. Due to the fragility of glass and the danger of cuts, this technique is applicable only for materials easily penetrated by the tube. High-liquid-content bottom sediments may exhibit washout characteristics similar to liquid samples. In many cases, the only way to determine if sample losses from the bottom of the tube will occur is to carefully test it to see what happens.

- Petite Ponar Grab Samplers are clamshell-type scoops activated by a counter-lever system. The shell is opened and latched in place, then lowered to the bottom. When tension on the sample line is released, the shell halves are unlatched. The lifting action of the cable on the lever system closes the clamshell. These dredges are capable of collecting most types of sludges or sediments from silts to granular materials up to a few centimeters in diameter. As agitation of the liquid above the sludge occurs during sampling, it is advisable to collect sediment samples

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after all liquid sampling is complete. This method is particularly useful for tanks and surface impoundments.

7.4.4 Sampling Liquids

Liquid wastes require distinctly different sampling methods than do solids and sludges, with the exception of some techniques for sampling submerged sediments, and should also account for parameters of interest (e.g., for volatile contaminants, it is important to prevent volatilization). Common liquid waste sources are drum handling units, tanks, and surface impoundments. A general safety concern associated with drums and tanks is the structural integrity. Safe-access procedures for sampling these units should be established prior to sample acquisition.

Liquid wastes handled in drums can be sampled before being loaded into the drum or, if necessary, after placement. For facilities that receive wastes in drums, sampling should be conducted prior to the removal of the waste material from the drum. For waste streams that can be sampled directly prior to drum loading, grab sampling techniques are appropriate. As always, sufficient samples should be collected to account for waste variation over time. Sampling of drums can be done using several different methods, including grab sampling with a dipper from the open drum, routine full-depth drum sampling using a disposable glass tube or COLIWASA, or with a sampling pump with tubing that is lowered into the drum for sampling.

Tanks are containment structures larger than drums that can hold more than a million gallons. Tanks include tanker trucks, above-ground tanks, and partially or fully underground tanks. Tanks usually have limited access due to small hatchway openings, or ladders or walkways that often extend across open-top tanks. Due to the greater depth of tanks versus drums, methods with extended-reach capabilities are necessary. Waste materials in tanks generally include liquids and bottom sludges. When retention time of liquid wastes in tanks is long, layering or stratification including settling out of sediments is likely to occur. Great care should be taken to minimize the disturbance of liquid layers while collecting samples. The surface should be broken gently and samplers lowered gradually. Liquid sampling utilizes either pump and tubing methods or discrete depth samplers, such as

Kemmerer Bottles or Bacon Bomb samplers. Bottom sediments that cannot be drawn up with a pump will require the use of small dredges, such as the Petite Ponar Grab sampler.

Surface impoundments can range from several hundred to several million gallons in capacity. Due to their large size, they are usually open to the atmosphere rather than covered. Sampling of an impoundment may be difficult, except near its edges or from walkways that extend over the impoundment. "Off-shore" sampling, when necessary, should be considered a serious, potentially dangerous operation and should be performed according to strict health and safety procedures. Common means of sampling off-shore locations are boats, floating platforms, cranes with suspended enclosed platforms, and mobile boom vehicles with platforms.

Whenever possible, the waste should be characterized prior to its transfer into the impoundment. For example, waste pipelines can be sampled from valves, and tanker trucks discharging waste into impoundments can be sampled prior to discharging. However, taking samples from the units is desirable, because changes in the concentrations reported for samples taken during transfer may have large impacts on the estimates of the amounts of hazardous waste or constituents in the impoundment.

Liquid sampling techniques for impoundments include Dippers (particularly in the pond sampler configuration with a telescoping handle), pump and tubing, Kemmerer Bottles, and Bacon Bomb samplers. The dipper or pond sampler method is the easiest to use; however, it is not capable of reaching off-shore locations or of collecting samples at varying depths below the surface.

Liquid sampling methods are described below:

- Dippers can be used to collect samples from the surface liquid layer of open drums, tanks, or impoundments. (Other techniques are required to collect samples from drums where the only access is through the bung hole in the lid). This method is appropriate only for wastes that are homogeneous and likely to be represented by a grab sample from the top layer. In most cases, a full-depth composite liquid sample is more

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representative. The dipper technique involves the use of an intermediate vessel that is submerged in the waste liquid. The sample is then poured into the designated sample container. Handles are attached to the vessel to make sampling easier and reduce direct contact of the sampling technician with the waste material. In one configuration, the dipper is attached to a telescoping pole for an extended reach; this configuration is called a pond sampler. The dipper sampling device is also useful for sampling from piping system valves.

- Glass tube samplers can collect a full-depth liquid sample from a drum and can be used through the bung hole on the drum lid such that the lid need not be removed. Conventionally, the glass tubes are 122 cm long and 6 to 16 mm in inside diameter. Larger diameter tubes can be used if the liquid to be sampled is more viscous. The major limitation of this method is spillage (i.e., liquid loss from the bottom of the tube is unavoidable). Smaller diameter tubes have fewer problems with sample loss than do large-bore tubes. This method is perhaps the most common drum sampling technique due to its relative ease of use and the minimal equipment decontamination required.

- COLIWASA samplers are a more formalized version of the glass-tube samplers. The COLIWASA (composite liquid waste sampler) utilizes an inner rod attached to a stopper at the bottom of the sampling tube. The sampler is slowly inserted into the drum with the bottom stopper open. When the sampler reaches the bottom, the inner rod is pulled up, sealing the sampling tube for removal of the sample. A COLIWASA can be made of many materials; however, inert materials (e.g., Teflon or glass) are the materials of choice.

- Pump and tubing (e.g., bladder pumps) systems are readily available and are useful for withdrawing liquid samples from up to 28-foot depth. Peristaltic pumps are available in many sizes and flow rates to accommodate many sampling situations. Full-depth composite samples can be collected by gradually lowering the tubing into the material being sampled. One limitation of this system is that the pump applies a vacuum to the sample that can alter the chemical equilibrium in the sample.

resulting in the loss of volatile organic components. A modification to this basic system can be made by placing a sample vessel in-line between the tubing and the pump to prevent sample material from contacting the pump parts. In this configuration, collection of numerous samples is facilitated because pump tubing need not be cleaned or replaced between sampling events.

High flow rates are not advisable because rapid overflowing of sample bottles may occur. A lower flow rate will assist in minimizing the disturbance of liquid layers in the tank and will cause less agitation of the sample as it enters the sample bottle. The peristaltic pump and tubing system can be utilized in two configurations -- one with the tubing connected directly to the pump and a second with an intermediary sample vessel in-line between the pump and tubing. The second configuration also eliminates pump decontamination between samples. When sufficient waste characterization data are available, small submersible pumps can also be used; however, these pumps are not generally made of chemically resistant or relatively inert materials. The utility of these small submersibles depends on their ability to provide samples from greater depths. Peristaltic pumps have an upper limit of approximately 8 meters, whereas submersibles can be used for most depths of concern.

- Kemmerer Bottles are discrete-depth liquid samplers that are usually appropriate for tank or impoundment sampling. The Kemmerer Bottle is a spring-loaded device that is lowered into the liquid in the open position, allowing the liquid sample to flow through it while it is descending. At the desired depth, a messenger is dropped down the sample line, releasing the spring-loaded closing device to obtain the sample. Limitations of Kemmerer Bottles include the poor availability of devices constructed of relatively inert materials, the difficulty in decontamination between sampling, and the inability of this sampler to collect purely depth-discrete samples (because the sampler's surfaces are exposed to materials in the liquid layers as the sampler passes through them to arrive at the designated depth).

- Bacon Bomb samplers are lowered on a sample line. A second line attached to an opening rod, which runs down the center of the bomb, will open the sampler when pulled. The sample can be collected with a minimal amount of agitation since the rod can open the top and bottom of the bomb, allowing the sample to enter the bottom and air to exit through the top. Bacon Bomb samplers are readily available from laboratory supply houses and are frequently constructed of chrome-plated brass. Relatively inert construction materials, such as Teflon or stainless steel, are preferable. Careful maintenance and regular inspection of samplers is advised. Samplers with plating materials flaking off should be removed from use. If waste characteristics are known, sample changes caused by the sampler can be avoided by using materials compatible with the type of waste being sampled. An advantage of the Bacon Bomb sampler is its ability to be lowered to the desired depth in the closed position before collecting a sample. This technique minimizes cross-contamination from liquid layers above.

SECTION 8

HEALTH AND ENVIRONMENTAL ASSESSMENT

8.1 Overview

This section describes the Health and Environmental Assessment (HEA) that will be conducted by the regulatory agency as part of the RFI. The primary element of this assessment is a set of health and environmental criteria (chemical concentrations) to which measured and in some cases predicted (e.g., for the air medium) concentrations of hazardous constituents developed during the release characterization will be compared. When these criteria ("action levels") are exceeded or there is a reasonable likelihood of this occurring, a Corrective Measures Study (CMS) will generally be required, although the owner or operator may, because of site specific factors, present data and information to support a determination that no further action is necessary. This section describes the HEA process (Section 8.2), the determination of potential exposure routes for each environmental medium of concern (Section 8.3), and the development and use of the health and environmental criteria (Section 8.4), leading to an evaluation of the need for appropriate interim corrective measures and/or a CMS. The evaluation of chemical mixtures is discussed in Section 8.5. Special considerations involved in the evaluation of soil and sediment contamination are discussed in Section 8.6. Section 8.6 also provides a review of statistical procedures that may be used to evaluate ground-water monitoring data. Section 8.7 discusses qualitative and other factors which may be used by the regulatory agency in conducting the health and environmental assessment. Interim corrective measures are discussed in Section 8.8. References used in developing this section are listed in Section 8.9. Finally, Section 8.10 presents the health and environmental criteria and provides several worksheets which may be used to conduct the HEA.

The health and environmental criteria used in determining the need for a CMS are based primarily on EPA-established chronic-exposure limits. These values and their use are described herein. Subchronic exposure limits and qualitative criteria are also discussed. It should be emphasized that the health and environmental criteria provided in this section do not necessarily represent clean-up target levels that must be achieved through the implementation of corrective measures. Rather,

they establish presumptive levels that indicate that a closer examination is necessary. This closer analysis would generally take place as part of a CMS.

The guidance provided in this section presents a general framework for conducting a HEA. It is intended to provide a flexible approach for interpreting release characterization data, as case-specific factors may enter into consideration. For example, State-established criteria and consideration of past environmental problems (e.g., fish-kills) may also be considered.

The regulatory agency may require both interim corrective measures and a CMS as a result of the HEA. One difference between interim corrective measures and definitive corrective measures may be timing. The development and implementation of a comprehensive corrective action program can be a time-consuming process. Between the time of the identification of a contaminant release and the implementation and completion of definitive corrective measures, existing conditions or further contaminant migration could endanger human health and the environment. Under these conditions, interim corrective measures, which may be temporary or short-term measures (e.g., providing bottled water or removing leaking drums) designed to prevent or minimize adverse exposure, can be applied. Case Study No. 11 in Volume IV (Case Study Examples) provides an illustration of the HEA process.

The HEA procedures described in this section apply to releases from all units except releases to ground water from "regulated units" as defined under 40 CFR Part 264.90(a)(2). Releases to ground water from "regulated units" must be addressed according to the requirements of 40 CFR §264.91 through §264.100 for purposes of detection, characterization, and appropriate response.

8.2 Health and Environmental Assessment Process

The HEA is a continuous process that begins with the initiation of the RFI. As investigation data (from monitoring and/or modeling) become available, both within and at the conclusion of discrete phases, they should be reported to the regulatory agency as required. The regulatory agency will compare these data to applicable health and environmental criteria, including evaluation against qualitative criteria, to determine the need for (1) interim corrective measures; and/or (2) a CMS. Notwithstanding this process, the owner or operator has a

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continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator should follow the RCRA Contingency Plan required under 40 CFR Part 264, Subpart D and Part 265, Subpart D.

The results of the media-specific investigations described in Volumes II and III of this Guidance will be used to identify the constituents of concern, constituent concentrations within the release, general release characteristics (e.g., organic, inorganic), the affected environmental media, exposed or potentially exposed human or environmental receptors, the rate of migration of the release, and the extent of the release. The objective of the HEA is to integrate these results to determine whether interim corrective measures and/or a CMS may be necessary. In general, this objective is achieved in a two-step process.

First, potential human and environmental exposure routes are determined. Section 8.3 provides guidance for determining potential exposure routes for the media of concern. For ground water, surface water, soil, and air, methods are described for making exposure route-specific comparisons with the health and environmental criteria. Subsurface gas migration and inter-media transport of contamination from other media to air (e.g., ground-water contamination resulting in seepage of volatile constituents to basements) are addressed as air problems to the extent that they contribute hazardous constituents to ambient air, whether indoors or outdoors. Evaluation of the migration of methane gas in the subsurface is also addressed in this section (Section 8.8) as part of the guidance on interim corrective measures, due to the immediate explosion potential of methane.

Second, the measured (or in some cases, such as releases to air, predicted) constituent concentrations in the release are compared to EPA-established exposure-limit criteria. At any time during the RFI when contaminant concentrations in the release are found to exceed the health and environmental criteria, a CMS will generally be required by the regulatory agency, although the owner or operator may, because of site-specific factors, present data and information to support a determination that no further action is necessary. In addition, when health and environmental criteria are exceeded, the need for appropriate interim corrective measures will also be determined. This process

involves an evaluation of exposed or potentially exposed human and environmental populations. This process is discussed in more detail in Section 8.8.

The determination of whether a CMS may be necessary will be made by the regulatory agency, by comparing constituent concentrations determined at locations within the release to the health and environmental criteria discussed in Section 8.4. These criteria serve as "action levels" for determining whether a CMS will be necessary. Figure 8-1 depicts a hypothetical facility with individual solid waste management units and a contaminant release originating from one of the units. For ground water, surface water, soil, and subsurface gas, the comparison of constituent concentrations with the criteria will be made for all measurements within the release at and beyond the limit of the waste management area.

The evaluation procedure for releases to air differs from the other media in that comparison of constituent concentrations with the health and environmental criteria will be made at the facility property boundary. However, onsite air comparisons may be necessary in cases where people reside at the facility or when worker safety regulations are deemed inadequate to protect human health and the environment, although onsite air contamination normally would fall under the jurisdiction of OSHA. As indicated in the Air Section (Section 12), the values compared can be either measured values derived from monitoring or predicted values derived from modeling.

8.3 Determination of Exposure Routes

Some of the more significant potential exposure routes for each environmental medium are presented in Table 8-1. This table should be used to determine the appropriate health and environmental criteria to be used in the comparison with measured or predicted constituent release concentrations. For example, when releases to ground water have been identified, a primary exposure route of concern is drinking water. For each constituent identified in the ground-water release, the measured concentrations are compared with the appropriate criterion values discussed for drinking water in Section 8.4.

Suspected or known inter-media transfers of contamination should have been characterized (i.e., nature, extent and rate) during the RFI process. For example, if

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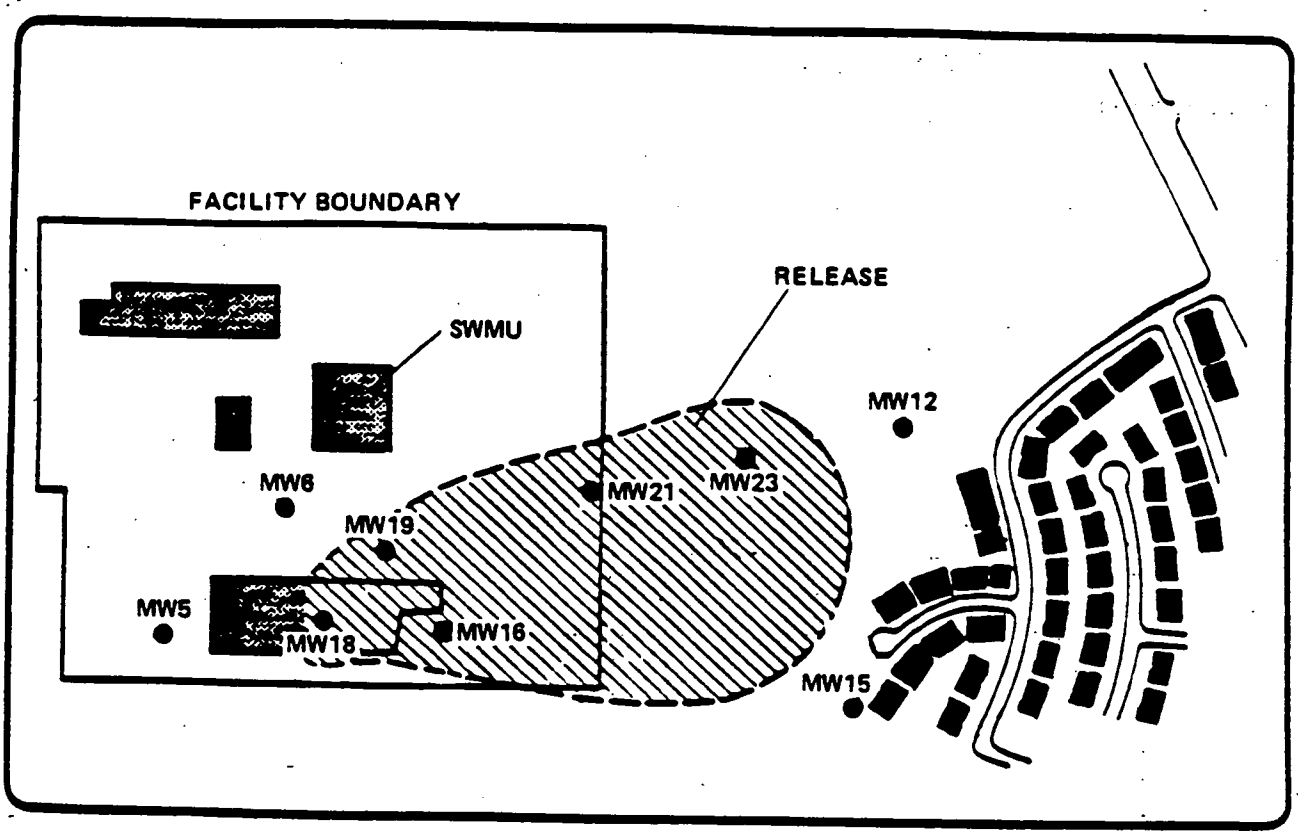

LEGEND:

● SAMPLING LOCATIONS

FIGURE 8-1. HYPOTHETICAL FACILITY WITH INDIVIDUAL SOLID WASTE MANAGEMENT UNITS AND A CONTAMINANT RELEASE ORIGINATING FROM ONE OF THE UNITS.

TABLE 8-1

Some Potential Exposure Routes

Contaminated Medium	Exposure Route
Soil[1]	Soil Ingestion (surficial soil), Dermal Contact
Ground Water	Ingestion of Drinking Water
Subsurface Gas[2]	Inhalation
Air	Inhalation
Surface Water[1]	Ingestion of Drinking Water Consumption of Contaminated Biota (e.g., fish)

1 Exposure routes for deep contaminated soils and bottom sediments underlying surface water bodies are addressed separately in Section 8.6.

2 Migration of methane gas in the subsurface presents a problem due to the explosive properties of methane. This is treated as an immediate hazard and is discussed under interim corrective measures (Section 8.8).

[Note: Other important exposure pathways can include inhalation of volatile constituents released during domestic use of contaminated ground water or when such ground water seeps into residential basements. Similarly, various exposure pathways can lead to adverse effects on environmental receptors (i.e., animals and plants).]

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the initial contaminant release was to the soil medium and eroded soils have been transported to surface water, both soil and surface water contamination should have been adequately characterized during the RFI. In this example, the regulatory agency will consider exposure in both media. In cases where subsurface gas, soil, or ground-water releases have caused contaminant seepage to basements, inter-media transfer to the air may pose an inhalation hazard. In such cases, contamination of basement areas should have been adequately characterized during the RFI process.

8.4 Health and Environmental Criteria

The preliminary set of health and environmental criteria are presented in Tables 8-5 through 8-10 in Section 8.10. The constituents shown in Tables 8-5 through 8-10 are a subset of the hazardous constituents listed in Appendix VIII of 40 CFR Part 261. It should be noted that the definition of constituent may also include components of 40 CFR Part 264, Appendix IX that are not also on Appendix VIII, but are normally monitored for during ground-water investigations. Tables 8-5 through 8-10 identify such constituents, where criteria for these constituents are available.

The concentrations shown for each constituent are derived from EPA-established chronic (and in some cases acute) toxicity criteria for ingestion (soil and drinking water) or inhalation exposure routes, and were calculated using a set of intake assumptions for the various media, as shown in Table 8-2. As indicated in the footnotes accompanying Tables 8-5 through 8-10, the criteria presented are subject to change. Therefore, these numbers should be confirmed by the regulatory agency prior to use.

8.4.1 Derivation of Health and Environmental Criteria

Maximum Contaminant Levels (MCLs) -- Table 8-5 provides the maximum contaminant levels (MCLs) for drinking water promulgated under the Safe Drinking Water Act. In developing these values, total environmental exposure to a particular contaminant from various sources (e.g., air, food, water) and gastrointestinal absorption were considered.

TABLE 8-2

Intake Assumptions for Selected Routes of Exposure

Surficial Soils (Ingestion):
0.1 g/day for 70 kg person/70 year exposure period for carcinogens
0.2 g/day for a 16 kg child/5-year exposure period for systemic toxicants*
Surface and Ground Water (Ingestion):
2 liters/day for 70 kg adult/70-year exposure period
Air (Inhalation):
20 m^3 air/day for 70 kg adult/70-year exposure period

* Corresponds to the period of 1 to 6 years of age.

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The MCL, when available for a constituent released to ground water or surface water, should be used as the evaluation criterion for human drinking water consumption for that constituent. If an MCL does not yet exist for a particular constituent, criteria in the other tables presented in Section 8.10 should be used, where available. If air, surficial soil, or sediment (See Section 8.6) are the media of concern, or when evaluating aquatic life exposure or human consumption of aquatic organisms, the MCL is not used. In such cases, the criteria in the other tables should be used, as described below. [Note: EPA is in the process of developing a number of new MCLs to be issued over the next several years.]

Carcinogens -- Table 8-6 presents the human health-based criteria for carcinogens. These criteria, calculated from Risk-Specific Doses (RSDs), were developed according to EPA Guidelines for Carcinogen Risk Assessment (U.S. EPA, 1986). The RSD is an upper bound estimate of the average daily dose of a carcinogenic substance that corresponds to a specified excess cancer risk for lifetime exposure. The values presented in Table 8-6 are environmental concentrations that, under the intake assumptions shown in Table 8-2, correspond to excess lifetime cancer risks of 10^{-6} for Class A and B carcinogens, or 10^{-5} for Class C carcinogens. Table 8-6 presents the class (A, B or C) of the carcinogen (See U.S. EPA, 1986, for a description of carcinogen classification).

The criteria presented in Table 8-6 were calculated from RSDs in the following manner:

$$C_i = (R/q_1^*) \times (W/I) \qquad \text{(Equation 8-1)}$$

where

C_i = the criterion concentration for the constituent of interest;

R = the specified risk level (e.g., 10^{-6});

q_1^* = the carcinogen slope factor (CSF) in $(mg/kg/day)^{-1}$ developed by the Carcinogen Assessment Group (CAG) of the EPA, Office of Health and Environmental Assessment, or the Agency's Carcinogen Risk Assessment Verification Endeavor (CRAVE) Workgroup;

(R/q_1^*) = the RSD;

W = the assumed weight of the exposed individual; and

I = the intake amount for a given time period.

For example, the health-based criterion (C_i) for aldrin, a Class A carcinogen, was calculated for water in the following manner:

$$C_i = (R/q_1^*) \times (W/I)$$

$$= (10^{-6}/1.7E + 01\ (mg/kg/day)^{-1}) \times (70\ kg/2\ liters/day)$$

$$= 2.1 \times 10^{-6}\ mg/liter$$

$$= 2.1 \times 10^{-3}\ \mu g/liter$$

Calculation of the criteria for soil ingestion and air inhalation shown in Table 8-6 takes essentially the same form. However, the values for the assumed intake rate (I) differ. The assumed intake rate for soil that is used in the calculations for carcinogens is 0.1 g/day for a 70-kg person. The current conservative, linear models that the Agency uses in cancer risk assessments consider the expression of carcinogenic effects to be a function of cumulative dose, and thus assume that, in general, elevated exposures during early childhood alone are not that significant in determining lifetime cancer risk. Therefore, the soil intake value of 0.1 g/day is an upper-range estimate of soil ingestion for adults. The intake rate (I) for air inhalation is 20 m^3/day for a 70-kg person.

Many of the health-based criteria for carcinogens shown in Table 8-6 are below current analytical detection limits (See Section 3.6 for a discussion of detection limits). For example, the concentration for dieldrin in Table 8-6 is 2.2×10^{-3} µg/l for the drinking water exposure route, while the corresponding current limit of detection for this constituent is approximately 5×10^{-2} µg/l. In those cases where the HEA criterion is less than the limit of detection, the detection limit will be used as a default value when making comparisons to investigation data, unless acceptably determined modeling values can be applied (i.e., values from air dispersion models).

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The criteria provided in Table 8-6 address the surficial soil (ingestion), water (ingestion), and air (inhalation) routes of exposure. For human health assessment, the carcinogen criteria for water should be used when ground water or surface water is the medium of concern, unless MCLs exist or there are lower values for the constituents of concern in Table 8-7. The carcinogen criteria for surficial soil (ingestion) and air (inhalation) should be used if surficial soil or air, respectively, is the medium of concern, unless a lower value appears in Table 8-7. If a particular constituent is not identified in Table 8-6, the criteria in Table 8-7 (systemic toxicants) should be used, if available. As alluded to above, constituents that are both known carcinogens and systemic toxicants (e.g., chloroform) will have values in both Tables 8-6 and 8-7. In such cases, the lower of the two values should be used as the action level. Both values are presented in the tables if needed for determining the additive toxicity of mixtures (see Section 8.5).

Systemic Toxicants -- Table 8-7 presents the human health-based criteria for systemic toxicants. These criteria, calculated from Reference Doses (RfDs), are an estimate of the daily exposure an individual (including sensitive individuals) can experience without appreciable risk of health effects during a lifetime. For water ingestion, the systemic criteria are calculated for a 70-kg adult for a chronic lifetime exposure period (i.e., 70 years). For soil ingestion, the assumed intake rate of 0.2 g/day is based on a 5-year exposure period for a 16-kg child. These exposure assumptions for soil are reflective of an average scenario in which children ages 1-6 (who exhibit the greatest tendency to ingest soil) are assumed to ingest an average amount of soil on a daily basis. The concentrations shown in Table 8-7 were calculated using the intake assumptions presented in Table 8-2 for the selected exposure routes, as shown in the following equation:

$$C_i = (RfD) \times (W/I) \qquad \text{(Equation 8-2)}$$

For example, the concentration (C_i) for surface water and ground water for pentachlorobenzene shown in Table 8-7 was calculated in the following manner:

C_i = Criterion concentration for constituent of interest

RfD = Reference Dose for pentachlorobenzene

$= 8 \times 10^{-4}$ mg/kg/day

I = ingestion rate (from Table 8-2)

$= \frac{2 \text{ liters}}{\text{day}}$

W = adult body weight (from Table 8-2)

= 70 kg

$C_i = (8 \times 10^{-4}$ mg/kg/day) x (70 kg/2 liters/day)

$= 2.8 \times 10^{-2}$ mg/liter

$C_i = 2.8 \times 10^{1}$ µg/liter (which rounds off to 3×10^{1} µg/liter)

As with the carcinogen criteria, some of the systemic criteria presented in Table 8-7 may be below current analytical detection limits. (See Section 3.6 for a discussion of detection limits.) In cases where the criterion is less than the limit of detection, the detection limit will be used as a default value when making comparisons to investigation data, unless acceptably determined modeling values can be applied (i.e., values from air dispersion models).

EPA is in the process of developing inhalation criteria for 49 systemic toxicants based on inhalation toxicity studies. Inhalation criteria for several of these systemic toxicants are currently available. These criteria are identified in Table 8-7. When additional criteria are developed, they will be incorporated into the Integrated Risk Information System (IRIS) data base (see Section 8.4.2). In addition, EPA is currently conducting research on development of systemic toxicity criteria for dermal exposure through contact with contaminated soil.

The systemic criteria for the water (human ingestion) route of exposure should be used unless MCLs or lower carcinogen criteria exist. For other routes of exposure (e.g., soil ingestion), carcinogen criteria should be used unless lower systemic criteria exist. As indicated previously, some toxicants are both carcinogenic and

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systemically toxic (e.g., chloroform) and, thus appear in both Tables 8-6 and 8-7. In such cases, the lower of the two values should be used for human health assessment.

Water Quality Criteria -- A summary of the EPA Water Quality Criteria (WQC) appears in Tables 8-8 and 8-9. These criteria exist to protect both marine and fresh-water aquatic life and address both acute and chronic toxicity. WQC also exist for protection of human health through water and fish consumption (incorporating both routes of exposure), and for fish consumption only. If human consumption of both the surface water and contaminated aquatic organisms is a factor, the set of criterion values based on ingestion of contaminated aquatic organisms and drinking water should be used. The values based on consumption of fish alone should be used only when human consumption of the surface water is not of concern. WQC should be used only when surface water is the medium of concern. If aquatic life exposure and human exposure are both of concern, the more stringent criterion should be used. Aquatic life criteria may be applied even if human exposure is not of concern. [Note: In states which have adopted numerical Water Quality Standards, or where numerical standards can be calculated from non-numeric state standards, such standards may be used in lieu of EPA WQC or other available levels on a constituent-specific basis.]

Acute and Subchronic Criteria -- These criteria address impacts on both children and adults, and are presented in Table 8-10. These criteria are most commonly applied for the determination of the need for interim corrective measures. Their use is described in Section 8.8.

8.4.2 Use of Criterion Values

As indicated previously, the criteria presented in Tables 8-5 through 8-10 are subject to change. These tables do not present action levels for all of the 40 CFR Part 261, Appendix VIII constituents. In addition, action levels for components of 40 CFR Part 264, Appendix IX that are not also on Appendix VIII, but are normally monitored for during ground-water investigations, may also be applied. As existing health effects data are reviewed and more information becomes available from laboratory and epidemiological studies, these tables may be expanded to include additional hazardous constituents, including those from Appendix IX.

Current information on the health and environmental effects of various toxicants, including information on RSDs and RfDs, and supporting toxicological studies, may be obtained from review of the following document:

U.S. EPA. Integrated Risk Information System (IRIS) Chemical Files. Office of Health and Environmental Assessment, Office of Research and Development. Washington, D.C. 20460.

The Integrated Risk Information System (IRIS), is a computerized library of current information that is up-dated on a continuous basis. It contains health risk assessment information on chemicals which have undergone a detailed review of toxicity data by work groups composed of EPA scientists from several Agency program offices, and represent EPA consensus. IRIS may be accessed by the EPA Regions, and State and local governments through the EPA electronic mail system (Dialcom) or through the Public Health Network of the Public Health Foundation (contact the Network at (202) 898-5600 for details). IRIS is also available to the general public through the EPA electronic mail system (Dialcom-(202) 488-0550). In addition, IRIS is also available on floppy diskettes in ASCII format through the National Technical Information Service (NTIS-(703) 487-4763).

If EPA has not yet developed criteria for constituents which may be pertinent to a particular release, there are various options which may be exercised by the regulatory agency. A literature search may be performed to locate any health effects data which can be used to develop an interim criterion value or, at least, information such as type of health effect (e.g., carcinogenicity) which can be used to make judgments. The regulatory agency, for example, may obtain and review EPA summaries of health and environmental effects produced for a particular constituent. These summaries include Health and Environmental Effects Profiles (HEEPs), Health Effects Assessment (HEA) documents, and other documents produced by EPA to summarize health and environmental effects for particular constituents. These documents are collectively known as Health and Environmental Effects Documents (HEEDs), and are available for many of the 40 CFR Part 261, Appendix VIII constituents through EPA's RCRA Docket and library, located at EPA Headquarters in Washington, D.C. A listing of all the HEEDs currently available is

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contained in the following document, which is also available through EPA's RCRA Docket and library:

U.S. EPA, 1987. Background Document, Resource Conservation and Recovery Act, Subtitle C -- Identification and Listing of Hazardous Waste, Appendix A -- Health and Environmental Effects Documents. Office of Solid Waste. Washington, D.C. 20460.

Additionally, the HEA documents can be obtained from the National Technical Information Service (NTIS). Table 8-3 presents a list of all chemicals for which HEAs are currently available, and also identifies the NTIS ordering number.

If little or no useful information regarding a particular constituent can be located, the initiation of a toxicity bioassay may be considered. The Technical Assessment Branch, Health Assessment Section of the Office of Solid Waste, located in Washington, D.C., may be contacted for toxicological information [(202)382-4761)]. This office may also be contacted to determine whether a toxicity bioassay for a particular constituent is planned or is in progress. Comparison of background concentrations (as action levels) to constituent concentrations in the release may be made by the regulatory agency when health and environmental effects information are not available.

Note also that the criteria presented in Tables 8-5 through 8-10 do not address all routes of exposure or forms of toxicity which may be of concern in particular circumstances. For example, dermal toxicity (absorption of toxicants through the skin) may also be of concern in particular cases. Phytoxicity (toxicity to plants) and other forms of environmental toxicity, such as terrestrial toxicity (toxicity to animals and birds) may also be of concern. Additional information regarding other routes of exposure and forms of toxicity may be obtained from the following reference:

U.S. EPA. October, 1986. Superfund Public Health Evaluation Manual. EPA 540/1-68/060. NTIS PB87-183125. OSWER Directive No. 9285.4-1. Office of Emergency and Remedial Response. Washington, D.C. 20460.

Worksheet 8-1 in Section 8.10 may be used to present release characterization data and to facilitate the comparison of constituent concentrations to health and

TABLE 8-3

CHEMICAL AND CHEMICAL GROUPS HAVING EPA HEALTH EFFECTS ASSESSMENT (HEA) DOCUMENTS[1]

CHEMICAL	NTIS[2] PB NUMBER
Acetone	86 134277/AS
Arsenic and Compounds	86 134319/AS
Asbestos	86 134608/AS
Barium and Compounds	86 134327/AS
Benzene	86 134483/AS
Benzo (a) pyrene	86 134335/AS
Cadmium and Compounds	86 134491/AS
Carbon Tetrachloride	86 134509/AS
Chlordane	86 134343/AS
Chlorobenzene	86 134517/AS
Chloroform	86 134210/AS
Chromium III and Compounds	86 134467/AS
Chromium VI and Compounds	86 134301/AS
Coal Tars	86 134350/AS
Copper and Compounds	86 134368/AS
Cresol	86 134616/AS
Cyanides	86 134228/AS
DDT	86 134376/AS
1,1-Dichloroethane	86 134384/AS
1,2-Dichloroethane (DCE)	86 134137/AS
1,1-Dichloroethylene	86 134624/AS
1,2-cis-Dichloroethylene	86 134269/AS
1,2-trans-Dichloroethylene	86 134525/AS
Dichloromethane	86 134392/AS
Ethylbenzene	86 134194/AS
Glycol Ethers	86 134632/AS
Hexachlorobenzene	86 134285/AS
Hexachlorobutadiene	86 134640/AS
Hexachlorocyclopentadiene	86 134129/AS
gamma-Hexachlorocyclohexane (Lindane)	86 134673/AS
Iron and Compounds	86 134657/AS
Lead and Compounds (Inorganic)	86 134665/AS

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TABLE 8-3 (Continued)

CHEMICAL AND CHEMICAL GROUPS HAVING EPA HEALTH EFFECTS ASSESSMENT (HEA) DOCUMENTS[1]

CHEMICAL	NTIS[2] PB NUMBER
Manganese and Compounds	86 134681/AS
Mercury	86 134533/AS
Methyl Ethyl Ketone	86 134145/AS
Naphthalene	86 134251/AS
Nickel and Compounds	86 134293/AS
Pentachlorophenol	86 134541/AS
Phenanthrene	86 134400/AS
Phenol	86 134186/AS
Polychlorinated Biphenyls (PCBs)	86 134152/AS
Polynuclear Aromatic Hydrocarbons	86 134244/AS
Pyrene	86 134418/AS
Selenium and Compounds	86 134699/AS
Sodium Cyanide	86 134236/AS
Sulfuric Acid	86 134426/AS
2,3,7,8-TCDD (Dioxin)	86 134558/AS
1,1,2,2-Tetrachloroethane	86 134434/AS
Tetrachloroethylene	86 134202/AS
Toluene	86 134442/AS
1,1,1-Trichloroethane	86 134160/AS
1,1,2-Trichloroethane	86 134566/AS
Trichloroethylene	86 134574/AS
2,4,5-Trichlorophenol	86 134459/AS
2,4,6-Trichlorophenol	86 134582/AS
Vinyl Chloride	86 134475/AS
Xylene	86 134178/AS
Zinc and Compounds	86 134590/AS
Complete Set of 58 HEAs	86 134111/AS

1 As of the date of publication for this guidance document.

2 National Technical Information Service.

environmental criteria. Additional worksheets are provided for evaluating hazards posed by mixtures of constituents. Evaluation of chemical mixtures is discussed in the following section.

8.5 Evaluation of Chemical Mixtures

There are several situations when the overall potential for adverse effects posed by multiple constituents may be assessed. For example, if no individual constituent exceeds its action level in a given medium, but there are many constituents present in the medium, the overall (additive) health risk may be assessed to determine whether a CMS may be required. In other cases, an evaluation of the health risk posed by a mixture of constituents may be used in assessing the need for interim measures, particularly where exposure is actually occurring. The Guidelines for the Health Risk Assessment of Chemical Mixtures (U.S. EPA, 1986) describe the recommended approach to be used in evaluating the chronic effects of exposure to a chemical mixture. According to the guidelines, a mixture is defined as "any concentration of two or more chemicals regardless of source or of spatial or temporal proximity." Under these guidelines, additivity of effects for carcinogens can be assumed. The guidelines also allow for additivity of systemically toxic constituents which cause similar systemic effects. Carcinogens and systemic toxicants must be evaluated separately. When evaluating mixtures of systemic toxicants, constituents should be grouped by the same mode of toxicological action (i.e., those which induce the same toxicological endpoint, such as liver toxicity).

The overall risk posed by a mixture of constituents is evaluated through the use of a Hazard Index (HI) that is generated for each health endpoint. For systemic toxicants, the hazard index (HI_T) takes the form:

$$HI_T = \sum_{i=1}^{n} \frac{E_i}{AL_i} \qquad \text{(Equation 8-3)}$$

where

n = total number of toxicants;

223 E_i = exposure level of the ith toxicant; and

AL_i = maximum acceptable level for the ith toxicant.

The hazard index for carcinogens (HI_c) is similar:

$$HI_c = \sum_{i=1}^{n} \frac{E_j}{DR_j} \qquad \text{(Equation 8-4)}$$

where

n = total number of carcinogens;

E_j = exposure level to the jth carcinogen; and

DR_j = dose at a set level of risk for the jth carcinogen.

If any calculated hazard index exceeds unity (i.e., one), then the need for interim corrective measures and/or a CMS may be assessed.

The use of the hazard index in the evaluation of chemical mixtures is described below for an example case in which three carcinogens were measured within a contaminant release. Trichloroethylene and carbon tetrachloride levels in the ground water were measured at 2 and 1 µg/l, respectively. A breakdown product of carbon tetrachloride, chloroform, was also measured at a level of 3 µg/l. None of these concentrations exceed the individual criteria presented in Tables 8-5 through 8-10. (The MCL for both trichloroethylene and carbon tetrachloride is 5.0 µg/l, and the carcinogenic criteria for chloroform is 5.7 µg/l.) However, the hazard Index (HI_c) for these three chemicals exceeds unity. Rewriting Equation (8-4) in terms of the measured concentration (E_j) and the criterion concentrations (DR_j) shown in Tables 8-5 through 8-10 gives:

$$HI_c = E_1/DR_1 + E_2/DR_2 + E_3/DR_3$$

$$HI_c = \frac{2\ \mu g/l}{5.0\ \mu g/l} + \frac{1\ \mu g/l}{5.0\ \mu g/l} + \frac{3\ \mu g/l}{5.7\ \mu g/l}$$

$$HI_c = 0.4 + 0.2 + 0.53$$

$$HI_c = 1.13$$

Thus, in this situation, the need for interim corrective measures and/or a CMS may be assessed.

Contaminant additivity is possible both within a medium and across media. When appropriate, the regulatory agency may use the hazard index approach for multiple contaminants within a given medium to help determine the need for interim corrective measures and/or a CMS. Similarly, contaminant additivity may be applied across media, especially when site-specific factors indicate a likelihood of chronic exposure to constituents from multiple media. Information on the toxicological effects of individual systemic toxicants may be found in the HEEDs, and the IRIS data base, referenced earlier.

Worksheet 8-2 (Section 8.10) provides a format that the regulatory agency may use to assess the toxic effects of chemical mixtures based on the hazard index. An example case worksheet is also presented.

8.6 Evaluating Deep Soil and Sediment Contamination and Use of Statistical Procedures for Evaluating Ground-Water Contamination

As indicated previously, determining whether deep soil and sediment contamination warrants consideration of interim corrective measures and/or a CMS may involve the application of specific exposure assumptions and consideration of other factors. Guidance regarding these topics is presented in Subsections 8.6.1 and 8.6.2. This guidance may be revised in future editions of this document as a result of ongoing EPA studies. Subsection 8.6.3 presents a discussion on statistical procedures that may be used for evaluating ground-water contamination.

8.6.1 Deep and Surficial Soil Contamination

As described in the Soil Section of this Guidance (Section 9), releases of hazardous waste or constituents to soil can be described as surficial or deep. Surficial soil is generally described as the top 2 feet of soil; in site-specific conditions, it may extend to 12 feet. Land use that involves housing developments is an example of when the surficial soil depth may extend to 12 feet, because foundation excavation may result in deep contaminated soils being moved to the surface.

Because of the potential for inter-media transport of contamination, the potential routes for exposure to surficial soil contaminants are soil, air, surface

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water, and ground water. While air, surface water, and ground-water routes are all important, the most relevant and major route of exposure is through direct contact with and/or ingestion of soil.

Surficial soils may be contaminated with organics, inorganics, organometals, or a combination of these. At high concentrations, some contaminants will cause at least irritation at the point of skin contact. For many contaminants, however, toxicity occurs after they pass through certain barriers (e.g., the wall of the gastrointestinal tract or the skin itself), and enter blood or lymph, and gain access to various organs or systems of the body. Generally, because of the chemical forms in which metals are usually found in soils (e.g., salts, ligand, and chelate complexes), the concern is with their ingestion rather than with dermal contact.

Surficial soil contaminated with lead and/or cadmium presents a unique health risk to children because of the possible ingestion of contaminated soil through their normal exploratory behavior, coupled in some instances with pica, and because of the cumulative nature of lead and cadmium poisoning.

Currently, there is no verified Reference Dose (RfD) or Risk Specific Dose (RSD) for lead. The Carcinogen Assessment Group (CAG) of ORD is evaluating lead as a potential human carcinogen via the oral route of exposure and is currently working on estimating a Carcinogenic Slope Factor (CSF) for lead based on current toxicity studies. The Agency is also attempting to develop a RfD for lead based on new toxicological data on the non-carcinogenic, neuro-behavioral effects of lead exposure. It is not likely, however, that either the RfD or the RSD will be developed and approved soon.

Another metal of concern is cadmium. Although the Agency has not formally approved an RfD for cadmium, a value of 0.0005 mg/kg/day will likely be approved as an RFD. This value would translate to an acceptable soil level of 9 mg/kg.

Toxicological information on lead and cadmium are undergoing extensive Agency review, and decisions on relevant health-based standards are currently being made. The Integrated Risk Information System (IRIS) chemical files should be searched periodically for updated material concerning lead and cadmium.

The criteria discussed in Section 8.4 that apply to soil (and shown in Tables 8-6 and 8-7 in Section 8.10) pertain to ingestion of surficial soils. Because ingestion of deep soils may not be a likely exposure scenario, different evaluation methods may be used for deep soils, as described below.

In making the determination of whether interim corrective measures and/or a CMS should be considered for deep contaminated soils, the regulatory agency may evaluate the potential for the contamination within deep soils to contaminate underlying ground water. If the potential exists for contaminated deep soils to release hazardous constituents to ground water, such that the criteria levels for ground water discussed in Section 8.4 may be exceeded, interim corrective measures and/or a CMS will be considered. This applies not only to situations where ground water has not yet been impacted by deep soil contamination, but also to situations where deep contaminated soils are acting as a continuous source of contamination to already contaminated ground water. In addition, the regulatory agency may apply this evaluation to surficial soils, particularly in cases where the soil ingestion criteria (Section 8.4) are not exceeded and where the surficial soil may pose a future or continuing threat to ground water.

In order to determine whether contaminated soils pose a future or continuing threat to ground water, leaching tests and/or other evaluation procedures may be performed on representative samples of contaminated soils following the guidance presented in Section 9.4.4.3. If the concentration of constituents of concern measured in leachate resulting from leaching tests and/or other procedures exceeds the applicable criteria for ground water discussed in Section 8.4, interim corrective measures and/or a CMS may be necessary, unless the owner or operator demonstrates (following the guidance presented in Section 9.4.4.3) that attenuation and other mechanisms will reduce these concentrations to acceptable levels prior to entry into the ground water.

Case Study No. 16 in Volume IV (Case Study Examples) illustrates the application of leaching tests and the evaluation of other site-specific information to determine whether contaminated soil poses a threat to ground water.

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8.6.2 Sediment Contamination

As with deep contaminated soils, direct human exposure to contaminated sediments underlying surface waters is unlikely. However, such sediments may pose risks to both the surface water ecosystem and humans due to toxicity and/or bioaccumulation and biomagnification through the food chain. The regulatory agency may therefore assess the potential for contaminated sediments underlying surface water to act as a continuing or future source of contamination to the water column, to aquatic life that may be present in the surface water, and consequently to humans who may ingest the surface water and/or the aquatic life within the surface water.

Section 13, in addressing releases to surface water, recommends that, whenever metal species or organic constituents having bioaccumulative potential are known to be present in bottom sediments (or in the water column), biomonitoring (e.g., sampling and analysis of aquatic species) be conducted. If potentially bioaccumulative organic or inorganic contaminants (as discussed in Section 13) are measured in the aquatic species of interest, interim corrective measures and/or a CMS may be necessary.

If other hazardous constituents (e.g., those which are not known to be potentially bioaccumulative) are measured in the sediment that can be subsequently released from the sediment into the surface-water column at concentrations above the applicable criteria discussed in Section 8.4, interim corrective measures and/or a CMS may also be required by the regulatory agency.

However, the owner or operator may attempt to show that constituents within the sediment have not bioaccumulated or will not bioaccumulate. The owner or operator may also attempt to show, through use of static or flow-through testing (i.e., analysis of water or aquatic species following a period of contact with the contaminated sediment) or through the use of chemical stability/solubility information, that sediment contaminants will not be released to the water column in concentrations that would exceed the applicable criteria discussed in Section 8.4.

It should also be noted that EPA is working to establish numerical sediment quality criteria that can be applied on a site-specific basis, depending primarily on

the physical/chemical characteristics of the sediment (e.g., sediment organic carbon content). The approach being investigated to assessing sediment contamination examines the correspondence between sediment contaminant concentration, laboratory bioassay, and in situ assessments of biomass and species diversity. Although these criteria are still in the development/validation process, when issued, they may be applied in the case of sediment contamination to determine whether interim corrective measures and/or a CMS may be necessary. Contact the EPA Criteria and Standards Division for additional information at (202) 475-7301.

8.6.3 Use of Statistical Procedures For Evaluating Ground-Water Contamination

On October 11, 1988, EPA promulgated the final rule for Statistical Methods for Evaluating Ground-Water Monitoring Data From Hazardous Waste Facilities (53 FR 39720). This rule, part of 40 CFR Part 264, Subpart F, requires ground-water monitoring at permitted hazardous waste land disposal facilities to detect ground-water contamination. This rule amends the requirement that the Cochran's Approximation to the Behrens Fisher Student's t-test (CABF), be applied to ground-water monitoring data to determine whether there is a statistically significant exceedance of background or other allowable concentration levels of specified chemical parameters. Concerns with the CABF procedure were brought to EPA's attention, and after a review of comments on the procedure, EPA promulgated 5 different statistical methods that are more appropriate for the analysis of ground-water monitoring data. These 5 methods are 1) Parametric analysis-of-variance, 2) Analysis-of-variance based on ranks, 3) Tolerance intervals, 4) Prediction intervals, and 5) Control charts.

Analysis-of-variance models are used to analyze the effects of an independent variable on a dependent variable. For ground-water monitoring data, a well or group of wells is the independent variable, and the aqueous concentration of certain constituents or of a specified contaminant or contaminants is the dependent variable. An analysis-of-variance can determine whether observed variations in aqueous concentrations between different wells or groups of wells are statistically significant. Use of analysis-of-variance models is appropriate in situations where background concentrations for the specific constituent can be determined.

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Tolerance intervals define, with a specified probability, a range of values that contain a discrete percentage of the sample population. With ground-water monitoring data, tolerance intervals can be constructed with concentrations from the background well(s); these intervals are then expressed as an interval centered at the mean background well concentration. Possible ground-water contamination is indicated when concentrations of the specified constituent(s) at the compliance well(s) plot outside of the tolerance interval limits.

Prediction intervals are intervals in which the user is confident at a specified percentage that the next observation will lie within the interval, and are based on the number of previous observations, the number of new measurement to be made, and the level of confidence that the user wishes to obtain. This method of statistical analysis can be used in both detection and compliance monitoring programs. It is useful in a detection monitoring program when constituent concentrations from individual compliance wells are compared to one or more background wells. The mean concentration and standard deviation are estimated from the background well sample. In a compliance monitoring program, prediction intervals are constructed from compliance well concentrations beginning when the facility entered the compliance monitoring program. Each compliance well observation is tested to determine if it lies within the prediction interval, and if it is greater than the historical prediction limits, quality has deteriorated to such a point that further action may be warranted.

Control charts are based on repeated random sampling done over various time intervals from the population distribution of a given variable. Different statistical measurements, such as the mean of replicate values at a point in time, are computed and plotted together with upper and/or lower predetermined limits on a chart whose x-axis represents time. When a data point plots outside these boundaries, the process is "out of control", and when it plots within the boundaries the process is "in control". Control charts can be used to analyze the inherent statistical variation of ground-water monitoring data and to note aberrations. Further investigation of out of control points is necessary before taking any direct action. Control charts are also used to evaluate ground-water monitoring data when these data are adjusted and/or transformed as necessary. A control chart can be constructed for each constituent in each well to monitor the concentration of

that constituent over time. New samples can be compared to the historical data from the well to determine if the well is in or out of control.

The October 11, 1988 final rule (53 FR 39720) should be reviewed for further information. In particular, the rule provides a glossary of some of the terminology commonly used in the field of statistics, which may be particularly helpful. The EPA Office of Solid Waste Land Disposal Branch may be contacted for further information at (202) 382-4658.

8.7 Qualitative Assessment and Criteria

Qualitative criteria may also be used to assess the need for interim corrective measures and/or a CMS. Qualitative criteria for interim corrective measures are discussed in Section 8.8. Qualitative criteria for assessing the need for conducting a CMS are discussed below.

The regulatory agency may require that a CMS be performed even though quantitative criteria (See Section 8.4) have not been exceeded. Circumstances under which such actions may be appropriate include the following:

- Presence of sensitive ecosystems or endangered species;
- Data indicating that release concentrations may be increasing over time;
- Information indicating that other contaminant sources may be contributing to overall adverse exposure;
- Information indicating that exposure routes other than those addressed by quantitative criteria (e.g., dermal contact and phytotoxicity) are important; and
- Additional exposure as a result of normal use of a contaminated medium (e.g., use of contaminated ground water or surface water for drinking as well as for washing, cooking, showering, watering the lawn, etc.).

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The above list of circumstances is not exhaustive. The regulatory agency may identify other factors on a case-specific basis.

8.8 Interim Corrective Measures

If interim corrective measures are determined to be necessary, population exposure should be prevented or minimized to the extent necessary and further release migration should also be prevented or minimized. The process of determining whether interim corrective measures should be taken, and the selection and implementation of such measures, is similar to removal actions that may be taken under CERCLA (Superfund). In many cases, such action may be relatively simple (e.g., removal of drums from the land surface with proper storage or disposal), while in other cases more extensive action may be necessary.

In evaluating whether interim corrective measures may be necessary, the regulatory agency will review pertinent information about the source and nature of the release or potential threat of release. The regulatory agency will apply scientific judgment in evaluating the potential threat to human health or the environment. The decision to apply interim corrective measures will be made in consideration of the immediacy and magnitude of the potential threat, the nature of appropriate corrective action, and the implications of deferring corrective measures until the RFI/CMS is completed. The following factors will be considered in determining the need for interim corrective measures:

- Actual or potential exposure of nearby human populations or animals to hazardous wastes or constituents;
- Actual or potential contamination of drinking water supplies or sensitive ecosystems;
- Presence of hazardous wastes or constituents in drums, barrels, tanks, or other bulk storage containers that may pose a threat of release;
- Presence of high concentrations of hazardous wastes or constituents in soils largely at or near the surface that may migrate readily to receptors, or to which the public may be inadvertently or unknowingly exposed;

- Weather conditions that may cause hazardous wastes or constituents to migrate or be released;

- Threat of fire or explosion; and

- Other situations or factors that may pose actual or imminent threats to human health or the environment.

Exceedance of any of the criteria discussed in Section 8.4 does not necessarily mean that interim corrective measures will be required. Although the regulatory agency should be notified if health and environmental criteria are exceeded, the overall circumstances will be considered by the regulatory agency in determining whether interim corrective measures should be applied. Notwithstanding this process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For such situations, the owner or operator should follow the RCRA Facility Contingency Plan as required under 40 CFR Part 264, Subpart D and Part 265, Subpart D.

It should also be noted that the regulatory agency may apply health criteria based on acute or subchronic effects, to the determination of the need for interim corrective measures. For example, the EPA Office of Drinking Water has developed drinking water health advisories for a number of compounds, which address acute (1 day) and subchronic (10 day) exposures for both children and adults. A list of the currently available drinking water health advisories is provided in Table 8-10. Health advisory numbers may be periodically revised and can be found in IRIS. For further information on health advisory numbers, call the EPA Office of Drinking Water Hotline at (202) 382-5533 or 1-800-426-4791.

The regulatory agency will base the decision on the need to apply interim corrective measures on a determination of the type and magnitude of the potential hazard and an evaluation of the likelihood and effects of actual or potential human or environmental exposures. For example, in the hypothetical case depicted in Figure 8-1, initial measurements at the indicated sampling locations identified constituent concentrations in excess of health and environmental criteria.

Accordingly, the owner or operator notified the regulatory agency immediately. The circumstances indicated that human population would be exposed to release constituents before definitive corrective measures could be selected and implemented. Therefore, immediate steps to address the hazard were required of the owner or operator. Examples of specific interim corrective measures are provided in Table 8-4. For additional information see RCRA Corrective Action Interim Measures (U.S. EPA, 1987).

To determine whether an actual or potential threat to human health or the environment requires interim corrective measures, the regulatory agency will consider such factors as receptor locations, and rate and extent of release migration. Worksheet No. 3 in Section 8.10.2 presents a list of questions that the regulatory agency may consider in making a determination.

The decision to apply interim corrective measures may involve estimates of the rate of release migration and an assessment of potential human or environmental receptors. Estimates of the rate of release migration will generally be based on simple calculations, analytical models, or well-understood numerical models. For example, the rate of contaminant migration in ground water is likely to be based on time of travel (TOT) calculations or other simple methods for estimating rate. Additional information on determining media-specific migration and the characterization of exposed populations is provided in the Superfund Public Health Evaluation Manual (U.S. EPA, 1986) and the Draft Superfund Exposure Assessment Manual (U.S. EPA, 1987). In addition, information describing data requirements for exposure related measurements is expected to be published by the EPA Office of Research and Development Exposure Assessment Group in the Federal Register in late 1988 or early 1989.

As discussed above, the determination of the type and magnitude of the potential hazard posed by most contaminant releases will be accomplished as part of the assessment, including the comparison of projected or actual exposure concentrations to the health and environmental criteria, as described in Section 8.4. However, the evaluation of subsurface releases of methane gas may pose a direct explosion hazard as a result of a concentration build-up (e.g., in building structures). Explosions of methane gas can occur at the Lower Explosive Limit (LEL) in the presence of a heat source (e.g., a spark). EPA has promulgated criteria for explosive

TABLE 8-4

EXAMPLES OF INTERIM CORRECTIVE MEASURES

SOILS • Sampling/Analysis/Disposal • Run-off/Run-on Control (Diversion or Collection Devices) • Temporary Cap/Cover	**CONTAINERS** • Overpack/Re-drum • Construct Storage Area/Move to Storage Area • Segregation • Sampling and Analysis • Treatment, Storage and/or Disposal • Temporary Cover
GROUND WATER • Delineation/Verification of Gross Contamination • Sampling and Analysis • Interceptor Trench/Sump/Subsurface Drain • Pump and Treat • In-situ Treatment • Temporary Cap/Cover	**TANKS** • Overflow/Secondary Containment • Leak Detection/Repair/Partial or Complete Removal
SURFACE WATER RELEASE (Point and Non-Point) • Overflow/Underflow Dams • Filter Fences • Run-off/run-on Control (Diversion or Collection Devices) • Regrading/Revegetation • Sample and Analyze Surface Waters and Sediments or Point Source Discharges	**SURFACE IMPOUNDMENTS** • Reduce Head • Remove Free Liquids and or Highly Mobile Wastes • Stabilize/Repair Side Walls, Dikes or Liner(s) • Provide Temporary Cover • Run-off/Run-on Control (Diversion of Collection Devices) • Sample and Analysis to Document the Concentration of Constituents Left in Place When a Surface Impoundment Handling Characteristic Wastes is Clean Closed • Interim Ground-water Measures (See Ground-water Section)
GAS MIGRATION CONTROL • Barriers/Collection/Treatment/Monitoring • Evacuation (Buildings)	**LANDFILL** • Run-off/Run-on Control (Diversion or Collection Devices) • Reduce Head on Liner and/or in Leachate Collection System • Inspect Leachate Collection/Removal System or French Drain • Repair Leachate Collection/Removal System or French Drain • Temporary Cap • Waste Removal (See Soils Section) • Interim Ground-water Measures (See Ground-water Section)

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TABLE 8-4 (continued)

EXAMPLES OF INTERIM CORRECTIVE MEASURES

PARTICULATE EMISSIONS • Truck Wash (Decontamination Unit) • Re-vegetation • Application of Dust Suppressant	**WASTE PILE** • Run-off/Run-on Control (Diversion to Collection Devices) • Temporary Cover • Waste Removal (See Soils Section) • Interim Ground-Water Measures (See Ground-water Section)
OTHER TYPES OF ACTIONS • Fencing to Prevent Direct Contact • Extend Contamination Studies to Off-site Areas if Permission is Obtained as Required Under Section §3004(v) • Alternate Water Supply to Replace Contaminated Drinking Water • Temporary Relocation of Exposed Population • Temporary or Permanent Injunction • Suspend or Revoke Authorization to Operate Under Interim Status	

gases under the RCRA, Subtitle D program in 40 CFR Part 257.3. These criteria state that the concentration of explosive gases generated by the facility shall not exceed: (1) 25 percent of the lower explosive limit (LEL) for the gases in facility structures, and (2) the lower explosive limit for the gases at the property boundary. Where these criteria are being approached or exceeded, interim corrective measures for gas migration will generally be necessary.

8.9 References

U.S. EPA. 1986. Superfund Public Health Evaluation Manual. EPA/540-1-86-060. NTIS PB87-183125. OSWER Directive No. 9285.4-1. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. September 24, 1986. Guidelines for Carcinogen Risk Assessment. Federal Register 51(185):33992-34003.

U.S. EPA. September 24, 1986. Guidelines for the Health Risk Assessment of Chemical Mixtures. Federal Register 51(185):34014-34025.

U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes. EPA/SW-846. GPO No. 955-001-00000.1. Office of Solid Waste. Washington, D.C. 24060.

U.S. EPA. 1986. Superfund Exposure Assessment Manual. Draft. Office of Emergency and Remedial Response. Washington, D.C. 20460.

U.S. EPA. 1987. Data Quality Objectives for Remedial Response Activities: Volume 1 - Development Process, Volume 2: Example Scenario. EPA 540/G-87/003a. OSWER Directive No. 9335.0-7B. Office of Emergency and Remedial Response and Office of Waste Programs Enforcement. Washington, D.C. 20460.

U.S. EPA. 1987. Integrated Risk Information System (IRIS) Chemical Files. EPA/600/8-86/032b. Office of Health and Environmental Assessment, Office of Research and Development. Washington, D.C. 20460.

U.S. EPA. 1987. Background Document, Resource Conservation and Recovery Act, Subtitle C--Identification and Listing of Hazardous Waste, Appendix A--Health and Environmental Effects Documents. Office of Solid Waste. Washington, D.C. 20460.

U.S. EPA. 1987. RCRA Corrective Action Interim Measures. Office of Solid Waste. Washington, D.C. 20460.

8.10 Criteria Tables and Worksheets

This section presents both the health and environmental assessment criteria tables and worksheets that the regulatory agency may use in conducting the health and environmental assessment.

8.10.1 Criteria Tables

The following are the health and environmental assessment criteria tables discussed in Section 8.4 and 8.8. Table 8-5 presents the Maximum Contaminant Levels (MCLs) promulgated under the Safe Drinking Water Act. Table 8-6 presents human health-based criteria for carcinogens (based on Risk-Specific Doses or RSDs). Table 8-7 presents human health-based criteria for systemic toxicants (based on Reference Doses or RfDs). Table 8-8 presents a summary of the EPA Water Quality Criteria developed under the Clean Water Act. Table 8-8 identifies individual constituents as well as groups of constituents (e.g., chlorinated benzenes). Table 8-9 presents a list of all the individual constituents contained in the chemical groups identified in Table 8-8. Table 8-10 presents drinking water health advisories developed by EPA's Office of Drinking Water.

Table 8-5

MAXIMUM CONTAMINANT LEVELS (MCLs) PROMULGATED UNDER THE SAFE DRINKING WATER ACT*

Chemical	CAS No.	MCL (mg/l)
Arsenic	7440-38-2	0.05
Barium	7440-39-3	1.0
Benzene	71-343-2	0.005
Cadmium	7440-43-9	0.01
Carbon tetrachloride	56-23-5	0.005
Chromium (hexavalent)	7440-47-3	0.05
2,4-Dichlorophenoxy acetic acid	94-75-7	0.1
1,4-Dichlorobenzene	106-46-7	0.075
1,2-Dichloroethane	107-06-2	0.005
1,1-Dichloroethylene	75-35-4	0.007
Endrin	72-20-8	0.0002
Fluoride	--	4
Lindane	58-89-9	0.004
Lead	7439-92-1	0.05
Mercury	7439-97-6	0.002
Methoxychlor	72-43-5	0.1
Nitrate	--	10
Selenium	7782-49-2	0.01
Silver	7440-22-4	0.05
Toxaphene	8001-35-2	0.005
1,1,1-Trichloroethane	71-55-6	0.2
Trichloroethylene	79-01-6	0.005
2,4,5-Trichlorophenoxy acetic acid	93-76-5	0.01
Vinyl chloride	75-01-4	0.002

* These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-6. Health-Based Criteria for Carcinogens[1]

Constituent	CAS No.	Class (A, B, C)[2]	Oral Exposure Route RSD[3]			Inhalation Exposure Route RSD[3]	
			CSF (mg/kg/day)$^{-1}$	Soil (mg/kg)	Water (µg/l)	CSF (mg/kg/day)$^{-1}$	Air (µg/m^3)
Acrylamide[4]	79-06-1	B	3.85E+00	1.82E-01	9.09E-03	3.85E+00	9.09E-04
Acrylonitrile	107-13-1	B	5.4E-01	1.30E+00	6.5E-02	2.4E-01	1.5E-02
Aldrin	309-00-2	B	1.7E+01	4.1E-02	2.1E-03	1.7E+01	2.1E-04
Aniline[4]	62-53-3	C	2.6E-02	2.7E+02	1.3E+01	2.59E-02	1.35E+00
Arsenic[4]	7440-38-2	A	--	--	See MCL	1.51E+01	2.32E-04
Benz(a)anthracene[4]	56-55-3	B	3.12E+00	2.24E-01	1.12E-02	3.12E+00	1.12E-03
Benzene[4]	71-43-2	A	2.9E-02	2.4E+01	See MCL	2.9E-02	1.2E-01
Benzidine	92-87-5	A	2.3E+02	3.0E-03	1.5E-04	2.3E+02	1.5E-05
Benzo(a)pyrene[4]	50-32-8	B	1.15E+01	6.09E-02	3.04E-03	1.15E+01	3.04E-04
Beryllium[4]	7440-41-7	B	4.90+00	1.43E-01	7.14E-03	8.40E+00	4.17E-04
Bis(2-chloroethyl) ether	111-44-4	B	1.1E+00	6.4E-01	3.2E-02	1.1E+00	3.2E-03
Bis(chloromethyl) ether (BCME)[4]	542-88-1	A	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
Bis(2-ethylhexyl) phthalate	117-81-7	B	8.4E-03	8.3E+01	4.2E+00	--	--
Cadmium	7440-43-9	B	--	--	See MCL	7.8E+00	4.5E-04
Carbon tetrachloride	56-23-5	B	1.3E-01	5.4E+00	See MCL	1.3E-01	2.7E-02
Chlordane	57-74-9	B	1.3E+00	5.4E-01	2.7E-02	1.3E+00	2.7E-03
1-Chloro-2, 3-epoxypropane (Epichlorohydrin)	106-89-8	B	9.9E-03	7.1E+01	3.5E+00	4.8E-03	7.3E-01
Chloroform	67-66-3	B	6.1E-03	1.1E+02	5.7E+00	8.1E-02	4.3E-02
Chloromethyl methyl ether[4] (CMME)	107-30-2	A	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
Chromium (hexavalent)	7440-47-3	A	--	--	See MCL	4.1E+01	8.5E-05
DDD	72-54-8	B	2.4E-01	2.9E+00	1.5E-01	--	--
DDE	72-55-9	B	3.4E-01	2.1E+00	1.0E-01	--	--
DDT	50-29-3	B	3.4E-01	2.1E+00	1.0E-01	3.4E-01	1.0E-02
Dibenz(a,h) anthracene[4]	53-70-3	B	4.90E+01	1.43E-02	7.14E-04	4.90E+01	7.14E-05
1,2-Dibromo-3-chloropropane[4] (DBCP)	96-12-8	B	2.21E+01	3.17E-02	1.58E-03	2.21E+01	1.58E-04

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-6. (continued)[1]

Constituent	CAS No.	Class (A, B, C)[2]	Oral Exposure Route RSD[3]			Inhalation Exposure Route RSD[3]	
			CSF (mg/kg/day)$^{-1}$	Soil (mg/kg)	Water (µg/l)	CSF (mg/kg/day)$^{-1}$	Air (µg/m^3)
1,2-Dibromoethane	106-93-4	B	--	--	--	7.6E-01	4.6E-03
Dibutylnitrosamine	924-16-3	B	5.40E+00	1.30E-01	6.48E-03	5.40E+00	6.48E-04
1,2-Dichloroethane	107-06-2	B	9.1E-02	7.7E+00	See MCL	9.1E-02	3.8E-02
1,1-Dichloroethylene	75-35-4	C	6.0E-01	1.2E+01	See MCL	1.2E+00	2.9E-02
Dichloromethane (Methylene chloride)	75-09-2	B	7.5E-03	9.3E+01	4.7E+00	1.4E-02	2.5E-01
1,3-Dichloropropene	542-75-6	B	1.8E-01	3.9E+00	1.9E-01	--	--
Dieldrin	60-57-1	B	1.6E+01	4.4E-02	2.2E-03	1.6E+01	2.2E-04
Diethylnitrosamine	55-18-5	B	1.5E+02	4.6E-03	2.3E-04	1.5E+02	2.3E-05
Diethylstilbestrol[4] (DES)	56-53-1	A	4.90E+02	1.43E-03	7.14E-05	4.90E+02	7.14E-06
2,4-Dinitrotoluene	121-14-2	B	3.08E-01	2.27E+00	1.14E-01	--	1E-01
1,4-Dioxane	123-91-1	B	4.90E-03	1.43E+02	7.14E+00	4.90E-03	7.14E-01
1,2-Diphenylhydrazine	122-66-7	B	8.0E-01	8.8E-01	4.4E-02	8.0E-01	4.4E-03
Ethylene oxide[4]	75-21-8	B	3.50E-01	2.00E+00	1.00E-01	3.50E-01	1.00E-02
Heptachlor	76-44-8	B	4.5E+00	1.6E-01	7.8E-03	4.5E+00	7.8E-04
Heptachlor epoxide	1024-57-3	B	9.1E+00	7.7E-02	3.8E-03	9.1E+00	3.8E-04
Hexachlorobenzene[4]	118-74-1	B	1.72E+00	4.07E-01	2.03E-02	1.72E-02	2.03E-01
Hexachlorobuta-diene	87-68-3	C	7.8E-02	9.0E+01	4.5E+00	7.8E-02	4.5E-01
Hexachlorodibenzo-p-dioxin	19408-74-3	B	6.2E+03	1.1E-04	5.6E-06	6.2E+03	5.6E-07
Hexachloroethane	67-72-1	C	1.4E-02	5.0E+02	2.5E+01	1.4E-02	2.5E+00
Hydrazine	302-01-2	B	3.0E+00	2.3E-01	1.2E-02	1.02E+01	3.43E-04
Hydrazine sulfate	10034-93-2	B	3.0E+00	2.3E-01	1.2E-02	--	--
Lindane (gamma-Hexachlorocyclo-hexane)[4]	58-89-9	C	1.3E+00	5.4E+00	See MCL	1.3E+00	2.7E-02
3-Methyl-cholanthrene[4]	56-49-5	B	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
4,4-Methylene-bis-(2-chloroaniline)[4]	101-14-4	B	1.65E-01	4.24E+00	2.12E-01	1.65E-01	2.12E-02
Nickel[4]	1440-02-0	A	--	--	--	8.40E-01	4.17E-03
Nickel (refinery dust)	7440-02-0	A	--	--	--	8.4E-01	4.2E-03

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-6. (continued)[1]

Constituent	CAS No.	Class (A, B, C)[2]	Oral Exposure Route RSD[3]			Inhalation Exposure Route RSD[3]	
			CSF (mg/kg/day)$^{-1}$	Soil (mg/kg)	Water (µg/l)	CSF (mg/kg/day)$^{-1}$	Air (µg/m^3)
Nickel subsulfide	12035-72-2	A	--	--	--	1.7E+00	2.1E-03
2-Nitropropane[4]	79-46-9	B	9.45E+00	7.41E-02	3.70E-03	9.45E+00	3.70E-04
N-Nitrosodi-ethanolamine	1116-54-7	B	2.8E+00	2.5E-01	1.3E-02	--	--
N-Nitrosodimethyl-amine (Dimethyl-nitrosamine)	62-75-9	B	5.1E+01	1.4E-02	6.9E-04	5.1E+01	6.9E-05
N-Nitrosodi-N-propylamine	621-64-7	B	7.0E+00	1.0E-01	5.0E-03	--	--
N-Nitroso-N-methylethylamine	10595-95-6	B	2.2E+01	3.2E-02	1.6E-03	--	--
N-Nitroso-N-methyl urea[4]	684-93-5	B	3.01E+02	2.33E-03	1.16E-04	3.01E+02	1.16E-05
N-Nitroso-pyrrolidine	930-55-2	B	2.1E+00	3.3E-01	1.7E-02	2.1E+00	1.7E-03
PCB's	1336-36-2	B	7.7E+00	9.1E-02	4.5E-03	--	--
Pentachloronitro-benzene[4]	82-68-8	C	2.56E-01	2.73E+01	1.37E+00	2.56E-01	1.37E-01
Perchloroethylene (Tetrachloro-ethylene)	127-18-4	C	5.1E-02	1.4E+02	6.9E+00	2.5E-01	1.4E-01
Pronamide (Kerb)[4]	23950-58-5	C	--	--	--	--	2E+00
Reserpine[4]	50-55-5	B	1.05E+01	6.67E-02	3.33E-03	1.05E+01	3.33E-04
Styrene	100-42-5	B	3.0E-02	2.3E+01	1.2E+00	2.0E-03	1.8E+00
1,1,2,2-Tetrachloroethane	79-34-5	C	2.00E-01	3.50E+01	1.75E+00	2.00E-01	1.75E-01
Thiourea[4]	62-56-6	B	1.93E+00	3.63E-01	5.18E-02	1.93E+00	5.18E-03
Toxaphene	8001-35-2	B	1.1E+00	6.4E-01	See MCL	1.1E+00	3.2E-03
1,1,2-Trichloroethane	79-00-5	C	5.7E-02	1.2E+02	6.1E+00	5.7E-02	6.1E-01
Trichloroethylene	79-01-6	B	1.1E-02	6.4E+01	See MCL	1.3E-02	2.7E-01
2,4,6-Trichlorophenol	88-06-2	B	2.0E-02	3.5E+01	1.8E+00	2.0E-02	1.8E-01

1 These criteria are subject to change and will be confirmed by the regulatory agency prior to use.
2 The EPA Carcinogen Classification system is discussed in 51 FR 33992-34003 (Guidelines for Carcinogen Risk Assessment)
3 See Table 8-2 for the appropriate intake assumptions used to derive these criteria.
4 Indicates criteria undergoing EPA review.

Table 8-7. Health-Based Criteria for Systemic Toxicants[1]

Constituent	CAS No.	RfD[2] (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m³)
Acetone	67-64-1	1E-01	8E+03	4E+03	--
Acetonitrile	75-05-8	6E-03	5E+02	2E+02	--
Acetophenone	98-86-2	1E-01	8E+03	4E+03	--
Aldicarb	116-06-3	1E-03	8E+01	4E+01	5E+00
Aldrin	309-00-2	3E-05	2E+00	1E+00	--
Allyl alcohol	107-18-6	5E-03	4E+02	2E+02	--
Aluminum phosphide	20859-73-8	4E-04	3E+01	1E+01	--
Antimony	7440-36-0	4E-04	3E+01	1E+01	--
Barium	7440-39-3	5E-02	4E+03	See MCL	--
Barium cyanide	542-62-1	7E-02	6E+03	2E+03	--
Benzidine	92-87-5	2E-03	2E+02	7E+01	--
Beryllium	7440-41-7	5E-03	4E+02	2E+02	--
Bis(2-ethylhexyl) phthalate	117-81-7	2E-02	2E+03	7E+02	--
Bromodichloromethane	75-27-4	2E-02	2E+03	7E+02	7E+01
Bromoform	75-25-2	2E-02	2E+03	7E+02	--
Bromomethane	74-83-9	4E-04	3E+01	1E+01	--
Calcium cyanide	592-01-8	4E-02	3E+03	1E+03	--
Carbon disulfide	75-15-0	1E-01	8E+03	4E+03	--
Carbon tetrachloride	56-23-5	7E-04	6E+01	See MCL	--
Chlordane	57-74-9	5E-05	4E+00	2E+00	--
Chlorine cyanide	506-77-4	5E-02	4E+03	2E+03	--
Chlorobenzene	108-90-7	3E-02	2E+03	1E+03	--
1-Chloro-2,3 epoxypropane (Epichlorohydrin)	106-89-8	2E-03	2E+02	7E+01	--
Chloroform	67-66-3	1E-02	8E+02	4E+02	--
Chromium (III)	16065-83-1	1E+00	8E+04	4E+04	--
Chromium (VI)	7440-47-3	5E-03	4E+02	See MCL	--
Copper cyanide	544-92-3	5E-03	4E+02	2E+02	--
Cresols	1319-77-3	5E-02	4E+03	2E+03	--
Crotonaldehyde	123-73-9	1E-02	8E+02	4E+02	--
Cyanide		2E-02	2E+03	7E+02	--
Cyanogen	460-19-5	4E-02	3E+03	1E+03	--
2,4-D	94-75-7	1E-02	8E+02	See MCL	--
DDT	50-29-3	5E-04	4E+01	2E+01	--
Di-n-butylphthalate	84-74-2	1E-01	8E+03	4E+0	--

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-7. (continued)[1]

Constituent	CAS No.	RfD[2] (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m3)
Dichlorodifluoro-methane	75-71-8	2E-01	2E+04	7E+03	--
1,1-Dichloroethylene	75-35-4	9E-03	7E+02	See MCL	--
Dichloromethane (Methylene chloride)	75-09-2	6E-02	5E+03	2E+03	--
2,4-Dichlorophenol	120-83-2	3E-03	2E+02	1E+02	1E+01
1,3-Dichloropropene	26952-23-8	3E-04	2E+01	1E+01	--
Dieldrin	60-57-1	5E-05	4E+00	2E+00	--
Diethyl phthalate	84-66-2	8E-01	6E+04	3E+04	--
Dimethoate	60-51-5	2E-02	2E+03	7E+02	--
2,4-Dinitrophenol	51-28-5	2E-03	2E+02	7E+01	7E+00
Dinoseb	88-85-7	1E-03	8E+01	4E+01	--
Diphenylamine	127-39-4	3E-02	2E+03	1E+03	--
Disulfoton	298-04-4	4E-05	3E+00	1E+00	--
Endosulfan	115-29-7	5E-05	4E+00	2E+00	2E-01
Endothal	145-73-3	2E-02	2E+03	7E+02	--
Endrin	72-20-8	3E-04	2E+01	See MCL	1E+00
Ethylbenzene	100-41-4	1E-01	8E+03	4E+03	--
Heptachlor	76-44-8	5E-04	4E+01	2E+01	--
Heptachlor epoxide	1024-57-8	1E-05	8E-01	4E-01	--
Hexachlorobuta-diene	87-68-3	2E-03	2E+02	7E+01	--
Hexachlorocyclo-pentadiene	77-47-4	7E-03	6E+02	2E+02	--
Hexachloroethane	67-72-1	1E-03	8E+01	4E+01	--
Hydrogen cyanide	74-90-8	2E-02	2E+03	7E+02	--
Hydrogen sulfide	7783-06-4	3E-03	2E+02	1E+02	--
Isobutyl alcohol	78-83-1	3E-01	2E+04	1E+04	1E+03
Isophorone	78-59-1	2E-01	2E+04	7E+03	--
Lindane (hexa-chlorocyclohexane)	58-89-9	3E-04	2E+01	See MCL	--
Maleic hydrazide	108-31-6	5E-01	4E+04	2E+04	--
Methacrylonitrile	126-98-7	1E-04	8E+00	4E+00	--
Methomyl	16752-77-5	3E-02	2E+03	1E+03	--
Methyl ethyl ketone	78-93-3	5E-02	4E+03	2E+03	--
Methylisobutyl-ketone	108-10-01	5E-02	4E+03	2E+03	--

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-7. (continued)[1]

Constituent	CAS No.	RfD[2] (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m3)
Methyl mercury	22967-92-6	3E-04	2E+01	1E+01	--
Methyl parathion	298-00-0	3E-04	2E+01	1E+01	1E+00
Nickel	7440-02-0	2E-02	2E+03	7E+02	--
Nitric oxide	10102-43-9	1E-01	8E+03	4E+03	--
Nitrobenzene	98-95-3	5E-04	4E+01	2E+01	--
Nitrogen dioxide	10102-44-0	1E+00	8E+04	4E+04	--
Octamethylpyro-phosphoramide	152-16-9	2E-03	2E+02	7E+01	--
Parathion	56-38-2	3E-04	2E+01	1E+01	--
Pentachlorobenzene	608-93-5	8E-04	6E+01	3E+01	3E+00
Pentachloronitro-benzene	82-68-8	3E-03	2E+02	1E+02	--
Pentachlorophenol	87-86-5	3E-02	2E+03	1E+03	1E+02
Perchloroethylene (Tetrachloro-ethylene)	127-18-4	1E-02	8E+02	4E+02	--
Phenol	108-95-2	4E-02	3E+03	1E+03	--
Phenyl mercuric acetate	62-38-4	8E-05	6E+00	3E+00	--
Phosphine	7803-51-2	3E-04	2E+01	1E+01	--
Potassium cyanide	151-50-8	5E-02	4E+03	2E+03	--
Potassium silver cyanide	506-61-6	2E-01	2E+04	7E+03	--
Pronamide (Kerb)	23950-58-5	8E-02	6E+03	3E+03	--
Pyridine	110-86-1	1E-03	8E+01	4E+01	--
Selenious Acid	7782-49-2	3E-03	2E+02	See MCL	--
Selenourea	630-10-4	5E-03	4E+02	2E+02	--
Silver	7440-22-4	3E-03	2E+02	See MCL	--
Silver cyanide	506-64-9	1E-01	8E+03	4E+03	--
Silvex (2,4,5-TP)	93-72-1	8E-03	6E+02	3E+02	--
Sodium cyanide	143-33-9	4E-02	3E+03	1E+03	--
Strychnine	57-24-9	3E-04	2E+01	1E+01	--
Styrene	100-42-5	2E-01	2E+04	7E+03	--
1,2,4,5-Tetrachlorobenzene	95-94-3	3E-04	2E+01	1E+01	1E+00

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-7. (continued)[1]

Constituent	CAS No.	RfD[2] (mg/kg/day)	Soil (mg/kg)	Water (µg/l)	Air (µg/m³)
2,3,4,6-Tetrachlorophenol	58-90-2	3E-02	2E+03	1E+03	1E+02
Tetraethyl lead	78-00-2	1E-07	8E-03	4E-03	4E-04
Thallic oxide	1314-32-5	4E-04	3E+01	1E+01	--
Thallium acetate	563-68-8	5E-04	4E+01	2E+01	--
Thallium carbonate	6533-73-9	4E-04	3E+01	1E+01	--
Thallium chloride	7791-12-0	4E-04	3E+01	1E+01	--
Thallium nitrate	10102-45-1	5E-04	4E+01	2E+01	--
Thallium selenite	12039-52-0	5E-04	4E+01	2E+01	--
Thallium sulfate	10031-59-1	3E-04	2E+01	1E+01	--
Thiram	137-26-8	5E-03	4E+02	2E+02	--
Toluene	108-88-3	3E-01	2E+04	1E+04	--
1,2,4-Trichlorobenzene	120-82-1	2E-02	2E+03	7E+02	--
1,1,1-Trichloroethane	71-55-6	9E-02	7E+03	See MCL	--
1,1,2-Trichloroethane	79-00-5	2E-01	2E+04	7E+03	--
Trichloromono-fluoromethane	75-69-4	3E-01	2E+04	1E+04	--
2,4,5-Trichlorophenol	95-95-4	1E-01	8E+03	4E+03	4E+02
2,4,5-Trichloro-phenoxy acetic acid (2,4,5-T)	93-76-5	3E-03	2E+02	See MCL	--
1,1,2-Trichloropropane	598-77-6	5E-03	4E+02	2E+02	--
1,2,3-Trichloropropane	96-18-4	1E-03	8E+01	4E+01	--
Vanadium pentoxide	1314-62-1	2E-02	2E+03	7E+02	--
Warfarin	81-81-2	3E-04	2E+01	1E+01	--
Xylene (total)	1330-20-7	2E+00	2E+05	7E+04	--
Zinc cyanide	557-21-1	5E-02	4E+03	2E+03	--
Zinc phosphide	1314-84-7	3E-04	2E+01	1E+01	--

1 These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

2 See Table 8-2 for the appropriate intake assumptions used to derive these criteria.

Table 8-8. Water Quality Criteria Summary[1]

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Acenapthene[11]	1,700[8]	520[8]	970[8]	710[8]			1980FR
Acrolein	68[8]	21[8]	55[8]		320 µg	780µg	1980FR
Acrylonitrile	7,550[8]	2,600[8]			0.058 µg[9]	0.65µg[9]	1980FR
Aldrin	3.0		1.3		0.074ng[9]	0.079ng[9]	1980FR
Alkalinity[11]		20,000					1976RB
Ammonia[2,11]							1985FR
Antimony	9,000[8]	1,600[8]			146µg	45,000 µg	1980FR
Arsenic					2.2ng[9]	17.5ng[9]	1980FR
Arsenic (PENT)	850[8]	48[8]	2,319[8]	13[8]			1985FR
Arsenic (TRI)	360	190	69	36			1985FR
Asbestos[11]					30k f/L[9]		1960FR
Bacteria[3,11]							1966FR
Barium					1mg		1976RB
Benzene	5,300[8]		5,100[8]	700[8]	0.66µg[9]	40µg[9]	1980FR
Benzidine	2,500[8]				0.12ng[9]	0.53ng[9]	1980FR
Beryllium	130[8]	5.3[8]			6.8ng[9]	117ng[9]	1980FR
BHC	100[8]		0.34[8]				1980FR
Cadmium	3.9[7]	1.1[7]	43	9.3	10µg		1985FR
Carbon tetrachloride	35,200[8]		50,000[8]		0.4µg[9]	6.94µg[9]	1980FR
Chlordane	2.4	0.0043	0.09	0.004	0.46ng[9]	0.48ng[9]	1980FR
Chlorindated Benzenes	250[8]	50[8]	160[8]	129[8]	488µg		1980FR
Chlorinated Naphthalenes	1,600[8]		7.5[8]				1980FR
Chlorine[11]	19	11	13	7.5			1985FR
Chloroalkyl Ethers[11]	238,000[8]						1980FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-8. (continued)[1]

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Chloroethyl ether (BIS-2),					0.03µg[9]	1.36µg[9]	1980FR
Chloroform	28,900[8]	1,240[8]			0.19µg[9]	15.7µg[9]	1980FR
Chloroisopropyl ether (BIS-2)[11]					34.7µg	4.36mg	1980FR
Chloromethyl ether (BIS)					0.00000376 ng[9]	0.00184µg[9]	1980FR
Chlorophenol 2[11]	4,380[8]	2,000[8]					1980FR
Chlorophenol 4			29,700[8]				1980FR
Chlorophenoxy Herbicides (2,4,5-TP)					10µg		1980FR
Chlorophenoxy Herbicides (2,4,-D)					100µg		1976FR
Chlorpyrifos[11]	0.083	0.041	0.011	0.0056			1986FR
Chloro-4 methyl-3 phenol	30[8]						1980FR
Chromium (HEX)	16	11	1,100	50	50µg		1985FR
Chromium (TRI)	1,700[7]	210[7]	10,300[8]		170mg	3,433mg	1985FR
Color[4,11]							1976RB
Copper[11]	18[7]	12[7]	2.9	2.9			1985FR
Cyanide	22	5.2	1	1	200µg		1985FR
DDT	1.1	0.001	0.13	0.001	0.024ng[9]	0.024ng[9]	1980FR
DDT Metabolite (DDE)	1,050[8]		14[8]				1980FR
DDT Metabolite (TDE)	0.06[8]		3.8[8]				1980FR
Demeton[11]		0.1		0.1			1976RB
Dibutyl phthalate					35mg	154mg	1980FR
Dichlorobenzenes	1,120[8]	763[8]	1,970[8]		400µg	2.6mg	1980FR
Dichlorobenzidine					0.01µg[9]	0.020µg[9]	1980FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)[1]

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Dichloroethane 1,2	118,000[8]	20,000[8]	113,000[8]		0.94µg[9]	243µg[9]	1980FR
Dichloroethylenes	11,600[8]		224,000[8]		0.033µg[9]	1.85µg[9]	1980FR
Dichlorophenol 2,4	2,020[8]	365[8]			3.09mg		1980FR
Dichloropropane	23,000[8]	5,700[8]	10,300[8]	3,040[8]			1980FR
Dichloropropene	6,060[8]	244[8]	790[8]		87µg	14.1mg	1980FR
Dieldrin	2.5	0.0019	0.71	.0019	0.071ng[9]	0.076ng[9]	1980FR
Diethyl phthalate					350mg	1.8g	1980FR
Dimethyl phenol 2,4	2,120[8]						1980FR
Dimethyl phthalate					313mg	2.9g	1980FR
Dinitrotoluene 2,4					0.11µg[9]	9.1µg[9]	1980FR
Dinitrotoluene					70µg	14.3µg	1980FR
Dinitrotoluene	330[8]	230[8]	590[8]	370[8]			1980FR
Dinitro-o-Cresol 2,4					13.4µg	765µg	1980FR
Dioxin (2,3,7,8-TCDD)	0.01[8]	0.00001[8]			0.000013 ng[9]	0.000014ng[9]	1984FR
Diphenylhydrazine					42ng[9]	0.56µg[9]	1980FR
Diphenylhydrazine 1,2	270[8]						1980FR
Di-2-ethyl hexyl phthalate					15mg	50mg	1980FR
Endosulfan	0.22	0.056	0.034	0.0087	74µg	159µg	1980FR
Endrin	0.18	0.0023	0.037	0.0023	1µg		1980FR
Ethylbenzene[11]	32,000[8]		430[8]		1.4mg	3.28mg	1980FR
Fluoranthene	3,980[8]		40[8]	16[8]	42µg	54µg	1980FR
Gases, Total[4,11] Dissolved							1976RB
Guthion[11]		0.01		0.01			1976RB

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-8. (continued)[1]

Chemical	WATER CONCENTRATIONS IN µgL FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Haloethers	360[8]	122[8]					1980FR
Halomethanes	11,000[8]		12,000[8]	8,400[8]	0.19µg[9]	15.7µg[9]	1980FR
Heptachlor	0.52	0.0038	0.053	0.0036	0.28ng[9]	0.29ng[9]	1980FR
Hexachloroethane	960[8]	540[8]	940[8]		1.9µg	8.74µg	1980FR
Hexachlorobenzene					0.72ng[9]	0.74ng[9]	1980FR
Hexachloro-butadiene	90[8]	9.3[8]	32[8]		0.45µg[9]	50µg[9]	1980FR
Hexachlorocyclo-hexane (Lindane)	2.0	0.08	0.16				1980FR
Hexachlorocyclo-hexane-Alpha[11]					9.2ng[9]	31ng[9]	1980FR
Hexachlorocyclo-hexane-Beta[11]					16.3ng[9]	54.7ng[9]	1980FR
Hexachlorocyclo-hexane-Gamma[11]					18.6ng[9]	62.5ng[9]	1980FR
Hexachlorocyclo-hexane-Technical[11]					12.3ng[9]	41.4ng[9]	1980FR
Hexachlorocyclo-pentadine	7[8]	5.2[8]	7[8]		206µg		1980FR
Iron[11]		1,000			0.3mg		1976RB
Isophorone[11]	117,000[8]		12,900[8]		5.2mg	520mg	1980FR
Lead	82[7]	3.2[7]	140	5.6	50µg		1985FR
Malathion[11]		0.1		0.1			1976RB
Manganese[11]					50µg	100µg	1976RB
Mercury	2.4	0.012	2.1	0.025	144ng	146ng	1985FR
Methoxychlor		0.03		0.03	100µg		1976RB
Mirex[11]		0.001		0.001			1976RB
Monochloro-benzene					488µg		1980FR
Naphthalene	2,300[8]	620[8]	2,350[8]				1980FR
Nickel	1,400[7]	160[7]	75	8.3	13.4µg	100µg	1986FR
Nitrates[11]					10mg		1976RB

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Table 8-8. (continued)[1]

Chemical	WATER CONCENTRATIONS IN ug/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Nitrobenzene	27,000[8]		6,680[8]		19.8mg		1980FR
Nitrophenols	230[8]	150[8]	4,850[8]				1980FR
Nitrosamines	5,650[8]		3,300,000[8]		0.8ng[9]	1240ng[9]	1980FR
Nitrosodibutyl-amine N					6.4ng[9]	587ng[9]	1980FR
Nitrosodiethyl-amine N					0.8ng[9]	1,240ng[9]	1980FR
Nitrosodimethyl-amine N					1.4ng[9]	16,000ng[9]	1980FR
Nitrosodiphenyl-amine N					4,900ng[9]	16,100ng[9]	1980FR
Nitrosopyrrolidine N					16ng[9]	91,900ng[9]	1980FR
Oil and Grease[4,11]							1976RB
Oxygen Dissolved[5,11]							1986FR
Parathion	0.065	0.013					1986FR
PCB's	2.0	0.014	10	0.03	0.079ng[9]	0.079ng[9]	1980FR
Pentachlorinated Ethanes	7,240[8]	1,100[8]	390[8]	281[8]			1980FR
Pentachloro-benzene					74g	85ug	1980FR
Pentachlorophenol	20[10]	13[10]	13	7.9[8]	1.01mg		1966FR
pH[11]		6.5-9		6.5-8.5			1976RB
Phenol	10,200[8]	2,560[8]	5,800[8]		3.5mg		1980FR
Phosphorus Elemental[11]				0.1			1976RB
Phthalate Esters	940[8]	3[8]	2,944[8]	3.4[8]			1980FR
Polynuclear Aromatic Hydrocarbons			300[8]		2.8ng[9]	31.1ng[9]	1980FR
Selenium	260	35	410	54	10ug		1980FR
Silver	4.1[7]	0.12	2.3		50ug		1980FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

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Table 8-8. (continued)[1]

Chemical	WATER CONCENTRATIONS IN µg/L FOR AQUATIC LIFE				WATER CONCENTRATIONS IN UNITS PER LITER FOR HUMAN EXPOSURE		Date Reference
	Fresh Acute Criteria	Fresh Chronic Criteria	Marine Acute Criteria	Marine Chronic Criteria	Water and Fish Ingestion	Fish Consumption Only	
Solids Dissolved and Salinity[11]					250mg		1976RB
Solids Suspended and Turbidity[4,11]							1976RB
Sulfide-Hydrogen Sulfide		2		2			1976RB
Temperature[6,11]							1976RB
Tetrachlorinated Ethanes	9,320[8]						1980FR
Tetrachloro-benzene 1,2,4,5					38µg	48µg	1980FR
Tetrachloroethane 1,1,2,2		2,400[8]	9,020[8]		0.17µg[9]	10.7µg[9]	1980FR
Tetrachloroethanes	9,320[8]						1980FR
Tetrachloro-ethylene	5,280[8]	840[8]	10,200[8]	450[8]	0.8µg[9]	8.85µg[9]	1980FR
Tetrachlorophenol 2,3,5,6				440[8]			1980FR
Thallium	1,400[8]	40[8]	2,130[8]		13µg	48µg	1980FR
Toluene	17,500[8]		6,300[8]	5,000[8]	14.3mg	424mg	1980FR
Toxaphene	0.73	0.0002	0.21	0.0002	0.71ng[9]	0.73ng[9]	1986FR
Trichlorinated Ethanes	18,000[8]						1980FR
Trichloroethane 1,1,1			31,200[8]		18.4mg	1.03g	1980FR
Trichloroethane 1,1,2		9,400[8]			0.6µg[9]	41.8µg[9]	1980FR
Trichloroethylene	45,000[8]	21,900[8]	2,000[8]		2.7µg[9]	80.7µg[9]	1980FR
Trichlorophenol 2,4,5					2,600µg		1980FR
Trichlorophenol 2,4,6		970[8]			1.2µg[9]	3.6µg[9]	1980FR
Vinyl Chloride					2µg[9]	525µg[9]	1980FR
Zinc[11]	120[7]	110[7]	95	86			1987FR

Note: These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

Footnotes for Table 8-8:

1 This table is for general information purposes only; see criteria documents or detailed summaries in Quality Criteria for Water 1986 for more information. These criteria are subject to change and will be confirmed by the regulatory agency prior to use.

2 Criteria are pH and temperature dependent - See Document (1)

3 For primary recreation and shellfish uses - See Document (1)

4 Narrative statement - See Document (1)

5 Warmwater and coldwater criteria matrix - See Document (1)

6 Species dependent criteria - See Document (1)

7 Hardness Dependent Criteria (100 mg/l used)

8 Insufficient data to develop criteria. Value presented is lowest observed effect level.

9 Human health criteria for carcinogens reported for three risk levels. Value presented in this table is the 10^{-6} risk level.

10 pH dependent criteria - 7.8 pH used.

11 Indicates chemical or parameter not on Appendix VIII. The regulatory agency will exercise discretion prior to requiring such chemicals or parameters to be monitored during the RFI.

General -

g	=	grams	FR	=	Federal Register
mg	=	milligrams	RB	=	Quality Criteria for Water, 1976 (Redbook)
µg	=	micrograms			
ng	=	nanograms			
f	=	fibers			

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Table 8-9. Individual Listing of Constituents Contained Within Chemical Groups Identified in Table 8-8

Chemical Group	Individual Constituents
Chlorinated Benzenes	Chlorobenzene 1,2,4-Trichlorobenzene Hexachlorobenzene
Chlorinated Ethanes	1,2-Dichloroethane 1,1,1-Trichloroethane Hexachloroethane 1,1-Dichloroethane 1,1,2-Trichloroethane Chloroethane
Chloroalkyl Ethers	Bis(chloromethyl) ether Bis(2-chloroethyl ether 2-Chloroethyl vinyl ether (mixed)
Chlorinated Naphthalene	2-Chloronaphthalene
Chlorinated Phenols	2,4,5-Trichlorophenol Parachlorometa cresol
Dichlorobenzenes	1,2-Dichlorobenzene 1,3-Dichlorobenzene 1,4-Dichlorobenzene
Dichlorobenzidine	3,3'-Dichlorobenzidine
Dichloroethylenes	1,1-Dichloroethylene 1,2-Trans-dichloroethylene
Dichloropropane and Dichloropropene	1,2-Dichloropropane 1,2-Dichloropropylene (1,3-dichloropropene)
Dinitrotoluene	2,4-Dinitrotoluene 2,5-Dinitrotoluene
Haloethers	4-Chlorophenyl phenyl ether 4-Bromophenyl phenyl ether Bis (2-chloroisopropyl) ether Bis (2-chloroethoxy) methane
Halomethanes	Methylene chloride (dichloromethane) Methyl chloride (chloromethane) Methyl bromide (bromomethane) Bromoform (tribromomethane) Dichlorobromomethane Trichlorofluoromethane Dichlorodifluoromethane Chlorodibromomethane

Table 8-9. (Continued)

Chemical Group	Individual Constituents
Nitrophenols	2-Nitrophenol 4-Nitrophenol 2,4-Dinitrophenol 4,6-Dinitro-o-cresol
Nitrosamines	N-Nitrosodimethylamine N-Nitrosodiphenylamine N-Nitrosodi-n-propylamine
Phthalate Esters	Bis (2-ethylhexyl) phthalate Butyl benzyl phthalate Di-n-butyl phthalate Di-n-octyl phthalate Diethyl phthalate Dimethyl phthalate
Polynuclear Aromatic Hydrocarbons	Benzo(a) anthracene (1,2-benzanthracene) Benzo(a) pyrene 3,4-Benzofluoranthene Benzo(k) fluoranthene (11,12-benzofluoranthene) Chrysene Acenaphthylene Anthracene Benzo(ghi)Perylene (1,12-benzoperylene) Fluorene Phenanthrene Dibenzo(a,h)anthracene (1,2,5,6-dibenzanthracene) Indeno (1,2,3-cd)pyrene Pyrene
Endosulfan and Metabolites	a-Endosulfan-Alpha p-Endosulfan-Beta Endosulfan sulfate
Endrin and Metabolites	Endrin
Heptachlor and Metabolites	Heptachlor Heptachlor epoxide
Polychlorinated Biphenyls	PCB-1242 (Arochlor 1242) PCB-1254 (Arochlor 1254) PCB-1221 (Arochlor 1221) PCB-1232 (Arochlor 1232) PCB-1248 (Arochlor 1248) PCB-1260 (Arochlor 1260) PCB-1016 (Arochlor 1016)

Table 8-10

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards: Status Reg.*	Standards: NIPDWR (ug/l)	Standards: MCLG (ug/l)	Standards: MCL (ug/l)	Health Advisories: Status HA*	10-kg Child: One-day ug/l	10-kg Child: Ten-day ug/l	10-kg Child: Longer-term ug/l	70-kg Adult: Longer-term ug/l	70-kg Adult: RfD ug/kg/day	70-kg Adult: DWEL ug/l	70-kg Adult: Lifetime ug/l	ug/l at 10-4 Cancer Risk	Cancer Group
Organics														
Acenaphthylene	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Acifluorfen	-	-	-	-	F	2000	200	100	400	13	400	-	100	B2
Acrylamide	P	-	zero	TT	F	150	300	20	70	0.2	7	-	1	B2
Acrylonitrile	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Adipates	T	-	zero	-	-	-	-		-	-	-	-	-	-
Alachlor	P	-	zero	2	F	100	100	-	-	10	400	-	40	B2
Aldicarb	P	-	10	10	F	10	10	10	40	1.3	40	10	-	D
Aldicarb sulfone	P	-	40	40	F	60	60	60	200	6.0	200	40	-	D
Aldicarb sulfoxide	P	-	10	10	F	10	10	10	40	1.3	40	10	-	D
Ametryn	-	-	-	-	F	9000	9000	900	3000	9	300	60	-	D
Ammonia	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Ammonium Sulfamate	-	-	-	-	F	20000	20000	20000	80000	250	8000	2000	-	D
Anthracene	L	-	-	-	-	-	-	-	-	-	-	-	-	D
Atrazine	P	-	3	3	F	100	100	50	200	5	200	3	-	C
Baygon	-	-	-	-	F	40	40	40	100	4	100	3	-	C
Bentazon	-	-	-	-	F	300	300	300	900	2.5	90	20	-	D
Benz(a)anthracene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Benzene	F	-	zero	5	F	200	200	-	-	-	-	-	100	A
Benzo(a)pyrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Benzo(b)fluoranthene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Benzo(g,h,i)perylene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	D
Benzo(k)fluoranthene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
bis-2-Chloroisopropyl ether	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Bromacil	-	-	-	-	F	5000	5000	3000	9000	130	5000	90	-	C
Bromobenzene	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Bromochloroacetonitrile	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Bromochloromethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Bromodichloromethane (THM)	L	100	-	-	D	-	-	-	-	2	-	-	-	-
Bromoform (THM)	L	100	-	-	D	-	-	-	-	20	-	-	-	-
Bromomethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Butyl benzyl phthalate (BBP)	T	zero	-	-	-	-	-	-	-	200	-	-	-	C
Butylate	-	-	-	-	F	2000	2000	1000	1000	50	2000	350	-	D
Butylbenzene n-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Butylbenzene sec-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Butylbenzene tert-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Carbaryl	-	-	-	-	F	1000	1000	1000	1000	100	4000	700	-	D
Carbofuran	P	-	40	40	F	50	50	50	200	5	200	40	-	E
Carbon Tetrachloride	F	-	zero	5	F	4000	200	70	300	0.7	30	-	30	B2

Table 8-10 (Continued)

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards				Health Advisories									
						10-kg Child			70-kg Adult					
	Status Reg.*	NIPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA*	One-day ug/l	Ten-day ug/l	Longer-term ug/l	Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	Cancer Group
Carboxin	-	-	-	-	F	1000	1000	1000	4000	100	4000	700	-	D
Chloramben	-	-	-	-	F	3000	3000	200	500	15	500	100	-	D
Chloramine	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorate	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlordane	P	-	zero	2	F	60	60	0.5	0.5	0.045	2	-	3	B2
Chlorine	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorine dioxide	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorite	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chloroacetaldehyde	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorodibromomethane (THM)	L	100	-	-	D	-	-	-	-	2	-	-	-	-
Chloroethane	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chloroform (THM)	L	100	-	-	D	-	-	-	-	10	-	-	600	B2
Chloromethane	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Chlorophenol (2,4,6-)	L	-	-	-	D	-	-	-	-	-	-	-	300	B2
Chlorophenol (2,4-)	L	-	-	-	D	-	-	-	-	3	100	-	-	-
Chlorophenol (2-)	L	-	-	-	D	-	-	-	-	5	200	-	-	-
Chloropicrin	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Chlorothalonil	-	-	-	-	F	200	200	200	500	15	500	-	200	B2
Chlorotoluene o-	L	-	-	-	D	-	-	-	-	20	-	-	-	D
Chlorotoluene p-	L	-	-	-	D	-	-	-	-	0.1	-	-	-	D
Chrysene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Cyanazine	L	-	zero	-	F	100	100	20	70	2	70	10	-	D
Cyanogen Chloride	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Cymene p-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
2,4-D	P	100	70	70	F	1000	300	100	400	10	400	70	-	D
Dacthal (DCPA)	-	-	-	-	F	80000	80000	5000	20000	500	20000	4000	-	D
Dalapon	T	-	200	-	F	3000	3000	300	900	26	900	200	-	D
DCE (cis-1,2-)	P	-	70	70	F	4000	1000	1000	1000	10	400	70	-	D
DCE (trans-1,2-)	P	-	100	100	F	20000	2000	2000	6000	20	600	100	-	D
Diazinon	-	-	-	-	F	20	20	5	20	0.09	3	0.6	-	E
Dibenz(a,h)anthracene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	B2
Dibromoacetonitrile	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dibromochloropropane (DBCP)	P	-	zero	0.2	F	200	50	-	-	-	-	-	3	B2
Dibromomethane	L	-	-	-	D	-	-	-	-	-	-	-	-	D
Dibutyl phthalate (DBP)	T	-	zero	-	-	-	-	-	-	100	-	-	-	D
Dicamba	L	-	-	-	F	300	300	300	1000	30	1000	200	-	D
Dichloroacetaldehyde	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloroacetic acid	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloroacetonitrile	L	-	-	-	D	-	-	-	-	8	-	-	-	C

Table 8-10 (Continued)

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards				Health Advisories									
						10-kg Child			70-kg Adult					
	Status Reg.*	NIPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA*	One-day ug/l	Ten-day ug/l	Longer-term ug/l	Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	Cancer Group
Dichlorobenzene p- †	F	-	75	75	F	10000	10000	10000	40000	100	4000	75	-	C
Dichlorobenzene o-,m-	P	-	600	600	F	9000	9000	9000	30000	89	3000	600	-	D
Dichlorodifluoromethane	-	-	-	-	D	-	-	-	-	20	-	-	-	-
Dichloroethane (1,1-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloroethane (1,2-)	F	-	zero	5	F	700	700	700	2600	-	-	-	40	B2
Dichloroethylene (1,1-)	F	-	7	7	F	2000	1000	1000	4000	9	400	7	-	C
Dichloromethane	T	-	zero	-	F	10000	2000	-	-	60	2000	-	500	B2
Dichloropropane (1,1-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropane (1,2-)	P	-	zero	5	F	-	90	-	-	-	-	-	60	B2
Dichloropropane (1,3-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropane (2,2-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropene (1,1-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dichloropropene (1,3-)	L	-	-	-	F	30	30	30	100	0.3	10	-	20	B2
Dieldrin	L	-	-	-	F	0.5	0.5	0.5	2	0.05	2	-	0.2	B2
Diethyl phthalate (DEP)	T	-	zero	-	D	-	-	-	-	800	-	-	-	D
Diethylhexyl phthalate (DEHP)	T	-	zero	-	D	-	-	-	-	20	-	-	-	B2
Dimethrin	-	-	-	-	F	10000	10000	10000	40000	300	10000	2000	-	D
Dimethyl phthlate (DMP)	L	-	-	-	-	-	-	-	-	-	-	-	-	D
Dinitrotoluene (2,4-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Dinoseb	T	-	7	-	F	300	300	10	40	1	40	7	-	-
Dioxane p-	-	-	-	-	F	4000	400	-	-	-	-	-	700	B2
Diphenamid	-	-	-	-	F	300	300	300	1000	30	1000	200	-	D
Diquat	T	-	20	-	-	-	-	-	-	2.2	-	-	-	-
Disulfoton	-	-	-	-	F	10	10	3	9	0.04	1	0.3	-	E
Diuron	-	-	-	-	F	1000	1000	300	900	2	70	10	-	D
Endothall	T	-	100	-	F	800	800	200	200	20	700	100	-	D
Endrin	T	0.2	2	-	F	20	20	3	10	3	9	2	-	D
Epichlorohydrin	P	-	zero	TT	F	100	100	70	70	2	70	-	400	B2
Ethylbenzene	P	-	700	700	F	30000	3000	1000	3000	100	3000	700	-	D
Ethylene dibromide (EDB)	P	-	zero	0.05	F	8	8	-	-	-	-	-	0.04	B2
Ethylene glycol	-	-	-	-	F	20000	6000	6000	20000	2000	40000	7000	-	D
ETU	L	-	-	-	F	300	300	100	400	0.03	1	-	20	B2
Fenamiphos	-	-	-	-	F	9	9	5	20	0.25	9	2	-	D
Fluometuron	-	-	-	-	F	2000	2000	2000	5000	13	400	90	-	D
Fluorene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	D
Fluorotrichloromethane	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Fonofos	-	-	-	-	F	20	20	20	70	2	70	10	-	D
Formaldehyde	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Gasoline	-	-	-	-	D	-	-	-	-	-	-	-	-	-

Table 8-10 (Continued)

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards				Health Advisories										Cancer Group
						10-kg Child			70-kg Adult						
	Status Reg.*	NIPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA*	One-day ug/l	Ten-day ug/l	Longer-term ug/l	Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk		
Glyphosate	T	-	700	-	F	20000	20000	1000	1000	100	4000	700	-		D
Heptachlor	P	-	zero	0.4	F	10	10	5	5	0.5	20	-	0.8		B2
Heptachlor epoxide	P	-	zero	0.2	F	10	-	0.1	0.1	0.013	0.4	-	0.4		B2
Hexachlorobenzene	T	-	zero	-	F	50	50	50	200	0.8	30	-	2		B2
Hexachlorobutadiene	-	-	-	-	D	-	-	-	-	2	-	-	50		C
Hexachlorocyclopentadiene	T	-	50	-	-	-	-	-	-	7	200	-	-		-
Hexane (n-)	-	-	-	-	F	10000	4000	4000	10000	-	-	-	-		D
Hexazinone	-	-	-	-	F	3000	3000	3000	9000	30	1000	200	-		D
Hypochlorite	L	-	-	-	-	-	-	-	-	-	-	-	-		-
Hypochlorous acid	L	-	-	-	-	-	-	-	-	-	-	-	-		-
Indeno(1,2,3,-c,d)pyrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-		B2
Isophorone	L	-	-	-	D	-	-	-	-	150	-	-	-		-
Isopropylbenzene	-	-	-	-	D	-	-	-	-	-	-	-	-		-
Lindane	P	4	0.2	0.2	F	1000	1000	30	100	0.3	10	0.2	3		C
Maleic hydrazide	-	-	-	-	F	10000	10000	5000	20000	500	20000	4000	-		D
MCPA †	-	-	-	-	F	100	100	100	400	0.5	20	4	-		E
Methomyl	-	-	-	-	F	300	300	300	300	25	900	200	-		D
Methoxychlor	P	100	400	400	F	6000	2000	500	2000	50	2000	400	-		D
Methyl ethyl ketone	-	-	-	-	F	80000	8000	3000	9000	50	900	200	-		D
Methyl parathion	-	-	-	-	F	300	300	30	100	0.25	9	2	-		D
Methyl tert butyl ether	L	-	-	-	D	-	-	-	-	-	-	-	-		-
Metolachlor	L	-	-	-	F	2000	2000	2000	5000	150	5000	100	-		C
Metribuzin	L	-	-	-	F	5000	5000	300	900	25	900	200	-		D
Monochloroacetic acid	L	-	-	-	D	-	-	-	-	-	-	-	-		-
Monochlorobenzene	P	-	100	100	F	2000	2000	2000	7000	20	700	100	-		D
Naphthalene	-	-	-	-	D	-	-	-	-	410	-	-	-		-
Oxamyl (Vydate)	T	-	200	-	F	200	200	200	900	25	900	200	-		E
Ozone by-products	L	-	-	-	-	-	-	-	-	-	-	-	-		-
Paraquat	-	-	-	-	F	100	100	50	200	4.5	200	30	-		E
Pentachloroethane	-	-	-	-	D	-	-	-	-	-	-	-	-		-
Pentachlorophenol	P	-	0/200	0/200	F	1000	300	300	1000	30	1000	0/200	-		B2/D
Phenanthrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-		-
Phenol	-	-	-	-	D	-	-	-	-	600	-	-	-		-
Picloram	T	-	500	-	F	20000	20000	700	2000	70	2000	500	-		D
Polychlorinated byphenols (PCBs)	P	-	zero	0.5	P	-	-	1	4	-	-	-	0.5		B2
Prometon	-	-	-	-	F	200	200	200	500	15	500	100	-		D
Pronamide	-	-	-	-	F	800	800	800	3000	75	3000	50	-		C
Propachlor	-	-	-	-	F	500	500	100	500	13	500	90	-		D
Propazine	-	-	-	-	F	1000	1000	500	2000	20	700	10	-		C

Table 8-10 (Continued)

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards				Health Advisories									Cancer Group
						10-kg Child			70-kg Adult					
	Status Reg.*	NIPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA*	One-day ug/l	Ten-day ug/l	Longer-term ug/l	Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	
Propham	-	-	-	-	F	5000	5000	5000	20000	20	600	100	-	D
Propylbenzene n-	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Pyrene (PAH)	T	-	zero	-	-	-	-	-	-	-	-	-	-	D
Simazine	T	-	4	-	F	500	500	50	200	5	200	4	-	C
Styrene	P	-	zero/100	5/100	F	20000	2000	2000	7000	200	7000	0/100	1	B2/C
2,4,5-T	L	-	-	-	F	800	800	800	1000	10	350	70	-	D
2,3,7,8-TCDD (Dioxin)	T	-	zero	-	F	0.001	1E-04	1E-05	4E-05	1E-06	4E-05	-	2E-05	B2
Tebuthiuron	-	-	-	-	F	3000	3000	700	2000	70	2000	500	-	D
Terbacil	-	-	-	-	F	300	300	300	900	13	400	90	-	E
Terbufos	-	-	-	-	F	5	5	1	5	0.13	5	0.9	-	D
Tetrachloroethane (1,1,1,2-)	L	-	-	-	D	-	-	-	-	30	-	-	-	-
Tetrachloroethane (1,1,2,2-)	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Tetrachloroethylene	P	-	zero	5	F	2000	2000	1000	5000	10	500	-	70	B2
Toluene	P	-	2000	2000	F	20000	3000	3000	10000	300	10000	2000	-	-
Toxaphene	P	5	zero	5	F	500	40	-	-	100	-	-	3	B2
2,4,5-TP	P	10	50	50	F	200	200	70	300	7.5	300	50	-	-
Trichloroacetaldehyde	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichloroacetic acid	L	-	-	-	D	-	-	-	-	600	-	-	-	-
Trichloroactonitrile	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichlorobenzene (1,2,4-)	T	-	9	-	D	-	-	-	-	-	-	-	-	-
Trichlorobenzene (1,3,5-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichloroethane (1,1,1-) †	F	-	200	200	F	100000	40000	40000	100000	90	1000	200	-	D
Trichloroethane (1,1,2-)	T	-	3	-	D	-	-	-	-	30	-	-	-	C
Trichloroethanol (2,2,2-)	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Trichloroethylene	F	-	zero	5	F	-	-	-	-	7	300	-	300	B2
Trichloropropane (1,1,1-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Trichloropropane (1,2,3-)	-	-	-	-	D	-	-	-	-	6	-	-	-	-
Trifluralin	L	-	-	-	F	30	30	30	30	3	100	2	-	C
Trimethylbenzene (1,2,4-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Trimethylbenzene (1,3,5-)	-	-	-	-	D	-	-	-	-	-	-	-	-	-
Vinyl chloride	F	-	zero	2	F	3000	3000	10	50	-	-	-	1.5	A
Xylenes	P	-	10000	10000	F	40000	40000	40000	10000	2000	60000	10000	-	D

Table 8-10 (Continued)

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards				Health Advisories									Cancer Group
						10-kg Child			70-kg Adult					
	Status Reg.*	NIPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Status HA*	One-day ug/l	Ten-day ug/l	Longer-term ug/l	Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	
Inorganics														
Aluminum	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Antimony	T	-	3	-	D	-	-	-	-	0.4	-	-	-	-
Arsenic	T	50	zero	-	D	-	-	-	-	1	-	-	3	A
Asbestos (fibers/l > 10um)	P	-	7E+06	7E+06	-	-	-	-	-	-	-	-	-	-
Barium	P	1000	5000	5000	F	5000	5000	5000	5000	-	-	5000	-	D
Beryllium	T	-	zero	-	D	-	-	-	-	5	-	-	-	B2
Boron	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Cadmium	P	10	5	5	F	40	40	5	20	0.5	20	5	-	D
Chromium (total)	P	50	100	100	F	1000	1000	200	800	5	200	100	-	D
Copper	P	-	1300	1300										
Cyanide	T	-	200	-	F	200	200	200	800	22	800	200	-	D
Fluoride	F	-	4000	4000	-	-	-	-	-	60	-	-	-	-
Lead (at source)	P	-	zero	5	-	-	-	-	-	-	-	-	-	-
Lead (at tap)	P	50	zero	TT	-	-	-	-	-	-	-	-	-	-
Manganese	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mercury	P	2	2	2	F	-	-	-	6	0.3	10	2	-	D
Molybdenum	L	-	-	-	D	20000	200	6	20	0.6	20	4	-	D
Nickel	T	-	100	-	F	1000	1000	100	600	20	600	100	-	D
Nitrate (as N)	P	10000	10000	10000	F	-	1000	-	-	-	-	-	-	D
Nitrite (as N)	P	-	1000	1000	F	-	1000	-	-	-	-	-	-	D
Nitrate + Nitrite	P	-	10000	10000	-	-	-	-	-	-	-	-	-	-
Selenium	P	10	50	50	-	-	-	-	-	-	-	-	-	-
Silver	L	50	-	-	D	-	-	-	-	3	-	-	-	-
Sodium	L	-	-	-	D	-	-	-	-	-	20000 ***	-	-	-
Strontium	L	-	-	-	D	-	-	-	-	-	-	-	-	-
Sulfate	T	-	300	-	-	-	-	-	-	-	-	-	-	-
Thallium	T	-	0.4	-	D	-	-	-	-	0.07	-	-	-	-
Vanadium	L	-	-	-	D	-	-	-	-	20	-	-	-	-
Zinc	L	-	-	-	D	-	-	-	-	-	-	-	-	-

Table 8-10 (Continu

DRINKING WATER STANDARDS AND HEALTH ADVISORIES --DRAFT--

Chemicals	Standards: Status Reg.*	NIPDWR (ug/l)	MCLG (ug/l)	MCL (ug/l)	Health Advisories: Status HA*	10-kg Child: One-day ug/l	Ten-day ug/l	Longer-term ug/l	70-kg Adult: Longer-term ug/l	RfD ug/kg/day	DWEL ug/l	Lifetime ug/l	ug/l at 10-4 Cancer Risk	Cancer Group
Microbiology and Turbidity														
Cryptosporidium	L	-	-	-	-	-	-	-	-	-	-	-	-	-
Giardia lamblia	P	-	zero	TT	-	-	-	-	-	-	-	-	-	-
Legionella	P	-	zero	TT	F	-	-	-	-	-	-	-	-	-
Standard plate count	P	-	NA	TT	-	-	-	-	-	-	-	-	-	-
Total coliform (current MCL based on density)	P	<1/100 ml	zero	**	-	-	-	-	-	-	-	-	-	-
Turbidity	P	1 NTU	0.1 NTU	PS	-	-	-	-	-	-	-	-	-	-
Viruses	P	-	zero	TT	-	-	-	-	-	-	-	-	-	-
MOU Chemicals														
Diisopropyl methylphosphonate	-	-	-	-	F	8000	8000	8000	30000	80	3000	600	-	D
Fog Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HMX	-	-	-	-	F	5000	5000	5000	20000	50	2000	400	-	D
Nitrocellulose (non-toxic)	-	-	-	-	F	-	-	-	-	-	-	-	-	-
Nitroguanidine	-	-	-	-	-	-	-	-	-	-	-	-	-	-
RDX	-	-	-	-	F	100	100	100	400	3	100	2	30	C
Trinitroglycerol	-	-	-	-	F	5	5	5	5	-	-	5	-	-
Trinitrotoluene	-	-	-	-	F	20	20	20	20	0.5	20	2	100	C
White Phosphorus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc chloride	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Radionuclides														
Beta particle and photon activity (formerly man-made radionuclides)	T	4mrem/yr	zero	-	-	-	-	-	-	-	-	-	4 mrem/yr	A
Gross alpha particle activity	T	15 pCi/l	zero	-	-	-	-	-	-	-	-	-	-	A
Radium 226/228	T	5 pCi/l	zero	-	-	-	-	-	-	-	-	-	29 pCi/l	A
Radon	T	-	zero	-	-	-	-	-	-	-	-	-	160 pCi/l	A
Uranium	T	-	zero	-	-	-	-	-	-	-	-	-	160 pCi/l	A

Legend for draft version of Drinking Water Standards and Health Advisories table.

Abbreviations column descriptions are:

NIPDWR - National Interim Primary Drinking Water Regulation. Interim enforceable drinking water regulations first established under the Safe Drinking Water Act that are protective of public health to the extent feasible.

MCLG - Maximum Contaminant Level Goal. A non-enforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.

MCL - Maximum Contaminant Level. Maximum permissible level of a contaminant in water which is delivered to any user of a public water system.

RfD - Reference Dose. An estimate of a daily exposure to the human population that is likely to be without appreciable risk of deleterious effects over a lifetime.

DWEL - Drinking Water Equivalent Level. A lifetime exposure concentration protective of adverse, non-cancer health effects, that assumes all of the exposure to a contaminant is from a drinking water source.

(*) The codes for the Status Reg and Status HA columns are as follows:

F - final

D - draft

L - listed for regulation

P - proposed (Phase II draft proposal)

T - tentative (Phase V)

Other codes found in the table include the following:

NA - not applicable

PS - performance standard 0.5 NTU - 1.0- NTU

TT - treatment technique

** - No more than 5% of the samples may be positive. For systems collecting fewer than 40 samples/month, no more than 1% may be positive.

*** - guidance

† - Large discrepancies between Lifetime and Longer term HA values may occur because of the Agency's conservative policies, especially with regard to carcinogenicity, relative source contribution, and less than lifetime exposures in chronic toxicity testing. These factors can result in a cumulative UF (uncertainty factor) of 10 to 1000 when calculating a Lifetime HA.

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8.10.2 Worksheets

Worksheets 8-1 and 8-2 may be used by the regulatory agency in comparing constituent concentrations in the release to health and environmental criteria. Example filled in worksheets are also shown. These worksheets address the following:

- 8-1: Comparison of individual contaminant concentrations with criteria
- 8-2: Use of hazard indices for exposure to chemical mixtures.

A questionnaire that may be used in determining if interim corrective measures are necessary is provided in Worksheet 8-3. Questions are posed to help focus the determination. These questions will be addressed to the extent possible based on available information. The regulatory agency will not necessarily need answers for all questions in order to make a decision as to whether interim corrective measures are necessary. If release concentration information is available, Worksheets 8-1 and 8-2 may also be filled out.

WORKSHEET 8-1

COMPARISON OF INDIVIDUAL CONSTITUENT CONCENTRATIONS WITH HEALTH AND ENVIRONMENTAL CRITERIA

Facility Name _____
Releasing Unit _____
Contaminated Media _____
Sample Location _____
Sample Number(s) _____
Date _____
Analyst _____

Exposure Medium	Constituent Released	Release Concentration	Table No. and Criterion Type Used	Criterion Value	Release Concentrations Exceed Criterion?
WATER					
SOIL					
AIR					

INSTRUCTIONS

1. List chemicals with human-health and environmental criteria for the appropriate exposure medium.
2. List chemical concentration for the appropriate exposure medium.
3. List type of human-health and environmental criteria used and applicable table number.
4. List appropriate criteria values.
5. Compare chemical concentration and criteria values and identify whether release concentration exceeds criteria.

EXAMPLE WORKSHEET 8-1

COMPARISON OF INDIVIDUAL CONSTITUENT CONCENTRATIONS WITH HEALTH AND ENVIRONMENTAL CRITERIA

Site Name: Site X
Releasing Unit: Impoundment 2
Contaminated Media: Ground Water/Air/Soil
Sample Location: MW 2/X-7 (see Map)
Sample Number(s): MW2-1/X-7-1
Date: 9/4/86
Analyst: JDP

Exposure Medium	Constituent Released	Release Concentration	Table No. and Criterion Type Used	Criterion Value	Release Concentrations Exceed Criterion?
WATER	Trichloroethylene	2 µg/l	MCL Table 8-7	5 µg/l	No
	Carbon tetrachloride	1 µg/l	MCL Table 8-7	5 µg/l	No
	Chloroform	3 µg/l	Carcinogen Table 8-6	5.7 µg/l	No
SOIL	Chlorobenzene	10 mg/kg	Systemic Tox. Table 8-7	2000 mg/kg	No
	Pentachlorobenzene	7 mg/kg	Systemic Tox. Table 8-7	60 mg/kg	No
AIR	Trichloroethylene	0.1 µg/m^3	Carcinogen Table 8-6	0.27 µg/m^3	No

INSTRUCTIONS

1. List chemicals with human-health and environmental criteria for the appropriate exposure medium.
2. List chemical concentration for the appropriate exposure medium.
3. List type of human-health and environmental criteria used and applicable table number.
4. List appropriate criteria values.
5. Compare chemical concentration and criteria values and identify whether release concentration exceeds criteria.

WORKSHEET 8-2

USE OF HAZARD INDICES FOR EXPOSURE TO CHEMICAL MIXTURES

Facility Name _____
Releasing Unit _____
Contaminated Media _____
Sample Location _____
Sample Number(s) _____
Date _____
Analyst _____

Exposure Medium	Constituent Released	Ratio of Release Concentration to Criterion Value	HAZARD INDICES	
			Medium Total	Value Exceeds Unity?
WATER				
SOIL				
AIR				

INSTRUCTIONS

1. List chemicals in each environmental medium, as shown in Worksheet 8-1.
2. Compare chemical concentrations and appropriate health criteria values, as shown in Worksheet 8-1. Determine ratio of release concentration to the criteria values.
3. Determine a hazard index for the chemicals in each medium by summing the ratios calculated by comparing chemical concentrations and health criteria.
4. Determine if the hazard index for the chemical mixture found in each individual exposure medium exceeds unity.

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EXAMPLE WORKSHEET 8-2

USE OF HAZARD INDICES FOR EXPOSURE TO CHEMICAL MIXTURES

Site Name: Site X
Releasing Unit: Impoundment 2
Contaminated Media: Ground Water/Air/Soil
Sample Location: MW 2/X-7 (see Map)
Sample Number(s): MW2-1/X-7-1
Date: 9/4/86
Analyst: JDP

Exposure Medium	Constituent Released	Ratio of Release Concentration to Criterion Value	HAZARD INDICES	
			Medium Total	Value Exceeds Unity?
WATER	Trichloroethylene	0.4		
	Carbon tetrachloride	0.2		
	Chloroform	0.53		
			1.13	Yes
SOIL	Chlorobenzene	0.0005		
	Pentachlorobenzene	0.12		
			0.125	No
AIR	Trichloroethylene	0.37	0.37	No

INSTRUCTIONS

1. List chemicals in each environmental medium, as shown in Worksheet 8-1.
2. Compare chemical concentrations and appropriate health criteria values, as shown in Worksheet 8-1. Determine ratio of release concentration to the criteria values.
3. Determine a hazard index for the chemicals in each medium by summing the ratios calculated by comparing chemical concentrations and health criteria.
4. Determine if the hazard index for the chemical mixture found in each individual exposure medium exceeds unity.

WORKSHEET 8-3

QUESTIONS TO BE CONSIDERED IN DETERMINING IF INTERIM CORRECTIVE MEASURES MAY BE NECESSARY

In considering the actual or potential threat to human health or the environment posed by a contaminant release, the regulatory agency will consider factors such as type and extent of the release and site demographics. The following questions may be used in evaluating these factors. If sufficient information is available, the worksheets presented on the previous pages may also be used in evaluating the need for interim corrective measures. For further details, see RCRA Corrective Action Interim Measures (U.S. EPA, 1987).

A. Release Characterization

1. What is the source(s) (e.g., nature, number of drums, area, depth, amount, location(s))?

2. Regarding hazardous wastes or constituents at the source(s):

   a. Which hazardous wastes (listed, characteristic) and hazardous constituents are present?

   b. What are their concentrations?

   c. What is the background level of each hazardous waste or constituent?

3. What are the known pathways through which the contamination is migrating or may migrate and the extent of contamination?

   a. Through which media is the release spreading or likely to spread? Direction? Rate?

   b. How far has the release migrated? At what concentrations?

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c. How mobile is the constituent?

d. What are the estimated quantities and/or volumes released?

4. What is the projected fate and transport?

B. Potential Human Exposure and Effects

1. What is or will be the exposure pathway(s) (e.g., air, fire/explosion, ground water, surface water, direct contact, ingestion)?

2. What are the location and demographics of populations and environmental resources (potentially) at risk from exposure (e.g., residential areas, schools, drinking water supplies, sole source aquifers near vital ecology or protected natural resources)?

3. What are the potential effects of human exposure (short- and long-term effects)?

4. Has human exposure actually occurred? Or when may human exposure occur?

   a. What is the exposure route(s) (e.g., inhalation, ingestion, skin contact)?

   b. Are there any reports of illness, injury, or death?

   c. How many people will be affected?

   d. What are the characteristics of the exposed populations(s) (e.g., presence of sensitive populations such as infants or nursing home residents)?

5. If response is delayed, how will the situation change (e.g., what will be the implications to human health)?

C. Potential Environmental Exposure and Effects

1. What media have been and may be contaminated (e.g., ground water, air, surface water)?

2. What are the likely short-term and long-term threats and effects on the environment of the released waste or constituents?

3. What natural resource and environmental effects have occurred or are possible (terrestrial, aquatic organisms, aquifers whether or not used for drinking water)?

4. What are the known or projected ecological effects?

5. When is this threat/effect likely to materialize (days, weeks, months)?

6. What are the projected long term effects?

7. If response is delayed, how will the situation change?

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APPENDIX A

AERIAL PHOTOGRAPHY, MAPPING, AND SURVEYING

APPENDIX A

AERIAL PHOTOGRAPHY, MAPPING, AND SURVEYING

Aerial photographs, maps, and surveys can assist in verifying and characterizing contaminant releases and are particularly helpful sources of information that can be used during the development of a monitoring plan. They can also be used, when viewed in historical sense (e.g., over the same location, but at different points in time), to locate old solid waste management units, stream beds, and other facility features. Stereo viewing (using a stereoscope) can further enhance the interpretation of photographs and maps because vertical as well as horizontal spatial relationships can be observed. This Appendix discusses the potential applications of aerial photography, mapping, and surveying in the RFI process.

Case Study Numbers 12, 13 and 14 in Volume IV (Case Study Examples) illustrate the use of several of the techniques presented in this Appendix.

AERIAL PHOTOGRAPHY

Introduction

Aerial photography may be used to gather release verification and characterization information during the RFI. Although detailed aerial photographic analysis usually requires a qualified photo-interpreter, the site information that it can readily provide may warrant its use. Aerial photography can provide valuable information on the environmental setting as well as indications of the nature and extent of contaminant releases. However, when using aerial photographic techniques, important release information should be verified through field observations.

Information Obtained From Aerial Photographs

The basic recognition elements commonly utilized in photographic interpretation are shape, texture, pattern, size, shadow, tone and/or color. Natural

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color, false color or color infrared, and black and white film are routinely used in aerial photographic applications. Color imagery may be more readily interpreted than black and white film, by providing enhanced differentiation of subtle evidence of such items as surface leachate (e.g., seeps) and surface water quality. Color infrared film offers an added element of information with its near infrared sensitivity by enabling assessment of vegetation type, damage, or stress, and providing a wide range for detection of moisture conditions in soils.

Subsurface characteristics can be inferred by surface information in the photographs. For example, vegetative stress may indicate leachate and gas migration where the water table is shallow or in discharge areas. Infrared may be able to detect vegetative stress not noticeable during a field inspection. Geologic features (variation in the distribution of geologic units, bedrock fractures, fault zones, etc.) that can affect ground-water flow pathways can also be identified from aerial photographs. Fractures at shallow depths in consolidated rocks can serve as pathways for contaminated ground water and for rapid infiltration of surface runoff. Contamination of surface water bodies can be detected by discoloration or shading in aerial photography. Land surface elevation determinations and contour maps can be compiled, and ground-water flow direction in shallow systems can be estimated using this information. The time of year is also an important consideration when interpreting geologic and hydrologic features. For example, the presence of heavy vegetation during the summer months may obscure certain geologic and hydrologic features. As another example, drainage patterns and seasonal high water tables are more readily observed after or during winter snowmelt.

Other information available from aerial photographs includes: Natural topography, drainage and erosional features, vegetative cover and damage, indications of leachate, damaged unit containment structures, etc. Observable patterns, colors, and relief can make it possible to distinguish differences in geology, soils, soil moisture, vegetation, and land use. Aerial photography can also indicate important hydrologic features. Springs and marshy areas represent ground-water discharge areas. In cases of releases to ground water, aerial photographs can indicate the existence of likely contaminant migration pathways (e.g., recharge areas, sink holes, karst terrains, subsurface flow patterns, fissures, and joints). For releases to surface water, aerial photographs can indicate the

location of potential contaminant receiving bodies (e.g., ponds and streams) and site runoff channels. Aerial photography can also be used to obtain input information for designing monitoring plans (e.g., defining boundary conditions such as ponds, streams, springs, paved areas, large buildings, irrigation canals).

Major benefits in using aerial photography as a supplement to other investigative methods include:

- Obtaining information on relatively large areas, including surrounding land use and environmental features;
- Indicating effects of contamination; and
- Providing indirect indications of subsurface conditions.

The following limitations should be considered when using aerial photography:

- It does not provide direct information on subsurface characteristics;
- There may be variations in photo quality with age, season of flight, film type, photo scale, cloud cover, etc.; and
- Information obtained from photographs should not be used alone in evaluating surface/subsurface conditions. They should always be verified through field observations.

Use of Existing Aerial Photographs (Historical Analysis)

Existing aerial photographs may be available that show the site prior to the existence of some or all hazardous waste management activities. Individual photographs provide an opportunity to identify specific features and activities at a single point in time. By identifying conditions at a site at several points in time (i.e., historical analysis), the sequence of events leading to the current conditions can be better understood. This process may identify changes in surface drainage conditions through time, locations of landfills, waste treatment ponds/lagoons and

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their subsequent burial and abandonment, the burial of waste drums, number of drums, estimated depth and horizontal extent of burial pits, sources of spillage, and discharge of liquid wastes, etc. Historical photographic analysis can be used to make maps that reflect conditions that previously existed at a facility if enough control points are provided (e.g., road intersections, power lines, buildings, railroad tracks). This information may be very useful in determining appropriate monitoring locations. Analysis problems that should be considered when using historical photos include variations in placement of the site within a given frame of photography and variations in scale.

Sources

Town or county offices may have aerial photographs on file. Also, most of the United States has been photographed in recent years for various Federal agencies. A map entitled "Status of Aerial Photography in the United States" has been compiled that lists all areas (by county) that have been photographed by or for the Agricultural Stabilization and Conservation Service, the Soil Conservation Service, Forest Service, U.S. Geological Survey, Army Corps of Engineers, Air Force, and commercial firms. These maps are available from:

Map Information Office
U.S. Department of the Interior
Geologic Survey
507 National Center
Reston, VA 22092
(703) 860-6045

The names and addresses of agencies holding negatives for photographs are printed on the back of the map.

The U.S. EPA may also have taken aerial photos of certain facilities. The owner or operator may inquire at specific federal and state regulatory offices for access to any photos that may have been taken. Other sources of aerial photographs are listed below.

Federal government--The following two U.S. Geological Survey locations can provide indices of all published maps and include order blanks, prices, and detailed

ordering instructions. They may also provide a list of addresses of local map reference libraries, local map dealers, and Federal map distribution centers.

Eastern Distribution Branch
U.S. Geological Survey
1200 South Eads Street
Arlington, VA 22202

Western Distribution Branch
U.S. Geological Survey
Box 25286 Denver Federal Center
Denver, CO 80225

Other Federal Agencies Include:

Aerial Photography Field Office ASCS-U.S. Department of Agriculture (USDA) P.O. Box 30010 Salt Lake City, Utah 84130 (801) 524-5856	(Has all Agricultural Stabilization and Conservation Service photos, Forest Service photos, etc.)
EROS Data Center U.S. Geological Survey Sioux Falls, SD 57198 (605) 594-6511 (ext. 151)	(Landsat and U-2 photos, black and white at 1:80,000 scale. Computer listings of all available photos can be accessed)
Soil Conservation Service USDA-SCS P.O. Box 6567 Fort Worth, TX 76117 (817) 334-5292	(Supplies mostly low altitude, 1:20,000 scale, photos)
National Archives 841 South Pickett Street Alexandria, VA 22304 (703) 756-6700	(For historical photos)

All of the above agencies will require some information identifying the site location to locate relevant photos. This information may be in the form of a town engineer's map; Department of Transportation map; description of the township, range, section; a hand-drawn map of the site in relation to another town; precise longitude and latitude coordinates of the site area; or a copy of the portion of a U.S. Geological Survey quadrangle that shows the site.

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For facilities near the United States-Canada border, the following agency may provide aerial photographs:

The National Air Photo Library
Surveys and Mapping Branch
Department of Energy, Mines and Resources
615 Booth Street
Ottawa, Ontario K1A OE9

State government--State agencies may also have aerial photographs on file. These include:

- Pollution control agencies;
- Health departments;
- Water resources departments;
- Forestry or Agricultural departments;
- Highway departments; and
- Geological survey departments.

Private companies--Photographs required for the site of concern may be held by private aerial survey companies and can often be ordered directly from these sources. Local telephone listings and Photogrammetric Engineering, the Journal of the American Society of Photogrammetry, can provide sources of information.

Aerial photographic surveys--If existing photographs are not available or do not provide enough information, the owner or operator may arrange for an aerial photographic survey to be conducted. When deciding whether an aerial survey is appropriate, the owner or operator should consider whether the information needs can be filled with data obtained from an aerial survey (or from another source or investigative technique) and the size of the site (for a small site, a ground survey may be more economical). This survey should be conducted by professionals who

will plan, schedule, and perform the flight, collect data with appropriate scale and/or film requirements, analyze results, and compile maps, if necessary.

Conducting New Aerial Photographic Surveys--A local telephone listing, the Journal of the American Society of Photogrammetry, or the government agencies listed in this section may provide names of companies or organizations that conduct aerial photographic surveys. When requesting that an aerial photographic survey be conducted, the owner or operator should supply the site location (e.g., marked on a topographic map). Property boundaries and waste management areas should be outlined. If photographic interpretation is also requested, a brief site description, type and number of solid waste management units, and types of wastes handled would also be helpful.

MAPPING

To assist in adequately characterizing a release, various types of maps may be useful. Maps can be used to show geology, hydrology, topography, climate, land use, and vegetative characteristics. Maps can be generated through compilation of existing maps, aerial photographs, or through ground surveys. This section discusses the usefulness of mapping in verifying and characterizing the nature and extent of a release. In general, displaying information from all types of maps can be presented on the facility's existing topographic map as discussed below.

Topographic Maps

The owner or operator should use, to the extent possible, the topographic map and associated information that meets the requirements of 40 CFR Part 270 14(b)(19) of EPA's Hazardous Waste Permit Program which states:

> "A topographic map showing a distance of 1000 feet around the facility at a scale of 2.5 centimeters (1 inch) equal to not more than 61.0 meters (200 feet). Contours must be shown on the map. The contour interval must be sufficient to clearly show the pattern of surface water flow in the vicinity of and from each operational unit of the facility. For example, contours with an interval of 1.5 meters (5 feet), if relief is greater than 6.1 meters (20 feet), or an interval of 0.6 meters (2 feet), if relief is less than 6.1 meters (20 feet). Owners and operators of HWM facilities located in mountainous areas should use large contour intervals to adequately show topographic profiles of facilities. The map shall clearly show the following:

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(i) Map scale and date.
(ii) 100-year floodplain area.
(iii) Surface waters including intermittent streams.
(iv) Surrounding land uses (residential, commercial, agricultural, recreational).
(v) A wind rose (i.e., prevailing wind-speed and direction).
(vi) Orientation of the map (north arrow).
(vii) Legal boundaries of the HWM facility site.
(viii) Access control (fences, gates).
(ix) Injection and withdrawal wells both onsite and offsite.
(x) Buildings; treatment; storage, or disposal operations; or other structures (recreation areas, runoff control systems, access and internal roads, storm, sanitary, and process sewerage systems, loading and unloading areas, fire control facilities, etc.).
(xi) Barriers for drainage or flood control.
(xii) Location of operational units within the HWM facility site, where hazardous waste is (or will be) treated, stored, or disposed (include equipment cleanup areas)."

Additional information that should be noted on the topographic map is specified in the requirements of 40 CFR Part 270.14(c)(3), which states:

> "On the topographic map required under paragraph (b)(19) of this section, a delineation of the waste management area, the property boundary, the proposed "point of compliance" as defined under §264.95, the proposed location of ground water monitoring wells as required under §264.97, and, to the extent possible, the information required in paragraph (c)(2) of this section.", that being . . . "(2) Identification of the uppermost aquifer and aquifers hydraulically interconnected beneath the facility property, including ground water flow direction and rate, and the basis for such identification (i.e., the information obtained from hydrogeologic investigations of the facility area)."

The use of topographic maps will enable the owner or operator to identify and display many features useful in characterizing a release, such as potential surface water receiving bodies, runoff pathways, and engineered structures.

Sources

Topographic maps of the facility area may be available or obtained from:

- U.S.G.S. (generally with 10-foot contour intervals);
- Local town offices (e.g., Building Department, Board of Assessors);

- Onsite surveying to obtain site specific elevation information; and

- Use of an aerial photographic consultant to fly the site and surrounding area and develop a map.

A site-specific topographic map may be constructed by measuring and plotting land elevations by a stadia survey. This method of surveying determines distances and elevations by means of a telescopic instrument having two horizontal lines through which the marks on a graduated rod are observed. A local telephone directory will usually list companies providing this service.

Existing topographic maps may also be obtained from:

Eastern Distribution Branch
U.S. Geological Survey
1200 South Eads Street
Arlington, VA 22202

(East of the Mississippi River)

Western Distribution Branch
U.S. Geological Survey
Box 25286
Denver Federal Center
Denver, CO 80225

(West of the Mississippi River)

Before requesting a map, the proper quadrangle must be determined. Maps are indexed by geographic location--longitude and latitude. The quadrangle size is given in minutes or degrees. 7.5 minute quadrangles provide the best resolution.

Other sources of topographic information include:

- Local colleges or universities that may have index map sets;

- Local town officials (town engineers, planners, etc.) who know which quadrangles cover their area;

- Nearby institutions or firms that deal with land holdings are likely to have USGS quadrangles for that area; and

- Local USGS offices, map distributors and other suppliers.

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Although for the most part the above identified sources will not supply topographic maps which satisfy the requirements of 40 CFR Part 270, they may still be useful for pointing out old solid waste mangement units and other facility features which may be useful in planning the RFI.

Land Use Maps

Land uses, including residential, commercial, industrial, agricultural, and recreational, should also be shown on the site topographic map. This information is useful for assessing the need for interim corrective measures, and in evaluating potential exposure points and the need for a Corrective Measures Study when air is the medium of contamination.

Sources

Information may be obtained by contacting local officials, conducting first-hand observations, and using a USGS quadrangle. USGS maps indicate structures, including dwellings, places of employment, schools, churches, cemeteries, barns, warehouses, golf courses, and railroad tracks. Various types of boundary lines delineate city limits, national and state reservations, small parks, land grants, etc. Other land use information may be obtained by contacting local planning boards, regional planning commissions, and State agencies. Also, the USGS has special land use maps available for some areas. Inquiries regarding the availability of such maps may be directed to:

Geography Program
Land Information and Analysis Office
USGS-MS 710
Reston, VA 22092
(703) 860-6045

Climatological Maps

Relevant climatological data should be identified. For example, a wind rose graphically displays wind speed and direction. Such information may be critical in the characterization of an air release. Other climatological and meteorological information (e.g., precipitation and temperature) are often important in

characterizing releases to the various environmental media. Because many of these types of meteorological and climatological information may not be effectively displayed on the 40 CFR Part 270 topographic map, they should be identified in a separate map or other document.

Sources

National Climatic Center
Department of Commerce
Federal Building
Ashville, NC 28801
(704) 258-2850

The National Climatic Center may also refer the owner or operator to a data collection office in the vicinity of the area of concern. In addition, local libraries and other sources may provide local climatological data for various period storms (e.g., the 100-year storm), and other information.

Floodplain Maps

The 100-year floodplain area, if applicable, should also be included on the facility's topographic map. Special flooding factors (e.g., wave action) or special flood control features included in the design, construction, operation or maintenance of a facility should also be noted. The topographic map submitted should include the boundaries of the site property in relation to floodplain areas.

Sources

The National Flood Insurance Program (NFIP) has prepared Flood Hazard Boundary Maps for flood-prone areas. These maps delineate the boundaries of the 100-year floodplain. Such maps are often included as part of the Flood Insurance Study for a particular political jurisdiction along a waterway. The U.S. Federal Emergency Management Administration (FEMA) located in Washington, D.C. ((202) 246-2500) publishes such studies. Hydraulic analyses used to determine flood level, community description, and principal flood problems and flood protective measures (provided in the flood insurance studies) should also be included. The USGS, U.S. Army Corps of Engineers, U.S. Soil Conversation Service and the Office of Coastal Zone Management may be contacted for further floodplain information.

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Additional Information

Other information that should be shown on the topographic map includes:

- Access control (fences, gates, etc.);
- Buildings, treatment, storage, disposal operation areas and other structures nearby or onsite;
- Buried pipeline, sewers and electrical conduits;
- Barriers for drainage or flood control;
- Areas of past spills;
- Location of all existing (active and inactive) solid waste management units;
- Location and nature of industrial and product process and storage units; and
- Facility design features such as run-on/runoff control systems and wind dispersal control systems.

Sources

This information can be obtained from aerial photographs, field observations, operating records, construction and inspection records, etc. The owner or operator may need to locate additional site-specific information. This information may be available on existing maps, such as:

Geomorphology	-	surficial geology maps historical aerial photographs topographic maps
Eolian Erosion and Deposition	-	county soil maps (historical) aerial photographic

		interpretation topographic maps
Fluvial Erosion and Deposition	-	floodplain maps county soil maps (historical) aerial photographic interpretation topographic maps
Drainage Patterns	-	topographic maps county soil maps hydrologic maps aerial photgraphic interpretation
Geologic Features	-	bedrock geology maps county soil maps topographic maps
Land Use	-	zoning maps current aerial photos local conservation commission maps county soil recent topographic maps
Hydrologic Features	-	hydrologic maps topographic maps wetlands maps well data aerial photographic interpretation local conservation commission maps

Some examples of how the above information may be useful to the owner or operator in characterizing a release are given below:

- Knowledge of floodplain areas, surface water bodies, drainage patterns and flood control systems identifies potential migration pathways for surface and ground water contamination;

- Wind speed and direction may help identify air contaminant dispersion areas;

- Injection and withdrawal wells may provide locations and information (e.g., influences in ground-water flow patterns) for ground-water monitoring;

- Structures on or offsite can provide ideal locations for subsurface gas monitoring; and

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- Potential sources of contamination in close proximity to the facility may be revealed by investigating surrounding land use practices.

SURVEYING

Ground surveying is a direct process for obtaining topographic and other terrain features in the field. A local telephone directory should be consulted for companies providing surveying services.

Information that can be obtained from a ground survey includes:

- Facility boundary;
- Location of engineered structures (e.g., buildings, pipelines);
- Natural formations at the site (e.g., bedrock outcrops);
- Topographic features;
- Drainage patterns and ponding areas;
- Elevation benchmarks ("permanent" elevation reference points that can be used in the future);
- Location of ground-water monitoring wells (e.g., surface location and elevation); and
- Profiles of surface water bodies (e.g., depths of lakes/ponds) that are not possible by aerial means.

The above information, obtained during a survey of the facility, may be useful in characterizing a contaminant release through:

- Identification of engineered structures that may inhibit or promote contaminant migration (e.g., accumulation areas for subsurface gas)

- Identification of natural features at the site (e.g., barriers or pathways) affecting contaminant migration;

- Topographic influences (e.g., drainage patterns and ponding areas);

- Location of ground water or subsurface gas monitoring wells;

- Ground-water depth (knowledge of location and elevation of wells, enables measurement of ground-water depth); and

- Depths of surface water bodies that may be useful in predicting surface water contamination and in determining ground-water breakout.

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REFERENCES

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APPENDIX B

MONITORING CONSTITUENTS AND INDICATOR PARAMETERS

LIST 1: Indicator Parameters Generally Applicable to Specific Media

List 2: 40 CFR 264 Appendix IX Constituents Commonly Found in Contaminated Ground Water and Amenable to Analysis by EPA Method 6010-Inductively Coupled Plasma (ICP) Spectroscopy (Metals) and by Method 8240 (Volatile Organics)

LIST 3: Monitoring Constituents Potentially Applicable to Specific Media

LIST 4: Industry Specific Monitoring Constituents

LIST 1

INDICATOR PARAMETERS
GENERALLY APPLICABLE TO SPECIFIC MEDIA

SOIL

INDICATOR PARAMETERS

Aluminum	Potassium
Boron	Silica
Calcium	Sodium
Carbonate/bicarbonate	Soil Eh
Chloride	Soil pH (Hydrogen Ion)
Cobalt	Strontium
Copper	Sulfate
Fluoride	Total Kjeldahl Nitrogen (TKN)
Iron	Total Organic Carbon (TOC)*
Magnesium	Total Organic Halogen (TOX)*
Manganese	Total Phenols
Nitrate (as N)	Vanadium
Phosphorus	Zinc

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* Although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that the use of these parameters may not provide an adequate indication of contamination. Both methods suffer precision and accuracy problems. The normal procedure for TOC can strip samples of the volatile fraction, and the presence of chlorine/chloride has been shown to interfere with the TOX determination. In addition, the sensitivity of these methods (generally in the parts per million level) are often too high for constituents of concern.

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LIST 1 (Continued)

GROUND WATER (See also 40 CFR 264, Appendix IX)

INDICATOR PARAMETER

Aluminum	pH (Hydrogen Ion)
Boron	Potassium
Calcium	Silica
Carbonate/bicarbonate	Sodium
Chloride	Strontium
Cobalt	Sulfate
Copper	Specific Conductance
Fluoride	Total Organic Carbon (TOC)*
Iron	Total Organic Halogen (TOX)*
Magnesium	Total Phenols
Manganese	Vanadium
Nitrate (as N)	Zinc

* Although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that the use of these parameters may not provide an adequate indication of contamination. Both methods suffer precision and accuracy problems. The normal procedure for TOC can strip samples of the volatile fraction, and the presence of chlorine/chloride has been shown to interfere with the TOX determination. In addition, the sensitivity of these methods (generally in the parts per million level) are often too high for constituents of concern.

SUBSURFACE GAS

INDICATOR PARAMETERS

Methane
Carbon dioxide
Total Hydrocarbons (THC)
Colorimetric Indicators (e.g., Draeger Tubes)
Explosivity

AIR

INDICATOR PARAMETERS

Total Hydrocarbons (THC)
Colorimetric Indicators (e.g., Draeger tubes)

LIST 1 (Continued)

SURFACE WATER

INDICATOR PARAMETERS

Alkalinity (mg/l as $CaCO_3$)
Biochemical Oxygen Demand (BOD)
Calcium
Chemical Oxygen Demand (COD)
Chloride
Dissolved Oxygen (DO)
Dissolved solids
Magnesium
Nitrates
Nitrites
pH
Salinity
Sodium
Specific Conductance
Sulfate
Suspended solids
Temperature
Total solids
Total Organic Carbon (TOC)*
Total Organic Halogen (TOX)*
Total Phenols
Turbidity

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* Although TOC and TOX have historically been used as indicator parameters for site investigations, the latest data suggests that the use of these parameters may not provide an adequate indication of contamination. Both methods suffer precision and accuracy problems. The normal procedure for TOC can strip samples of the volatile fraction, and the presence of chlorine/chloride has been shown to interfere with the TOX determination. In addition, the sensitivity of these methods (generally in the parts per million level) are often too high for constituents of concern.

LIST 2

40 CFR 264 APPENDIX IX CONSTITUENTS COMMONLY FOUND IN CONTAMINATED GROUND WATER AND AMENABLE TO ANALYSIS BY EPA METHOD 6010 - INDUCTIVELY COUPLED PLASMA (ICP) SPECTROSCOPY (METALS) AND BY METHOD 8240 (VOLATILE ORGANICS)

Common Name	Chemical Abstracts Number	Method[1] 8240	Method 6010
Acetone	67-64-1	x	
Acrolein	107-02-8	x[a]	
Acrylonitrile	107-13-1	x[a]	
Allyl chloride	107-05-1	x[b]	
Antimony	(total)		x
Arsenic	(total)		x
Barium	(total)		x
Benzene	71-43-2	x[c]	
Beryllium	(total)		x
Bromodichloromethane	75-27-4	x[b]	
Bromoform, Tribromomethane	75-25-2	x[b]	
Cadmium	(total)		x
Carbon disulfide	75-15-0	x	
Carbon tetrachloride	56-23-5	x[b]	
Chlorobenzene	108-90-7	x[b]	
Chloroethane, Ethyl chloride	75-00-3	x[b]	
Chloroform	67-66-3	x[b]	
Chloroprene	126-99-8	x[b]	
Chromium	(total)		x
Cobalt	(total)		x
Copper	(total)		x
Dibromochloromethane, Chlorodibromomethane	124-48-1	x[b]	
1,2-Dibromo-3-chloropropane, DBCP	96-12-8	x[b]	
1,2-Dibromoethane, Ethylene dibromide	106-93-4	x[b]	

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LIST 2 (Continued)

Common Name	Chemical Abstracts Number	Method[1] 8240	Method 6010
trans-1,4-Dichloro-2-butene	110-57-6	x	
Dichlorodifluoromethane	75-71-8	x[b]	
1,1-Dichloroethane	75-34-3	x[b]	
1,2-Dichloroethane, Ethylene dichloride	107-06-2	x[b]	
1,1-Dichloroethylene, Vinylidene chloride	75-35-4	x[b]	
trans-1,2-Dichloroethylene	156-60-5	x[b]	
1,2-Dichloropropane	78-87-5	x[b]	
cis-1,3-Dichloropropene	10061-01-5	x[b]	
trans-1,3-Dichloropropene	10061-02-6	x[b]	
Ethylbenzene	100-41-4	x[c]	
Ethyl methacrylate	96-63-2	x[d]	
2-Hexanone	591-78-6	x	
Lead	(total)		x
Methacrylonitrile	126-98-7	x[d]	
Methyl bromide, Bromomethane	74-83-9	x[b]	
Methyl chloride, Chloromethane	74-87-3	x[b]	
Methylene bromide, Dibromomethane	74-95-3	x[b]	
Methylene chloride, Dichloromethane	76-09-2	x[b]	
Methyl ethyl ketone, MEK	78-93-3	x[d]	
Methyl iodide, Iodomethane	74-88-4	x[b]	
Methyl methacrylate	80-62-6	x[d]	
4-Methyl-2-pentanone, Methyl isobutyl ketone	108-10-1	x[d]	
Nickel	(total)		x
Pentachloroethane	76-01-7	x	

LIST 2 (Continued)

Common Name	Chemical Abstracts Number	Method[1] 8240	Method 6010
2-Picoline	109-06-8	x	
Propionitrile, Ethyl cyanide	107-12-0	x[d]	
Pyridine	110-86-1	x[e]	
Selenium	(total)		x
Silver	(total)		x
Styrene	100-42-5	x[c]	
1,1,1,2-Tetrachloroethane	630-20-6	x[b]	
1,1,2,2-Tetrachloroethane	79-34-5	x[b]	
Tetrachloroethylene, Perchloroethylene, Tetrachloroethene	127-18-4	x[b]	
Thallium	(total)		x
Toluene	108-88-3	x[c]	
1,1,1-Trichloroethane, Methyl chloroform	71-55-6	x	
1,1,2-Trichloroethane	79-00-5	x[b]	
Trichloroethylene, Trichloroethene	79-01-6	x[b]	
Trichlorofluoromethane	96-18-4	x[b]	
1,2,3-Trichloropropane	96-18-4	x[b]	
Vanadium	(total)		x
Vinyl Acetate	108-05-4	x	
Vinyl Chloride	75-01-4	x[b]	
Xylene (total)	1330-20-7	x[c]	
Zinc	(total)		x

NOTE: Method 6010 is not recommended for Mercury and Tin.

1 Caution, these are representative methods and may not always be the most suitable for a given application.

a Method 8030 is also suggested.
b Method 8010 is also suggested.
c Method 8020 is also suggested.
d Method 8015 is also suggested.
e Method 8070 is also suggested.

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MONITORING CONSTITUENTS POTENTIALLY APPLICABLE TO SPECIFIC MEDIA

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Acetonitrile	75-05-8	X	X	X		X
Acetophenone	98-86-2	X	X	X		X
2-Acetylaminofluorene	53-96-3	X	X	X		
Acetyl chloride	75-36-5					
1-Acetyl-2-thiourea	591-08-2					
Acrolein	107-02-8	X	X	X		X
Acrylamide	79-06-1					X
Acrylonitrile	107-13-1	X	X	X		X
Aflatoxins	1402-68-2					
Aldicarb	116-06-3					X
Aldrin	309-00-2	X	X	X		
Allyl alcohol	107-18-6					
Allyl chloride	107-05-1	X	X	X		
Aluminum phosphide	20859-73-8					
4-Aminobiphenyl	92-67-1	X	X	X		
5-(Aminomethyl)-3-isoxazolol	2763-96-4					
4-Aminopyridine	504-24-5					
Amitrole	61-82-5					
Ammonium vanadate	7803-55-6					
Aniline	62-53-3	X	X	X		X
Antimony and compounds, N.O.S.[1]	7440-36-0	X	X	X		
Aramite	140-57-8	X	X	X		
Arsenic and compounds, N.O.S.[1]	7440-38-2	X	X	X		X
Arsenic acid	7778-39-4			X		
Arsenic pentoxide	1303-28-2			X		
Arsenic trioxide	1327-53-3			X		
Auramine	492-80-8					
Azaserine	115-02-6					
Barium and compounds, N.O.S.[1]	7440-39-3	X	X	X		
Barium cyanide	542-62-1			X		
Benz(c)acridine	225-51-4					

LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Benz(a)anthracene	56-55-3	X	X	X		
Benzal chloride	98-87-3			X		
Benzene	71-43-2	X	X	X	X	X
Benzenearsonic acid	98-05-5					
Benzidine	92-87-5			X		
Benzo(b)fluoranthene	205-99-2	X	X	X		
Benzo(j)fluoranthene	205-82-3					
Benzo(a)pyrene	50-32-8	X	X	X		
p-Benzoquinone	106-51-4			X		
Benzotrichloride	98-07-7			X		X
Benzyl chloride	100-44-7			X		X
Beryllium and compounds, N.O.S.[1]	7440-41-7	X	X	X		
Bis(2-chloromethoxy)ethane	111-91-1	X	X	X		
Bis(2-chloroethyl) ether	111-44-4	X	X	X		
Bis(2-chloroisopropyl) ether	39638-32-9	X	X	X	X	
Bis(chloromethyl) ether	542-88-1			X		X
Bis(2-ethylhexyl)phthalate	117-81-7	X	X	X		X
Bromoacetone	589-31-2					
Bromoform	75-25-2	X	X	X		X
4-Bromophenyl phenyl ether	101-55-3	X	X	X		
Brucine	357-57-3					
Butyl benzyl phthalate	85-68-7	X	X	X		
Cacodylic acid	75-60-5					
Cadmium and compounds, N.O.S.[1]	7440-43-9	X	X	X		X
Calcium chromate	13765-19-0			X		
Calcium cyanide	592-01-8			X		
Carbon disulfide	75-15-0	X	X	X	X	X
Carbon oxyfluoride	353-50-4					X
Carbon tetrachloride	56-23-5	X	X	X	X	X
Chloral	75-87-6					

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LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Chlorambucil	305-03-3					
Chlordane, alpha and gamma isomers	57-74-9	X	X	X		X
Chlorinated benzenes, N.O.S.[1]		X	X	X	X	X
Chlorinated ethanes, N.O.S.[1]		X	X	X	X	X
Chlorinated fluorocarbons, N.O.S.[1]						X
Chlorinated naphthalene, N.O.S.[1]		X	X	X		
Chlorinated phenol, N.O.S.[1]				X		X
Chlornaphazine	494-03-1					
Chloroacetaldehyde	107-20-0					
Chloroalkyl ethers, N.O.S.[1]						
p-Chloroaniline	106-47-8	X	X	X		X
Chlorobenzene	108-90-7	X	X	X	X	X
Chlorobenzilate	510-15-6	X	X	X		
p-Chloro-m-cresol	59-50-7	X	X	X		
1-Chloro-2,3-epoxypropane	106-89-8					X
2-Chloroethyl vinyl ether	110-75-8			X		
Chloroform	67-66-3	X	X	X	X	X
Chloromethyl methyl ether	107-30-2					
beta-Chloronaphthalene	91-58-7	X	X	X		
o-Chlorophenol	95-57-8	X	X	X		X
1-(o-Chlorophenyl) thiourea	5344-82-1					
Chloroprene	126-99-8	X	X	X		X
3-Chloropropionitrile	542-76-7			X		
Chromium and compounds, N.O.S.[1]	7440-47-3	X	X	X		X
Chrysene	218-01-9	X	X	X		
Citrus red No. 2	6358-53-8					
Coal tars	8005-45-2			X		
Copper cyanide	544-92-3			X		X
Creosote	8001-58-9			X		
Cresols (Cresylic acid)	1319-77-3	X	X	X		X
Crotonaldehyde	4170-30-3					X

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Cyanides (soluble salts and complexes) N.O.S.[1]		X	X	X		X
Cyanogen	460-19-5					X
Cyanogen bromide	506-68-3					
Cyanogen chloride	506-77-4					
Cycasin	14901-08-7					
2-Cyclohexyl-4,6-dinitrophenol	131-89-5					
Cyclophosphamide	50-18-0					
2,4-D, salts and esters	94-75-7	X	X	X		X
Daunomycin	20830-81-3					
DDD	72-54-8	X	X	X		
DDE	72-55-9	X	X	X		
DDT	50-29-3	X	X	X		
Diallate	2303-16-4	X	X	X		
Dibenz(a,h)acridine	226-36-8					
Dibenz(a,j)acridine	224-42-0					
Dibenz(a,h)anthracene	53-70-3	X	X	X		
7H-Dibenzo(c,g)carbazole	194-59-2					
Dibenzo(a,e)pyrene	192-65-4			X		
Dibenzo(a,h)pyrene	189-64-0			X		
Dibenzo(a,i)pyrene	189-55-9			X		
1,2-Dibromo-3-chloropropane	96-12-8	X	X	X		
Dibutylphthalate	84-74-2	X	X	X		
o-Dichlorobenzene	95-50-1	X	X	X		X
m-Dichlorobenzene	541-73-1	X	X	X		X
p-Dichlorobenzene	106-46-7	X	X	X		X
Dichlorobenzene, N.O.S.[1]	25821-22-6	X	X	X		X
3,3'-Dichlorobenzidine	91-94-1	X	X	X		
1,4-Dichloro-2-butene	764-41-0	X	X	X		X
Dichlorodifluoromethane	75-71-8	X	X	X	X	X
1,2-Dichloroethylene	156-60-5	X	X	X	X	

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LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Dichloroethylene, N.O.S.[1]	25323-30-2	X	X	X		X
1,1-Dichloroethylene	75-35-4	X	X	X		X
2,4-Dichlorophenol	120-83-2	X	X	X		
2,6-Dichlorophenol	87-65-0	X	X	X		
Dichlorophenylarsine	696-28-6					
Dichloropropane, N.O.S.[1]	26638-19-7	X	X	X		X
Dichloropropanol, N.O.S.[1]	26545-73-3					
Dichloropropene, N.O.S.[1]	26952-23-8	X	X	X		X
1,3-Dichloropropene	542-75-6	X	X	X		X
Dieldrin	60-57-1	X	X	X		
1,2,3,4-Diepoxybutane	1464-53-5					
Diethylarsine	692-42-2					
1,4-Diethyleneoxide	123-91-1	X	X	X		X
N,N'-Diethylhydrazine	1615-80-1					
O,O-Diethyl S-methyldithiophosphate	3288-58-2					
Diethyl-p-nitro phenyl phosphate	311-45-5			X		
Diethylphthalate	84-66-2	X	X	X		X
0,0-Diethyl 0-pyrazinyl phosphorothioate	297-97-2	X	X	X		
Diethylstilbesterol	56-53-1					
Dihydrosafrole	94-58-6					
3,4-Dihydroxy-alpha-(methylamino)methyl benzyl alcohol	329-65-7					
Diisopropylfluorophosphate (DFP)	55-91-4					
Dimethoate	60-51-5	X	X	X		
3,3'-Dimethoxybenzidine	119-90-4	X	X	X		
p-Dimethoxyminoazobenzene	60-11-7	X	X	X		
7,12-Dimethylbenz(a)anthracene	57-97-6	X	X	X		
3,3'-Dimethylbenzidine	119-93-7	X	X	X		
Dimethylcarbamoyl chloride	79-44-7					
1,1-Dimethylhydrazine	57-14-7					X
1,2-Dimethylhydrazine	540-73-8					

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LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
alpha, alpha-Dimethylphenethylamine	122-09-8	X	X	X		
2,4-Dimethylphenol	105-67-9	X	X	X		X
Dimethylphthalate	131-11-3	X	X	X		
Dimethyl sulfate	77-78-1					
Dinitrobenzene, N.O.S.[1]	25154-54-5	X	X	X		
4,6-Dinitro-o-cresol and salts	534-52-1	X	X	X		
2,4-Dinitrophenol	51-28-5	X	X	X		
2,4-Dinitrotoluene	121-14-2	X	X	X		X
2,6-Dinitrotoluene	606-20-2	X	X	X		
Dinoseb	88-85-7	X	X	X		
Di-n-octylphthalate	117-84-0	X	X	X		
Diphenylamine	122-39-4	X	X	X		
1,2-Diphenylhydrazine	122-66-7			X		X
Di-n-propylnitrosamine	621-64-7	X	X	X		
Disulfoton	298-04-4	X	X	X		
Dithioburet	541-53-7					
Endosulfan	115-29-7	X	X	X		
Endothal	145-73-3					
Endrin	72-20-8	X	X	X		
Ethyl carbamate (urethane)	51-79-6					
Ethyl cyanide	107-12-0			X		
Ethylenebisdithiocarbamic acid, salts, and esters	111-54-6					
Ethylene dibromide	106-93-4					X
Ethylene dichloride	107-06-2				X	X
Ethylene glycol monoethyl ether	110-80-5					
Ethyleneimine	151-56-4					X
Ethylene oxide	75-21-8					X
Ethylenethiourea	96-45-7					
Ethylidene dichloride	75-34-3				X	X
Ethyl methacrylate	97-63-2	X	X	X		

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LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Ethylmethane sulfonate	62-50-0	X	X	X		
Famphur	52-85-7	X	X	X		
Fluoranthene	206-44-0	X	X	X		
Flourine	7782-41-4			X		
Fluoroacetamide	640-19-7					
Fluoroacetic acid, sodium salt	62-74-8					
Formaldehyde	50-00-0					X
Glycidylaldehyde	765-34-4					
Halomethane, N.O.S.[1]		X	X	X	X	X
Heptachlor	76-44-8	X	X	X		X
Heptachlor epoxide	1024-57-8	X	X	X		
Hexachlorobenzene	118-74-1	X	X	X		
Hexachlorobutadiene	87-68-3	X	X	X		X
Hexachlorocyclopentadiene	77-47-4	X	X	X		
Hexachlorodibenzo-p-dioxins		X	X	X		
Hexachlorodibenzofurans		X	X	X		
Hexachloroethane	67-72-1	X	X	X		X
Hexachlorophene	70-30-4	X	X	X		
Hexachloropropene	1888-71-7	X	X	X		
Hexaethyltetraphosphate	757-58-4					
Hydrazine	302-01-2					X
Hydrogen cyanide	74-90-8					X
Hydrogen fluoride	7664-39-3					
Hydrogen sulfide	7783-06-4			X	X	X
Indeno(1,2,3cd)pyrene	193-39-5	X	X	X		
Iron dextran	9004-66-4					
Isobutyl alcohol	78-83-1	X	X	X		X
Isodrin	465-73-6	X	X	X		
Isosafrole	120-58-1	X	X	X		
Kepone	143-50-0	X	X	X		
Lasiocarpine	303-34-4					
Lead and compounds, N.O.S.[1]	7439-92-1	X	X	X		X
Lead acetate	301-04-2			X		

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Lead phosphate	7446-27-7			X		
Lead subacetate	1335-32-6					
Lindane	58-89-9	X	X	X		
Maleic anhydride	108-31-6					X
Maleic hydrazide	123-33-1					
Malonitrile	109-77-3			X		
Melphalan	148-82-3					
Mercury fulminate	628-86-4					
Mercury and compounds N.O.S.[1]	7439-97-6	X	X	X		X
Methacrylonitrile	126-98-7	X	X	X		X
Methapyrilene	91-80-5	X	X	X		
Methomyl	16752-77-5					
Methoxychlor	72-43-5	X	X	X		
Methyl bromide	74-83-9	X	X	X		X
Methyl chloride	74-87-3	X	X	X		X
Methychlorocarbonate	79-22-1					
Methyl chloroform	71-55-6	X	X	X	X	X
3-Methylcholanthrene	56-49-5	X	X	X		
4,4',Methylenebis(2-chloroaniline)	101-14-4	X	X	X		
Methylene bromide	74-95-3	X	X	X		
Methylene chloride	75-09-2	X	X	X	X	X
Methyl ethyl ketone (MEK)	78-93-3	X	X	X		X
Methyl ethyl ketone peroxide	1338-23-4			X		X
Methyl hydrazine	60-34-4					
Methyl iodide	74-88-4	X	X	X		X
Methyl isocyanate	624-83-9					X
2-Methyllactonitrile	75-86-5					X
Methyl methacrylate	80-62-6	X	X	X		X
Methyl methanesulfonate	66-27-3	X	X	X		
Methyl parathion	298-00-0	X	X	X		

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Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Methylthiouracil	56-04-2					
Mitomycin C	50-07-7					
MNNG	70-25-7					
Mustard gas	505-60-2					
Naphthalene	91-20-3	X	X	X		X
1,4-Naphthoquinone	130-15-4	X	X	X		
alpha-Naphthylamine	134-32-7	X	X	X		
Beta-Naphthylamine	91-59-8	X	X	X		
alpha-Napththylthiourea	86-88-4					
Nickel and compounds, N.O.S.[1]	7440-02-0	X	X	X		X
Nickel carbonyl	13463-39-3					
Nickel cyanide	557-19-7			X		
Nicotine and salts	54-11-5					
Nitric oxide	10102-43-9			X		X
p-Nitroaniline	100-01-6	X	X	X		
Nitrobenzene	98-95-3	X	X	X		X
Nitrogen dioxide	10102-44-0			X		
Nitrogen mustard and hydrochloride salt	51-75-2			X		
Nitrogen mustard N-oxide and hydrochloride salt	126-85-2					
Nitroglycerin	55-63-0					X
p-Nitrophenol	100-02-7	X	X	X		X
2-Nitropropane	79-46-9					
4-Nitroquinoline-1-oxide	56-57-5	X	X	X		
Nitrosamine, N.O.S.[1]	35576-91-1	X	X	X		
N-Nitrosodi-n-butylamine	924-16-3	X	X	X		
N-Nitrosodiethanolamine	1116-54-7					
N-Nitrosodiethylamine	55-18-5	X	X	X		
N-Nitrosodimethylamine	62-75-9	X	X	X		
N-Niroso-N-ethyl urea	759-73-9					
N-Nitrosomethylethylamine	10595-95-6	X	X	X		
N-Nitroso-N-methylurea	684-93-5					

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LIST 3 (continued)

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
N-Nitroso-N-methylurethane	615-53-2					
N-Nitrosomethylvinylamine	4549-40-0					
N-Nitrosomorpholine	59-89-2	X	X	X		
N-Nitrosonornicotine	16543-55-8					
N-Nitrosopiperidine	100-75-4	X	X	X		
Nitrosopyrolidine	930-55-2	X	X	X		
N-Nitrososarcosine	13256-22-9					
5-Nitro-o-toluidine	99-55-8	X	X	X		
Octamethylpryophosphoramide	152-16-9					
Osmium tetroxide	20816-12-0					X
Paraldehyde	123-63-7					
Parathion	56-38-2	X	X	X		X
Pentachlorobenzene	608-93-5	X	X	X		X
Pentachlorodibenzo p dioxins		X	X	X		
Pentachlorodibenzofurans		X	X	X		
Pentachloroethane	76-01-7	X	X	X		X
Pentachloronitrobenzene (PCNB)	82-68-8	X	X	X		
Pentachlorophenol	87-86-5	X	X	X		X
Phenacetin	62-44-2	X	X	X		
Phenol	108-95-2	X	X	X		X
Phenylenediamine	25265-76-3					
Phenylmercury acetate	62-38-4					
Phenylthiourea	103-85-5					
Phosgene	75-44-5					X
Phosphine	7803-51-2					X
Phorate	298-02-2	X	X	X		X
Phthalic acid esters, N.O.S.[1]						
Phthalic anhydride	85-44-9					X
2-Picoline	109-06-8	X	X	X		
Polychlorinated biphenyls N.O.S.[1]		X	X	X		X
Potassium cyanide	151-50-8			X		
Potassium silver cyanide	506-61-6			X		
Pronamide	23950-58-5	X	X	X		

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Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
1,3-Propane sultone	1120-71-4					
n-Propylamine	107-10-8					
Propargyl alcohol	107-19-7					
Propylene dichloride	78-87-5					X
1,2-Propylenimine	75-55-8					
Propylthiouracil	51-52-5					
Pyridine	110-86-1	X	X	X		X
Reserpine	50-55-5					X
Resorcinol	108-46-3			X		X
Saccharin and salts	81-07-2					
Safrole	94-59-7	X	X	X		
Selenium dioxide	7783-00-8					
Selenium and compounds, N.O.S.	7782-49-2	X	X	X		
Selenium sulfide	7446-34-6			X		
Selenourea	630-10-4					
Silver and compounds, N.O.S.[1]	7440-22-4	X	X	X		
Silver cyanide	506-64-9			X		
Silvex (2,4,5-TP)	93-72-1	X	X	X		
Sodium cyanide	143-33-9					
Streptozotocin	18883-66-4					
Strontium sulfide	1314-96-1			X		
Strychnine and salts	57-24-9					
TCDD	1746-01-6	X	X	X		X
1,2,4,5-Tetrachlorobenzene	95-94-3	X	X	X		
Tetrachlorodibenzo-p-dioxins		X	X	X		
Tetrachlorodibenzofurans		X	X	X		
Tetrachloroethane, N.O.S.[1]	25322-20-7	X	X	X	X	
1,1,1,2-Tetrachloroethane	630-20-6	X	X	X		
1,1,2,2-Tetrachloroethane	79-34-5	X	X	X	X	
Tetrachloroethylene	127-18-4	X	X	X	X	X

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
2,3,4,6-Tetrachlorophenol	58-90-2	X	X	X		
Tetraethyldithiopyrophosphate	3689-24-5	X	X	X		
Tetraethyl lead	78-00-2					X
Tetraethylpyrophosphate	107-49-3			X		
Tetranitromethane	509-14-8			X		
Thallium and compounds, N.O.S.[1]	7440-28-0	X	X	X		
Thallic oxide	1314-32-5			X		
Thallium (1) acetate	563-68-8			X		
Thallium (1) carbonate	6533-73-9			X		
Thallium (1) chloride	7791-12-0			X		
Thallium (1) nitrate	10102-45-1			X		
Thallium selenite	12039-52-0			X		
Thallium (1) sulfate	10031-59-1			X		
Thioacetamide	62-55-5					X
Thiofanox	39196-18-4					
Thiomethanol	74-93-1					X
Thiophenol	108-98-5			X		
Thiosemicarbazide	79-19-6					
Thiourea	62-56-6					
Thiram	137-26-8					
Toluene	108-88-3	X	X	X	X	X
Toluenediamine	25376-45-8					
2,4-Toluenediamine	95-80-7					X
2,6-Toluenediamine	823-40-5					
3,4-Toluenediamine	496-72-0					
Toluene diisocyanate	584-84-9			X		X
p-Toluidine	106-49-0					
o-Toluidine hydrochloride	636-21-5					
Toxaphene	8001-35-2	X	X	X		X
1,2,4-Trichlorobenzene	120-82-1	X	X	X		X
1,1,2-Trichloroethane	79-00-5	X	X	X	X	

Common Name	Chemical Abstracts No.	Ground Water*	Surface Water[2]	Soil[3]	Subsurface Gas[4]	Air
Trichloroethylene	79-01-6	X	X	X	X	X
Trichloromethanethiol	75-70-7			X		
Trichloromonofluoromethane	75-69-4	X	X	X		
2,4,5-Trichlorophenol	95-95-4	X	X	X		
2,4,6-Trichlorophenol	88-06-2	X	X	X		
2,4,5-T	93-76-5	X	X	X		
Trichloropropane, N.O.S.[1]		X	X	X		X
1,2,3-Trichloropropane	96-18-4	X	X	X		X
0,0,0-Triethylphosphorothioate	126-68-1	X	X	X		
sym-Trinitrobenzene	99-35-4	X	X	X		
Tris(1-aziridinyl)phosphine sulfide	52-24-4					
Tris(2,3-dibromopropyl)phosphate	126-72-7					
Trypan blue	72-57-1					
Uracil mustard	66-75-1					
Vanadium pentoxide	1314-62-1			X		X
Vinyl chloride	75-01-4	X	X	X	X	X
Warfarin	81-81-2					
Zinc cyanide	557-21-1			X		
Zinc phosphide	1314-84-7			X		

* See also 40 CFR 264, Appendix IX.

1 The abbreviation N.O.S. (not otherwise specified) signifies those members of the general class not specifically listed by name.

2 Applies to the water column only. Additional constituents may be of concern if sediment and/or biota are to be sampled and subjected to analysis (See Section 13).

3 Includes both saturated and unsaturated soils. Some of these are gases at ambient temperature and pressure which may be present in wet or saturated soils. Degradation as a result of chemical, biological or physical processes, may result in decreasing concentrations of constituents over time, and is dependent on moisture content as well as other factors.

4 Compounds indicated are those which may be present within a carrier gas (e.g., methane).

LIST 4

INDUSTRY SPECIFIC MONITORING CONSTITUENTS

REFERENCES FOR INDUSTRY SPECIFIC MONITORING CONSTITUENTS

1. 40 CFR 122, National Pollutant Discharge Elimination System

2. U.S. EPA, Development Document for Effluent Limitation Guidelines and Standards for the ... Point Source Category.
(Total of 30 Industries)

3. U.S. EPA, 1980, Treatability Manual. Volume I. Treatability Data

4. U.S. EPA Regional Offices for Industry Specific Data.

LIST 4*

SW-846 Chemical Classifications - See Supplemental Tables

Industrial Category	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15
Auto and Other Laundries	●	●	●	●		●		●		●		●		●	●
Coal Mining	●	●	●	●		●		●		●		●		●	●
Coal Coating	●	●		●		●		●		●		●		●	●
Copper Forming	●		●	●		●				●		●		●	●
Electroplating	●					●				●				●	●
Electrical and Electronic Components	●	●	●	●		●		●		●		●		●	●
Explosives Manufacturing	●	●	●			●				●		●		●	●
Foundries	●	●	●	●		●		●		●		●		●	●
Gum and Wood Chemicals	●					●		●		●		●		●	●
Inorganic Chemicals Manufacturing	●	●	●	●		●				●		●	●	●	●
Iron and Steel Manufacturing	●	●	●	●	●	●		●		●		●	●	●	●
Leather Tanning and Finishing	●	●		●		●				●		●		●	●
Metal Finishing	●	●	●	●	●	●		●		●		●	●	●	●
Nonferrous Metals Manufacturing	●	●	●	●		●		●		●		●		●	●
Ore Mining	●	●				●		●		●		●		●	●
Organic Chemicals Manufacturing	●	●	●	●		●		●		●		●		●	●
Paint and Ink Formulation	●	●	●			●		●		●		●		●	●
Pe[illegible] and Herbicides	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

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LIST 4 (Continued)*

SW-846 Chemical Classifications - See Supplemental Tables

Industrial Category	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13	2-14	2-15
Petroleum Refining	●	●		●		●		●		●		●		●	●
Pharmaceutical Preparations	●	●	●	●		●		●		●		●	●	●	●
Photographic Equipment and Supplies	●	●	●	●		●				●		●		●	●
Plastics Molding and Forming	●	●		●		●		●		●		●		●	●
Porcelain Enameling	●	●				●				●		●		●	●
Pulp and Paper Mills	●	●	●	●		●		●		●		●	●	●	●
Rubber Processing	●	●	●			●				●		●	●	●	●
Soap and Detergent Manufacturing	●	●		●		●		●		●		●		●	●
Steam Electric Power Plants	●	●	●	●		●		●		●		●	●	●	●
Textile Mills	●	●	●	●	●	●		●		●		●	●	●	●
Timber Products	●			●		●		●		●		●		●	●
Wood Preserving	●	●	●	●		●		●		●		●	●	●	●

* - A "●" indicates that one or more constituents within a category are likely candidates for monitoring.

- This list does not contain all industries that may be subject to an RFI.

- The constituents within the categories indicated may not be mutually exclusive. If a chemical category is checked for a particular industry, the owner or operator may be responsible for all constituents within the category, regardless of whether the constituent is contained in other categories.

SUPPLEMENT TO LIST 4

REPRINTED TABLES FROM TEST METHODS FOR EVALUATING SOLID WASTES:
3RD ED. U.S. EPA SW-846. GPO No. 955-001-0000-1. 1986.

Table 2-1: Phenols and Organic Acids

Benzoic acid
Benzyl alcohol
2-sec-Butyl-4,6-dinitrophenol (DNBP)
4-Chloro-3-methylphenol
2-Chlorophenol
Cresol (methyl phenols)
2-Cyclohexyl-4,6-dinitrophenol
2,4-Dichlorophenol
2,6-Dichlorophenol
2,4-Dimethylphenol
4,6-Dinitro-o-cresol
2,4-Dinitrophenol
2-Methyl-4,6-dinitrophenol
2-Nitrophenol
4-Nitrophenol
Pentachlorophenol
Phenol
Tetrachlorophenols
Trichlorophenols

Table 2-2: Phthalate Esters

Benzyl butyl phthalate
Bis(2-ethylhexyl)phthalate
Diethyl phthalate
Di-n-butyl phthalate
Dimethyl phthalate
Di-n-octyl phthalate

Table 2-3: Nitroaromatics and Cyclic Ketones

Dinitrobenzene
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Isophorone
Naphthoquinone
Nitrobenzene

Table 2-4: Polyaromatic Hydrocarbons

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(j)fluoranthene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene
Chrysene
Dibenz(a,h)acridine
Dibenz(a,j)acridine
Dibenz(a,h)anthracene (Dibenzo(a,h)anthracene)
7H-Dibenzo(c,g)carbazole
Dibenzo(a,e)pyrene
Dibenzo(a,h)pyrene
Dibenzo(a,i)pyrene
Fluoranthene
Fluorene
Indeno(1,2,3-cd)pyrene
3-Methylcholanthrene
Naphthalene
Phenanthrene
Pyrene

Table 2-5: Chlorinated Hydrocarbons

Benzotrichloride
Benzyl chloride
2-Chloronaphthalene
Dichlorobenzenes
Dichloromethylbenzenes(Dichlorotoluenes)
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclohexane
Hexachlorocyclopentadiene
Hexachloroethane
Pentachlorohexane
Tetrachlorobenzenes
Trichlorobenzenes

Table 2-6: Base/Neutral

Acenaphthene
Acenaphthylene
Acetophenone
Aldrin
Aniline
Anthracene
4-Aminobiphenyl
Aroclor-1016
Aroclor-1221
Aroclor-1232
Aroclor-1242
Aroclor-1248
Aroclor-1254
Aroclor-1260
Benzidine
Benzo(a)anthracene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(g,h,i)perylene
Benzo(a)pyrene
α-BHC
β-BHC
δ-BHC
γ-BHC
Bis(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
Bis(2-ethylhexyl)phthalate
4-Bromophenyl phenyl ether
Butyl benzyl phthalate
Chlordane
4-Chloroaniline
1-Chloronaphthalene
2-Chloronaphthalene
4-Chlorophenyl phenyl ether
Chrysene
4,4'-DDD
4,4'-DDE
4,4'-DDT
Dibenz(a,j)acridine
Dibenz(a,h)anthracene
Dibenzofuran
Di-n-butyl phthalate
1,3-Dichlorobenzene
1,4-Dichlorobenzene
1,2-Dichlorobenzene
3,3'-Dichlorobenzidine
Dieldrin
Diethyl phthalate
p-Dimethylaminoazobenzene
7,12-Dimethylbenz(a)anthracene
α-,α-Dimethylphethylamine
Dimethyl phthalate
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Diphenylamine
1,2-Diphenylhydrazine
Di-n-octyl phthalate
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Endrin ketone
Ethyl methanesulfonate
Fluoranthene
Fluorene
2-Fluorobiphenyl
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Indeno(1,2,3-cd)pyrene
Isophorone
Methoxychlor
3-Methylcholanthrene
Methyl methanesulfonate
2-Methylnaphthalene
Naphthalene
1-Naphthylamine
2-Naphthylamine
2-Nitroaniline
3-Nitroaniline
4-Nitroaniline
Nitrobenzene
N-Nitroso-di-n-butylamine
N-Nitrosodimethylamine
N-Nitrosodiphenylamine
N-Nitrosodipropylamine
N-Nitrosopiperidine
Pentachlorobenzene
Pentachloronitrobenzene
Phenacetin
Phenanthrene
2-Picoline
Pronamide
Pyrene
1,2,4,5-Tetrachlorobenzene
1,2,4-Trichlorobenzene
Toxaphene

Table 2-7: Organophosphorous Pesticides

Azinphos methyl
Bolstar (Sulprofos)
Chlorpyrifos
Coumaphos
Demeton
Diazinon
Dichlorvos
Dimethoate
Disulfoton
EPN
Ethoprop
Fensulfothion
Fenthion
Malathion
Merphos
Mevinphos
Monochrotophos
Naled
Parathion
Parathion methyl
Phorate
Ronnel
Stirophos (Tetrachlorvinphos)
Sulfotepp
TEPP
Tokuthion (Prothiofos)
Trichloronate

Table 2-8: Organochlorine Pesticides and PCB's

Aldrin
α-BHC
β-BHC
δ-BHC
γ-BHC (Lindane)
Chlordane
4,4'-DDD
4,4'-DDE
4,4'-DDT
Dieldrin
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Heptachlor
Heptachlor epoxide
Kepone
Methoxychlor
Toxaphene
PCB-1016 (Aroclor-1016)
PCB-1221 (Aroclor-1221)
PCB-1232 (Aroclor-1232)
PCB-1242 (Aroclor-1242)
PCB-1248 (Aroclor-1248)
PCB-1254 (Aroclor-1254)
PCB-1260 (Aroclor-1260)

Table 2-9: Chlorinated Herbicides

2,4-D
2,4-DB
2,4,5-T
2,4,5-TP (Silvex)
Dalapon
Dicamba
Dichloroprop
Dinoseb
MCPA
MCPP

Table 2-10: Halogenated Volatiles

Benzyl chloride
Bis(2-chloroethoxy)methane
Bis(2-chloroisopropyl)ether
Bromobenzene
Bromodichloromethane
Bromoform
Bromomethane
Carbon tetrachloride
Chloracetaldehyde
Chloral
Chlorobenzene
Chloroethane
Chloroform
1-Chlorohexane
2-Chloroethyl vinyl ether
Chloromethane
Chloromethyl methyl ether
Chlorotoluene
Dibromochloromethane
Dibromomethane
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichloroethylene (Vinylidene chloride)
trans-1,2-Dichloroethylene
Dichloromethane
1,2-Dichloropropane
1,3-Dichloropropylene
1,1,2,2-Tetrachloroethane
1,1,1,2-Tetrachloroethane
Tetrachloroethylene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethylene
Trichlorofluoromethane
Trichloropropane
Vinyl chloride

Table 2-11: Non-halogenated Volatiles

Acrylamide
Diethyl ether
Ethanol
Methyl ethyl ketone (MEK)
Methyl isobutyl ketone (MIBK)
Paraldehyde (trimer of acetaldehyde)

Table 2-12: Aromatic Volatiles

Benzene
Chlorobenzene
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
Ethyl benzene
Toluene
Xylenes (Dimethyl benzenes)

Table 2-13: Acetonitrile, Acrolein, Acrylonitrile

Acetonitrile
Acrolein (Propenal)
Acrylonitrile

Table 2-14: Volatiles

Acetone
Acrolein
Acrylonitrile
Benzene
Bromochloromethane
Bromodichloromethane
4-Bromofluorobenzene
Bromoform
Bromomethane
2-Butanone (Methyl ethyl ketone)
Carbon disulfide
Carbon tetrachloride
Chlorobenzene
Chlorodibromomethane
Chloroethane
2-Chloroethyl vinyl ether
Chloroform
Chloromethane
Dibromomethane
1,4-Dichloro-2-butane
Dichlorodifluoromethane
1,1-Dichloroethane
1,2-Dichloroethane
1,1-Dichlrorethene
trans-1,2-Dichloroethene
cis-1,3-Dichloropropene
trans-1,3-Dichloropropene
1,4-Difluorobenzene
Ethanol
Ethylbenzene
Ethyl methacrylate
2-Hexanone
Iodomethane
Methylene chloride
4-Methly-2-pentanone
Styrene
1,1,2,2-Tetrachloroethane
Toluene
1,1,1-Trichloroethane
1,1,2-Trichloroethane
Trichloroethene
Trichlorofluoromethane
1,2,3-Trichloropropane
Vinyl acetate
Vinyl chloride
Xylene

Table 2-15: (Partial): Metals

Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc

RFI GUIDANCE FEEDBACK QUESTIONNAIRE

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INTERIM FINAL

RCRA FACILITY INVESTIGATION (RFI) GUIDANCE

VOLUME II OF IV

SOIL, GROUND WATER AND SUBSURFACE GAS RELEASES

EPA 530/SW-89-031

MAY 1989

WASTE MANAGEMENT DIVISION
OFFICE OF SOLID WASTE
U.S. ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

On November 8, 1984, Congress enacted the Hazardous and Solid Waste Amendments (HSWA) to RCRA. Among the most significant provisions of HSWA are §3004(u), which requires corrective action for releases of hazardous waste or constituents from solid waste management units at hazardous waste treatment, storage and disposal facilities seeking final RCRA permits; and §3004(v), which compels corrective action for releases that have migrated beyond the facility property boundary. EPA will be promulgating rules to implement the corrective action provisions of HSWA, including requirements for release investigations and corrective measures.

This document, which is presented in four volumes, provides guidance to regulatory agency personnel on overseeing owners or operators of hazardous waste management facilities in the conduct of the second phase of the RCRA Corrective Action Program, the RCRA Facility Investigation (RFI). Guidance is provided for the development and performance of an investigation by the facility owner or operator based on determinations made by the regulatory agency as expressed in the schedule of a permit or in an enforcement order issued under §3008(h), §7003, and/or §3013. The purpose of the RFI is to obtain information to fully characterize the nature, extent and rate of migration of releases of hazardous waste or constituents and to interpret this information to determine whether interim corrective measures and/or a Corrective Measures Study may be necessary.

DISCLAIMER

This document is intended to assist Regional and State personnel in exercising the discretion conferred by regulation in developing requirements for the conduct of RCRA Facility Investigations (RFIs) pursuant to 40 CFR 264. Conformance with this guidance is expected to result in the development of RFIs that meet the regulatory standard of adequately detecting and characterizing the nature and extent of releases. However, EPA will not necessarily limit acceptable RFIs to those that comport with the guidance set forth herein. This document is not a regulation (i.e., it does not establish a standard of conduct which has the force of law) and should not be used as such. Regional and State personnel must exercise their discretion in using this guidance document as well as other relevant information in determining whether an RFI meets the regulatory standard.

Mention of company or product names in this document should not be considered as an endorsement by the U.S. Environmental Protection Agency.

RCRA FACILITY INVESTIATION (RFI) GUIDANCE

VOLUME II

SOIL, GROUND WATER AND SUBSURFACE GAS RELEASES

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LIST OF ACRONYMS

AA	-	Atomic Absorption
AI	-	Soil Adsorption Isotherm Test
ASCS	-	Agricultural Stabilization and Conservation Service
ASTM	-	American Society for Testing and Materials
BCF	-	Bioconcentration Factor
BOD	-	Biological Oxygen Demand
CAG	-	EPA Carcinogen Assessment Group
CPF	-	Carcinogen Potency Factor
CBI	-	Confidential Business Information
CEC	-	Cation Exchange Capacity
CERCLA	-	Comprehensive Environmental Response, Compensation, and Lability Act
CFR	-	Code of Federal Regulations
CIR	-	Color Infrared
CM	-	Corrective Measures
CMI	-	Corrective Measures Implementation
CMS	-	Corrective Measures Study
COD	-	Chemical Oxygen Demand
COLIWASA	-	Composite Liquid Waste Sampler
DNPH	-	Dinitrophenyl Hydrazine
DO	-	Dissolved Oxygen
DOT	-	Department of Transportation
ECD	-	Electron Capture Detector
EM	-	Electromagnetic
EP	-	Extraction Procedure
EPA	-	Environmental Protection Agency
FEMA	-	Federal Emergency Management Agency
FID	-	Flame Ionization Detector
foc	-	Fraction organic carbon in soil
FWS	-	U.S. Fish and Wildlife Service
GC	-	Gas Chromatography
GC/MS	-	Gas chromatography/Mass Spectroscopy
GPR	-	Ground Penetrating Radar
HEA	-	Health and Envioronmental Assessment
HEEP	-	Health and Environmental Effects Profile
HPLC	-	High Pressure Liquid Chromatography
HSWA	-	Hazardous and Solid Waste Amendments (to RCRA)
HWM	-	Hazardous Waste Management
ICP	-	Inductively Coupled (Argon) Plasma
ID	-	Infrared Detector
Kd	-	Soil/Water Partition Coefficient
Koc	-	Organic Carbon Absorption Coefficient
Kow	-	Octanol/Water Partition Coefficient
LEL	-	Lower Explosive Limit
MCL	-	Maximum Contaminant Level
MM5	-	Modified Method 5
MS/MS	-	Mass Spectroscopy/Mass Spectroscopy
NFIP	-	National Flood Insurance Program
NIOSH	-	National Institute for Occupational Safety and Health
NPDES	-	National Pollutant Discharge Elimination System
OSHA	-	Occupational Safety and Health Administration

LIST OF ACRONYMS (Continued)

OVA	-	Organic Vapor Analyzer
PID	-	Photo Ionization Detector
pKa	-	Acid Dissociation Constant
ppb	-	parts per billion
ppm	-	parts per million
PUF	-	Polyurethane Foam
PVC	-	Polyvinyl Chloride
QA/QC	-	Quality Assurance/Quality Control
RCRA	-	Resource Conservation and Recovery Act
RFA	-	RCRA Facility Assessment
RfD	-	Reference Dose
RFI	-	RCRA Facility Investigation
RMCL	-	Recommended Maximum Contaminant Level
RSD	-	Risk Specific Dose
SASS	-	Source Assessment Sampling System
SCBA	-	Self Contained Breathing Apparatus
SCS	-	Soil Conservation Service
SOP	-	Standard Operating Procedure
SWMU	-	Solid Waste Management Unit
TCLP	-	Toxicity Characteristic Leaching Procedure
TEGD	-	Technical Enforcement Guidance Document (EPA, 1986)
TOC	-	Total Organic Carbon
TOT	-	Time of travel
TOX	-	Total Organic Halogen
USGS	-	United States Geologic Survey
USLE	-	Universal Soil Loss Equation
UV	-	Ultraviolet
VOST	-	Volatile Organic Sampling Train
VSP	-	Verticle Seismic Profiling
WQC	-	Water Quality Criteria

SECTION 9

SOIL

9.1 Overview

The objective of an investigation of a release to soil is to characterize the nature, extent, and rate of migration of a release of hazardous waste or constituents to that medium. This section provides:

- An example strategy for characterizing releases to soils, which includes characterization of the source and the environmental setting of the release, and conducting a monitoring program that will characterize the release.
- Formats for data organization and presentation;
- Field methods that may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data needed in all instances; however, it identifies possible information that might be necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for release characterization. This list is not meant to be a list of requirements for all releases to soil. Some release investigations will involve the collection of only a subset of the items listed, while others may involve the collection of additional data.

9.2 Approach for Characterizing Releases to Soil

9.2.1 General Approach

A preliminary task in any soil investigation should be to review existing site information that might help to define the nature and magnitude of the release. Information supplied by the regulatory agency in permit conditions or an enforcement order will indicate known or suspected releases to soil from specific units at the facility needing investigation; and may also indicate situations where inter-media contaminant transfer should be investigated.

A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available. For soil investigations, this model should account for the ability of the waste to be dissolved by infiltrating percipitation, its affinity for soil particles (i.e., sorption), its degradability (biological and chemical), and its decomposition products. Unit-specific factors affecting the magnitude and configuration of the release should also be incorporated (e.g., large area releases from land treatment versus more localized releases from small drum storage areas). The conceptual model should also address the potential for transfer of contaminants in soil to other environmental media (e.g., overland runoff to surface water, leaching to ground water, and volatilization to the atmosphere).

Characterizing contaminant releases to soils may employ a phased approach. Data collected during an initial phase can be evaluated to determine the need for or scope of subsequent efforts. For example, if a suspected release was identified by the regulatory agency, the initial monitoring effort may be geared to release verification. Table 9-1 presents an example of a release characterization strategy. The intensity and duration of the investigation will depend on the complexity of the environmental setting and the nature and magnitude (e.g., spatial extent and concentrations) of the release.

TABLE 9-1

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SOIL*

INITIAL PHASE

1. Collect and review existing information on:

   - Waste
   - Unit
   - Environmental setting
   - Releases, including inter-media transport

2. Identify additional information necessary to fully characterize release

   - Waste
   - Unit
   - Environmental setting
   - Releases, including inter-media transport

3. Develop monitoring procedures:

   - Formulate conceptual model of release
   - Determine monitoring program objectives
   - Select constituents and indicators to be monitored
   - Plan initial sampling based on unit/waste/environmental setting characteristics and conceptual model. May include field screening methods, if appropriate.
   - Define study and background areas
   - Determine sampling methods, locations, depths and numbers
   - Sampling frequency
   - Analytical methods
   - QA/QC procedures

TABLE 9-1 (Continued)

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SOIL*

4 Conduct initial monitoring phase:

- Employ field screening methods, if appropriate
- Conduct initial soil sampling and other appropriate field measurements
- Collect geologic data
- Analyze samples for selected constituents and indicators

5. Collect, evaluate, and report results:

- Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that may warrant interim corrective measures - Notify regulatory agency
- Evaluate potential for inter-media contaminant transfer
- Summarize and present data in an appropriate format
- Determine if monitoring program objectives were met (e.g., monitoring locations, constituents and frequency were adequate to characterize release (nature, rate and extent))
- Report results to regulatory agency

SUBSEQUENT PHASES (if necessary)

1. Identify additional information necessary to characterize release:

- Determine need to expand or include further soil stratigraphic and hydrologic sampling
- Information needed to evaluate potential for inter-media contaminant transfer (e.g., leaching studies to evaluate potential for ground-water contamination)

2. Expand monitoring network as necessary:

- Expand area of field screening, if appropriate
- Expand sampling area and/or increase density
- Add or delete constituents and parameters of concern
- Increase or decrease monitoring frequency

TABLE 9-1 (Continued)

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO SOIL*

3. Conduct subsequent monitoring phases:

   - Perform expanded monitoring and field analyses
   - Analyze samples for selected constituents and parameters

4. Collect, evaluate, and report results/identify additional information necessary to characterize release:

   - Compare results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that warrant interim corrective measures - Notify regulatory agency
   - Summarize and present data in appropriate format
   - Determine if monitoring program objectives were met
   - Determine if monitoring locations, constituents, and frequency were adequate to characterize release (nature, extent, and rate)
   - Determine need to expand monitoring system
   - Evaluate potential for inter-media contaminant transfer
   - Report results to regulatory agency, including results of inter-media transfer evaluation, if applicable.

* The possibility for inter-media transfer of contamination should be anticipated throughout the investigation.

The owner or operator should plan the initial characterization effort with all available information on the site, including wastes and soil characteristics. During the initial phase, constituents of concern as well as indicator parameters should be identified that can be used to characterize the release and determine the approximate extent and rate of migration of the release. Table 9-2 lists tasks that can be performed to characterize a release to soils and displays the associated techniques and outputs from each of these tasks. Soil characteristics and other environmental factors include 1) surface features such as topography, erosion potential, land-use capability, and vegetation; 2) stratigraphic/hydrologic features such as soil profile, particle size distribution, hydraulic conductivity, pH, porosity, and cation exchange capacity; and 3) meteorological factors such as temperature, precipitation, runoff, and evapotranspiration. Relevant soil physical and chemical properties should be measured and related to waste properties to determine the potential mobility of the contaminants in the soil.

As monitoring data become available, both within and at the conclusion of discrete investigation phases, it should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (see Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For such situations, the owner or operator is directed to obtain and follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D, and Part 265, Subpart D.

As indicated above, depending on the results of the initial phase, the need for further characterization will be determined by the regulatory agency. Subsequent phases, if necessary, may involve expansion of the sampling network, changes in the study area, investigation of contaminant transfer to other media, or other

TABLE 9-2
RELEASE CHARACTERIZATION TASKS FOR SOILS

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
1 Waste/Unit Characterization	Refer to Sections 3 and 7	- Table of monitoring constituents and their chemical/physical properties - Table of unit features contributing to soil releases
2. Environmental Setting Characterization		
- Determine surface features and topography	- Aerial photography or mapping (See Appendix A	- Soil survey map Topographic map Photographs
- Characterize soil stratigraphy and hydrology	- Soil core examination	- Soil boring logs
	- Measurement of soil properties	- Soil profile, transect, or fence diagram - Particle size distribution - Table of unsaturated hydraulic conductivities for each soil layer - Table of soil chemistry and structure (e.g., pH, porosity) for each soil type
- Meteorological Conditions	- On-site meteorological monitoring	- Temperature charts - Tables of monthly and annual precipitation, runoff, and evapo-transpiration
3. Release Characterization	- Field Screening	- Maps and tables showing results of soil gas surveys - Tables and graphs showing results of chemical analyses performed in the field
	- Sampling and Analysis	- Map of sampling points - Table of constituent concentrations measured at each sampling point - Area and profile maps of site, showing distribution of contaminants
	- Soil Transport Modeling	- Table of input values, boundary conditions, output values, and modeling assumptions - Maps of present or future extent of contamination

objectives dictated by the initial findings. The owner or operator may propose to use mathematical models (e.g., chemical, physical) to aid in the choice of additional sampling locations or to estimate contaminant mobility in soil. The results of all characterization efforts should be organized and presented to the regulatory agency in a format appropriate to the data.

Case Study Numbers 2, 3, 15, 16 and 17 in Volume IV (Case Study Examples) illustrate various aspects of soil investigations.

9.2.2 Inter-media Transport

As mentioned above, the potential for inter-media transfer of releases from the soil medium to other media is significant. Contaminated soil can be a major source of contamination to ground water, air, subsurface gas and surface water. Hazardous wastes or constituents, particularly those having a moderate to high degree of mobility, can leach from the soil to the ground water. Volatile wastes or constituents can contribute to subsurface gas and releases to air. Contaminated soils can also contribute to surface water releases, especially through run-off during heavy rains. Application of the universal soil loss equation (See Section 13.6) can indicate whether inter-media transport from soil to surface water as a result of erosion can act as a source of contamination. The owner or operator should recognize the potential for inter-media transport of releases to soil and should communicate as appropriate with the regulatory agency when such transport is suspected or identified during the investigation.

Similarly, the potential for inter-media transport of constituents from other media to the soil also exists. For example, hazardous waste or constituents may be transported to the soil via atmospheric deposition (especially during rain or snowfall events) through the air medium, and also through releases of subsurface gas. The guidance provided in this section addresses characterization of releases to soil from units and also can be used to characterize releases to soil as a result of inter-media transport through other media. A key to such characterization is determining the nature of the contaminant source, which is described in Section 9.3.

It is also important to recognize that where multiple media appear to be contaminated, the investigation can be coordinated to provide results that can

apply to more than one of the affected media. For example, soil-gas analysis (e.g., using a portable gas chromatograph during the subsurface investigation) can be used to investigate releases to soil and subsurface gas releases, and may also provide information concerning the spatial extent of contaminated ground water

9.3 Characterization of the Contaminant Source and the Environmental Setting

9.3.1 Waste Characterization

The physical and chemical properties of the waste or its constituents affect their fate and transport in soil; and, therefore affect the selection of sampling and analytical methods. Identification of monitoring constituents and the use of indicator parameters is discussed in Section 3 and Appendix B. Sources of information and sampling techniques for determining waste characteristics are discussed in detail in Section 7.

Chemicals released to soil may undergo transformation or degradation by chemical or biological mechanisms, may be adsorbed onto soil particles, or may volatilize into soil pore spaces or into the air. Table 9-3 summarizes various physical, chemical, and biological transformation/transport processes that may affect waste and waste constituents in soil.

The chemical properties of the contaminants of concern also influence the choice of sampling method. Important considerations include the water solubility and volatility of the contaminants, and the potential hazards to equipment and operators during sampling. For example, water soluble compounds that are mobile in soil water may be detected by pore-water sampling and whole soil sampling. Volatile organic contaminants require specialized sampling and sample storage measures to prevent losses prior to analysis. Viscous substances require different sampling techniques due to their physical properties.

Reactive, corrosive, or explosive wastes may pose a potential hazard to personnel during soil sampling. High levels of organic contamination may also cause health problems due to toxicity. For example, landfills can produce methane gas that can explode if ignited by sparks or heat from the drilling operation.

TABLE 9-3
TRANSFORMATION/TRANSPORT PROCESSES IN SOIL

Process	Key Factor
Biodegradation	Waste degradability Waste toxicity Acclimation of microbial community Aerobic/anaerobic conditions pH Temperature Nutrient concentrations
Photodegradation	Solar irradiation Exposed surface area
Hydrolysis	Functional group of chemical Soil pH and buffering capacity Temperature
Oxidation/reduction	Chemical class of contaminant Presence of oxidizing agents
Volatilization	Partial pressure Henry's Law Constant Soil porosity Temperature
Adsorption	Effective surface area of soil Cation exchange capacity (CEC) Fraction organic content (F_{oc}) of soil Octanol/water partition coefficient (K_{ow})
Dissolution	Solubility Soil pH and buffering capacity Complex formation

Corrosive, reactive, or explosive wastes can also damage soil sampling equipment or cause fires and explosions. Appropriate precautions to prevent such incidents include having an adequate health and safety plan in place, using explosimeters or organic vapor detectors as early-warning devices, and employing geophysical techniques to help identify buried objects (e.g., to locate buried drums). All contaminated soil samples should be handled as if they contain dangerous levels of hazardous wastes or constituents.

Identity and composition of contaminants--The owner or operator should identify and provide approximate concentrations for any constituents of concern found in the original waste and, if available, in leachate from any releasing unit. Identification of other (non-hazardous) waste components that may affect the behavior of hazardous constituents or may be used as indicator parameters is also recommended. Such components may form a primary leachate causing transport behavior different from water and may also mobilize hazardous constituents bound to the soil. Estimations of transport behavior can help to focus the determination of sampling locations.

Physical state of contaminants--The physical state (solid, liquid, or gas) of the contaminants in the waste and soil should be determined by inspection or from site operating records. Sampling can then be performed at locations most likely to contain the contaminant.

Viscosity--The viscosity of any bulk liquid wastes should be determined to estimate potential mobility in soils. A liquid with a lower viscosity will generally travel faster than one of a higher viscosity.

pH--Bulk liquid pH may affect contaminant transport in at least two ways: (1) it may alter the chemical form of acids and bases, metal salts, and other metal complexes, thereby altering their water solubility and soil sorption properties, and (2) it may alter the soil chemical or physical makeup, leading to changes in sorptive capacity or permeability. For example, release of acidic (low pH) wastes in a karst (e.g., limestone) environment can lead to the formation of solution channels. See Section 10.3 for more information on karst formations.

Dissociation constant (pKa)--For compounds that are appreciably ionized within the expected range of field pH values, the pKa of the compound should be determined. Ionized compounds have either a positive or negative charge and are often highly soluble in water; therefore, they are generally more mobile than in their neutral forms when dissolved. Compounds that may ionize include organic and inorganic acids and bases, phenols, metal salts, and other inorganic complexes. Estimated contaminant concentration isopleths can be plotted with this information and can be used in determining sampling locations.

Density--The density of major waste components should be determined, especially for liquid wastes. Components with a density greater than water, such as carbon tetrachloride, may migrate through soil layers more quickly than components less dense than water, such as toluene, assuming viscosity to be negligible. Density differences become more significant when contaminants reach the saturated zone. Here they may sink, float, or be dissolved in the ground water. Some fraction of a "sinker" or "floater" may also be dissolved in the ground water.

Water solubility--This chemical property influences constituent mobility and sorption of chemicals to soil particle surfaces. Highly water-soluble compounds are generally very mobile in soil and ground water. Liquid wastes that have low solubility in water may form a distinct phase in the soil with flow behavior different from that of water. Additional sampling locations may be needed to characterize releases of insoluble species.

Henry's Law constant--This parameter indicates the partitioning ratio of a chemical between air and water phases at equilibrium. The larger the value of a constituent's Henry's Law Constant, the greater is the tendency of the constituent to volatilize from water surrounding soil particles into soil pore spaces or into above-ground air. The Henry's Law Constant should be considered in assessing the potential for inter-media transport of constituents in soil gas to the air. Therefore, this topic is also discussed in the Subsurface Gas and Air sections (Sections 11 and 12, respectively). Information on this parameter can help in determining which phases to sample in the soil investigation.

Octanol/Water partition coefficient (K_{ow})--The characteristic distribution of a chemical between an aqueous phase and an organic phase (octanol) can be used to

predict the sorption of organic chemicals onto soils. It is frequently expressed as a logarithm (log K_{ow}). In transport models, K_{ow} is frequently converted to K_{oc}, a parameter that takes into account the organic content of the soil. The empirical expression used to calculate K_{oc} is: $K_{oc} = 0.63\ K_{ow} f_{oc}$, where f_{oc} is the fraction by weight of organic carbon in the soil. The higher the value of K_{ow} (or K_{oc}) the greater the tendency of a constituent to adsorb to soils containing appreciable organic carbon. Consideration of this parameter will also help in determining which phases to sample in the soil investigation.

Biodegradability--There is a wide variety of microorganisms that may be present in the soil. Generally, soils that have significant amounts of organic matter will contain a higher microbial population, both in density and in diversity. Microorganisms are responsible for the decay and/or transformation of organic materials and thrive mostly in the "A" (uppermost) soil horizon where carbon content is generally highest and where aerobic digestion occurs. Because some contaminants can serve as organic nutrient sources that soil microorganisms will digest as food, these contaminants will be profoundly affected within organic soils. Digestion may lead to complete decomposition, yielding carbon dioxide and water, but more often results in partial decomposition and transformation into other substances. Transformation products will likely have different physical, chemical or toxicological characteristics than the original contaminants. These products may also be hazardous constituents (some with higher toxicities) and should therefore be considered in developing monitoring programs. The decomposition or degradation rate depends on various factors, including:

- The molecular structure of the contaminants. Certain manmade compounds (e.g., PCBs and chlorinated pesticides) are relatively nondegradable (or persistent), whereas others (e.g., methyl alcohol) are rapidly consumed by bacteria. The owner or operator should consult published lists of compound degradability, such as Table 9-4, to estimate the persistence of waste constituents in soil. This table provides relative degradabilities for some organic compounds and can be an aid to identifying appropriate monitoring constituents and indicator parameters. It may be especially useful for older releases where degradation may be a significant factor. For example, some of the parent compounds that are relatively degradable (see Table 9-4) may

TABLE 9-4. BOD_5/COD RATIOS FOR VARIOUS ORGANIC COMPOUNDS*

Compound	Ratio	Compound	Ratio
RELATIVELY UNDEGRADABLE		**MODERATELY DEGRADABLE (CONT'D)**	
Butane	~0	Mineral spirits	~0.02
Butylene	~0	Cyclohexanol	0.03
Carbon tetrachloride	~0	Acrylonitrile	0.031
Chloroform	~0	Nonanol	>0.033
1,4-Dioxane	~0	Undecanol	<0.04
Ethane	~0	Methylethylpyridine	0.04-0.75
Heptane	~0	1-Hexene	<0.044
Hexane	~0	Methyl isobutyl ketone	<0.044
Isobutane	~0	Diethanolamine	<0.049
Isobutylene	~0	Formic acid	0.05
Liquefied natural gas	~0	Styrene	>0.06
Liquefied petroleum gas	~0	Heptanol	<0.07
Methane	~0	sec-Butyl acetate	0.07-0.23
Methyl bromide	~0	n-Butyl acetate	0.07-0.24
Methyl chloride	~0	Methyl alcohol	0.07-0.73
Monochlorodifluoromethane	~0	Acetonitrile	0.079
Nitrobenzene	~0	Ethylene glycol	0.081
Propane	~0	Ethylene glycol monoethyl ether	<0.09
Propylene	~0	Sodium cyanide	<0.09
Propylene oxide	~0	Linear alcohols (12-15 carbons)	>0.09
Tetrachloroethylene	~0	Allyl alcohol	0.091
Tetrahydronaphthalene	~0	Dodecanol	0.097
1 Pentrene	<0.002	**RELATIVELY DEGRADABLE**	
Ethylene dichloride	0.002	Valeraldehyde	<0.10
1 Octene	>0.003	n-Decyl alcohol	>0.10
Morpholine	<0.004	p-Xylene	<0.11
Ethylenediaminetetracetic acid	0.005	Urea	0.11
Triethanolamine	<0.006	Toluene	<0.12
o-Xylene	<0.008	Potassium cyanide	0.12
m-Xylene	<0.008	Isopropyl acetate	<0.13
Ethylbenzene	<0.009	Amyl acetate	0.13-0.34
MODERATELY DEGRADABLE		Chlorobenzene	0.15
Ethyl ether	0.012	Jet fuels (various)	~0.15
Sodium alkylbenzenesulfonates	~0.017	Kerosene	~0.15
Monoisopropanolamine	<0.02	Range oil	~0.15
Gas oil (cracked)	~0.02	Glycerine	<0.16
Gasolines (various)	~0.02	Adiponitrile	0.17

TABLE 9-4. (Continued)

Compound	Ratio	Compound	Ratio
RELATIVELY DEGRADABLE (CONT'D.)		RELATIVELY DEGRADABLE (CONT'D.)	
Furfural	0.17-0.46	Ethyleneimine	0.46
2-Ethyl-3-propylacrolein	<0.19	Monoethanolamine	0.46
Methylethylpyridine	<0.20	Pyridine	0.46-0.58
Vinyl acetate	<0.20	Dimethylformamide	0.48
Diethylene glycol monomethyl ether	<0.20	Dextrose solution	0.50
Napthalene (molten)	<0.20	Corn syrup	~0.50
Dibutyl phthalate	0.20	Maleic anhydride	>0.51
Hexanol	~0.20	Propionic acid	0.52
Soybean oil	~0.20	Acetone	0.55
Paraformaldehyde	0.20	Aniline	0.56
n-Propyl alcohol	0.20-0.63<0.24	Isopropyl alcohol	0.56
Methyl methacrylate	<0.24	n-Amyl alcohol	0.57
Acrylic acid	0.26	Isoamyl alcohol	0.57
Sodium alkyl sulfates	0.30	Cresols	0.57-0.68
Triethylene glycol	0.31	Crotonaldehyde	<0.58
Acetic acid	0.31-0.37	Phthalic anhydride	0.58
Acetic anhydride	>0.32	Benzaldehyde	0.62
Ethylenediamine	<0.35	Isobutyl alcohol	0.63
Formaldehyde solution	0.35	2,4-Dichlorophenol	0.78
Ethyl acetate	<0.36	Tallow	~0.80
Octanol	0.37	Phenol	0.81
Sorbitol	<0.38	Benzoic acid	0.84
Benzene	<0.39	Carbolic acid	0.84
n-Butyl alcohol	0.42-0.74	Methyl ethyl ketone	0.88
Propionaldehyde	<0.43	Benzoyl chloride	0.94
n-Butyraldehyde	<0.43	Hydrazine	1.0
		Oxalic acid	1.1

*Source: U.S. EPA 1985. Handbook: Remedial Action at Waste Disposal Sites (Revised). EPA/625/6-85/006. NTIS PB82-239054. Office of Emergency and Remedial Response. Washington, D.C. 20460.

have been reduced to carbon dioxide and water or other decomposition products prior to sampling. Additional information on degradability can be found in Elliott and Stevenson, 1977; Sims et al, 1984; and U.S. EPA, 1985. See Section 9.8 for complete citations for these references.

- Moisture content. Active biodegradation does not generally occur in relatively dry soils or in some types of saturated soils, such as those that are saturated for long periods of time, as in a bog.

- The presence or absence of oxygen in the soil. Most degradable chemicals decompose more rapidly in aerobic (oxygenated) soil. Although unsaturated surficial soils are generally aerobic, anaerobic conditions may exist under landfills or other units. Soils that are generally saturated year round are relatively anaerobic (e.g., as in a bog); however, most saturated soils contain enough oxygen to support active biodegradation. Anaerobic biodegradation, however, can also be significant in some cases. For example, DDT degrades more rapidly under anaerobic conditions than under aerobic conditions.

- Microbial adaptation or acclimation. Biodegradation depends on the presence in the soil of organisms capable of metabolizing the waste constituents. The large and varied population of microorganisms in soil is likely to have some potential for favorable growth using organic wastes and constituents as nutrients. However, active metabolism usually requires a period of adaptation or acclimation that can range from several hours to several weeks or months, depending on the constituent or waste properties and the microorganisms involved.

- The availability of contaminants to micro-organisms. Releases that occur below the upper 6 to 8 inches of soil are less likely to be affected because fewer micro-organisms exist there. In addition, compounds with greater aqueous solubilities are generally more available for degradation. However, high solubility also correlates directly to the degree of mobility. If relatively permeable soil conditions prevail and constituents migrate rapidly, they are less likely to be retained long enough in the soil for biodegradation to occur.

- Other factors. Activity of organisms is also dependent on favorable temperature and pH conditions as well as the availability of other organic and inorganic nutrients for metabolism.

Rates of Hydrolysis, Photolysis, and Oxidation--Chemical and physical transformation of the waste can also affect the identity, amounts, and transport behavior of the waste constituents. Photolysis is important primarily for chemicals on the land surface, whereas hydrolysis and oxidation can occur at various depths. Published literature sources should be consulted to determine whether individual constituents are likely to degraded by these processes, but it should be recognized that most literature values refer to aqueous systems. Relevant references include Elliott and Stevenson, 1977; Sims et al, 1984; and U.S. EPA, 1985. Chemical and physical degradation will also be affected by soil characteristics such as pH, water content, and soil type.

9.3.2 Unit Characterization

Unit-related factors that may be important in characterizing a release include:

- Unit design and operating characteristics;
- Release type (point-source or nonpoint-source);
- Depth of the release;
- Magnitude of the release; and
- Timing of the release.

9.3.2.1 Unit Design and Operating Characteristics

Information on design and operating characteristics of a unit can be helpful in characterizing a release. Table 9-5 presents important mechanisms of contaminant release to soils for various unit types. This information can be used to identify areas for initial soil monitoring.

TABLE 9-5
POTENTIAL RELEASE MECHANISMS FOR VARIOUS UNIT TYPES

Unit Type	Release Mechanisms
Surface Impoundment	Loading/unloading areas Releases from overtopping Seepage
Landfill	Migration of releases outside the unit's runoff collection and containment system Migration of releases outside the containment area from loading and unloading operations Leakage through dikes or unlined portions to surrounding soils
Waste Pile	Migration of runoff outside the unit's runoff collection and containment system Migration of releases outside the containment area from loading and unloading operations. Seepage through underlying soils
Land Treatment Unit	Migration of runoff outside the containment area Passage of leachate into the soil horizon
Container Storage Area	Migration of runoff outside the containment area Loading/unloading areas Leaking drums
Above-ground or In-ground Tank	Releases from overflow Leaks through tank shell Leakage from coupling/uncoupling operations Leakage from cracked or corroded tanks
Incinerator	Routine releases from waste handling/preparation activities Leakage due to mechanical failure
Class I and IV Injection Wells	Leakage from waste handling operations at the well head

* Waste transfer stations and waste recycling operations generally have mechanisms of release similar to tanks.

9.3.2.2 Release Type (Point or Non-Point Source)

The owner or operator should establish whether the release involved a localized (point) source or a non-point source. Units that are likely sources of localized releases to soil include container handling and storage areas, tanks, waste piles, and bulk chemical transfer areas (e.g., loading docks, pipelines, and staging areas). Non-point sources may include airborne particulate contamination originating from a land treatment unit and widespread leachate seeps from a landfill. Land treatment can also result in widespread releases beyond the treatment zone if such units are not properly designed and operated; refer to EPA's Permit Guidance Manual on Hazardous Waste Land Treatment Demonstration, July, 1986 (NTIS PB86-229192) for additional information on determining contamination from land treatment units. This manual also discusses use of the RITZ model (Regulatory and Investigation Treatment Zone Model), which may be particularly useful for evaluating mobility and degradation within the treatment zone. This model is discussed in more detail in Section 9.4.4.2.

The primary characteristic of a localized release is generally a limited area of relatively high contaminant concentration surrounded by larger areas of relatively clean soil. Therefore, the release characterization should focus on determining the boundaries of the contaminated area to minimize the analysis of numerous uncontaminated samples. Where appropriate, a survey of the area with an organic vapor analyzer, portable gas chromatograph, surface geophysical instruments (see Appendix C), or other rapid screening techniques may aid in narrowing the area under investigation. Stained soil and stressed vegetation may provide additional indications of contamination. However, even if the extent of contamination appears to be obvious, it is the responsibility of the owner or operator to verify boundaries of the contamination by analysis of samples both inside and outside of the contaminated area.

Non-point type releases to soil may also result from deposition of particulates carried in the air, such as from incinerator "fallout". Such releases generally have a characteristic distribution with concentrations often decreasing logarithmically away from the source and generally having low variability within a small area. The highest contaminant concentrations tend to follow the prevailing wind directions (See also Section 12 on Air). Non-point releases occurring via other mechanisms

(e.g., land treatment) may be distributed more evenly over the affected area. In these situations, a large area may need to be investigated in order to determine the extent of contamination. However, the relative lack of "hot spots" may allow the number of samples per unit area to be smaller than for a point source type release.

9.3.2.3 Depth of the Release

The owner or operator should consider the original depth of the release to soil and the depth to which contamination may have migrated since the release. Often, releases occur at the soil surface as a result of spillage or leakage. Releases directly to the subsurface can occur from leaking underground tanks, buried pipelines, waste piles, impoundments, landfills, etc.

Differentiating between deep and shallow soil or surficial soil can be important in sampling and in determining potential impacts of contaminated soil. Different methods to characterize releases within deep and surficial soils may be used. For example, sampling of surficial soil may involve the use of shovels or hand-driven coring equipment, whereas deep-soil contamination usually requires the use of power-driven equipment (see Section 9.6 for more information). In addition, deep-soil and surficial-soil contamination may be evaluated differently in the health and environmental assessment process discussed in Section 8. Assessment of surficial-soil contamination will involve assessing risk from potential ingestion of the contaminated soil as well as assessing potential impacts to ground water. The assessment of deep-soil contamination may be limited to determining the potential for the soil to act as a continuing source of potential contamination to ground water.

For purposes of the RFI, surficial or shallow-zone soils may be defined as those comprising the upper 2 feet of earth, although specific sites may exhibit surficial soil extending to depths of up to 12 feet or more. Considerations for determining the depth of the shallow-soil zone may include:

- Meteorological conditions (e.g., precipitation, erosion due to high winds, evaporation of soil-pore gases);

- Potential for excessive surface runoff, especially if runoff would result in gully formation;

- Transpiration, particularly from the root zone, and effects on vegetation and animals, including livestock, that may feed on the vegetation; and

- Land use, including potential for excavation/construction, use of the soil for fill material, installation of utilities (e.g., sewer lines or electrical cables), and farming activities.

Land use that involves housing developments is an example of when the surficial soil depth may extend to 12 feet because foundation excavation may result in deep contaminated soils being moved to the surface. Deep-soil zones, for purposes of the RFI, may be defined as those extending from 2 feet below the land surface to the ground-water surface. If deep-soil contamination is already affecting ground water (through inter-media transport) at a specific site, consideration should be given to evaluating the potential for such contamination to act as a continuing source of ground-water contamination.

The depth to which a release may migrate depends on many factors, including volume of waste released, amount of water infiltrating the soil, age of the release, and chemical and physical properties of the waste and soil (as addressed in the previous section). In a porous, homogeneous soil, contaminants tend to move primarily downward within the unsaturated zone. Lateral movement generally occurs only through dispersion and diffusion. However, changes in soil structure or composition with depth (e.g., stratification), and the presence of zones of seasonally saturated soil, fractures, and other features may cause contaminants to spread horizontally for some distance before migrating downward. Careful examination of soil cores and accurate measurement of physical properties and moisture content of soil are therefore essential in estimating the potential for contaminant transport.

Transport of chemicals in the soil is largely caused by diffusion and mass flow. Diffusion results from random thermal motion of molecules. Mass flow, also known as convective flow, is transport by a flowing liquid or by a gaseous phase. Mass flow is typically downward (due to gravity); however, mass flow could also be upward

due to capillary action (e.g., if significant evaporation occurs at the surface). Mass flow is a much faster transport mechanism than is diffusion (Morrill et al., 1985).

Other factors that can promote downward contaminant migration include turnover of soil by burrowing animals, freeze/thaw cycles, and plowing or other human activities. All factors that may affect the depth of contamination should be considered. The owner or operator should use available information to estimate the depth of contamination and should then conduct sampling at appropriate depths to confirm these estimates.

Approaches to monitoring releases to soil will differ substantially depending on the depth of contamination. For investigations of both surficial and deep-soil contamination, a phased approach may be used. Initial characterization will often necessitate a judgmental approach in which sampling depths are chosen based on available information (e.g., topography, soil stratigraphy, and visual indication of a release). Information derived from this initial phase can then be used to refine estimates of contaminant distribution and transport. This information will serve as a basis for any subsequent monitoring that may be necessary.

Where the source or precise location of a suspected release has not been clearly identified, field screening methods (See Section 9.6) may be appropriate. Subsurface contamination can be detected by using geophysical methods or soil gas surveying equipment (e.g., organic vapor analyzers). Geophysical methods, for example, can help in locating buried drums. Soil gas surveys can be useful in estimating the lateral and vertical extent of soil contamination. Further delineation of the vertical extent of contamination may necessitate an additional effort such as core sampling and analysis. Sampling approaches for locating and delineating subsurface contaminant sources include systematic and random grid sampling. These approaches are discussed in Section 3. Geophysical methods are discussed in Section 10 (Ground Water) and in Appendix C (Geophysical Techniques).

9.3.2.4 Magnitude of the Release

Information on the magnitude of the release can be estimated from site operating records, unit design features, and other sources. The quantity (mass) of waste released to soil and the rate of release can affect the geographical extent and

nature of the contamination. Each soil type has a specific sorptive capacity to bind contaminants. If the sorptive capacity is exceeded, contaminants tend to migrate through the soil toward the ground water. Therefore, a " minor" release may be, at least temporarily, immobilized in shallow soils, whereas a "major" release is more likely to result in ground-water contamination. The physical processes of volatilization and dissolution in water are also affected by contaminant concentrations and should, therefore, be considered in assessing the potential for inter-media transport. Section 9.4.4.3 provides additional guidance on estimating the mobility of constituents within contaminated soils.

9.3.2.5 Timing of the Release

Time-related factors that should be considered in characterizing a release include:

- Age of the release;
- Duration of the release;
- Frequency of the release; and
- Season (time of year).

The length of time that has passed since a release occurred can affect the extent of contamination, the chemical composition of the contaminants present in soil, and the potential for inter-media transport. Recent releases tend to be more similar in composition to the parent waste material and may also be more concentrated within the original boundaries of the release. If a recent release occurred at the land surface, contaminant volatilization to air or dissolution in overland runoff may be important transport mechanisms. Older releases are more likely to have undergone extensive chemical or biological changes that altered their original composition and may have migrated a considerable distance from their original location. If the contaminants are relatively mobile in soil, transport to ground water may be a concern; whereas soil-bound contaminants may be more likely affected by surface transport, such as overland runoff or wind action. These

factors should be considered in the selection of monitoring constituents and sampling locations.

The duration and frequency of the release can affect the amounts of waste released to the soil and its distribution in the soil. For example, a release that consisted of a single episode, such as a ruptured tank, may move as a discrete "slug" of contamination through the soil. On the other hand, intermittent or continuous releases may present a situation in which contaminants exist at different distances from the source and/or have undergone considerable chemical and biological decomposition. Therefore, the design of monitoring procedures and estimations of contaminant fate and transport should consider release duration and frequency.

The time of year or season may also affect release fate and transport. Volatile constituents are more likely to be released to the air or to migrate as subsurface gas during the warmer summer months. During the colder winter months, releases may be less mobile, especially if freezing occurs.

9.3.3 Characterization of the Environmental Setting

The nature and extent of contamination is affected by environmental processes such as dispersion and degradation acting after the release has occurred. Factors which should be considered include soil physical and chemical properties, subsurface geology and hydrology, and climatic or meteorologic patterns. These factors are discussed below.

Characteristics of the soil medium which should be considered in order to obtain representative samples for chemical or physical analysis include:

- The potentially large spatial variability of soil properties and contaminant distribution;
- Spatial and temporal fluctuations in soil moisture content; and
- The presence of solid, liquid, and gaseous phases in the unsaturated zone.

9.3.3.1 Spatial Variability

Spatial variability, or heterogeneity, can be defined as horizontal and vertical differences in soil properties occurring within the scale of the area under consideration. Vertical discontinuities are found in most soil profiles as a result of climatic changes during soil formation, alterations in topography or vegetative cover, etc. Soil layers show wide differences in their tendency to sorb contaminants or to transmit contaminants in a liquid form; therefore, a monitoring program that fails to consider vertical stratification will likely result in an inaccurate assessment of contaminant distribution. Variability in soil properties may also occur in the horizontal plane as a result of factors such as drainage, slope, land use history, and plant cover.

Soil and site maps will aid in designing sampling procedures by identifying drainage patterns, areas of high or low surface permeability, and areas susceptible to wind erosion and contaminant volatilization. Maps of unconsolidated deposits may be prepared from existing soil core information, well drilling logs, or from previous geological studies. Alternately, the information can be obtained from new soil borings. Because soil coring can be a resource-intensive activity, it is generally more efficient to also obtain samples from these cores for preliminary chemical analyses and to conduct such activity concurrent with investigation of releases to other media (e.g., ground water).

The number of cores necessary to characterize site soils depends on the site's geological complexity and size, the potential areal extent of the release, and the importance of defining small-scale discontinuities in surficial materials. Another consideration is the potential risk of spreading the contamination as a result of the sampling effort. For example, an improperly installed well casing could lead to leakage of contaminated water through a formerly low permeability clay layer. The risks of disturbing the subsurface should be considered when determining the need for obtaining more data.

Chemical and physical measurements should be made for each distinct soil layer, or boundary between layers, that may be affected by a release. During drilling, the investigator should note on the drilling log the depths of soil horizons, soil types and textures, and the presence of joints, channels, and zones containing

plant roots or animal burrows. Soil variability, if apparent, should generally be accounted for by increasing the number of sample points for measurement of soil chemical and physical properties. Determination of the range and variability of values for soil properties and parameters will allow more accurate prediction of the mobility of contaminants in the soil.

9.3.3.2 Spatial and Temporal Fluctuations in Soil Moisture Content

As described earlier in this section, there are several mechanisms for transport of waste constituents in the soil. Release migration can be increased by the physical disturbance of the soil during freeze/thaw cycles or by burrowing animals. Movement can also be influenced by microbial-induced transformations. In addition, movement can occur through diffusion and mass flow of gases and liquids. Although all of these mechanisms exist, movement of hazardous waste or constituents through soil toward ground water occurs primarily by aqueous transport of dissolved chemicals in soil pore water. Soil moisture content affects the hydraulic conductivity of the soil and the transport of dissolved wastes through the unsaturated zone. Therefore, characterizing the storage and flow of water in the unsaturated zone is very important. Moisture in the unsaturated zone is in a dynamic state and is constantly acted upon by competing physical forces.

Water applied to the soil surface (primarily through precipitation) infiltrates downward under the influence of gravity until the soil moisture content reaches equilibrium with capillary forces. A zone of saturation (or wetting front) may occur beneath the bottom of a unit (e.g., an unlined lagoon) if the unit is providing a constant source of moisture. In a low porosity soil, such a saturation front may migrate downward through the unsaturated zone to the water table, and create a ground-water or liquid "mound" (see Figure 9-1). In a higher porosity soil, the saturation front may only extend a small distance below the unit, with liquid below this distance then moving through the soil under unsaturated conditions toward ground water (see Figure 9-1). In many cases, this area will remain partially saturated until the capillary fringe area is reached. The capillary fringe can be defined as the zone immediately above the water table where the pressure is less than atmospheric and where water and other liquids are held within the pore spaces against the force of gravity by interfacial forces (attractive forces between different molecules).

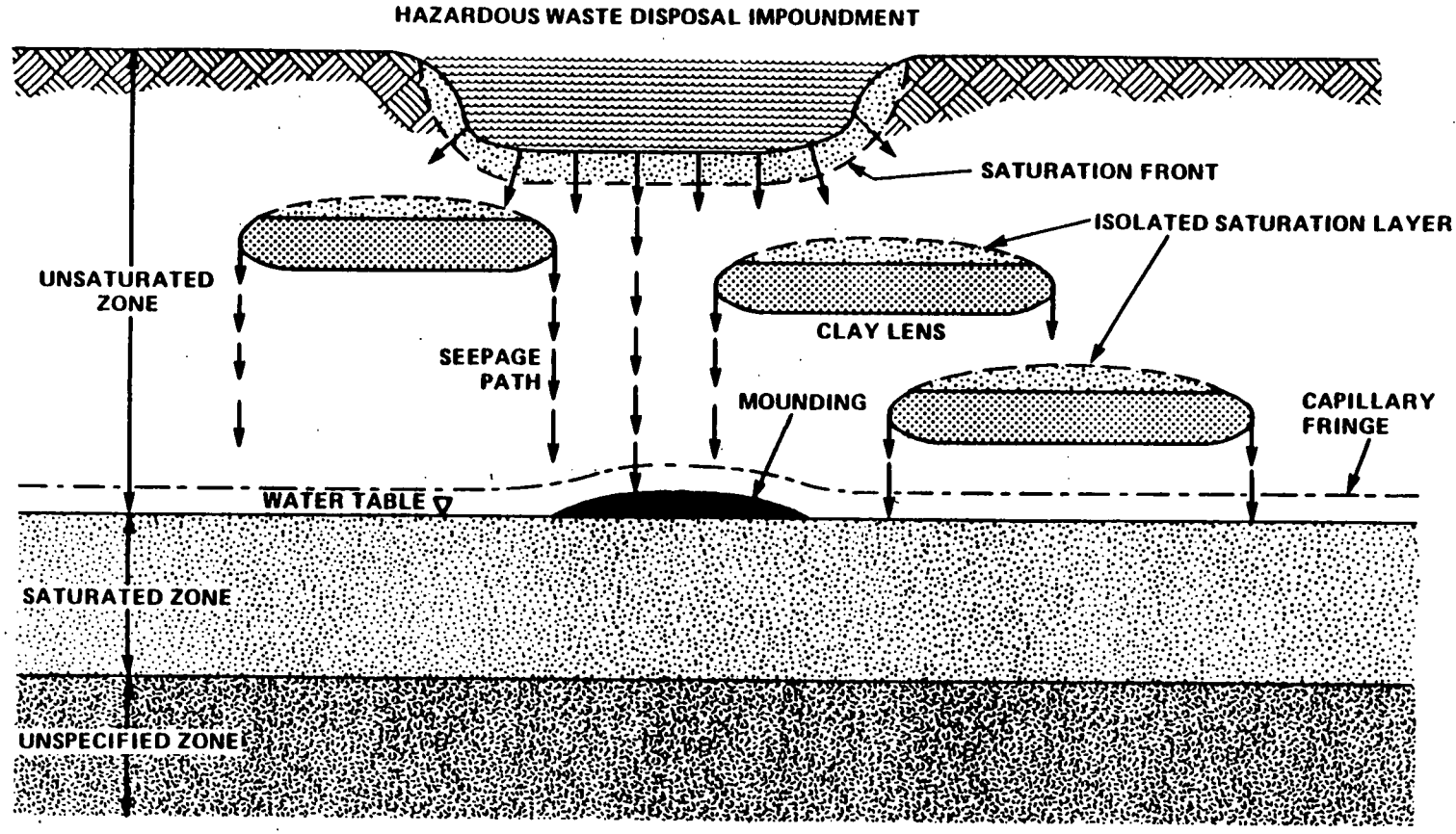

Figure 9-1. Hydrogeologic conditions affecting soil moisture transport

In certain cases, soil moisture characterization can also be affected by the presence of isolated zones of saturation and fluctuations in the depth to ground water, as illustrated in Figure 9-1. Where there is evidence of migration below the soil surface, these factors should be considered in the investigation by careful characterization of subsurface geology and measurement of hydraulic conductivity in each layer of soil that could be affected by subsurface contamination.

9.3.3.3 Solid, Liquid, and Gaseous Materials in the Unsaturated Zone

Soil in the unsaturated zone generally contains solid, liquid, and gaseous phases. Depending upon the physical and chemical properties of the waste or its constituents, contaminants of concern may be bound to the soil, dissolved in the pore water, as a vapor within the soil pores or interstitial spaces, or as a distinct liquid phase. The investigation should therefore take into consideration the predominant form of the contaminant in the soil. For example, some whole-soil sampling methods may lead to losses of volatile chemicals, whereas analysis of soil-pore water may not be able to detect low solubility compounds such as PCBs that remain primarily adsorbed in the solid phase. Release characterization procedures should consider chemical and physical properties of both the soil and the waste constituents to assist in determining the nature and extent of contamination.

Soil classification--The owner or operator should classify each soil layer potentially affected by the release. One or more of the classification systems discussed below should be used, based on the objectives of the investigation.

- USDA Soil Classification System (USDA, 1975)--Primarily developed for agricultural purposes, the USDA system also provides information on typical soil profiles (e.g., 1-foot fine sandy loam over gravelly sand, depth to bedrock 12 feet), ranges of permeabilities for each layer, and approximate particle size ranges. These values are not generally accurate enough for predictive purposes, however, and should not be used to replace information collected on site. Existing information on regional soil types is available but suitable for initial planning purposes only. U.S. Department of Agriculture (USDA) county soil surveys may be obtained for most areas.

- Unified Soil Classification Systems (USCS) (Lambe and Whitman, 1979)-- A procedure for qualitative field classification of soils according to ASTM D2487-69, this system should be used to identify materials in soil boring logs. The USCS is based on field determination of the percentages of gravel, sand and fines in the soil, and on the plasticity and compressibility of fine-grained soils. Figure 9-2 displays the decision matrix used in classifying soils by this system.

The above classification systems are adequate for descriptive purposes and for qualitative estimates of the fluid transport properties of soil layers. Quantitative estimation of fluid transport properties of soil layers requires determination of the particle size distribution for each soil layer, as described below.

Particle size distribution--A measurement of particle size distribution should be made for each layer of soil potentially affected by the release. The recommended method for measurement of particle size distribution is a sieve/hydrometer analysis according to ASTM D422 (ASTM, 1984).

The particle size distribution has two major uses in a soils investigation: (1) estimation of the hydraulic conductivity of the soil by use of the Hazen (or similar) formula, and (2) assessment of soil sorptive capacity.

1. The hydraulic conductivity(K) may be estimated from the particle size distribution using the Hazen formula:

$$K = A\,(d_{10})^2$$

where d_{10} is equal to the effective grain size, which is that grain-size diameter at which 10 percent by weight of the particles are finer and 90 percent are coarser (Freeze and Cherry, 1979). The coefficient A is equal to 1.0 when K is in units of cm/sec and d_{10} is in mm. Results should be verified with in-situ hydraulic conductivity techniques.

2. Particle size can affect sorptive capacity and, therefore, the potential for retardation of contaminants in the soil. Sandy soils generally have a low sorptive capacity whereas clays generally have a high affinity for heavy

Figure 9-2. Soil Terms

UNIFIED SOIL CLASSIFICATION (USCS)

COARSE GRAINED SOILS
More than half of material is LARGER than No. 200 sieve size

		FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3" & basing fractions on estimated weights)	GROUP SYMBOLS	TYPICAL NAMES
GRAVELS 50%(+) > 1/4" ●	CLEAN GRAVELS Low % fines	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures, little or no fines
		Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines
	GRAVELS W/FINES High % fines	Non plastic fines (for identification procedures see ML)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures
		Plastic fines (for identification procedures see CL)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures
SANDS 50% (+) < 1/4" ●	CLEAN SANDS Low % fines	Wide range in grain size and substantial amounts of all intermediate particle sizes	SW	Well graded sand, gravelly sands, little or no fines
		Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines
	SANDS W/FINES High % fines	Non plastic fines (for identification procedures see ML)	SM	Silty sands, poorly graded sand-silt mixtures
		Plastic fines (for identification procedures see CL)	SC	Clayey sands, poorly graded sand-clay mixtures

FINE GRAINED SOILS
More than half of material is SMALLER than No. 200 sieve size

Identification procedures on fraction smaller than No. 40 sieve size

	DRY STRENGTH (Crushing Characteristics)	DILATANCY (Reaction to Shaking)	TOUGHNESS (Consistency Near Plastic Limit)	GROUP SYMBOLS	TYPICAL NAMES
SILTS & CLAYS Liquid limit < 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity
	Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
	Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity
SILTS & CLAYS Liquid limit > 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts
	High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays
	Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity
HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel and frequently by fibrous texture			Pt	Peat and other organic soils

Boundary classifications-Soils possessing characteristics of two groups are designated by combining group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.
All sieve sizes on this chart are U.S. standard.

DENSITY OF GRANULAR SOILS

DESIGNATION	STANDARD PENETRATION RESISTANCE — BLOWS/FOOT
Very loose	0 - 4
Loose	5 - 10
Medium dense	11 - 30
Dense	31 - 50
Very dense	Over 50

CONSISTENCY OF COHESIVE SOILS

CONSISTENCY	UNC. COMPRESSIVE STR. TONS /SQ. FT.	STANDARD PENETRATION RESISTANCE — BLOWS/FOOT	FIELD IDENTIFICATION METHODS
Very soft	Less than 0.25	0 to 2	Easily penetrated several inches by fist
Soft	0.25 to 0.50	2 to 4	Easily penetrated several inches by thumb
Medium stiff	0.50 to 1.0	4 to 8	Can be penetrated several inches by thumb
Stiff	1.0 to 2.0	8 to 15	Readily indented by thumb
Very stiff	2.0 to 4.0	15 to 30	Readily indented by thumbnail
Hard	More than 4.0	Over 30	Indented with difficulty by thumbnail

ROCK TERMS

ROCK HARDNESS (FROM CORE SAMPLES)

DESCRIPTIVE TERMS	SCREWDRIVER OR KNIFE EFFECTS	HAMMER EFFECTS
Soft	Easily gouged	Crushes when pressed with hammer
Medium soft	Can be gouged	Breaks (one blow) Crumbly edges
Medium hard	Can be scratched	Breaks (one blow) Sharp edges
Hard	Cannot be scratched	Breaks conchoidally (several blows) Sharp edges

ROCK BROKENNESS

DESCRIPTIVE TERMS	ABBREVIATION	SPACING
Very broken	(V. Br.)	0 - 2"
Broken	(Br.)	2" - 1'
Blocky	(Bl.)	1' - 3'
Massive	(M.)	3' - 10'

LEGEND

SOIL SAMPLES - TYPES

S 2" O.D. Split Barrel Sample
ST 3" O.D. Undisturbed Sample
O Other Samples, Specify in Remarks

ROCK SAMPLES - TYPES

X NX (Conventional) Core (~ 2 1/8" O.D.)
Q NQ (Wireline) Core (~ 1 7/8" O.D.)
Z Other Core Sizes, Specify in Remarks

WATER LEVELS

12/18 ▽ 12.6' Initial Level w/Date & Depth
12/18 ▼ 12.6' Stabilized Level w/Date & Depth

metals and some organic contaminants. This is due in part to the fact that small clay particles have a larger surface area in relation to their volume than do larger sand particles. This larger surface area can result in stronger interactions with waste molecules. Clays may also bind contaminants due to the chemical structure of the clay matrix.

Porosity--Soil porosity is the percentage of the total soil volume not occupied by solid particles (i.e., the volume of the voids). In general, the greater the porosity, the more readily fluids may flow through the soil. An exception is clayey soils that tightly hold fluids by capillary forces. Porosity is usually measured by oven-drying an undisturbed sample and weighing it. It is then saturated with liquid and weighed again. Finally, the saturated sample is immersed in the same liquid, and the weight of the displaced liquid is measured. Porosity is the weight of liquid required to saturate the sample divided by the weight of liquid displaced, expressed as a decimal fraction.

Hydraulic conductivity--An essential physical property affecting contaminant mobility in soil is hydraulic conductivity. This property indicates the ease with which water at the prevailing viscosity will flow through the soil and is dependent on the porosity of the soil, grain size, degree of consolidation and cementation, and other soil factors.

Measurement of hydraulic conductivity in soil within the saturated zone is fairly routine. Field and laboratory methods to determine saturated conductivity are discussed in the section on ground-water investigations (Section 10). Measurement of unsaturated conductivity is usually more difficult because the value changes with changing soil moisture content. Therefore, conductivities for a range of moisture contents may need to be determined for each type of soil at the facility.

Techniques for determining saturated hydraulic conductivity are provided in Method 9100 (Saturated Hydraulic Conductivity, Saturated Leachate Conductivity, and Intrinsic Permeability) from SW-846, Test Methods for Evaluating Solid Waste, EPA, 3rd edition, September, 1986. Method 9100 includes techniques for:

- Laboratory

- constant head methods; and
- falling head methods.

- Field

  - sample collection;
  - well construction;
  - well development;
  - single well tests (slug tests); and
  - references for multiple well (pumping tests).

A detailed discussion of field and laboratory methods for determining saturated and unsaturated hydraulic conductivity is also contained in Soil Properties Classification and Hydraulic Conductivity Testing (U.S. EPA, 1984). In general, field tests are recommended when the soil is heterogeneous, while laboratory tests may suffice for a soil without significant stratigraphic changes. Estimation of hydraulic conductivity from the particle size distribution may be used as a rough estimate for comparison purposes and if precise values are not needed.

Relative permeability--The hydraulic conductivity of a soil is usually established using water as the infiltrating liquid. However, at sites where there is the likelihood of a highly contaminated leachate or a separate liquid waste phase, the owner or operator should also consider determining conductivity with that liquid. The ratio of the permeability of a soil to a non-aqueous solution and its permeability to water is known as relative permeability.

The importance of determining this value is due to the potential effects of leachate on soil hydraulic properties. Changes in conductivity from infiltration of leachate may result from differences in the viscosity or surface tension of the waste, or the leachate may affect the soil structure so as to alter its permeability. For example, studies of waste migration through landfill liners made of clay have demonstrated that certain wastes may cause shrinking or expansion of the clay molecular structures, dissolve clays and organic matter, clog soil pores with fine particles, and cause other changes that affect permeability.

Soil sorptive capacity and soil-water partition coefficient (K_d)--The mobility of contaminants in soil depends not only on properties related to the physical structure of the soil, but also on the extent to which the soil material will retain, or adsorb, the hazardous constituents. The extent to which a constituent is adsorbed depends on chemical properties of the constituent and of the soil. Therefore, the sorptive capacity must be determined with reference to particular constituent and soil pairs. The soil-water partition coefficient (K_d) is generally used to quantify soil sorption. K_d is the ratio of the adsorbed contaminant concentration to the dissolved concentration, at equilibrium.

There are two basic approaches to determining K_d: (1) soil adsorption laboratory tests, and (2) prediction from soil and constituent properties. The Soil Adsorption Isotherm (AI) test is widely used to estimate the extent of adsorption of a chemical (i.e., constituent) in soil systems. Adsorption is measured by equilibrating aqueous solutions containing varying concentrations of the test chemical with a known quantity of uncontaminated soil. After equilibrium is reached, the distribution of the chemical between the soil and water (K_d) is measured by a suitable analytical method.

The AI test has several desirable features. Adsorption results are highly reproducible. The test provides excellent quantitative data that are readily amenable to statistical analysis. In addition, it has relatively modest reagent, soils, laboratory space and equipment requirements. The ease of performing this test will depend on the physical/chemical properties of the contaminant and the availability of suitable analytical techniques to measure the chemical.

The AI test can be used to determine the soil adsorption potential of slightly water soluble to infinitely water soluble chemicals. In general, a chemical having a water solubility of less than 0.5 mg/l is not tested with this method because these chemicals are relatively immobile in soil. The U.S. EPA Office of Pesticides and Toxic Substances (U.S. EPA 1982a, 1982b) has compiled information on the use of the AI test, including a detailed discussion of apparatus, procedures, sources of error, statistical requirements, calculation methods, and limitations of the test.

A second approach for determining K_d is to estimate the value from soil and waste properties. Soil properties that should be considered when using this

approach are particle size distribution, cation exchange capacity, and soil organic carbon content. The waste properties that should be determined will vary depending on the type of waste. Lyman et al. (1981) discuss several methods for estimating K_d from chemical properties of the constituent (e.g., K_{ow} and water solubility) and the soil organic content. Data collection needs for waste properties were discussed earlier in this section.

Cation exchange capacity (CEC)--This parameter represents the extent to which the clay and humic fractions of the soil will retain charged species such as metal ions. The CEC is an important factor in evaluating transport of lead, cadmium, and other toxic metals. Soils with a high CEC will retain correspondingly high levels of these inorganics. Although hazardous constituents may be immobilized by such soils in the short-term, such conditions do not rule out the possibility of future releases given certain conditions (e.g., action of additional releases of low pH). A method for the determination of CEC is detailed in SW-846, Method 9081 (U.S. EPA, 1986).

Organic carbon content--The amount of natural organic material in a soil can have a strong effect on retention of organic pollutants. The greater the fraction by weight of organic carbon (F_{oc}), the greater the adsorption of organics. Soil F_{oc} ranges from under 2 percent for many subsurface soils to over 20 percent for a peat soil. An estimate of F_{oc} should be made based on literature values for similar soils if site-specific information is not available.

Soil pH--Soil pH affects the mobility of potentially ionized organic and inorganic chemicals in the soil. Compounds in these groups include organic and inorganic acids and bases, and metals.

Depth to ground water--The thickness of the unsaturated zone may affect the attenuation capacity of the soil and the time taken for contaminants to migrate to ground water. If significant, seasonal fluctuations in ground-water elevations should be identified as well as elevation changes due to pumping or other factors (e.g., tidal influences).

Pore-water velocity--Pore water velocity affects the time of travel of contaminants in unsaturated soil to ground water. For steady state flow and a unit

hydraulic gradient (i.e., moisture content does not change with depth), the pore-water velocity can be calculated by the following equation:

$$V = q/\theta$$

where: V = pore water velocity, cm/day
q = volumetric flux/unit area, cm/day
θ = volumetric water content, dimensionless

A simple approximation of volumetric flux (q) can be made by assuming that it is equal to percolation at the site. Percolation can be estimated by performing a water balance as described below. This approach for calculating pore-water velocity is limited by simplifying assumptions; however, the method may be used to develop an initial estimate for time of travel of contaminants. More detailed methods, which account for unsteady flow and differences in moisture content are described in the following reference:

U.S. EPA. 1986. Criteria for Identifying Areas of Vulnerable Hydrogeology Under the Resource Conservation and Recovery Act. NTIS PB86-224953. Office of Solid Waste. Washington, D.C. 20460.

Percolation (volumetric flux per unit area)--Movement of contaminants from unsaturated soil to ground water occurs primarily via dissolution and transport with percolating soil water. It is important, therefore, to determine the volume of water passing through the soil. The percolation rate, or volumetric flux, must be determined in order to calculate pore-water velocity through the unsaturated zone. The rate of percolation can be estimated from the water balance equation:

$$PER = P - ET - DR$$

where: PER = Percolation/recharge to ground water
P = Precipitation and irrigation
ET = Evapotranspiration
DR = Direct surface runoff

Annual averages for P, ET and DR should be obtained from existing local sources. Sources of information to estimate PER include:

- State or Regional water agencies;
- Federal water agencies (Geological Survey, Forest Service); and
- National Weather Service stations.

It is recommended that site-specific ET and DR data be used if possible, because local conditions can vary significantly from regional estimates. More information on percolation and ground-water recharge can be found in standard ground-water texts, such as Freeze and Cherry, 1979. Information on evapotranspiration and direct surface runoff may be found in the following references:

U.S. EPA. 1975. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. EPA/530/SW-168. Office of Solid Waste. Washington, D.C. 20460.

U.S. Geological Survey. 1982. National Handbook of Recommended Methods for Water Data Acquisition.

Volumetric water content--The volumetric water content is the percent of total soil volume that is filled with water. It is equal to the amount of water lost from the soil upon drying to constant weight at 105°C, expressed as the volume of water/bulk volume of soil. This parameter affects the unsaturated hydraulic conductivity and is required for calculation of pore-water velocity. At saturation, the volumetric water content is equal to the porosity of the soil.

Additional soil conditions--Additional soil conditions that may require special consideration in investigating releases to soil are discussed below.

- In certain dense, cohesive soils, water may move primarily through narrow solution channels or fracture zones rather than by permeating the bulk of the soil. This condition can sometimes be recognized by dark-

colored deposits indicating the fractures or by the tendency of soil cores to break apart at the discontinuity.

- Decomposed rock (e.g., transitional soils) may have a low primary porosity but a high secondary porosity due to relict joints or fractures or solution channels. Therefore, most flow may occur through these cracks and channels rather than through the soil pores. As a result, the rate of fluid flow is likely to be high, and the low surface area within the joint or fracture system generally results in a low sorptive capacity. Because field conditions are highly variable, the characterization of soil structure should be sufficiently detailed to identify such joints or fractures that may provide contaminant pathways.

- Certain clay soils known as vertisols, or expandable clays, may fracture into large blocks when dry. These cracks can be a direct route for ground-water contamination. Soil surveys should be consulted to determine whether these soils are present at the site. They occur in, but are not limited to, eastern Mississippi and central and southern Texas. Other clay soils may also develop desiccation cracks to a lesser degree. In these cases, it may be advisable to sample during both wet and dry seasons.

- Sampling saturated soils may be accomplished with the same drilling techniques used for unsaturated soil sampling. Particular care must be taken to prevent contamination between soil layers. Methods of telescoping smaller diameter casing downward through larger diameter, grouted casing are useful for minimizing cross-contamination between soil layers (See Section 9.6 for additional information on telescoping methods).

- Frequently, the choice of sampling technique is dictated by mechanical factors. Hard, rocky, or dense soils may prevent the use of manual tube samplers or augers. Power-driven auger drill rigs equipped with split-spoon samplers can penetrate most soils. Power augers can penetrate most unconsolidated materials, but will not drill through rock, for which an air-driven rotary drill is the recommended method. Loose sandy soils

will fail to be retained in a tube sampler; therefore a sampler equipped with a retaining device should be used in such cases. Core sampling should generally be carried out under the supervision of an experienced driller, in order to avoid poor results or damaged equipment.

- Where unfavorable soil conditions interfere with a proposed sampling location, the sampling point may have to be moved to a nearby location. In the event that such conditions are encountered, new locations should be chosen that are adequate to characterize the release.

9.3.4 Sources of Existing Information

Considerable information may already be available to assist in characterizing a release. Existing information should be reviewed to avoid duplication of previous efforts and to aid in scoping the RFI. Any existing information relating to releases from the unit and to hydrogeological, meteorological, and environmental factors that could influence the persistence, transport, or location of contaminants should be reviewed. This information may aid in:

- Delineating the boundaries of the sampling area;
- Choosing sampling and analytical techniques; and
- Identifying information needs for later phases of the investigation, if necessary.

Information may be obtained from readily available sources of geological and meteorological data, waste characteristics, and facility operating records. (See also Sections 2, 3, 7 and Appendix A).

9.3.4.1 Geological and Climatological Data

The Federal government and most state governments compile geological data, soil surveys, land use records, and climatological information. These sources should be consulted for local geology, soil types, historical precipitation, ground-water elevation records, and other useful data. Sources which may be consulted for soils

data include the Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), the U.S. Geological Survey (USGS), state soils bureaus and agricultural extension services, university soil science departments, and private consultants. Additional sources of geologic information include geotechnical boring logs for foundation studies, well logs made during drilling of water supply wells, and previous hydrogeologic investigation monitoring wells. These logs should indicate the depth, thickness, and character of geologic materials, and the depth to the water table. Climate and weather information can be obtained from:

National Climatic Center
Department of Commerce
Federal Building
Asheville, North Carolina 28801
Tel: (704)258-2850

9.3.4.2 Facility Records and Site Investigations

The owner or operator should plan investigation activities by focusing on the conditions specified in the permit or enforcement order. Facility records, the facility's RCRA permit application, and any previous site reports (e.g., the RFA report) should also be examined for any other information on unit characteristics, wastes produced at the facility, and other factors relevant to releases to soil. Facility operating records should have data on wastes treated, stored, or disposed of at the facility. Wastes regulated under RCRA are identified by a waste code that may also aid in identifying constituents of concern (see 40 CFR Part 261). Wastes originating within the facility may be identified through analysis of process control records. Unit releases (e.g., losses from leaking tanks) can sometimes be estimated from storage records.

9.4 Design of a Monitoring Program to Characterize Releases

9.4.1 Objectives of the Monitoring Program

Monitoring procedures that specify locations, numbers, depths, and collection techniques for soil samples should be prepared by the owner or operator prior to each sampling effort. These procedures should provide the justification for the

proposed samples, in terms of their expected contribution to the investigation. Examples of soil monitoring objectives include:

- Describing soil contamination in a drainage channel where a release is known to have occurred;

- Establishing a random or systematic grid sampling network to determine soil contamination concentrations in all zones of a large area affected by airborne deposition; and

- Filling in data gaps concerning the transport of waste constituents within a permeable soil layer.

In preparing soil monitoring procedures, the owner or operator should take into consideration those factors discussed in Sections 9.3.1 through 9.3.4 that apply to the facility. Also see Section 9.4.4.3 (Predicting Mobility of Hazardous Constituents in Soil).

As discussed previously, the release characterization may be conducted in phases. The objectives of the initial soil characterization are generally to verify suspected releases or to begin characterizing known releases. This characterization should use relevant soil physical and chemical measurements and other information as described earlier. In developing the approach, the owner or operator should determine the following:

- Constituents and indicator parameters to be monitored;

- Role of field screening methods, if any;

- Sampling methods;

- Approximate study and background areas;

- Sampling locations and approach (e.g., judgmental or systematic); and

- Number of samples to be collected.

The owner or operator may propose the use of field screening methods to aid in delineating the zone affected by a contaminant release to soil and/or ground water. Such methods may be applied just below the land surface or at greater depths, as within soil bore holes. An increasingly used method to detect organic vapors is generally known as a soil gas survey. Such a survey can yield qualitative and relative quantitative data on volatile constituents present in the soil gas, depending on the instrumentation used. For example, a total photoionization detector will provide an integrated value for the volatile organics present; whereas a portable gas chromatograph can identify and quantitate specific compounds present in the soil vapor. Field screening can also include chemical analyses of soil samples performed onsite in mobile laboratories.

When conducting a soil gas survey, it should be realized that any measured soil vapor concentrations of specific compounds cannot be directly correlated with their actual concentrations in the soil zone of concern. The concentrations in soil vapor resulting from a soil with given volatile contaminant concentrations will vary, depending on several factors, including barometric pressure, relative humidity in the soil, weather conditions (e.g., precipitation events, soil inhomogeneities, and temperature). Therefore, the results of a soil gas survey can reveal the relative abundances of volatile compounds in the soil gas, but not their actual concentrations in the soil.

The soil gas survey technique may also be applied when drilling boreholes to characterize site geology or when drilling to install ground-water monitoring wells. Soil samples taken at various depths within the borehole can be placed in separate sample bottles with septums.

A sample of the gas in the headspace can then be withdrawn with a syringe and injected into a portable gas chromatograph to identify the presence and relative abundances of specific volatile compounds in the soil gas. Analysis of drill cuttings in the open air is not as effective as the headspace technique in detecting volatile organic compounds; therefore, the headspace method is preferred.

Additional information on soil gas monitoring may be obtained from the following reference:

U.S. EPA. 1987. Soil Gas Monitoring Techniques Videotape. National Audio Visual Center. Capital Heights, Maryland 20743.

Screening methods may help to reduce the number of soil and/or ground-water samples needed to characterize a release by better delineating the area of concern in a relatively rapid manner. However, due to limitations (e.g., relatively high detection limits and inability to identify all the potential hazardous constituents of concern), some screening methods may not be adequate to verify the absence of a release. For such verification, an appropriate number of soil samples would need to be analyzed in the laboratory. Additional information on field screening methods is presented later in this section and in the Compendium of Field Operations Methods, (EPA, 1987).

Depending on the outcome of the initial characterization effort, the owner or operator may be required to obtain additional data to characterize the release. The findings of the initial phase will dictate the objectives of any later phases. Such subsequent phases will generally involve the following:

- Expanding the number of sampling locations to a wider area and/or depth, or increasing sampling density where data are sparse;

- Institution of a refined grid sampling approach to further assess releases identified by judgmental sampling (see Section 3);

- Addition or deletion of specific monitoring constituents or indicator parameters; and

- Sampling in areas of interest based on previous sampling or model predictions to confirm the suspected extent of the release.

There is no specified or recommended number of phases to complete a soil investigation. The owner or operator should determine through consultation with the regulatory agency whether the collected data are sufficient to meet the objectives of the investigation.

9.4.2 Monitoring Constituents and Indicator Parameters

The owner or operator should propose hazardous constituents for monitoring based on the composition of wastes known or suspected to be present or released to soils at the site (see Sections 3 and 7 and Appendix B). Additional measurements may include nonhazardous chemicals that could serve as indicators of the presence of hazardous constituents or that could mobilize or otherwise affect the fate and transport of hazardous constituents. Chemical and physical properties of the soil that can be measured from soil samples should also be included in the list of parameters (see Section 9.3.3.3).

Justification of monitoring constituent selection may be provided through detailed facility records or waste analyses, as explained in Section 3. If such justification is inadequate, it may be necessary to perform a broader analytical program (See Section 3 and Appendix B).

During or after the selection of monitoring constituents, the owner or operator should review guidance on compound-specific requirements for sampling and sample preservation. The laboratory should use EPA protocols and analytical procedures when available, and accepted QA/QC practices. Guidance and specific references in these areas are provided in Sections 2, 3, 4, and 7.

9.4.3 Monitoring Schedule

Monitoring frequency and duration determinations should be based primarily on the type of release to the soil. A single episode or intermittent release, as with any release, would require monitoring until the nature and extent of contamination has been characterized. This may be accomplished with one or two sample sets in some cases. Longer-term releases will usually necessitate a greater duration of sampling. Soil-pore liquid may require more frequent monitoring than in soil solids because changes generally occur faster in these fluids. Frequency may also be adjusted, if appropriate, as sampling results become available. As with single episode releases, longer-term releases are monitored until the nature and extent of contamination has been adequately characterized.

9.4.4 Monitoring Locations

9.4.4.1 Determine Study and Background Areas

Determination of the area of interest will depend on the facility layout, topography, the distribution of surface soils, soil stratigraphy, and information on the nature and source of the release. The size and type of unit may affect the area under consideration. For example, a small landfill may only require monitoring of the surrounding soil whereas an inactive land treatment facility may require sampling over the entire unit surface and beyond.

High variability in the chemical composition of soils makes determination of background levels for the constituents of concern essential. This is particularly important for quantification of toxic metals, because such metals commonly occur naturally in soil. Background areas not affected by any facility release should be selected based on their similarity to the study area in terms of soil type, drainage, and other physical factors. Background soil samples should be taken from areas that are not near a suspected source of contamination and from the same stratigraphic layer as the study area samples, if possible. Selection and sampling of appropriate background areas may be important because verification of a release in a contaminated area may involve a comparison of study and background concentrations.

The owner or operator may increase efficiency in the initial characterization effort by using rapid, field-screening methods (e.g., soil gas surveys using HNu, OVA or portable gas chromatograph) or through indicator parameter measurements to establish the extent of the study area. Subsurface soil contamination can sometimes be identified by geophysical techniques such as electromagnetic and resistivity techniques (See Section 10 and Appendix C). Indicator parameters can also be helpful in establishing the extent of the monitoring area. For example, Total Organic Halogen (TOX) or Total Organic Carbon (TOC) analysis may be useful in detecting total chlorinated and nonchlorinated organic solvents. Such parameters may be used to characterize the nature and extent of a release but should always be verified by an adequate number of specific constituent analyses.

It is generally recommended that a sampling grid be developed for the site, even for judgmental sampling. Gridding of the area to be sampled prior to the sampling effort will aid in determining appropriate sampling locations and in describing these locations. Refer to Section 3.6 for additional information on gridding of a study site.

9.4.4.2 Determine Location and Number of Samples

The owner or operator should propose monitoring locations and the number of samples to be collected and analyzed. Samples should be taken from the vicinity of all units identified in the conditions of the permit or order as suspected or known sources of soil contamination. The total number of samples necessary for the initial investigation will depend on the extent of prior information, the suspected extent and severity of the release, and the objectives of the characterization. However, the following general guidance should aid the owner or operator to sample efficiently.

- Sampling efficiency may be increased by use of a proportional sampling approach, which involves dividing the area of concern into zones, based on proximity to the release source and/or other factors. The number of samples taken in each zone should be proportional to the area of a zone.

- Use of composite samples may be able to allow detection of contamination over an area of concern with a smaller number of analyses. Compositing involves pooling and homogenization of multiple soil samples. The composite is then analyzed to give an average value for soil contamination in that area. However, as discussed in Sections 3 and 7, composites should have very limited application during the RFI and should always be accompanied by an appropriate number of individual grab samples. The following additional limitations on compositing should be observed:

  - Compositing is most useful when large numbers of soil samples can be easily collected (e.g., for surficial contamination). In order to obtain the maximum information from deep soil coring, individual grab samples are preferred over composites.

- Compositing should not be used when analyzing soils for volatile organics because the constituents of interest may be lost during homogenization and sample handling.

- The owner or operator should employ appropriate procedures for the evaluation and reporting of monitoring data. These procedures can vary in a site-specific manner but should result in determinations of the nature, extent, and rate of migration of the release. Where the release is obvious and/or chemically simple, it may be possible to characterize it readily from a descriptive presentation of concentrations found. However, where contamination is less obvious or the release is chemically complex, a statistical inference approach may be proposed. The owner or operator should plan initially to take a descriptive approach to data evaluation in order to broadly delineate the extent of contamination. Statistical comparisons of monitoring data among monitoring locations and over time may be appropriate if a descriptive approach does not provide a clear characterization of the release. Further guidance on use of statistical methods in soil investigations is provided in the following documents:

  Barth, D.S. and B.J. Mason. 1984. Soil Sampling Quality Assurance User's Guide. U.S. EPA 600/4-84-043. NTIS PB84-198621. Washington, D.C. 20460.

  Mason, B.J. 1983. Preparation of a Soil Sampling Protocol: Techniques and Strategies. NTIS PB83-206979. U.S. EPA 600/4-83-020. Washington, D.C. 20460.

- Characterization of contaminant distribution with depth necessitates sampling of each distinct soil layer that might be affected by the release and from boundaries between soil layers. If the soil profile contains thick layers of homogeneous soil, samples should be taken at regular intervals (e.g., every 5 feet). In addition, samples should be taken where borings intersect fracture systems, at interfaces of zones of high and low permeability materials, or at other features that could affect contaminant transport. The owner or operator should consider

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measurement of soil physical and hydraulic properties in each distinct soil layer. The objective of such measurements in the initial release characterization effort is to identify properties that vary with depth. This approach may indicate the use of stratified sampling in any future sampling phases. Determination of soil properties will also aid in refining conceptual models of contaminant transport and can be input for mathematical models of soil transport.

Modeling--Prediction of contaminant fate and transport can range from a "conceptual" model of contaminant behavior in the soil to complex computer programs requiring extensive input of soil and water budget data. The primary uses of predictive modeling in soil investigations are to locate appropriate sampling locations using site-specific input data and to estimate the future rate, extent, and concentration of contaminant releases.

Modeling of contaminant transport in the unsaturated zone is often difficult due to the generally high spatial variability in soil physical and hydraulic properties. Therefore, modeling should not be used to replace actual measured values (e.g., when establishing the limits of waste leaching or diffusion in soil). However, if used with caution, models can act as useful tools to guide sampling efforts by directing sampling towards site areas identified as preferred soil/water flowpaths (e.g., a permeable soil layer). The owner or operator should discuss the use of specific models with the regulatory agency prior to use.

Numerous models, including computer models, have been developed to calculate water flow and contaminant transport under saturated and unsaturated soil conditions. In using such models, site-specific data on soils and wastes should be used. Ground-water (saturated flow) models are discussed in Section 10. A U.S. Nuclear Regulatory Commission Report (Oster, 1982) may be reviewed for information on the applicability of 55 unsaturated flow and transport models. Use of the RITZ Model (found in U.S. EPA. 1986. Permit Guidance Manual on Hazardous Waste Land Treatment Demonstration. NTIS PB86-229192) may be particularly appropriate in certain situations. The RITZ model describes a soil column, 1 meter square, with a depth equal to the land treatment zone (usually 1.5 m). The soil column consists of a plow zone and lower treatment zone that are made up of four phases: soil grains, pore water, pore air, and pore oil. Mobilization of constituents

within the soil is accounted for by dispersion, advection, and migration between phases. The constituent may also be degraded by biochemical processes represented in the model. Output from the model includes the concentration (C) of a constituent at the bottom of the treatment zone, and the time (T) required for a constituent to travel a distance equal to the treatment zone depth. Although the RITZ model was developed for evaluating the effectiveness of land treatment units, the model may be used for other applications, as appropriate (see above referenced document).

EPA is in the process of developing a more sophisticated version of the RITZ model, known as the RITZ-VIP model. The VIP version differs in that it is designed to provide information for multiple waste loadings in a land treatment situation. The initial version of the RITZ model only applies where the waste or material in question is applied to the land once. The RITZ-VIP version is currently in the review/verification process. More information on this model may be obtained by writing to EPA at the following address:

U.S. Environmental Protection Agency
Robert S. Kerr Environmental Research Laboratory/ORD
P.O. Box 1198
Ada, Oklahoma 74820

Computer models if proposed for use in the RFI should (1) be well-documented; (2) have been peer reviewed; and (3) have undergone extensive field testing. As indicated previously, model documentation (e.g., model theory, structure, use, and testing) should be provided to the regulatory agency for review prior to use. Access to the relevant data sets should also be available upon request. The regulatory agency may also recommend that a sensitivity analysis be performed and that the results of the analysis be submitted with the model results. In selecting a model, the owner or operator should consider its applicability, limitations, data requirements, and resource requirements.

9.4.4.3 Predicting Mobility of Hazardous Constituents in Soil

Predicting the mobility of hazardous constituents in soil may be necessary in an RFI. The prediction may then be used to estimate the probable vertical or lateral

extent of contamination, which can be used to identify potential sampling locations. Mobility predictions may also be used in determining potential inter-media transfers from the soil to ground or surface water. Finally, mobility predictions may provide information that can be used during the Corrective Measures Study to differentiate between contaminated soil that should be removed from the site and that which may remain at the site without adversely affecting human health or the environment. Predicting mobility of soil constituents may be particularly relevant, as indicated in Section 8, for determining whether deep-soil contamination, or in some cases surficial-soil contamination, can lead to ground-water contamination at a level above health and environmental criteria (if such an impact has not already occurred).

There is no universally accepted, straightforward method for predicting the mobility of all hazardous constituents within soils under all possible sets of environmental conditions. Nor is there a fully tested method of estimating the impact of constituents originating in the unsaturated zone on ground-water quality. Therefore, to avoid unneeded efforts, the first question the owner or operator should address is whether this task is necessary. For example, the characterization of ground-water quality (conducted following the guidance in Section 10) may provide information sufficient to describe the extent of the release in soils as well, and to determine that a Corrective Measures Study is necessary. This may be the case in situations where contaminated soils are located solely within the ground water and when the contaminants are relatively mobile. The most recent ground-water impact characterization data may not, however, provide information on the future impact of contaminated soils on ground water (e.g., due to different leaching rates for different contaminants).

This section presents various approaches for predicting constituent mobility in both saturated and unsaturated soils; it also discusses how to estimate the impact on ground-water quality of the constituents leached from unsaturated soils. The limitations of these methods are also reviewed.

9.4.4.3.1 Constituent Mobility

There are several means of investigating mobility, including a descriptive approach (i.e., consideration of constituent and soil properties), the use of

mathematical models, and the use of laboratory models or leaching tests. Leaching tests have the advantage of being the only approach that integrates soil and constituent properties in a single evaluation. They may, in certain cases, provide a conservative (reasonable worst case) estimate of the concentration within leachate of waste constituents that may eventually impact ground water. Leaching test results must be coupled with site-specific factors, (e.g., soil cation exchange capacity, ground-water pH, and depth to ground water) when used to design monitoring programs, determine potential for inter-media impacts, and evaluate options for contaminated-soil corrective measures. When assessing leach test results, specific hazardous constituent concentrations in the leachate will be compared with the health and environmental criteria concentrations for water described in Section 8.

The descriptive approach and the use of mathematical models (such as the RITZ Model, discussed previously) may be appropriate in those cases where assumptions implicit in the use of leaching tests may not be applicable. For example, leaching tests may be overpredictive of leachate concentrations where extensive channeling (e.g., because of root zone or joints) through the contaminated zone is present; in this case, the contact time between the leaching fluid (e.g., infiltrating precipitation) and the soil, as well as the surface area of the soil exposed to the fluid, would be less than that simulated by the leaching test. Leaching tests may also not be applicable where low redox (reduction/oxidation) conditions are identified. Consideration of redox conditions is particularly relevant for inorganics.

The Agency has devised a soils/waste mixture leaching procedure, known as the Synthetic Precipitation Leach Test (Method 1312) that it generally believes may be appropriate for evaluating the potential impact of contaminated soils on ground-water quality. (See Appendix F for a description of this procedure). Although neither Method 1312 nor any other leaching test (such as the Toxicity Characteristic Leaching Procedure (Method 1311) have been validated for use on a wide range of contaminated-soil types, the Agency believes that Method 1312 may have the broadest applicability. Method 1312 may be particularly appropriate when no future waste management or other industrial activities likely to produce an acidic leaching medium are likely to be conducted at the site of the release.

However, other leaching tests may be appropriate under certain case-specific circumstances. For example, a test such as Method 1311 may be appropriate at a release site that will be used for management of municipal refuse or a similar waste in the future, because the refuse could produce an acidic leaching medium, which Method 1311 has been designed to simulate. The evaluation of leaching from cyanide-containing soils should be performed with neutral water, rather than an acidic leaching medium, because leaching of cyanide-containing waste under acidic conditions may result in the formation of toxic hydrogen cyanide gas. Other leaching test variations may be necessary if interactive effects on mobility are caused by non-aqueous solvents, for example, or if an aqueous phase leaching medium may underpredict potential mobility due to site and waste constituent characteristics.

9.4.4.3.2 Estimating Impact on Ground-Water Quality

In evaluating results obtained using the leach test for the evaluation of contaminants of concern at a specific release site, the Agency will consider relevant hazardous constituent properties; the physical and chemical characteristics of the soil/waste matrix at the site, and local climatological factors. Factors that will be considered include the following:

- Chemical structure, classification, and bonding (organic vs. inorganic, ionic vs. covalent, etc);
- Solubility of the constituents;
- Octanol/water or other partitioning coefficients;
- Density;
- Organic carbon adsorption coefficient;
- Volatility (e.g., Henry's Law constant);
- Dissociation constants (P_k);

- Degradation potential (hydrolysis, biodegradation);
- Soil/waste matrix characteristics;
- Cation exchange capacity;
- Soil pH and Eh;
- Soil classification (e.g., clay, silt, and sand content);
- Particle-size distribution;
- Porosity;
- Unsaturated hydraulic conductivity;
- Climatological characteristics;
- Precipitation patterns (volume, frequency, etc.); and
- pH of local or regional precipitation.

The results obtained from a specific leach test must be supported by an analysis of the relevant factors, such as those listed above, and considering the likely future use of the site (industrial, waste management, residential, etc.).

As an alternative approach to the use of a leach test for evaluating contaminated soil, the owner or operator may propose to perform an analysis of the waste, soil, and climatological conditions, considering such factors as are listed above, to demonstrate that the expected concentrations of any constituents that could leach from any contaminated section of the subsurface soils would not exceed the action levels for ground-water. This analysis, which would require appropriate technical justification and should rely as much as possible on data (such as the results of published field studies conducted under environmental conditions similar to those at the release site), must be based on conservative assumptions related to

future changes in environmental conditions and land use (e.g., the use of the site for future non-hazardous waste management).

At the present time, studies are being designed to more fully examine various methods for evaluating leaching of hazardous constituents from contaminated soils. Further guidance will be provided by the Agency upon completion of these studies. It is recommended that the owner or operator review the procedures and methods described in Sections 8 and 9 and Appendix J of Petitions to Delist Hazardous waste, EPA/530-SW-85-003, as well as SW-846, to assist in determining the appropriateness of any particular leaching procedures for evaluating contaminated soils. Until more definitive guidance is available, the owner or operator may propose what he believes to be the most appropriate leaching procedure, and provide technical justification to support the proposed procedure based on site and waste conditions at the time of the investigation. For additional assistance on selection of a leaching procedure, the owner or operator may contact the Technical Assessment Branch of the Office of Solid Waste in Washington, D.C. (202/382-4764).

As indicated above, waste and site-specific factors should be evaluated, together with leaching test concentrations, to arrive at predictions of the potential impacts to ground water. For example, if the depth to ground water is great enough, and the soil cation exchange capacity is high, the owner or operator may be able to predict that metal species would be adsorbed by the soil before the soil leachate reaches the ground water. Particular attention, in this example, would be needed to ensure that the cation exchange capacity of the soil could not be exceeded. The characteristics of the metal ions that are displaced from the exchange sites should also be considered.

As another example, the soil-water partition coefficient (K_d) is useful for describing chemical mobility in the subsurface environment, and is widely used in studies of ground-water contamination. For primarily aqueous solutions, the partitioning between the aqueous solution and the solid medium can be derived from thermodynamic principles (Freeze and Cherry, 1979).

More commonly, K_d is determined from batch experiments in which the contaminated solution and geologic material of interest are brought into contact.

After a period of time has elapsed (e.g., 24-hours), the degree of partitioning of the contaminant between the solution and the geologic material is determined. The partition coefficient is then calculated using the following equation:

$$K_d = \frac{\text{mass of sorbed chemical/gram of solid}}{\text{mass of chemical/ml of solution}}$$

The relative mobility of attenuated constituents in ground water can then be estimated as follows (after Mills, et al., 1985):

$$v = \frac{V_s}{(1 + K_d b)/n_e}$$

where

v	=	average linear velocity of attenuated constituent along centerline of plume, distance/time;
V_s	=	ground-water velocity, distance/time;
b	=	soil bulk density, mass/volume;
n_e	=	effective porosity, dimensionless; and
K_d	=	soil-water partition coefficient, volume/mass.

The relative mobility of selected constituents, based on typical partition coefficients, is shown in Table 9-6. It is important to note that K_d is a simplified measure of the relative affinity of a chemical for the solution and the soil. K_d is highly site-specific, varying as a function of pH, redox conditions, soil characteristics, and the availability of alternate solution phases (organic and inorganic liquids, or colloidal solids). The general effect of pH and organic matter content on partition coefficients for metals is shown in Figure 9-3.

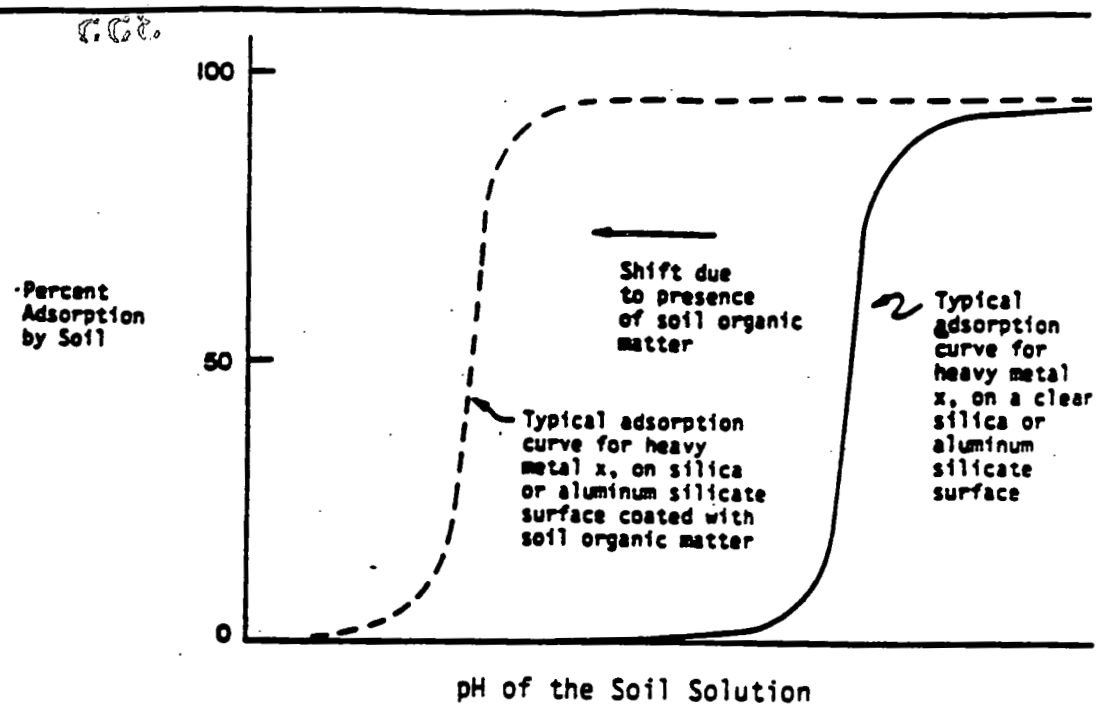
The K_d value selected for use in estimating chemical mobility should reflect the predominant chemical species in solution. One approach to estimating solution composition is to use thermodynamic stability diagrams, commonly illustrated as

TABLE 9-6 RELATIVE MOBILITY OF SOLUTES[1]

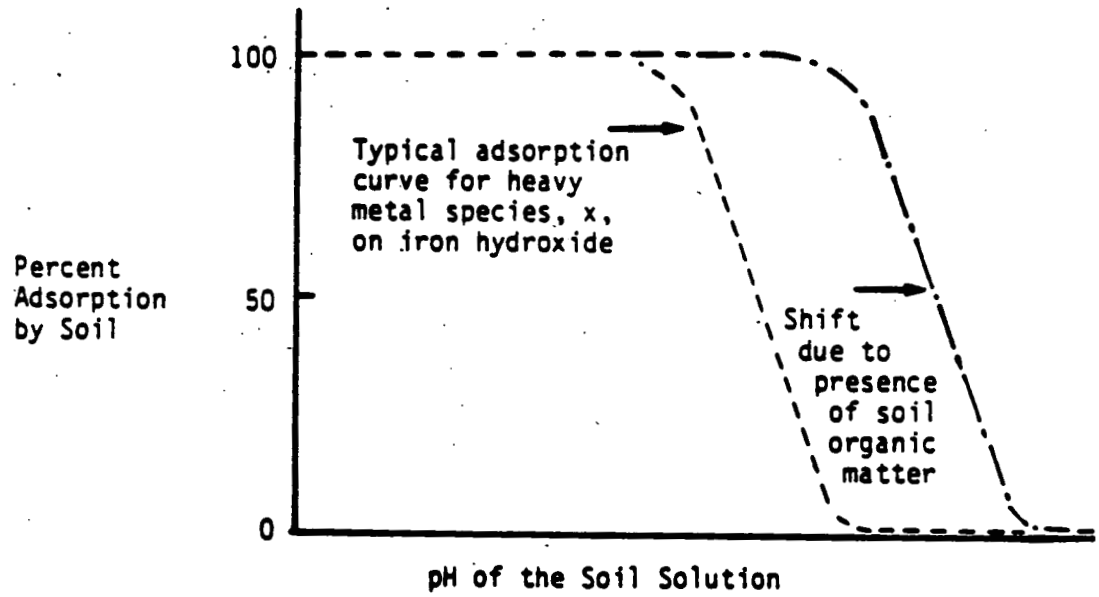
Group	Examples	Master Variables[2]
Conservative	Total Dissolved Solids	V
	Chloride	V
	Bromide	V
	Nitrate	V, Redox Conditions
	Sulfate	V, Redox Conditions
Slightly Attenuated	Boron	V, pH, organic matter
	Trichloro-ethylene	V, organic matter
Moderately Attenuated	Selenium	V, pH, Iron hydroxides,
	Arsenic	V, pH, Iron hydroxides,
	Benzene	V, organic matter
More Strongly Attenuated	Lead	V, pH, Sulfate
	Mercury	V, pH, Chloride
	Penta-chlorophenol	V, organic matter

1 Under typical ground-water conditions (i.e., neutral pH and oxidizing conditions). Under other conditions mobility may differ substantially. For example, acidic conditions can enhance the mobility of metals by several orders of magnitude.

2 Variables which strongly influence the fate of the indicated solute groups. Based on data from Mills et al., 1985 and Rai and Zachara, 1984. (V = Average Linear Velocity)



a) Generalized Heavy Metal Adsorption Curve for Cationic Species (e.g., $CuOH^+$)



b) Generalized Heavy Metal Adsorption Curve for Anionic Species (e.g., CrO_4^{2-})

Figure 9-3. **Hypothetical Adsorption Curves for A) Cations and B) Anions Showing Effect of pH and Organic Matter (Mills et al., 1985)**

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Eh-pH diagrams. These diagrams represent solution composition for specified chemicals as a function of redox potential (Eh) and of pH under equilibrium conditions.

Many metals of interest in ground-water contamination problems are influenced by redox conditions that result from changes in the oxidation state of the metal or from nonmetallic elements with which the metal can form complexes. Garrels and Christ (1965) present a comprehensive treatment of the subject and provide numerous Eh-pH diagrams that can be used for analysis of geological systems.

For any particular point in an Eh-pH diagram, a chemical reaction can be written that describes the equilibrium between the solid and dissolved phases of a particular constituent. The following equation represents the general form of the equilibrium reaction:

$$aA + bB = cC + dD$$

where: a, b, c, d = number of moles of constituent
A and B = reactants
C and D = products

At equilibrium, the solubility constant (K) expresses the relation between the reactants and the products following the law of mass action:

$$K = \frac{[C]^c [D]^d}{[A]^a [B]^b}$$

The brackets signify an effective concentration, or activity, that is reported as molality (moles per liter). Solubility constants for many reactions in water are reported by Stumm and Morgan (1981). Alternatively, solubility constants can be calculated from thermodynamic data (Gibbs free energy) for products and reactants. Freeze and Cherry (1979) describe the use of thermodynamic data to calculate solubility constants for several constituents common in ground water.

An example illustrating the use of Eh-pH diagrams and the influence of redox conditions on solution composition is shown for mercury (Hg) in Figure 9-4. The stability diagram shown in Figure 9-4 is constructed for mercury-contaminated water that contains chloride (Cl) and dissolved sulfur species. The solid lines in the diagram represent the Eh-pH values at which the various phases are in equilibrium. For pH values of less than about 7 and Eh values greater than 0.5 volts (strong oxidizing conditions), $HgCl_2$ is the dominant dissolved species. For pH values greater than 7, and at a high redox potential, $Hg(OH)_2$ is the dominant dissolved species. The main equilibrium reaction in this Eh-pH environment is:

$$HgO + H_2O = Hg(OH)_2$$

From the law of mass action, the solubility relationship for this reaction is written as follows:

$$K = \frac{[Hg(OH)_2]}{[HgO]\,[H_2O]}$$

At 25°C, the solubility constant (log K) for this reaction is -3.7 (Freeze and Cherry, 1979). The activity coefficients for a solid (HgO) and H_2O are assumed to be one; therefore, the concentration of $Hg(OH)_2$ in solution is calculated as follows:

$[Hg(OH)_2] = K = 10^{-3.7} = 1.995 \times 10^{-4}$ moles/l = 47 mg/l (mol. wgt. = 235 g/mole)

The Eh-pH diagram can be used to estimate the concentration of mercury in solution at any particular point in the diagram if the solubility constant for the appropriate equilibrium reaction is known. For lower redox conditions (pH = 6.0, Eh = 0.0), the concentration of mercury in solution would be approximately 0.025 mg/l (Callahan et al., 1979).

Several limitations are associated with the use of Eh-pH diagrams to predict dissolved chemical species, including the accuracy of thermodynamic data, the assumption of equilibrium conditions, and of other chemical processes such as adsorption that can maintain concentrations below those that would exist as a result of only solubility constraints. However, the Eh-pH diagrams serve to illustrate

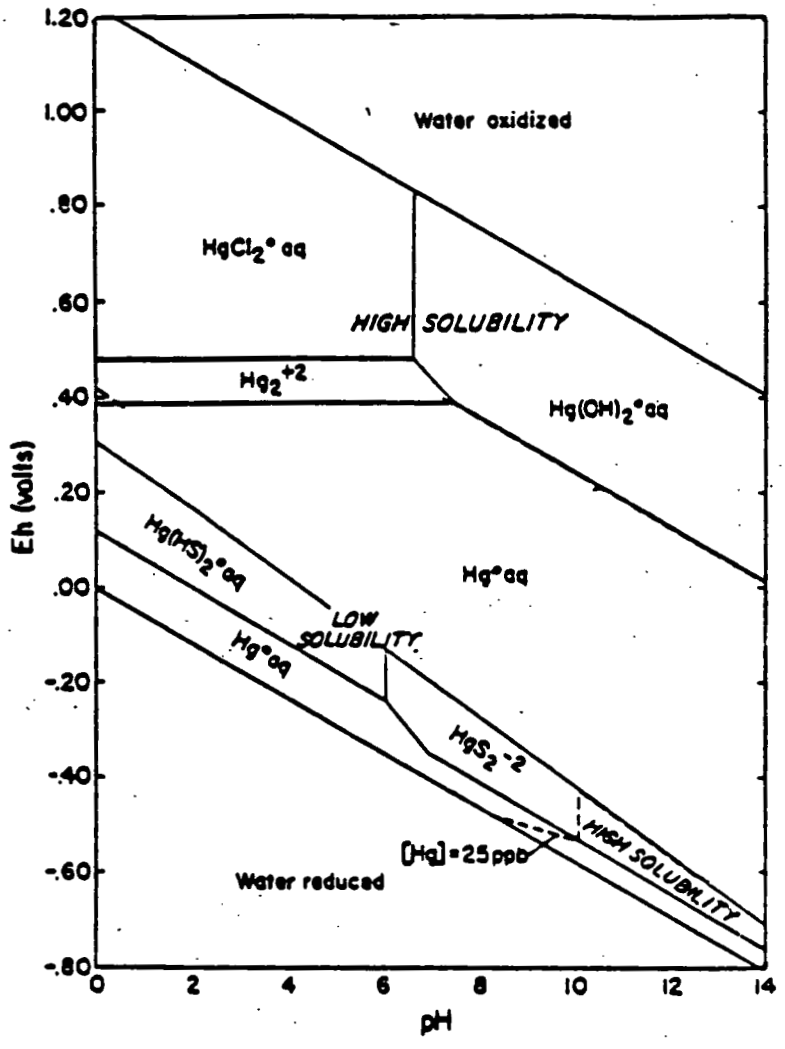


Figure 9-4. Fields of Stability for Aqueous Mercury at 25°C and Atmospheric Pressure (Callahan et al., 1979)

that solution composition depends on redox potential and that chemical mobility within a ground-water system may vary from one zone to another.

9.5 Data Presentation

The owner or operator will be required to report on the progress of the RFI at appropriate intervals during the investigation. The data should be reported in a clear and concise manner, with interpretations supported by the data. The following data presentation methods are suggested for soil investigations. Further information is provided in Section 5.

9.5.1 Waste and Unit Characterization

Waste and unit characteristics may be presented as:

- Tables of waste constituents and concentrations;
- Tables of relevant physical and chemical properties of waste and constituents;
- Narrative description of unit operations; and
- Surface map and plan drawings of the facility and waste unit(s).

9.5.2 Environmental Setting Characterization

Environmental characteristics may be presented as:

- A map and narrative description of soil classifications;
- Soil boring logs;
- Measurements of soil physical or hydrologic characteristics; and
- Onsite survey results (e.g., OVA, portable gas chromatograph, geophysical techniques).

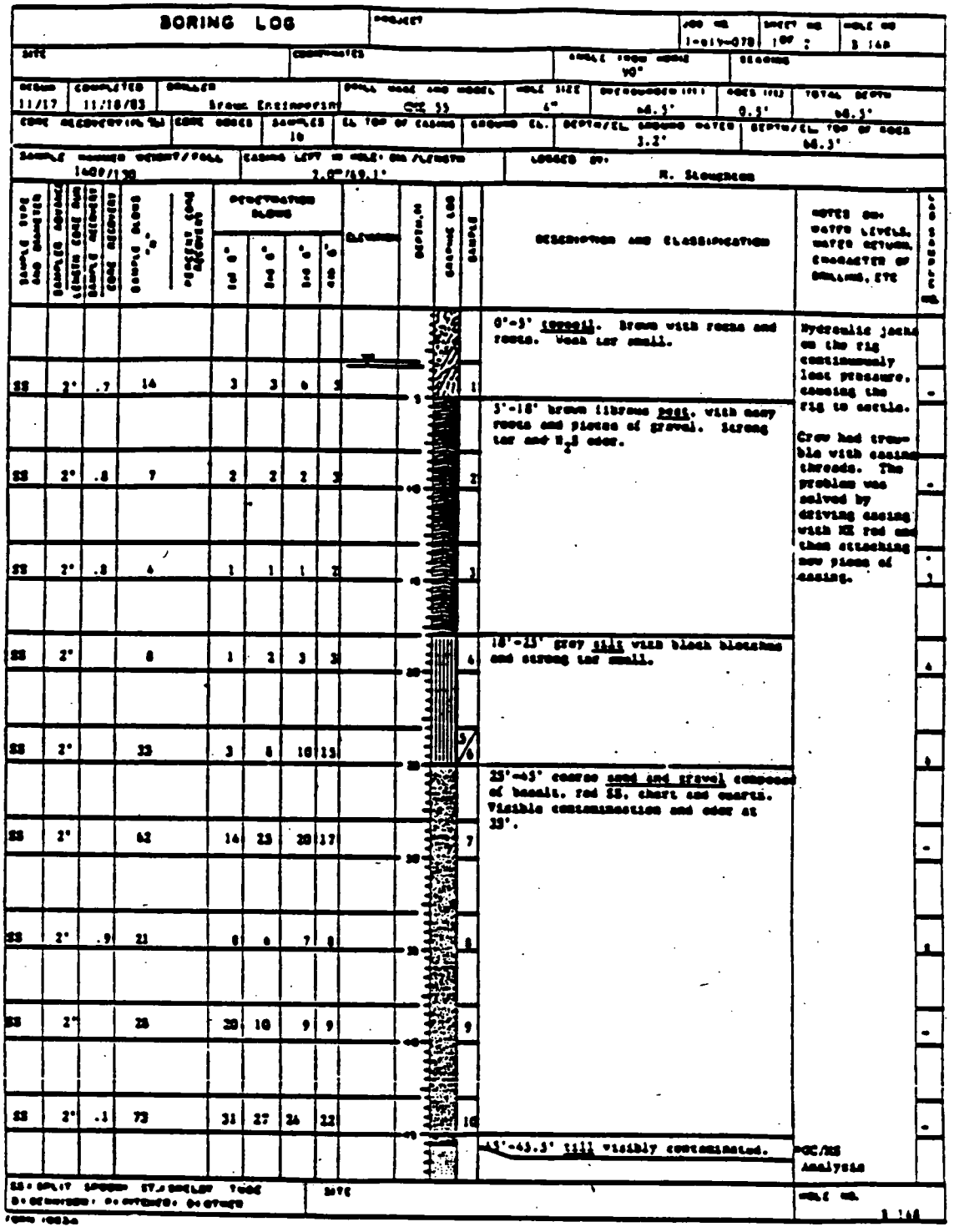
Soil and site map(s)--In addition to the required RCRA permit site topographic map, the owner or operator should prepare a map(s) displaying the location of surface soil types (described according to the appropriate classification system), paved areas, areas of artificially compacted soil, fill or other disturbed soil, and other features that could affect contaminant distribution. Specific guidance on the use of maps and other techniques such as aerial photographs and geophysical surveys is provided in Appendices A and C.

The owner or operator should develop maps of unconsolidated geologic materials at the site. These maps should identify the thicknesses, depths, and textures of soils, and the presence of saturated regions and other hydrogeological features. Subsurface soils should be identified according to accepted methods for description of soils (See Section 9.3.3.3). Figure 9-5 displays a typical soil boring log.

Graphical methods commonly used to display soil boring data are cross-sections, fence diagrams, and isopach maps. Cross-sections are typically derived from borings taken along a straight line through the site. Plotting the stratigraphy of surficial deposits against horizontal distance between sampling points gives a vertical profile or transect. Fence diagrams can depict the same type of information between points that are not in a straight line. An isopach map resembles a topographic map, however, the isopleth lines on an isopach map represent units of thickness of a particular soil layer rather than elevations. For example, a map of clay isopachs may be used to show the thickness in feet of a low permeability layer below a waste lagoon. Generally, to verify lateral continuity, more than one transect through a site will be necessary. When it is important to indicate the areal extent of a layer (e.g., where a clay lens is suspected to cause lateral transport in the unsaturated zone) both vertical and horizontal presentations may be necessary. Graphical methods are discussed in detail in Section 5 (Data Management and Presentation).

9.5.3 Characterization of the Release

Graphical displays of contaminant distributions in soil may include:



BORING LOG

11/17	11/18/83	Brown Engineering				4"	46.5'	0.5'	46.5'			
			10				3.2'		46.5'			
1400/130							R. Slaughter					

Sample	Blows 0-6"	Blows 6-12"	Blows 12-18"	Blows 18-24"	Depth	Description and Classification	Notes on water levels, water return, encounter of obstacles, etc	PID
						0'-3' topsoil. Brown with roots and roots. Weak tar smell.	Hydraulic jacks on the rig continuously lost pressure, causing the rig to settle. Crew had trouble with casing threads. The problem was solved by driving casing with HX rod and then attaching new piece of casing.	
SS 1	2" .7	14	3	3	6	5		-
					5	3'-18' brown fibrous peat, with many roots and pieces of gravel. Strong tar and H_2S odor.		
SS 2	2" .8	7	2	2	2	3		-
SS 3	2" .8	4	1	1	1	2		-
					10			
SS 4	2"	8	1	2	3	3	18'-23' gray silt with black blockage and strong tar smell.	4
					15			
SS 5	2"	33	3	8	10	13		5
					20	23'-43' coarse sand and gravel composed of basalt, red SS, chert and quartz. Visible contamination and odor at 23'.		
SS 6	2"	62	14	23	20	17	7	-
SS 7	2" .9	21	8	6	7	8	8	1
					25			
SS 8	2"	25	20	10	9	9	9	-
					30			
SS 9	2" .1	73	31	27	24	22	10	-
					35	43'-43.5' silt visibly contaminated.	PGC/MS Analysis	

SS = Split Spoon ST = Shelby Tube
D = Disturbed; U = Undisturbed; O = Other

Figure 9-5. Example of a completed boring log

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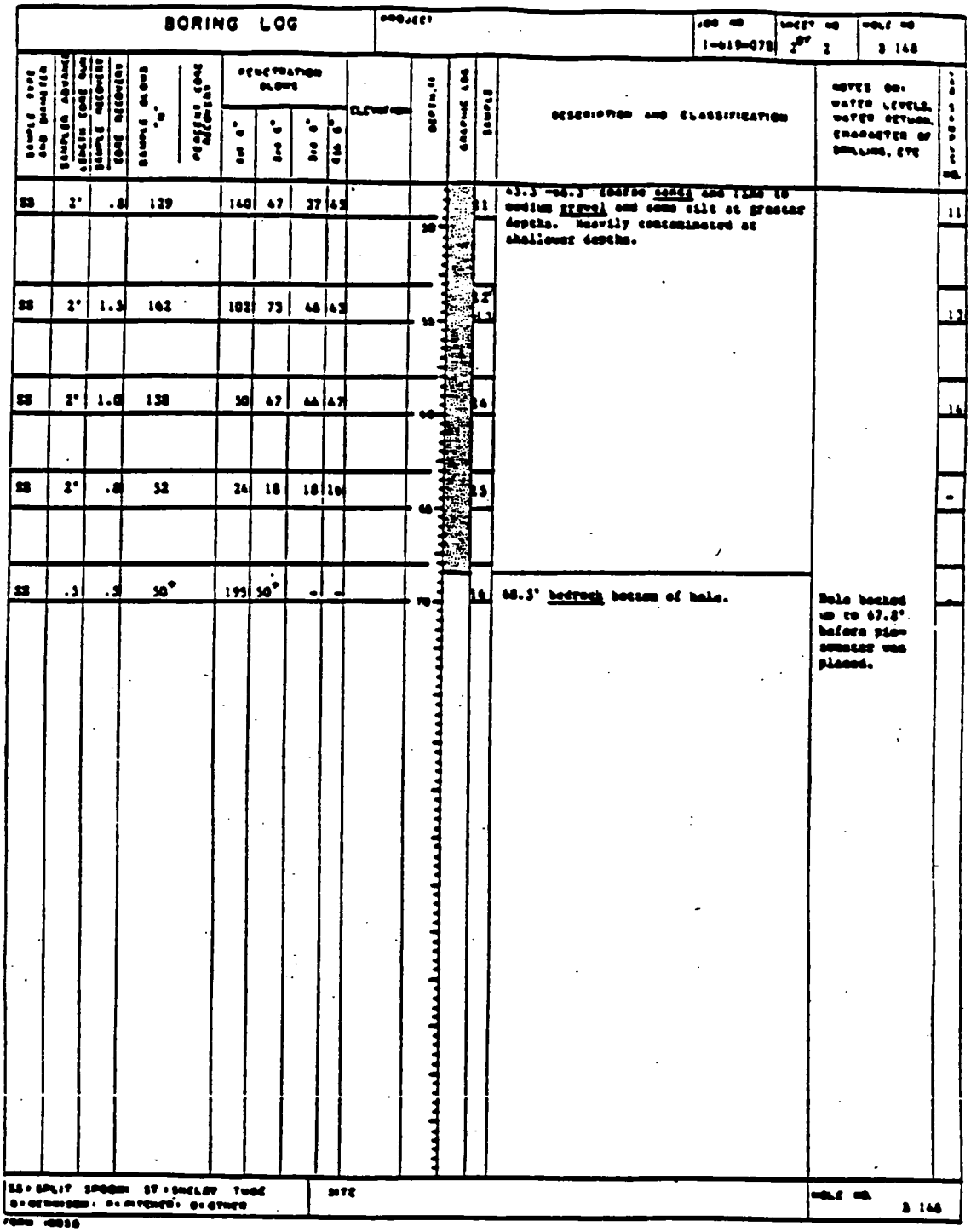

BORING LOG

PROJECT

JOB NO 1-619-078 | SHEET NO 2 OF 2 | HOLE NO B 148

Sample type and number	Sampler advance or drill core run	Sample recovery or core recovery	Sample blows "n" / Penetration core recovery	Penetration blows 1st 6"	2nd 6"	3rd 6"	4th 6"	Elevation	Depth, ft	Graphic log	Sample	Description and classification	Notes on: water levels, water return, character of drilling, etc	Penetration resistance, blows/ft
SS	2'	.8	129	140	47	37	45				11	43.3 -46.3' coarse sand and fine to medium gravel and some silt at greater depths. Heavily contaminated at shallower depths.		11
									30					
SS	2'	1.3	162	102	73	46	43				12			12
									50					
SS	2'	1.0	138	50	47	44	47				14			14
									60					
SS	2'	.8	52	24	18	18	16				15			-
									65					
SS	.3	.3	50*	195	50*	-	-				16	68.3' bedrock bottom of hole.	Hole backed up to 67.8' before piezometer was placed.	-
									70					

SS = SPLIT SPOON ST = SHELBY TUBE
D = DENISON; P = PITCHER; O = OTHER

DATE

HOLE NO. B 148

FORM 4B010

Figure 9-5 (Continued)

- Area/site maps with concentrations indicated by numerical values, symbols, or isoconcentration lines;

- Three-dimensional isopleth plots of concentrations (including stack maps), such as are produced by computer graphics; and

- Vertical concentration contours (isopleths) plotted along a transect or fence diagram.

All graphical displays should be accompanied by data tables showing concentrations for each sampling location.

9.6 Field Methods

Both soil and soil-pore water sampling may be utilized in the investigation. Chemical analysis of soil core samples may be used to characterize constituents of concern that are adsorbed to the solid matrix. Lysimeters can be installed in boreholes created during core sampling to identify mobile constituents that may migrate to ground water. In addition, field screening methods may be used to help determine the presence and extent of releases.

Appropriate sample collection and preservation techniques should be specified. When a soil sample is removed from its surroundings, chemical and physical changes can begin immediately. These changes include moisture loss, oxidation, gas exchange, loss of volatile components, increased or decreased biological activity, and potential contamination of the sample. Therefore, appropriate measures must be taken to store and preserve samples to minimize their degradation. Sampling techniques should not adversely affect analytical procedures and hence results. For example, use of fluids other than water during drilling can introduce organic or inorganic contaminants that may make quantification of the contaminants of concern impossible. The practice of coating metal parts of drilling equipment with oils or greases to prevent rust will have a similar effect.

Volatile compounds can sometimes be detected near the soil surface using rapid, field screening methods (e.g., portable photoionization detector such as HNu

or Photovac or an organic vapor analyzer (OVA)). Organic vapors can also be detected and measured in shallow boreholes or in ground-water monitoring wells. Vapor sampling is especially useful for initial characterization because it is a rapid, semi-quantitative technique. Benefits of field screening methods include:

- The investigator can, in certain cases, quickly determine whether a sample is contaminated, thus, aiding in the identification of areas of concern;

- Samples that may undergo chemical changes with storage can be evaluated immediately; and

- These techniques can be used to investigate releases to several media simultaneously (e.g., subsurface gas, ground water and soil).

However, there are limitations in using field screening methods, including:

- They cannot always account for all constituents that may be present in the release;

- They may not be able to quantify concentrations of specific constituents of concern; and

- Constituents may be present at levels below detection capability.

Field-screening methods are described in the Compendium of Field Operations Methods (EPA, 1987).

Soil sampling methods will commonly vary with the depth of interest. For purposes of the RFI, these methods are described as "surficial" or "subsurface". Surficial sampling in the upper 20 cm of soil can usually be accomplished with simple tools, including shovels, spatulas, soil punches, and ring samplers. Contaminants that have moved further downward in the soil profile often require tools such as tube samplers and augers. Manually operated tools are commonly useful to about 1 to 2 meters in depth, depending on the soil type. Below this depth, hydraulically or mechanically driven equipment is generally needed (See Everett et al, 1984 for

additional information on soil sampling techniques, as well as Sections 3 and 7 of this Guidance for discussions of additional sampling methods and references).

Methods to sample soil-pore water or other fluids are presented in Section 9.6.3.

9.6.1 Surficial Sampling Techniques

Surficial soils may also contain various materials, including rocks, vegetation, and man-made items. The owner or operator should propose how these materials will be treated (i.e., whether they will be discarded or analyzed separately). Care should be taken in choosing sampling equipment that will not adversely affect the analytical objectives (e.g., painted or chrome/nickel plated equipment may adversely affect metals analyses). Some commonly used surficial soil sampling techniques are discussed below.

9.6.1.1 Soil Punch

A soil punch is a thin-walled steel tube that is commonly 15 to 20 cm long and 1.3 cm to 5.1 cm in diameter. The tube is driven into the ground with a wooden mallet and twisted to free the sample. The punch is pulled out and the soil pushed or shaken from the tube. This technique is rapid but is generally not useful in rocky areas or in loose, granular soils that will not remain in the punch. Soil punching is not useful for soil structure descriptions because the method causes compaction that destroys natural fractures.

9.6.1.2 Ring Samplers

A ring sampler consists of a 15 to 30 cm diameter steel ring that is driven into the ground. The soil is subsequently removed for analysis. This technique is useful when results are to be expressed on a unit area basis, because the soil ring contains a known area of soil. Ring samplers will generally not be useful in loose, sandy soils or stiff clays.

9.6.1.3 Shovels, Spatulas, and Scoops

Collection of grab samples by shovel, spatula, or scoop is not recommended if sample area or volume determinations are required (the two previous methods are more accurate). The reproducibility of sample size is limited and subject to sample bias. The principal advantages of grab sampling are the efficiency of collection and the fact that samples may indicate the range of contaminant concentrations at the site.

9.6.1.4 Soil Probes (tube samplers)

Manual soil probes are designed to obtain samples from the upper two meters of the soil profile. The soil probe is commonly a stainless-steel or brass tube that is sharpened and beveled on one end and fitted with a T-handle. Soil probes are common agricultural tools and can be obtained in several diameters. The probe is pushed into the soil in 20 to 30 cm increments. At the desired depth, the tube is pulled out and the soil sample extruded. The sample may be considered "disturbed" or "undisturbed" depending on whether it can be removed intact. The samples, however, are generally considered to be disturbed for the purposes of engineering or physical measurements. Loose soils will be difficult to sample with this tool, and the borehole will tend to collapse when the tube is withdrawn to obtain samples.

9.6.1.5 Hand Augers

Augers have a spiral cutting blade that transports soil cuttings upwards. Hand-operated augers are generally used to a depth of approximately 6 feet. Single flight augers are pulled from the ground periodically and soil samples are taken from the threads of the auger. Continuous flight augers transport the loosened soil to the top of the borehole, where it can be collected. Augers provide highly disturbed samples. Limited information can be obtained on soil structure, bulk density, or permeability. Cross-contamination between soil layers is likely and depth information on various soil layers is not reliable. Therefore, reliance on augering as a sole sampling technique is not recommended. Augering may be used, however, in conjunction with tube sampling that obtains undisturbed samples.

9.6.2 Deep Sampling Methods

The subject of deep drilling is discussed more extensively in the section on ground-water sampling (see Section 10), because deep cores will generally be taken in conjunction with drilling for monitoring well emplacement. There are some techniques that are of particular importance to soil sampling and, therefore, a brief discussion is included here. Procedures for sampling with split-spoon and thin-wall tube corers and other equipment are presented in Section 7.

9.6.2.1 Hollow-Stem Augers

Hollow-stem augers have a continuous flight-cutting blade around a hollow metal cylinder. A stem with a plug is ordinarily kept inside the auger barrel to prevent soil from entering. When core samples are desired, the stem is withdrawn and a tube sampler may be inserted to the bottom of the borehole. This drilling method may be used for continuous soil sampling. An additional advantage of hollow-stem augers is that they do not require drilling fluids.

9.6.2.2 Solid-Stem Augers

Solid-stem augers, as the name implies, are augers that do not have an inner barrel. As with the manual variety, single-flight augers must be withdrawn each time a sample is desired, or samples may be taken from the cuttings brought to the surface by augers of the continuous flight type. Augers may be used in conjunction with tube samplers by withdrawing the auger and obtaining a sample from the bottom of the borehole. This sampling approach is only useful with soils that do not cave in or crumble after drilling.

9.6.2.3 Core Samplers

Soil coring devices that may be used with hydraulically or mechanically- driven drilling rigs include thin-walled Shelby tubes and split-spoon samplers. These are two of the most common samplers and are discussed below.

9.6.2.3.1 Thin-Walled Tube Samplers

The Shelby tube is a metal cylinder with the end sharpened and beveled for cutting into the soil. Common sizes used for field investigations are 1 to 3 inches in diameter. The tube is pushed down into the soil with a smooth even motion by applying downward pressure from a drilling rig or other apparatus. Thin-walled tubes produce high quality undisturbed cores that can be used for engineering and hydraulics testing but are useful only in cohesive soils as loose soils may fall out of the tube during removal. The soil must be extruded from the tube in a laboratory or in a field extruding unit because core removal is generally difficult. For rapid characterization of the soil stratigraphy in the field, split-spoon samplers are recommended.

9.6.2.3.2 Split-Spoon Samplers

A split-spoon consists of a hollow steel cylinder split in half and screwed into an "unsplit" outer tube and tip. This assembly can be connected to drill rods. The tube is commonly forced into the soil by applying a 140 pound sliding hammer, dropping 30 inches along the drill rod (ASTM, 1986). The number of hammer blows required to advance the sampler in six inch increments is recorded. The total blow count number for the second and third increments is related to a standard engineering parameter indicating soil density. After the tube is pulled from the soil, the cylinder is removed from the drill rod and opened, exposing the soil core. Core samples may be used to determine stratigraphy, for chemical and grain-size analysis, or for pore water extraction. Split-spoons are the preferred method for obtaining unconsolidated soil samples and may also be used to penetrate some types of rock.

9.6.2.4 Trenching

Trenches and test pits are useful where detailed examination of soil stratigraphy and geology is required. Trenching is generally limited for practicality to the top eight feet of soil. Shallow trenches may be dug manually, but in most instances, a backhoe will be faster and easier. Bulk soil samples may be obtained with this method.

9.6.3 Pore Water Sampling

When contaminants are suspected of migrating readily through the soil with infiltrating water, monitoring of water or other fluids in the unsaturated zone may be appropriate. Sampling soil pore water before it reaches the water table can provide an early warning of threats to ground water.

Compounds for which pore water sampling may be useful are those that are moderately to highly water soluble and thus are not appreciably retained on soil particles. Examples include poorly adsorbed inorganics such as cyanide or sulfate, halogenated solvents such as TCE, and organic acids. Due to the mobility of these compounds, pore water sampling will be most useful for current releases.

A common pore water collection technique uses a suction device called a pressure vacuum lysimeter, which consists of a porous ceramic cup connected by tubing to a collection flask and vacuum pump (Figure 9-6). The lysimeter cup may be permanently installed in a borehole of the appropriate depth, and if the hole is properly backfilled. Suction from the pump works against soil suction to pull water out of the silica flour surrounding the cup. This method will not work well in relatively dry soils.

An advantage of this method is that the installation is " permanent," allowing multiple samples from one spot to measure changes in pore water quality with time. Limitations include:

- Measurements cannot be correlated accurately with soil concentrations because the sample is obtained from an unknown volume of soil;

- Lysimeters are subject to plugging and are difficult to install in fractured or rocky soils;

- Some organic and inorganic constituents may be adsorbed by the ceramic cup (Teflon porous suction lysimeters may overcome this problem); and

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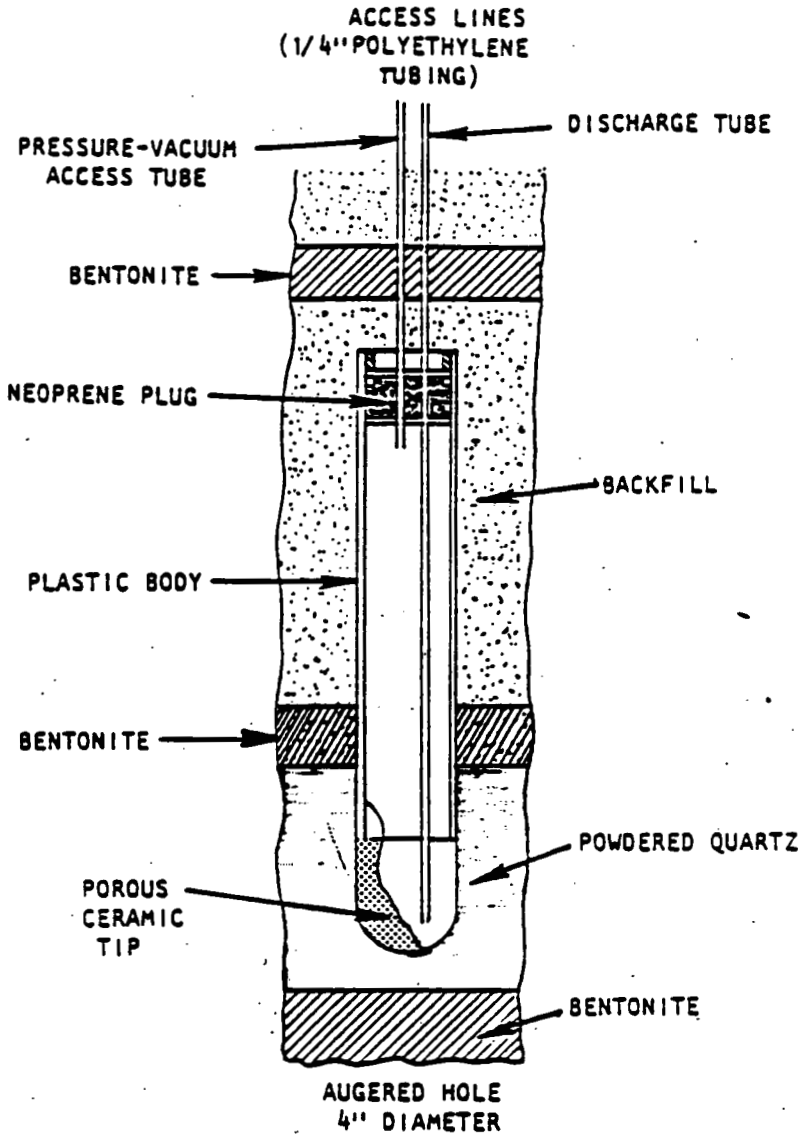

Figure 9-6. Typical Ceramic Cup Pressure/Vacuum Lysimeter

- Volatile organics will be lost unless a special organics trap is installed in the system.

9.7 Site Remediation

Although the RFI Guidance is not intended to provide detailed guidance on site remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

The guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

9.8 Checklist

RFI CHECKLIST - SOILS

Site Name/Location _____

Type of unit _____

1. Does waste characterization include the following information? (Y/N)

- Identity and composition of contaminants ____
- Physical state of contaminants ____
- Viscosity ____
- pH ____
- pKa ____
- Density ____
- Water Solubility ____
- Henry's Law Constant ____
- K_{ow} ____
- Biodegradability ____
- Rates of hydrolysis, photolysis and oxidation ____

2. Does unit characterization include the following information? (Y/N)

- Age of unit ____
- Construction integrity ____
- Presence of liner (natural or synthetic) ____
- Location relative to ground-water table or bedrock or other confining barriers ____
- Unit operation data ____
- Presence of cover ____
- Presence of on/offsite buildings ____
- Depth and dimensions of unit ____
- Inspection records ____
- Operation logs ____
- Presence of natural or engineered barriers near unit ____

3. Does environmental setting information include the following information? (Y/N)

- Site soil characteristics ____
- Surface soil distribution map ____
- Soil moisture content ____
- Predominant soil phase to sample (solid, liquid, gaseous) ____
- Soil classification ____
- Particle size distribution ____

- Porosity
- Hydraulic conductivity (saturated and unsaturated) ____
- Relative permeability ____
- Soil sorptive capacity ____
- Cation exchange capacity ____
- Organic carbon content ____
- Soil pH ____
- Depth to water table ____
- Pore water velocity ____
- Percolation ____
- Volumetric water content ____

4. Have the following data on the initial phase of the release characterization been collected? (Y/N)

- Geological and climatological data ____
- Facility records and site-specific investigations ____
- Area of contamination ____
- Distribution of contaminants within study area ____
- Depth of contamination ____
- Chemistry of contaminants ____
- Vertical rate of transport ____
- Lateral rate of transport in each stratum ____
- Persistence of contaminants in soil ____
- Potential for release from surface soils to air ____
- Potential for release from surface soils to surface water ____
- Existing soil/ground-water monitoring data ____
- Evidence of vegetative stress ____
- Potential for release to ground water ____
- Potential receptors ____

5. Have the following data on the subsequent phase(s) of the release characterization been collected? (Y/N)

- Further soil stratigraphic and hydrologic characterization data ____
- Expanded sampling data ____
- Geophysical data on release location ____

9.9 References

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SECTION 10

GROUND WATER

10.1 Overview

The objective of an investigation of a release to ground water is to characterize the nature, extent, and rate of migration of a release of hazardous waste or constituents to that medium. This section provides:

- An example strategy for characterizing releases to ground water, which includes characterization of the source and the environmental setting of the release, and conducting a monitoring program which will characterize the release itself;
- Formats for data organization and presentation;
- Field methods which may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data needed in all instances; however, it identifies possible information necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for release characterization. This list is not meant as a list of requirements for all releases to ground water. Some release investigations will involve the collection of only a subset of the items listed, while others may involve the collection of additional data.

10.2 Approach for Characterizing Releases to Ground Water

10.2.1 General Approach

A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available.

For ground-water investigations, this model should account for the ability of the waste to be dissolved or to appear as a distinct phase (i.e., "sinkers" and "floaters"), as well as geologic and hydrologic factors which affect the release pathway. Both the regional and site-specific ground-water flow regimes should be considered in determining the potential magnitude of the release, migration pathways and possible exposure routes. Exposure routes of concern include ingestion of ground water as drinking water and near-surface flow of contaminated ground water into basements of residences or other structures (see Appendix E). This "basement seepage" pathway can pose threats through direct contact, inhalation of toxic vapors and through fires and explosions if the contaminants are flammable. The model should consider the degradability (chemical and biological) of the waste and its decomposition products. The conceptual model should also address the potential for the transfer of contaminants in ground water to other environmental media (e.g., discharge to surface water and volatilization to the atmosphere).

Based on the conceptual model, the owner or operator should develop a monitoring program to determine the nature, extent, and rate of migration of contaminant releases from SWMUs* to ground water. Three-dimensional characterization is particularly important. The initial monitoring phase should

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* Guidance in this section applies to releases from all solid waste management units, except releases to ground water from "regulated units" as defined under 40 CFR Part 264.90(a)(2). Releases to ground water from "regulated units" must be addressed according to the requirements of 40 CFR Parts 264.91 thorugh 264.100 for purposes of detection, characterization and appropriate response.

include a limited number of monitoring wells, located and screened in such a way that they are capable of providing background water quality and of intercepting any release. The regulatory agency will evaluate the adequacy of an existing monitoring system, if proposed for use in the initial monitoring phase. The owner or operator may be required to install new wells if the existing well system is found to be inadequate.

Initial ground-water sampling and analysis may be conducted for a limited set of monitoring constituents. This set should include a subset of the hazardous constituents of concern, and may also include indicator parameters (e.g., TOX). Guidance regarding the selection of monitoring constituents and indicator parameters is provided in Sections 3 and 7 and in Appendix B. Sampling frequency and duration should also be proposed in the RFI Work Plan.

Investigation of a suspected release may be terminated based on results from an initial monitoring phase if these results show that an actual release has not, in fact, occurred. If, however, contamination is found, the release must be adequately characterized through a subsequent monitoring phase(s).

Subsequent characterization involves determining the detailed chemical composition and the areal and vertical (i.e., three dimensional) extent of the contaminant release, as well as its rate of migration. This should be accomplished through direct sampling and analysis and, when appropriate, can be supplemented by indirect means such as geophysical methods (See Appendix C) and modeling techniques.

Table 10-1 outlines an example of strategy for characterizing releases to ground water. Table 10-2 lists the specific tasks which may be used in implementing the strategy, and the corresponding data outputs. The steps delineated in these tables should generally be performed in sequential order, although some may be accomplished concurrently. For example, the site's hydrogeology may be investigated at the same time as waste and unit characterization; soil borings installed during hydrogeologic characterization may be converted into monitoring wells; and additional wells may be installed to more accurately characterize a release while a sampling and analysis program is in effect at existing wells.

TABLE 10-1

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO GROUND WATER[1]

INITIAL PHASE

1. Collect and review existing information on:

   - Waste
   - Unit
   - Environmental setting
   - Contaminant releases, including inter-media transport

2. Identify any additional information necessary to fully characterize release:

   - Waste
   - Unit
   - Environmental setting
   - Contaminant releases, including inter-media transport

3. Develop monitoring procedures:

   - Formulate conceptual model of release
   - Determine monitoring program objectives
   - Plan field screening if appropriate (e.g., geophysical investigations - see Appendix C)
   - Select monitoring constituents and indicator parameters
   - Identify QA/QC and analytical procedures
   - Appropriate initial area well locations (background and downgradient)
   - Collection of additional hydrogeologic data (if necessary)
   - Proper well screen interval selection
   - Borehole testing and use of test pitting
   - Sampling frequency and duration of monitoring
   - Identification of data presentation and evaluation procedures

4. Conduct initial monitoring phase:

   - Conduct field screening, if appropraite
   - Collect samples and perform appropriate field measurements
   - Analyze samples for selected parameters and constituents

5. Collect, evaluate and report results:

   - Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations that warrant interim corrective measures - Notify regulatory agency
   - Determine completeness and adequacy of collected data
   - Summarize and present data in appropriate format

TABLE 10-1 (Continued)

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES TO GROUND WATER[1]

INITIAL PHASE (Continued)

- Determine if monitoring program objectives were met
- Determine if monitoring locations, constituents and frequency were adequate to characterize release (nature, rate, and extent)

SUBSEQUENT PHASES (If Necessary)

1. Identify additional information necessary to characterize release:

   - Perform further hydrogeologic characterization, if necessary
   - Add and delete constituents or indicator parameters as appropriate
   - Employ geophysical and other methods to estimate extent of release and to determine suitable new monitoring locations
   - Inter-media transport

2. Expand monitoring network as necessary:

   - Increase density of monitoring locations
   - Expand monitoring locations to new areas
   - Install new monitoring wells

3. Conduct subsequent monitoring phases:

   - Collect samples and complete field analysis
   - Analyze samples for selected parameters and constituents

4. Collect, evaluate, and report results/identify additional information necessary to characterize release:

   - Compare monitoring results to health and environmental criteria and identify and respond to emergency situations and identify priority situations the warrant interim corrective measures - Notify regulatory agency
   - Summarize and present data in appropriate format
   - Determine if monitoring program objectives were met
   - Determine if monitoring locations, constitutents, and frequency were adequate to characterize release (nature, extent, and rate)
   - Identify additional information needs
   - Determine need to expand monitoring
   - Evaluate potential role of inter-media impact
   - Report results to regulatory agency

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1 The possibility for inter-media transport of contamination should be anticipated throughout the investigation.

TABLE 10-2
RELEASE CHARACTERIZATION TASKS FOR GROUND WATER

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
1. Waste/Unit Characterization		
- Identify waste properties (e.g., pH, viscosity)	- Review existing information and conduct waste sampling if necessary (See Sections 3 & 7)	- Tabular presentation (See Section 5)
- Identify constituents of concern/possible indicator parameters	- Review existing information and conduct waste sampling if necessary (See Sections 3 & 7)	- Tabular presentation (See Section 5)
- Determine physical/chemical properties of constituents	- Review existing information (See Section 7)	- Tabular presentation (See Section 5)
- Determine unit dimensions and other important design features and operational conditions	- Review existing information and conduct unit examinations (See Section 7)	- Tabular presentations, facility maps & photographs & narrative discussion (See Section 5 and Appendix A)
- Investigate possible unit release mechanisms to help determine flow characteristics	- Review existing information and conduct unit examinations (See Section 7)	- Facility maps & photographs & narrative discussions (See Appendix A)
2. Environmental Setting Characterization		
- Examine surface features & topography for indications of subsurface conditions	- Review existing information, facility maps, aerial & other photographs, site history, conduct surface geological surveys	- Facility map & photographs/text discussion (See Appendix A & C)
- Define subsurface conditions & materials, including soil and subsurface physical properties (e.g, porosity, cation exchange capacity)	- Review of existing geologic information	- Narrative discussions of geology
	- Soil borings and rock corings	- Boring and coring logs
	- Soil & subsurface material testing	- Subsurface profiles, transects & fence diagrams (See Appendix A & Section 5)
	- Geophysical technqiues (See Appendix C)	- Tabular presentations of soil & subsurface physical & chemical properties
		- Geologic cross sections & geologic & soil maps (See Section 5 & 9 & Appendix A)
		- Structure contour maps (plan view) of aquifer & aquitards (See Section 5 & Appendix A)

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TABLE 10-2
RELEASE CHARACTERIZATION TASKS FOR GROUND WATER (continued)

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
2. Environmental Setting Characterization (Continued)		
- Identification of regional flow cells, ground-water flow paths & general hydrology, including hydraulic conductivities & aquifer interconnections	- Review of existing information - Installation of piezometers & water level measurements at different depths - Flow cell & flow net analyses using measured heads - Pumping & slug tests & tracer studies - Geophysical techniques (See Appendix C)	- Narrative descriptions of ground-water conditions, flow cells, flow nets, flow patterns, including flow rates & direction - Water table or potentiometric maps (plan view) with flow lines (See Section 5) - hydrologic cross sectional maps (See Section 5) - Flow nets for vertical & horizontal flow - Tabular presentations of raw data & interpretive analysis
- Identification of potential receptors	- Review of existing information, area maps, etc.	- Narrative discussion & area maps
3. Release Characterization		
- Determine background levels & determine vertical and horizontal extent of release, including concentrations of constituents & determine rate & directions of release migration	- Sampling & analysis of ground-water samples from monitoring system - Geophysical methods (See Appendix C) for detecting & tracking plume - Modeling to estimate extent of plume & rate & direction of plume migration	- Tabular presentations of constituent & indicator parameter analyses (See Section 5) - Iso-concentrations maps of contamination (See Section 5) - Maps of rates of release migration & direction showing locations of possible receptors (See Section 5) - Narrative discussion & interpretations of tabular & graphical presentations

The specific tasks to be conducted for each release will be determined on a site-specific basis. It should be noted that some of the characterization tasks may have been previously accomplished in conjunction with the 40 CFR Parts 264 and 265, Subpart F (ground-water monitoring) regulations.

As monitoring data become available, both within and at the conclusion of discrete investigation phases, it should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (See Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to obtain and follow the RCRA Contingency Plan under 40 CFR Part 264, Subpart D.

Case Study numbers 10, 18, 19, 20, 21 and 22 in Volume IV (Case Study Examples) illustrate the conduct of various aspects of ground-water investigations.

10.2.2 Inter-media Transport

Indirect releases (inter-media transfer) to ground water may occur as a result of contaminant releases to soil and/or surface water that percolate or discharge to ground water. These releases may be recurrent or intermittent in nature, as in the case of overland run-off, and can vary considerably in areal extent. Direct releases to ground water may occur when waste materials are in direct contact with ground water (e.g., when a landfill rests below the water table).

Releases of contaminated ground water to other media may also occur, for example, in those cases where ground and surface waters are hydraulically

connected. Volatilization of contaminated ground water to the air within residential and other structures may occur via the basement seepage pathway, as described previously. It is important for the owner or operator to be aware of the potential for such occurrences, and to communicate these to the regulatory agency when discovered.

This section provides guidance on characterizing ground-water releases from units, as well as those cases where inter-media transport has contaminated ground water. The owner or operator should be aware that releases to several media can often be investigated using concurrent techniques. For example, soil gas surveys may help to characterize the extent of soil and subsurface gas releases and, at the same time, be used to estimate the extent of a ground-water release. Further guidance on the use of soil gas surveys for investigating releases to soil and ground water are presented in the Soil Section (Section 9).

10.3 Characterization of the Contaminant Source and the Environmental Setting

10.3.1 Waste Characterization

Knowledge of the waste constituents (historical and current) and their characteristics at the units of concern is essential in selecting monitoring constituents and well locations. Waste (source) information should include identifying volumes and concentrations of hazardous waste or constituents present, and their physical and chemical characteristics.

Identification of hazardous constituents may be a relatively simple matter of reviewing records of unit operations, but generally will require direct sampling and analysis of the waste in the unit. Hazardous constituents may be grouped by similar chemical and physical properties to aid in developing a more focused monitoring program. Knowledge of physical and chemical properties of hazardous constituents can help to determine their mobility, and their ability to degrade or persist in the environment. The mobility of chemicals in ground water is commonly related to their solubility, volatility, sorption, partitioning, and density.

Section 3 provides additional guidance on monitoring constituent selection and Section 7 provides additional guidance on waste characterization. The

following discussion describes several waste-related factors and properties which can aid in developing ground-water monitoring procedures:

- The mobility of a waste is highly influenced by its physical form. Solid and gaseous wastes are less likely to come in contact with ground water than liquid wastes, except in situations where the ground-water surface directly intersects the waste, or where infiltrating liquids are leaching through the unsaturated zone.

- The concentration of any constituent at the waste source may provide an indication of the concentration at which it may appear in the ground water.

- The chemical class (i.e., organic, inorganic, acid, base, etc.) provides an indication of how the waste might be detected in the ground water, and how the various components might react with the subsurface geologic materials, the ground water, and each other.

- The pH of a waste can provide an indication of the pH at which it would be expected to appear in the ground water. A low pH waste could also be expected to cause dissolution of some subsurface geologic materials (e.g., limestone), causing channelization and differential ground-water flow, as in karst areas.

- The acid dissociation constant of a chemical (pKa) is a value which indicates its equilibrium potential in water, and is equal to the pH at which the hydrogen ion is in equilibrium with its associated base. If direct pH measurements are not feasible, the concentration of a waste in combination with its pKa can be used to estimate the likely pH which will occur at equilibrium (in ground water), at a given temperature. Acid dissociation values can be found in most standard chemistry handbooks, and values for varying temperatures can be calculated using the Van't Hoff equation (Snoeyink and Jenkins, 1980).

- Viscosity is a measure of a liquid's resistance to flow at a given temperature. The more viscous a fluid is, the more resistant it is to flow.

Highly viscous wastes may travel more slowly than the ground water, while low-viscosity wastes may travel more quickly than the ground water.

- Water solubility describes the mass of a compound that dissolves in or is miscible with water at a given temperature and pressure. Water solubility is important in assessing the fate and transport of the contaminants in ground water because it indicates the chemical's affinity for the aqueous medium. High water solubility permits greater amounts of the hazardous constituent to enter the aqueous phase, whereas low water solubility indicates that a contaminant can be present in ground water as a separate phase. Therefore, this parameter can be used to establish the potential for a constituent to enter and remain in the ground water.

- The density of a substance (solid or liquid) is its weight per unit volume. The density of a waste will determine whether it sinks or floats when it encounters ground water, and will assist in locating well screen depths when attempting to monitor for specific hazardous constituents released to ground water.

- The log of the octanol/water partition coefficient (K_{ow}) is a measure of the relative affinity of a constituent for the neutral organic and inorganic phases represented by n-octanol and water, respectively. It is calculated from a ratio (P) of the equilibrium concentrations (C) of the constituent in each phase:

$$P = \frac{C_{octanol}}{C_{water}} \text{ and } K_{ow} = \log P$$

The K_{ow} has been correlated to a number of factors for determining contaminant fate and transport. These include adsorption onto soil organic matter, bioaccumulation, and biological uptake. It also bears a relationship to aqueous solubility.

- The Henry's Law Constant of a constituent is the relative equilibrium ratio of a compound in air and water at a constant temperature. It can be estimated from the equilibrium vapor pressure divided by the solubility in water and has the units of atm-m^3/mole. The Henry's Law Constant expresses the equilibrium distribution of the constituent between air and water and indicates the relative ease with which the constituent may be removed from aqueous solution.

- Other influences of the waste constituents should also be considered. Constituents may react with soils, thereby altering the physical properties of the soil, most notably hydraulic conductivity. Chemical interactions among waste constituents should also be considered. Such interactions may affect mobility, reactivity, solubility, or toxicity of the constituents. The potential for wastes or reaction products to interact with unit construction materials (e.g., synthetic liners) should also be considered.

The references listed in Section 7 may be used to obtain information on the parameters discussed above. Other waste information may be found in facility records, permits, or permit applications. It should be noted that mixtures of chemicals may exhibit characteristics different than those of any single chemical.

10.3.2 Unit Characterization

Unsound unit design and operating practices can allow waste to migrate from a unit and possibly mix with natural runoff. Examples include surface impoundments with insufficient freeboard allowing for periodic overtopping; leaking tanks or containers; or land based units above shallow, low permeability materials which, if not properly designed and operated, can fill up with water and spill over. In addition, precipitation falling on exposed wastes can dissolve and thereby mobilize hazardous constituents. For example, at uncapped active or inactive waste piles and landfills, precipitation and leachate are likely to mix at the toe of the active face or the low point of the trench floor.

Unit dimensions (e.g., depth and surface area) and configuration (e.g., rectangular, parallel trenches), as well as volume (e.g., capacity) should also be

described, because these factors will have a bearing on predicting the extent of the release and the development of a suitable monitoring network.

10.3.3 Characterization of the Environmental Setting

Hydrogeologic conditions at the site to be monitored should be evaluated for the potential impacts the setting may have on the development of a monitoring program and the quality of the resulting data. Several hydrogeologic parameters should be evaluated, including:

- Types and distribution of geologic materials;
- Occurrence and movement of ground water through these materials;
- Location of the facility with respect to the regional ground-water flow system;
- Relative permeability of the materials; and
- Potential interactions between contaminants and the geochemical parameters within the formation(s) of interest.

These conditions are interrelated and are therefore discussed collectively below.

There are three basic types of geologic materials through which ground water normally flows. These are: (1) porous media; (2) fractured media; and (3) fractured porous media. In porous media (e.g., sand and gravels, silt, loess, clay, till, and sandstone), ground water and contaminants move through the pore spaces between individual grains. In fractured media (e.g., dolomites, some shales, granites, and crystalline rocks), ground water and contaminants move predominantly through cracks or solution crevices in otherwise relatively impermeable rock. In fractured porous media (e.g., fractured tills, fractured sandstone, and some fractured shales), ground water and contaminants can move through both the intergranular pore spaces as well as cracks or crevices in the rock or soil. The occurrence and movement of ground water through pores and cracks or solution crevices depends on the relative effective porosity and degree of

channeling occurring in cracks or crevices. Figure 10-1 illustrates the occurrence and movement of ground water and contaminants in the three types of geologic materials presented above.

The distribution of these three basic types of geologic materials is seldom homogeneous or uniform. In most settings, two or more types of materials will be present. Even for one type of material at a given site, large differences in hydrologic characteristics may be encountered. The heterogeneity of the materials can play a significant role in the rate of contaminant transport, as well as in developing appropriate monitoring procedures for a site.

Once the geologic setting is understood, the site hydrology should be evaluated. The location of the site within the regional ground-water flow system, or regional flow net, should be determined to evaluate the potential for contaminant migration on the regional scale. Potentiometric surface data (water level information) for each applicable geologic formation at properly selected vertical and horizontal locations is needed to determine the horizontal and vertical ground-water flow paths (gradients) at the site. Figure 10-2(a) and (b) illustrate two geohydrologic settings commonly encountered in eastern regions of the United States, where ground water recharge exceeds evapotranspirational rates. Figure 10-2(c) illustrates a common geohydrologic setting for the arid western regions of the United States. The potential dimensions of a contaminant release would depend on a number of factors including ground-water recharge and discharge patterns, net precipitation, topography, surface water body locations, and the regional geologic setting.

Table 10-3 and Figures 10-3 through 10-16 illustrate regional, intermediate, and local ground water regimes for the major ground-water regions in the United States. Ground-water flow paths, and where possible, generalized flow nets are shown superimposed on cross-sections of the geological units. Much of the information presented in the figures and following text descriptions were taken from Heath et. al., 1 984 (Ground Water Regions of the U.S., U.S.G.S. Water Supply

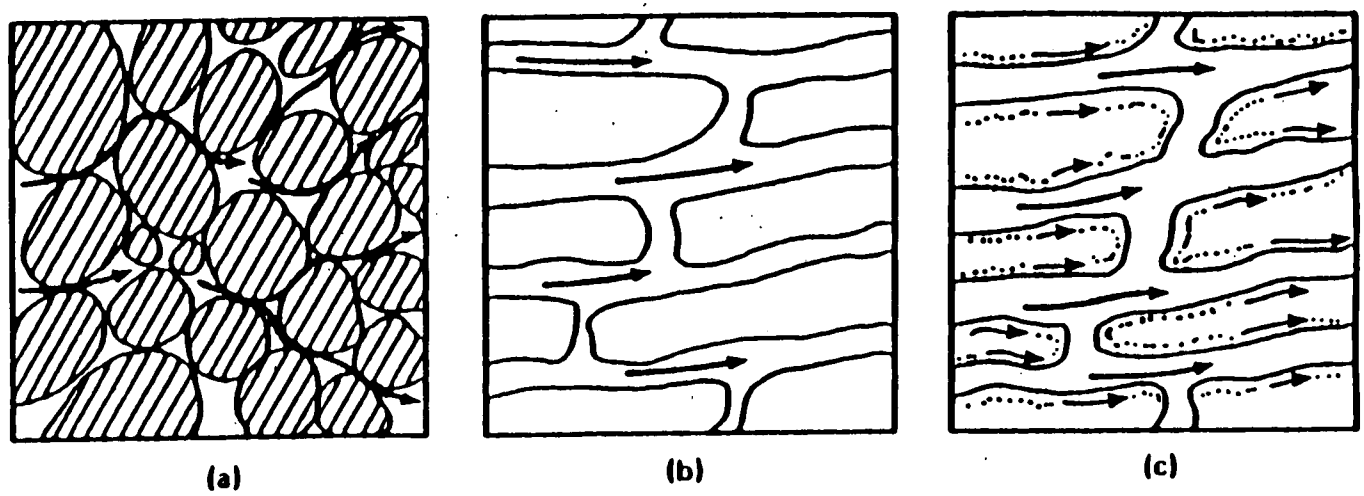

Figure 10-1. Occurrence and movement of ground water and contaminants through (a) porous media, (b) fractured or creviced media, (c) fractured porous media.

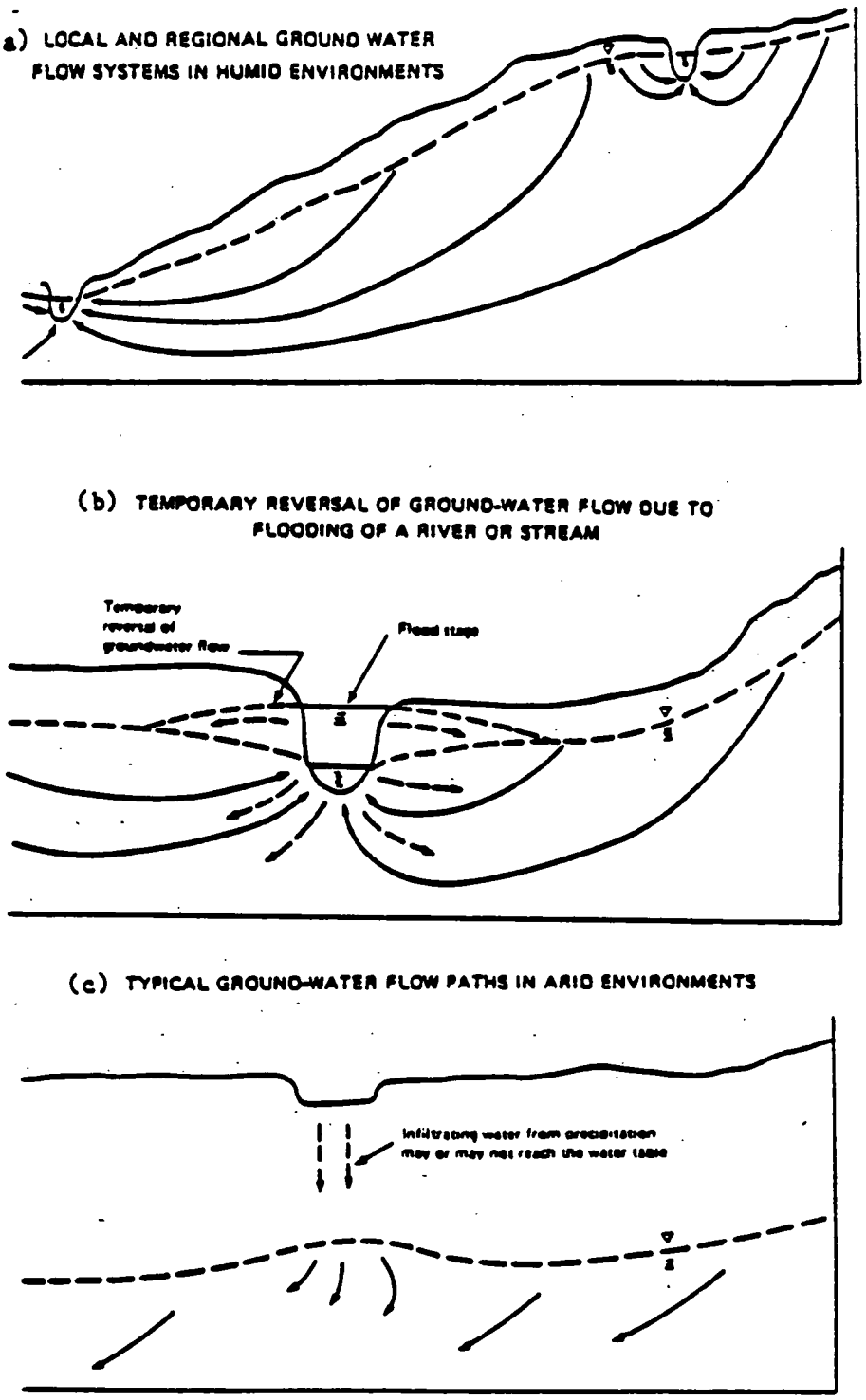

Figure 10-2. Ground-water flow paths in some different hydrogeologic settings.

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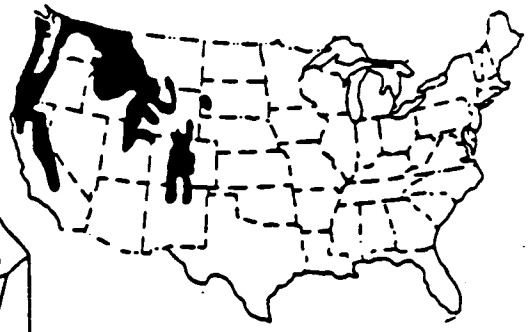
TABLE 10-3. SUMMARY OF U.S GROUND WATER REGIONS

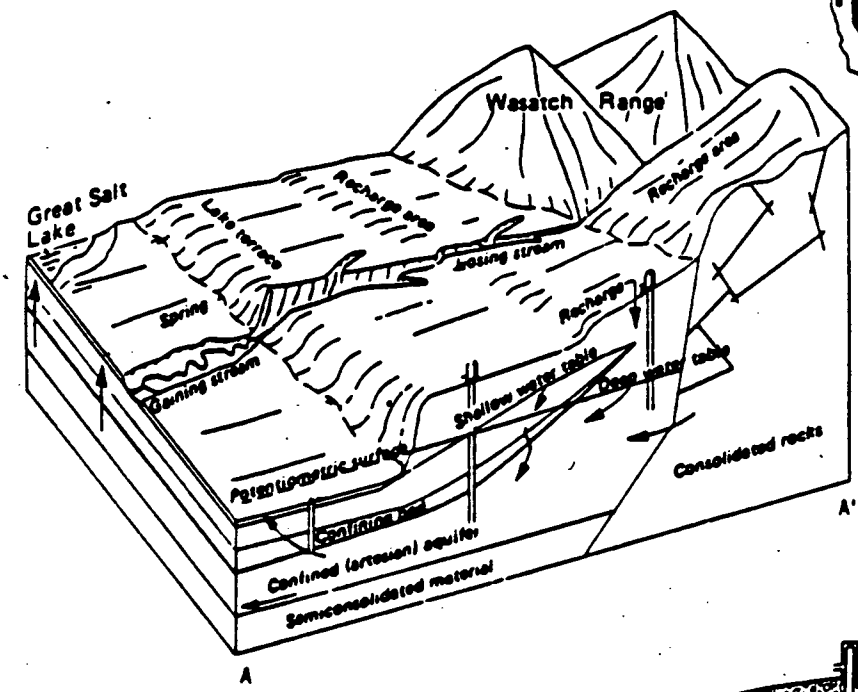
Region	Region Name (Heath, 1984)	Recharge Area	Discharge Area	Dimensions (miles)	Example
1	Western Mountain Ranges	infiltration in mountains and mountain fronts	streams and rivers	< 1-5 unconfined 5-60 confined	Wasatch Range, Utah
2	Alluvial Basins	plateau uplands	streams and rivers, some enclosed basins, localized springs and seeps in steeper terrain	< 1-20 unconfined 5-80 confined	Nevada
3	Columbia Lava Plateau	surface infiltration	rivers and streams	10-200 miles	Snake River Plain
4	Colorado Plateau	infiltration in plateau uplands; infiltration from surface waters	seeps, springs, and surface waters	5-80 miles	Southeast Utah
5	High Plains	surface infiltration	rivers and streams, seeps and springs along eastern escarpments	2-300 miles	Nebraska
6	Non-glaciated central	upland infiltration	springs, seeps, streams and rivers	< 1-40 miles	Ohio Great Miami
7	Glaciated Central	surface infiltration	springs, streams, rivers, and lakes	< 1-20 miles	Minnesota
8	Piedmont and Blue Ridge	surface infiltration	springs, seeps, and surface waters	< 1-5 miles	West Virginia
9	Northeast and Superior Uplands	upland infiltration	surface water	< 1-20 miles	Massachusetts
10	Atlantic & Gulf Coastal Plain	infiltration in outcrop areas	surface water or subsea leakage	10-150 miles	New Jersey
11	Southeast Coastal Plain	infiltration in outcrop areas	surface water or subsea leakage	1-80 miles	South Georgia
12	Hawaiian Islands	surface infiltration	springs, seeps, and surface waters	< 1-30 miles	Oahu, Hawaii
13	Alaska	variable*	variable*	variable*	North Slope

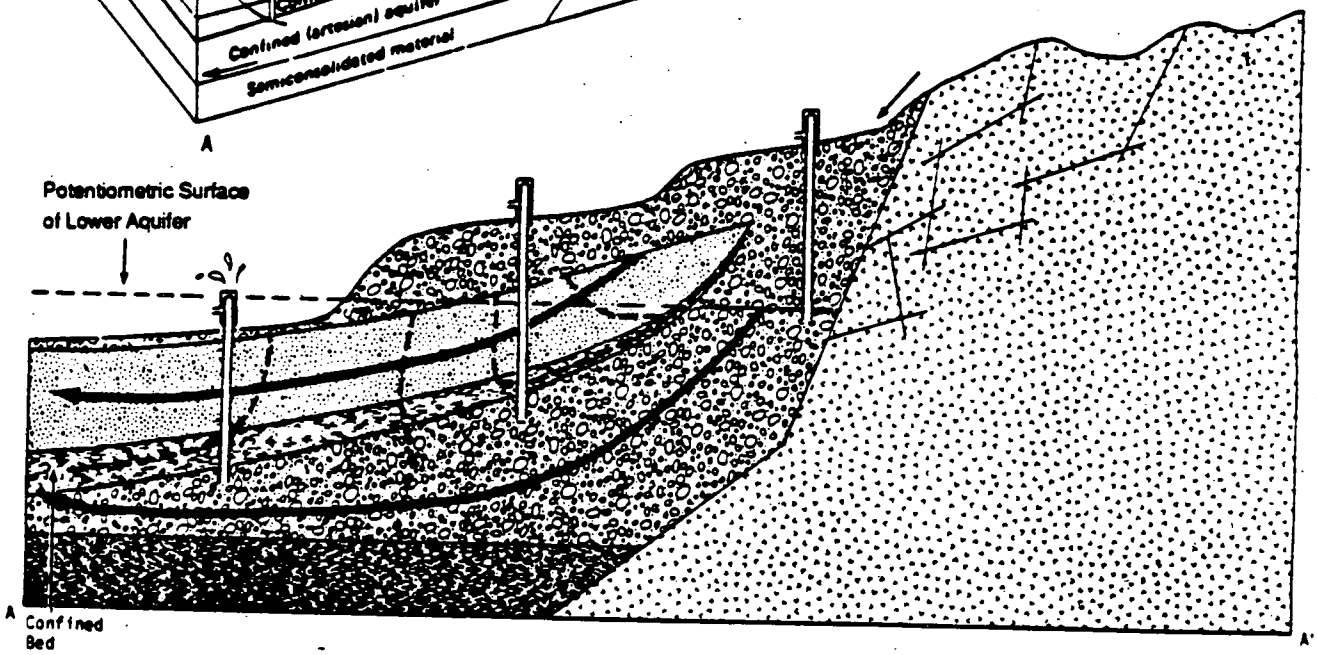
* The recharge area, discharge area, and dimensions of the flow cells within Alaska are highly variable due to the wide range in topography and geology found in this region.

WESTERN MOUNTAIN RANGES

(Mountains with thin soils over fractured rocks, alternating with narrow alluvial and, in part, glaciated valleys)







Sand
Coarse-Grained Sandstone
Clay Bed
Silty Clay
Crystalline Rocks
Joints
Flow Line
Equipotential Line

Figure 10-3. Western Mountain Ranges

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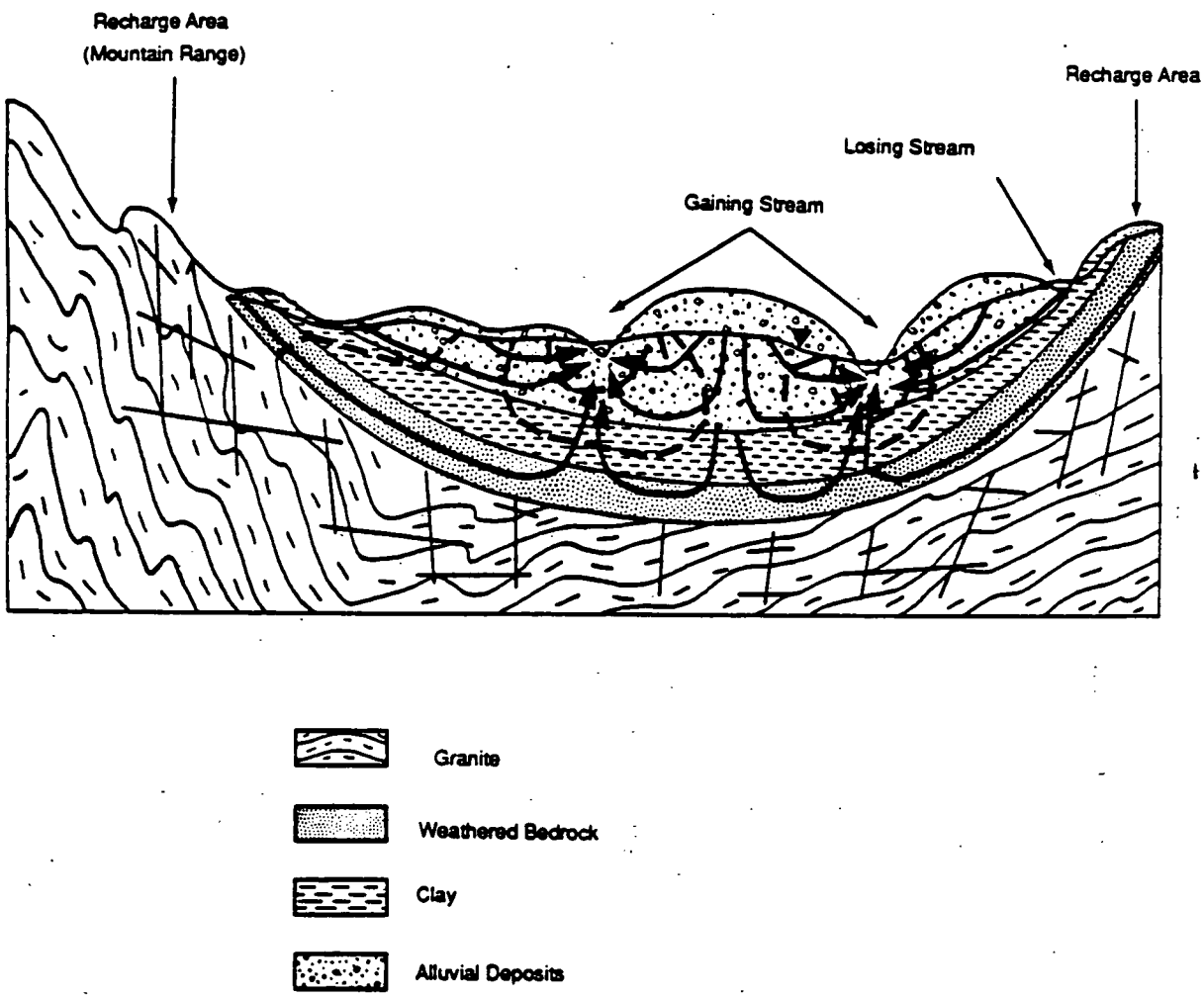
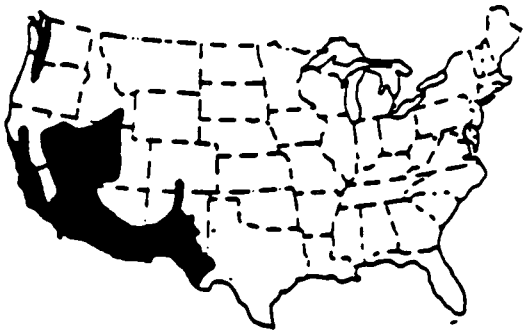
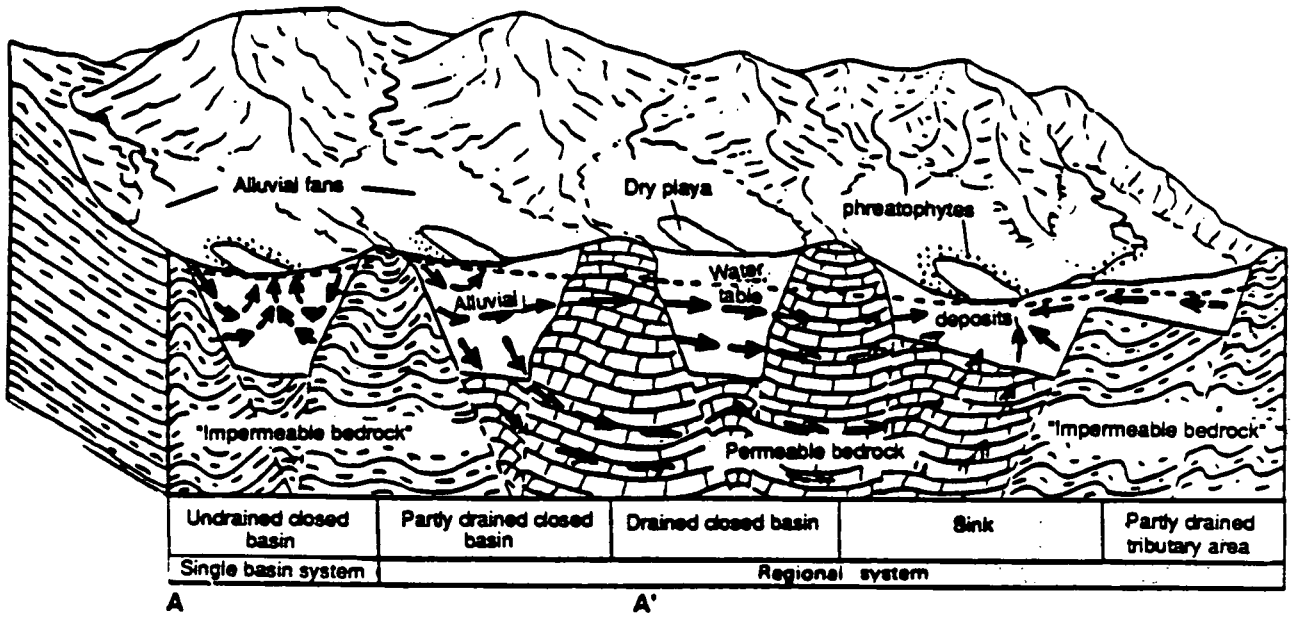


Figure 10-3. Western Mountain Ranges (continued)

ALLUVIAL BASINS

(Thick alluvial deposits in basins and valleys bordered by mountains)





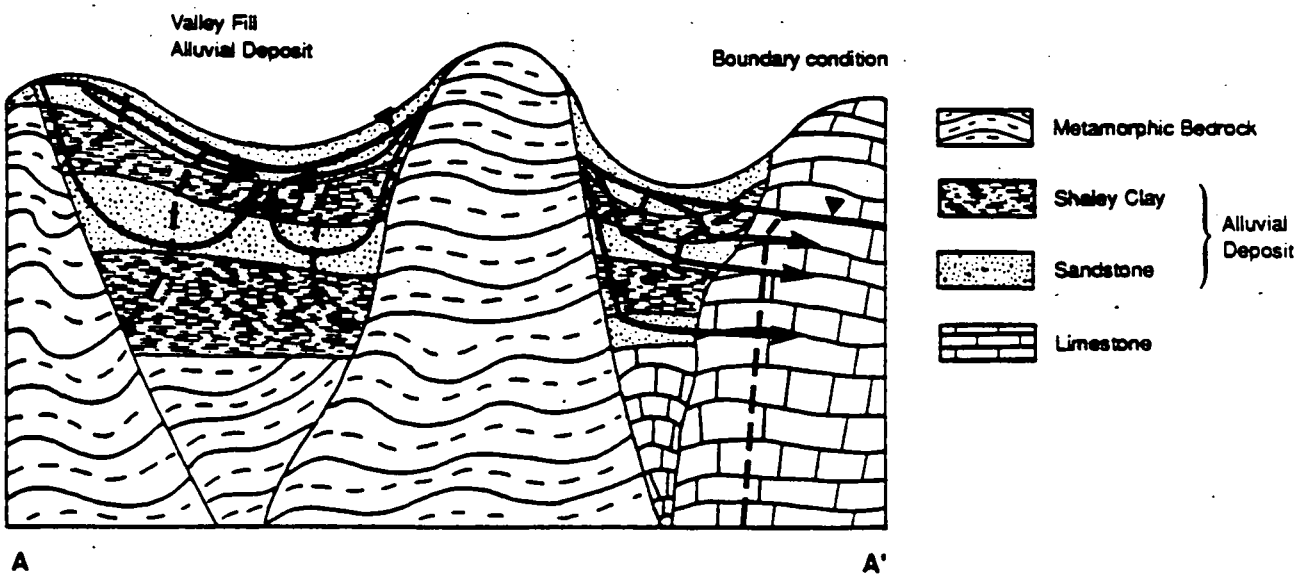


Figure 10-4. Alluvial Basins

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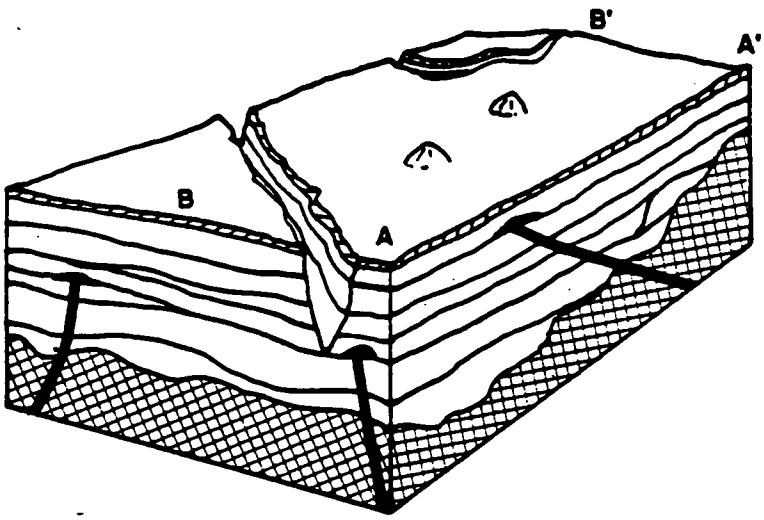
COLUMBIA LAVA PLATEAU

(Thick sequence of laval flows irregularly interbedded with thin unconsolidated deposits and overlain by thin soils)



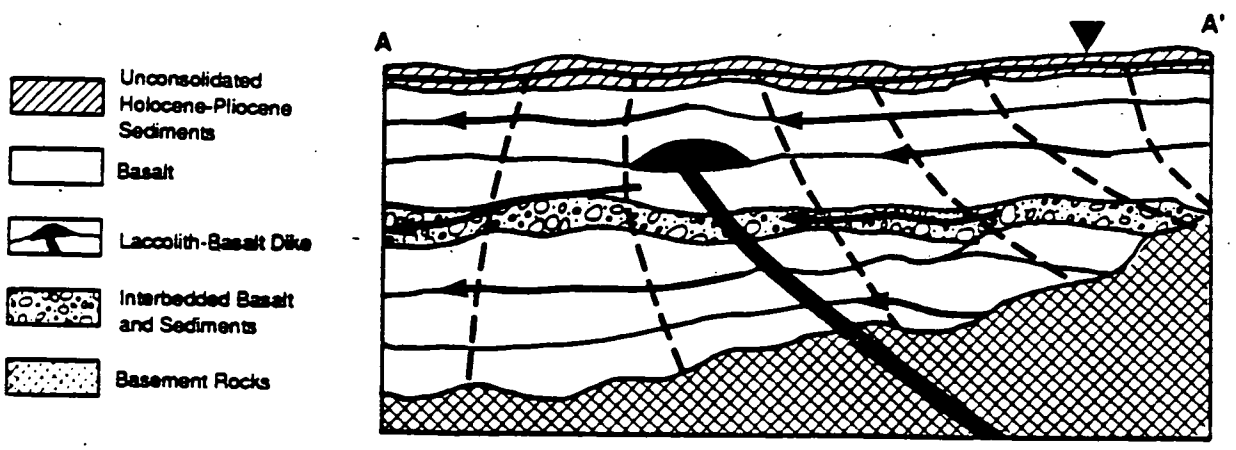
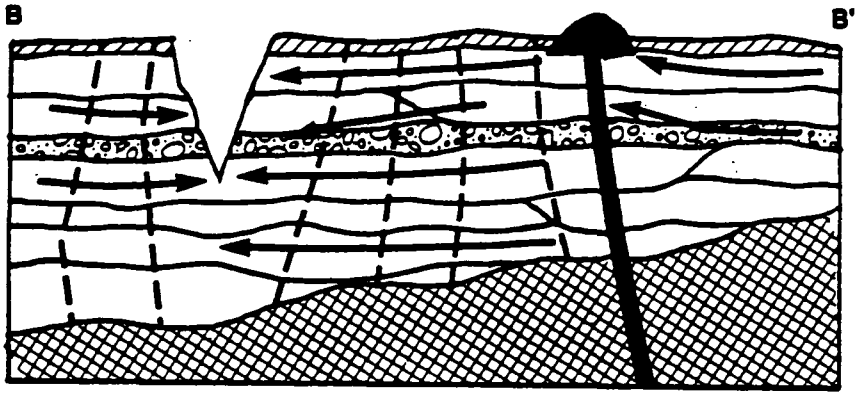
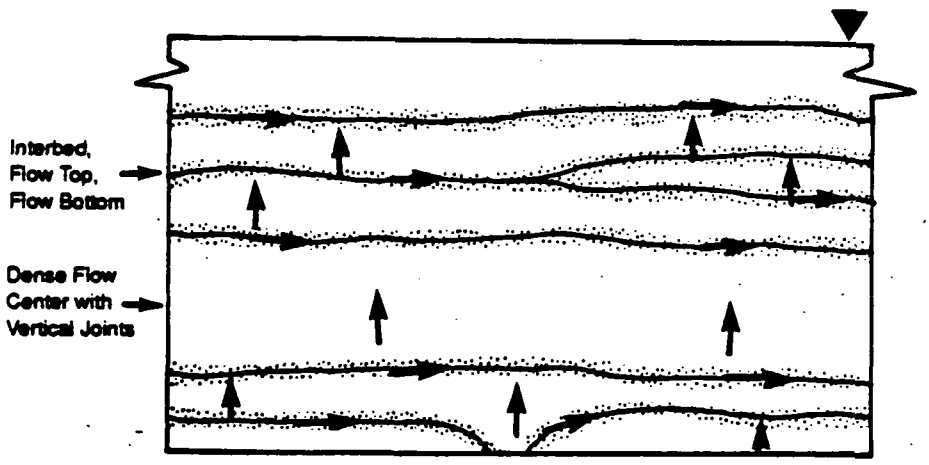


Figure 10-5. Columbia Lava Plateau



Schematic Diagram of
Ground Water Flow Regime Through a Saturated Cross Section

Note: Assume hydraulic heads increase with depth.



–High horizontal flow along flow tops

–Low vertical leakage through basalt interiors

Figure 10-5. Columbia Lava Plateau (continued)

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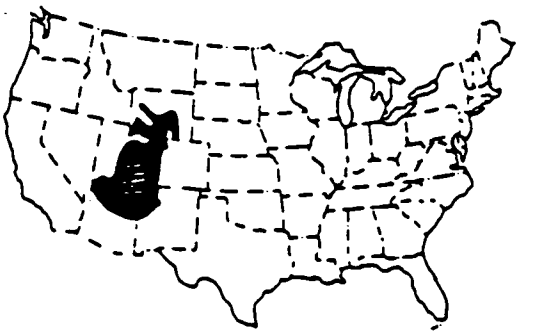
COLORADO PLATEAU AND WYOMING BASIN

(Thin soils over consolidated sedimentary rocks)



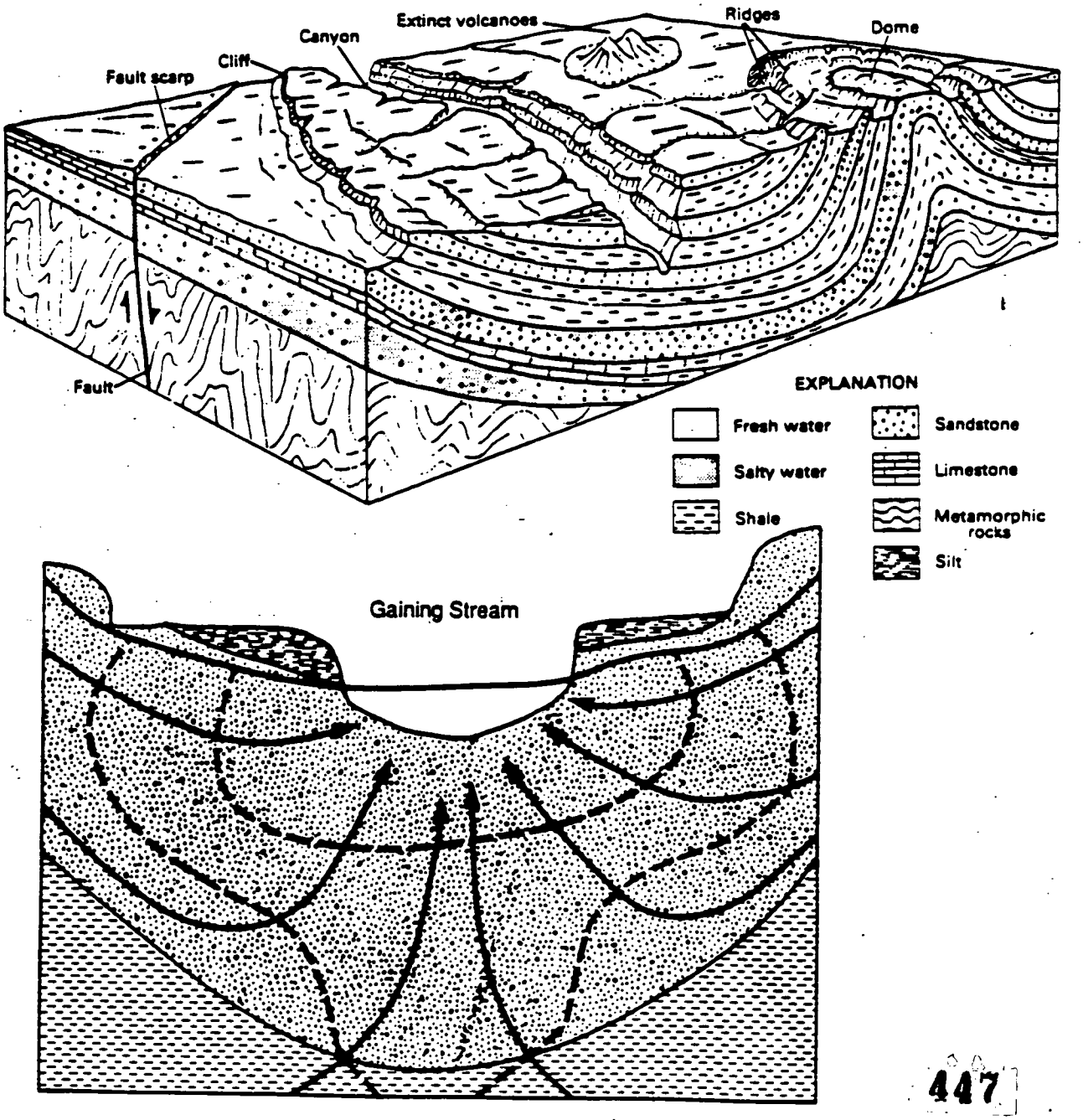
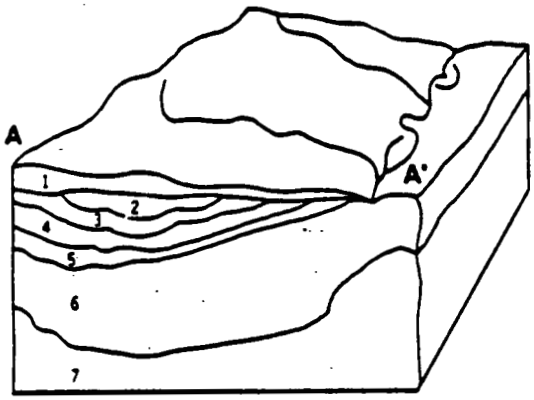


Figure 10-6. Colorado Plateau

HIGH PLAINS
(Thick Alluvial deposits over fractured sedimentary rocks)



1. Paleovalley Alluvial Aquifers
2. High Plains Aquifer System
3. Niobrara Sandstone Aquifer
4. Pierre Shale Aquitard
5. Dakota Sandstone Aquifer
6. Undifferentiated Aquifers in Cretaceous Rocks
7. Undifferentiated Aquifers in Paleozoic Rocks

Generalized local ground water regime for site within the High Plains Region.

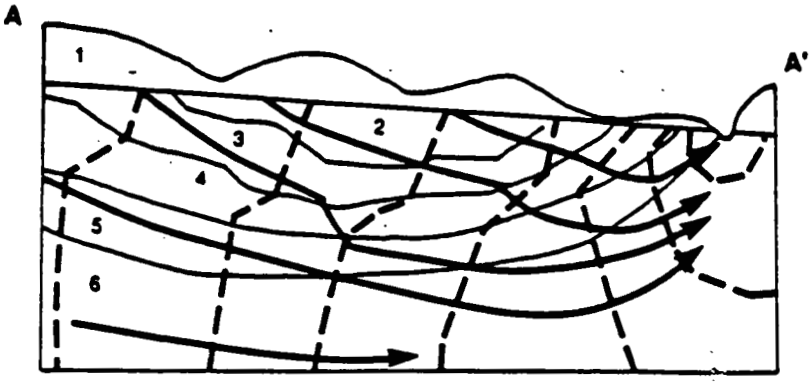


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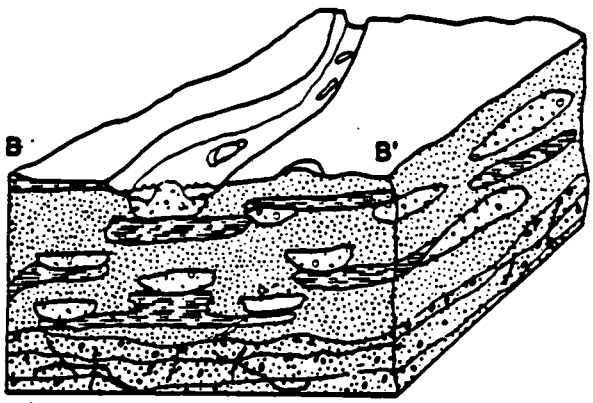
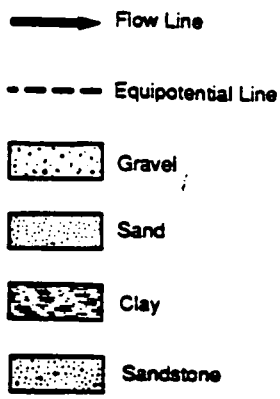
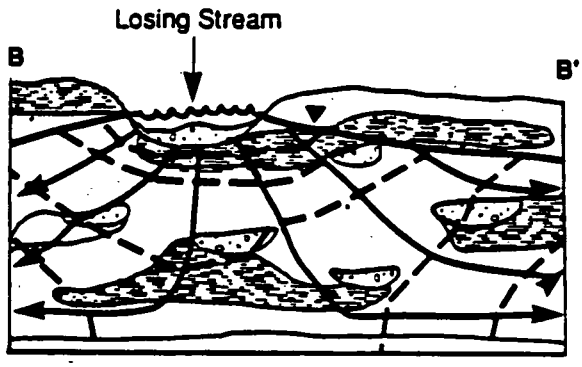
Figure 10-7. High Plains

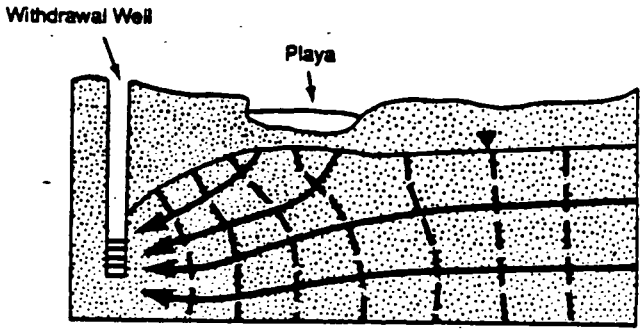
Ground water flow in
sandstone and clay lenses







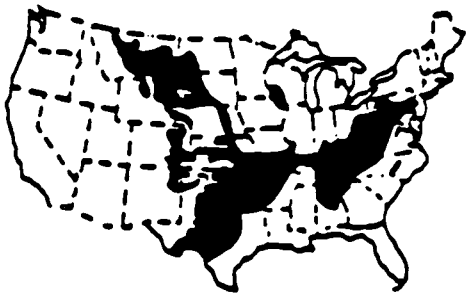
Generalized Regional Flow



Western Texas
(Recharge centered at playas)

Figure 10-7. High Plains (continued)

NONGLACIATED CENTRAL REGION
(Thin regolith over fractured sedimentary rocks)



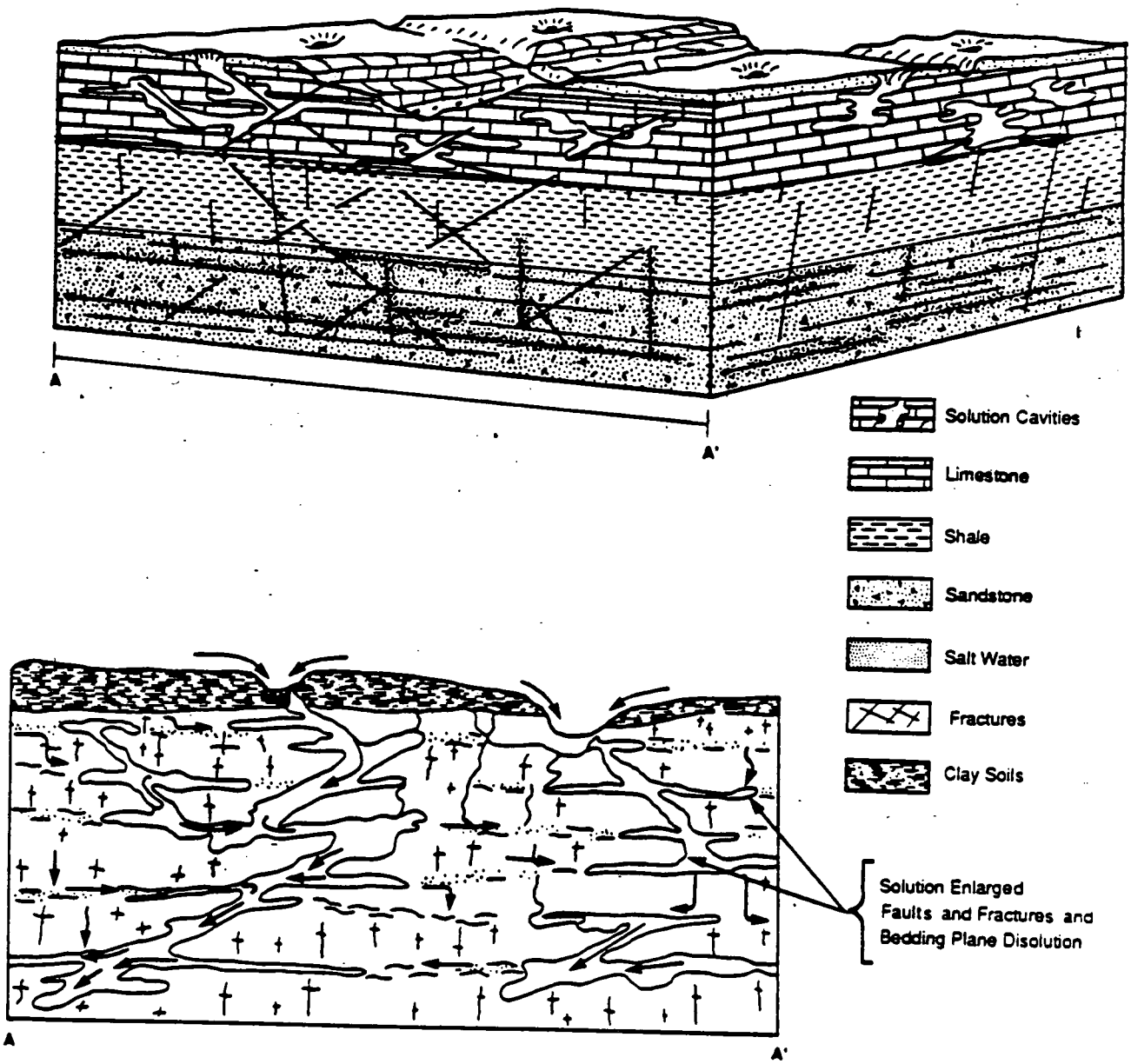


Figure 10-8. Non-glaciated Central

450

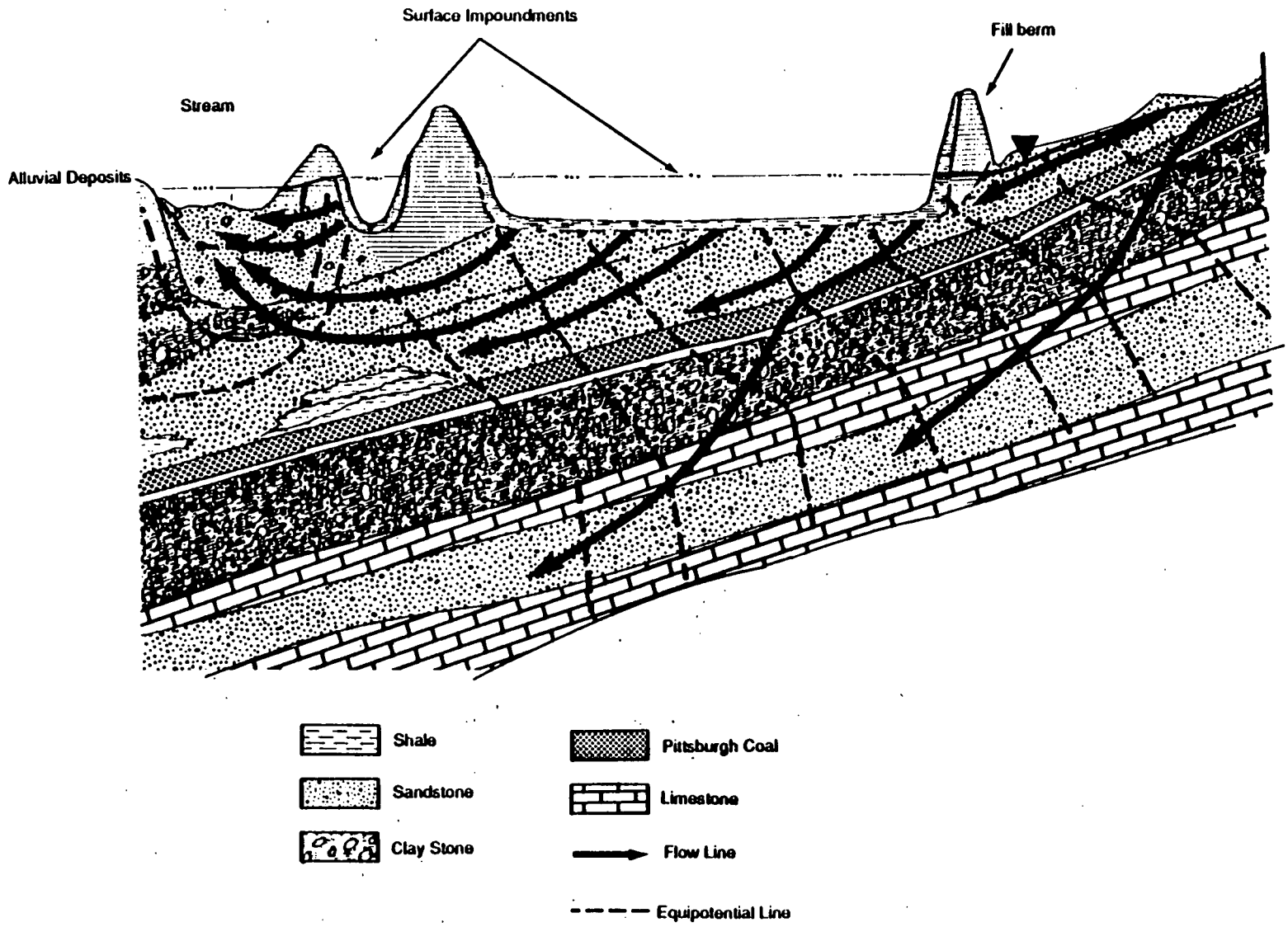
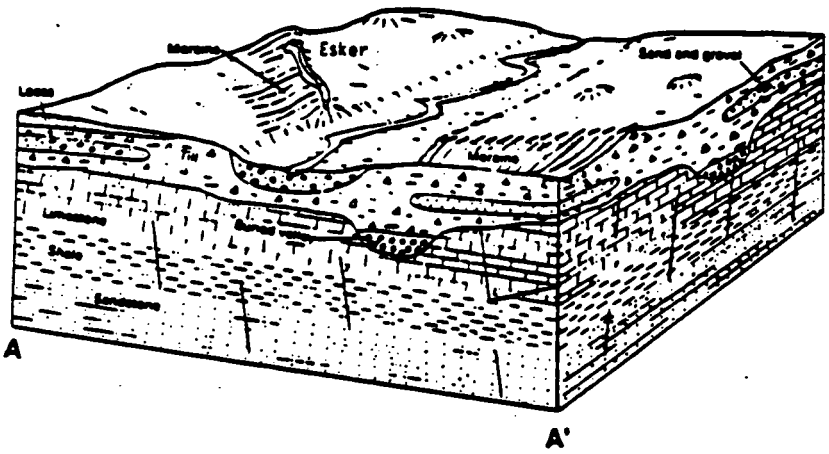
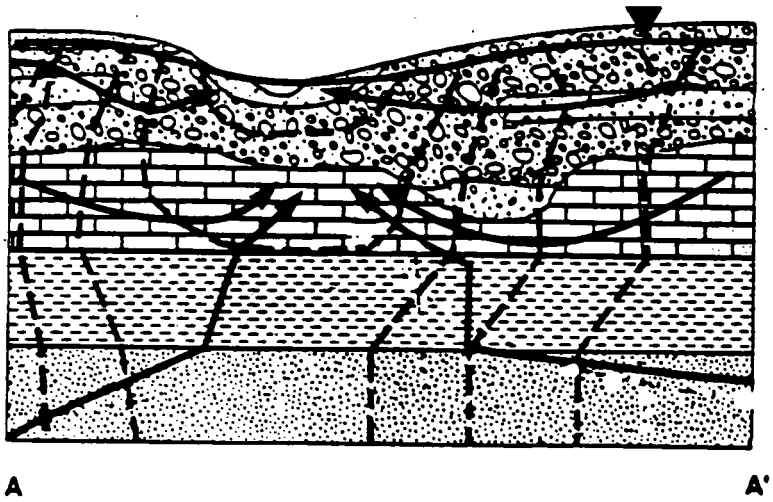


Figure 10-8. Example of a surface impoundment site in Non-Glaciated Central Region (continued)

GLACIATED CENTRAL REGION
(Glacial deposits over fractured sedimentary rocks)





Shale

Sand

Till

Outwashed Deposits and Preglacial Alluvium

Limestone

Sandstone

Flow Line

Equipotential Line

Figure 10-9. Glaciated Central

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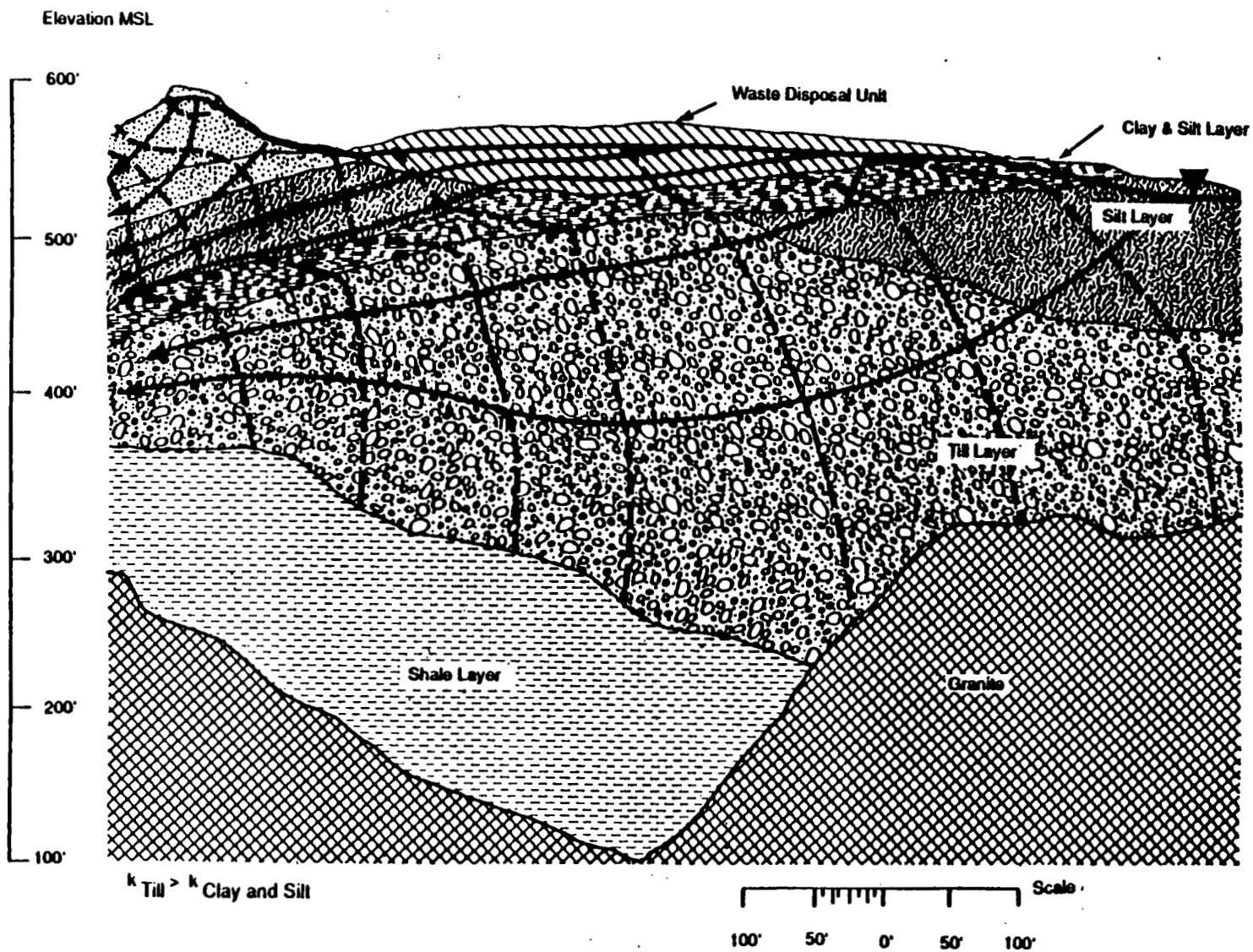


Figure 10-9. Glaciated Central (continued)

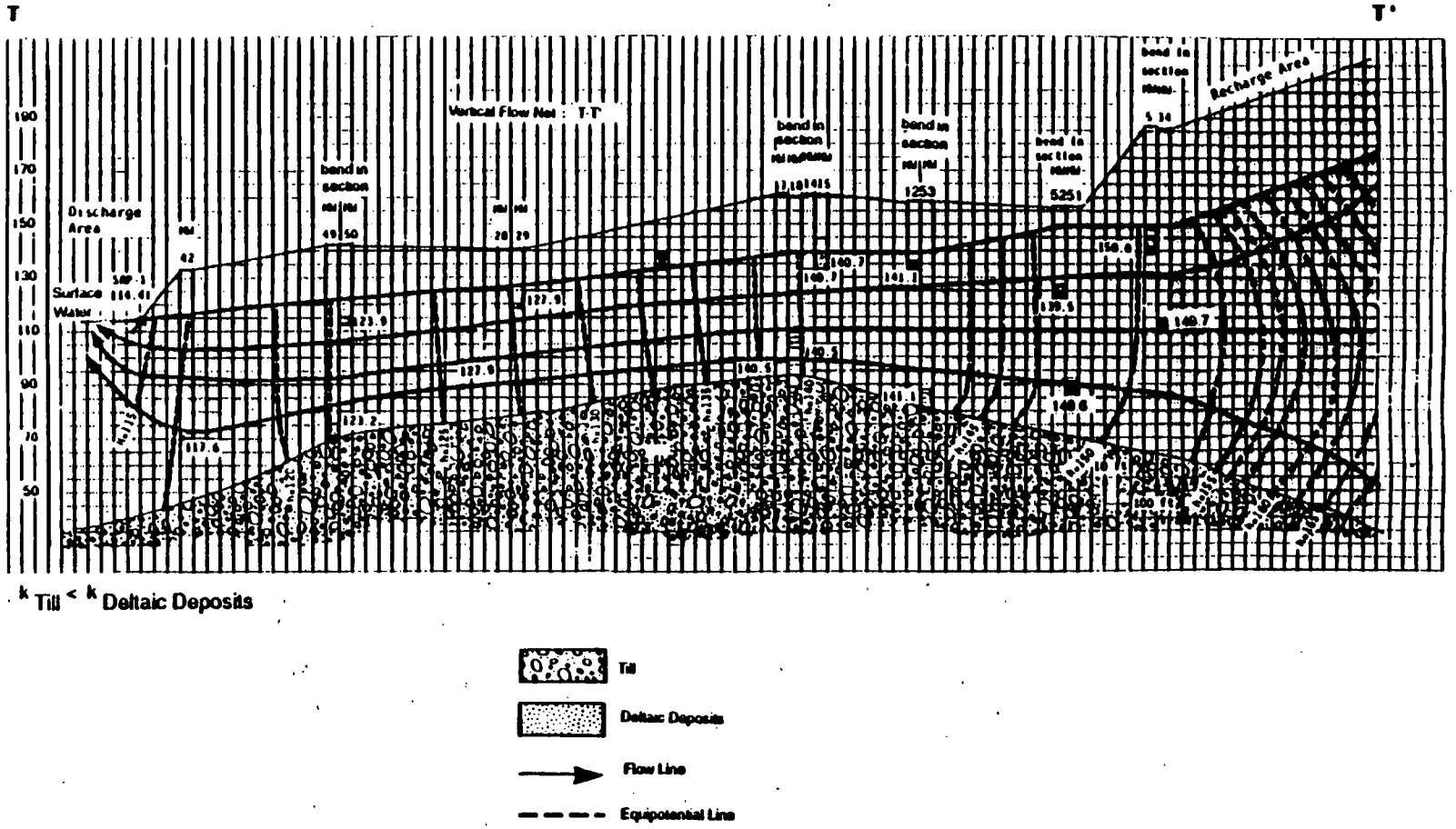
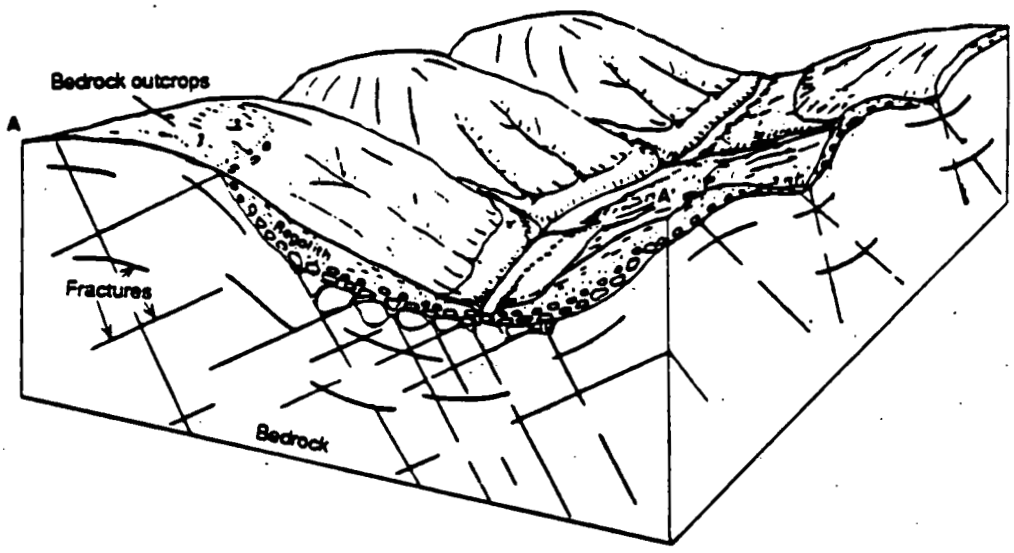
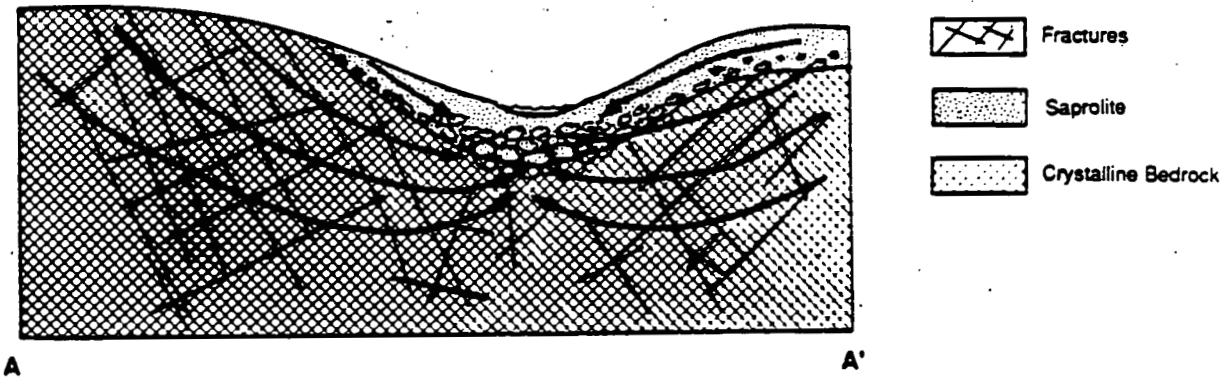


Figure 10-9. Glaciated Central (continued)

PIEDMONT BLUE RIDGE REGION
(Thick regolith over fractured crystalline and metamorphosed sedimentary rocks)

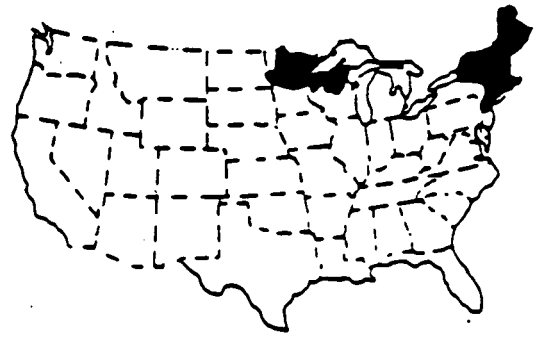


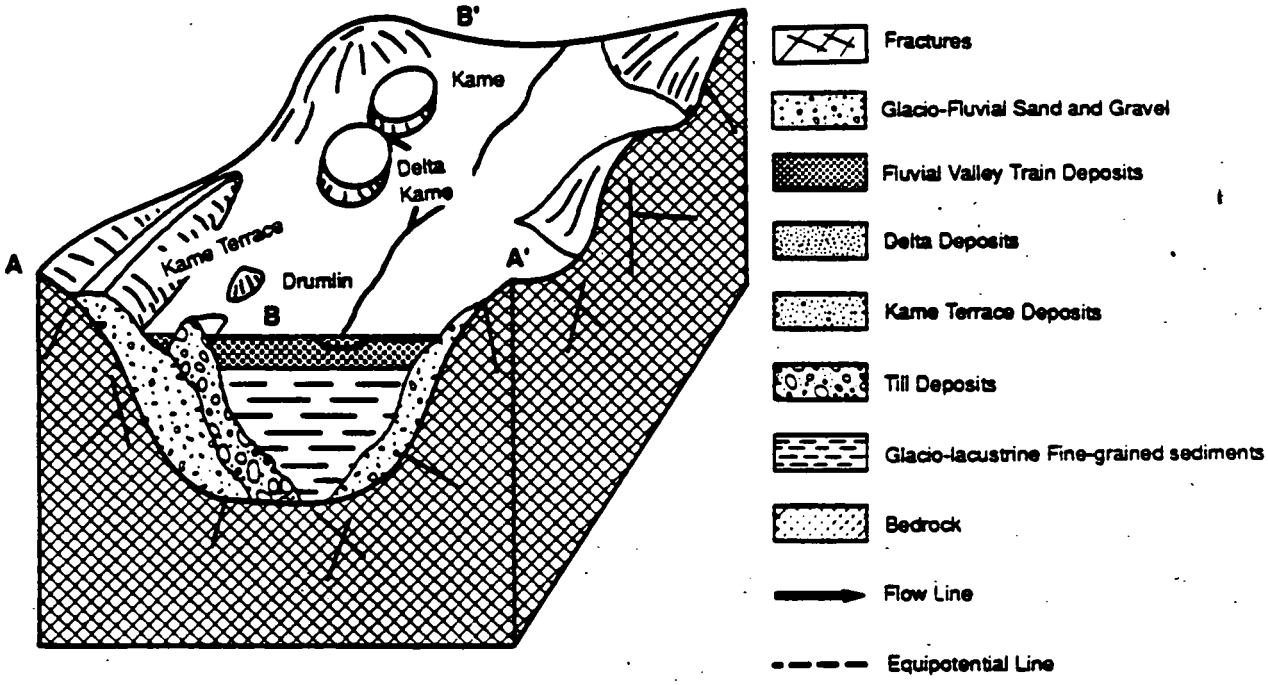


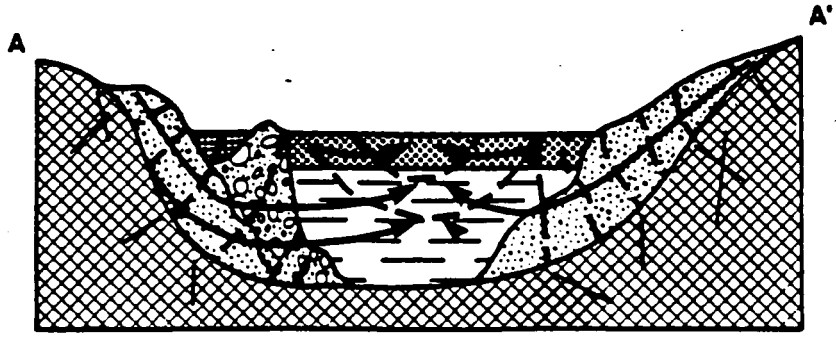
Note: In areas of fractured bedrock, flow through fractures is often greater than flow through the bedrock matrix. Flow through these fractures may not conform to Darcy's Law. The above flow lines represent generalized flow paths rather than quantitative flow lines used in a flow net.

Figure 10-10. Piedmont and Blue Ridge

NORTHEAST AND SUPERIOR UPLANDS
(Glacial Deposits Over Fractured
Crystalline rocks)







Note: Flow component along axis of valley, although not shown in this cross-section can often be important.

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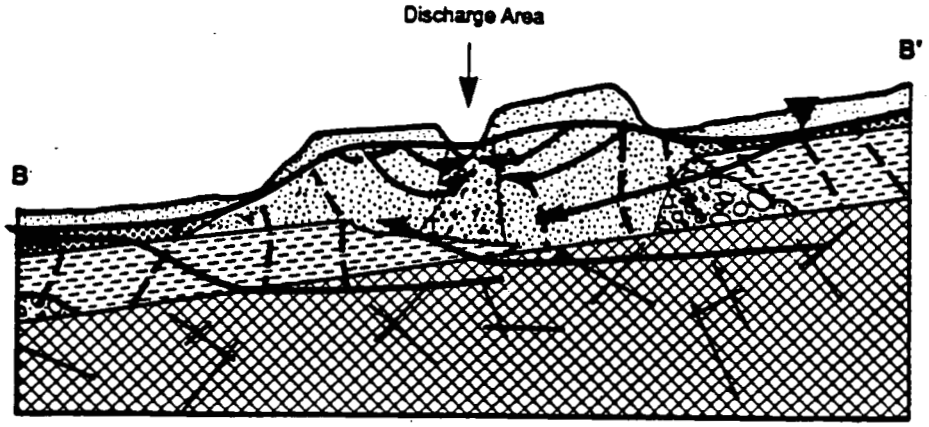
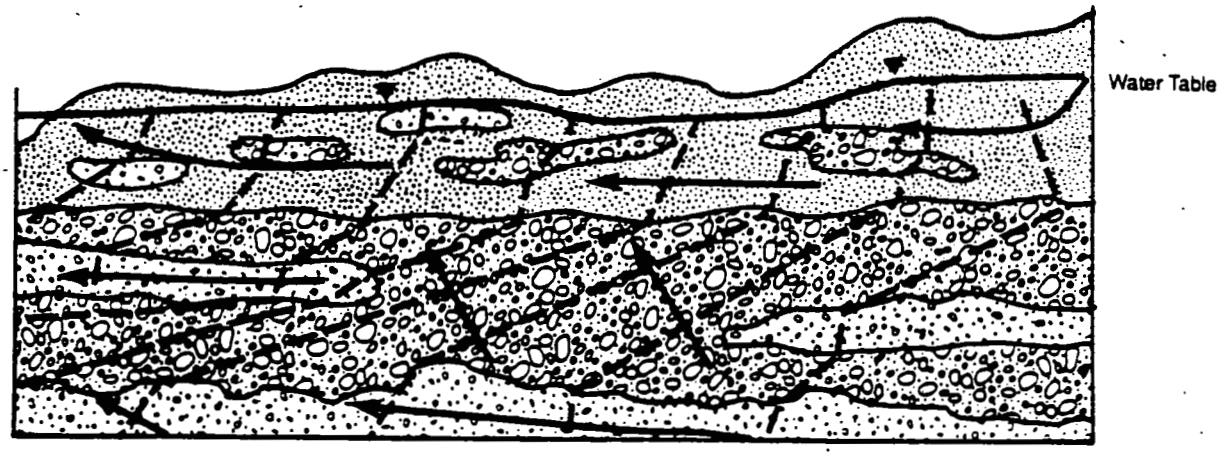
Figure 10-11. Northeast and Superior Uplands

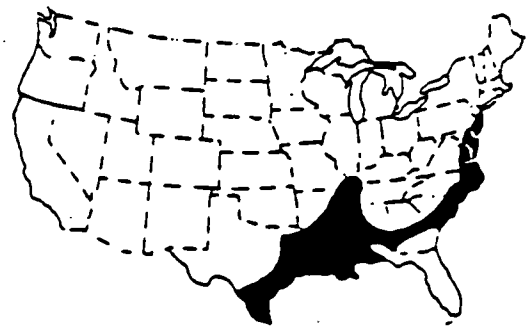


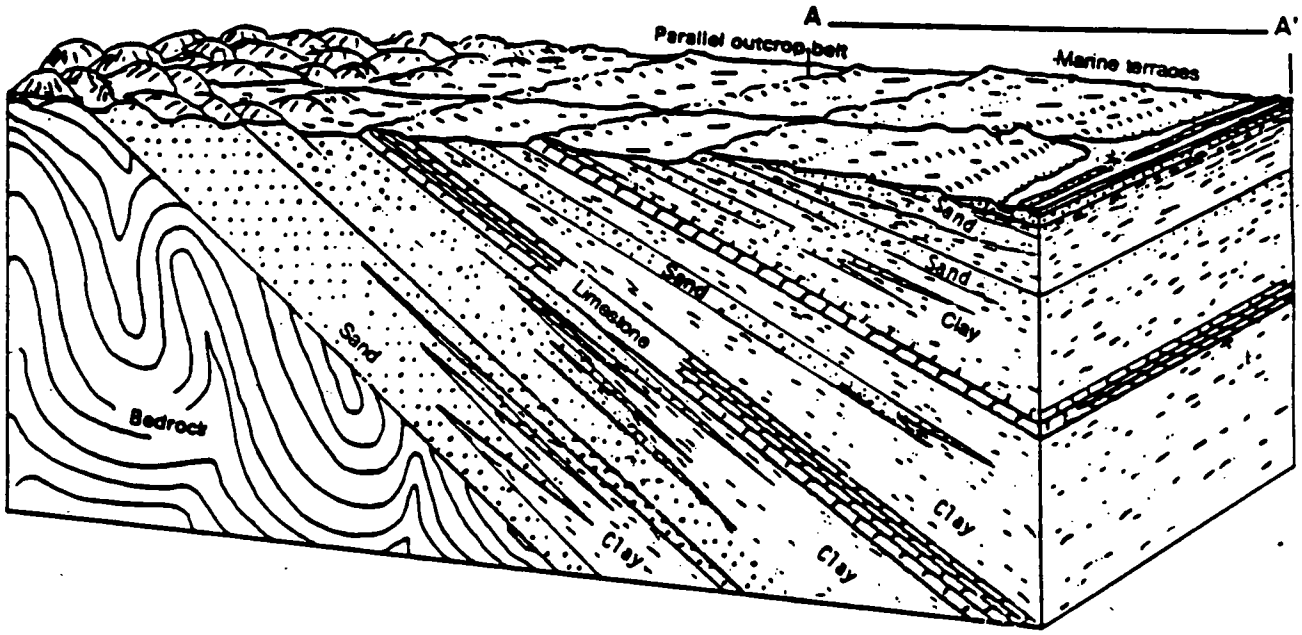


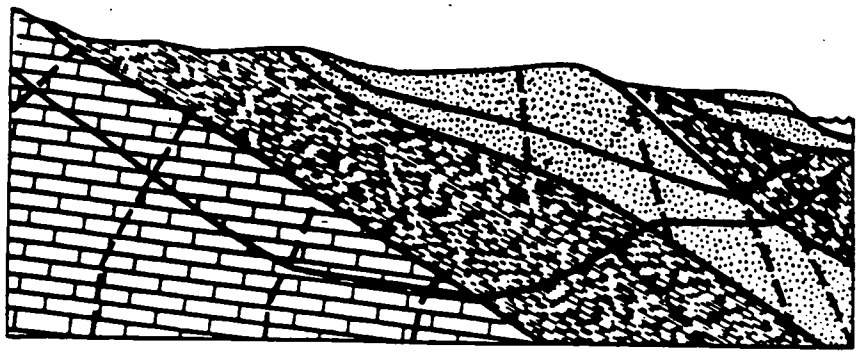
Generalized local ground water regime within the Northeast and Superior Uplands Region showing a confining layer of till.

Figure 10-11. Northeast and Superior Uplands (continued)

ATLANTIC AND GULF COASTAL PLAIN
(Complexly interbedded sand, silt, and clay)







Clay
Sand
Limestone

Figure 10-12. Atlantic and Gulf Coastal Plain

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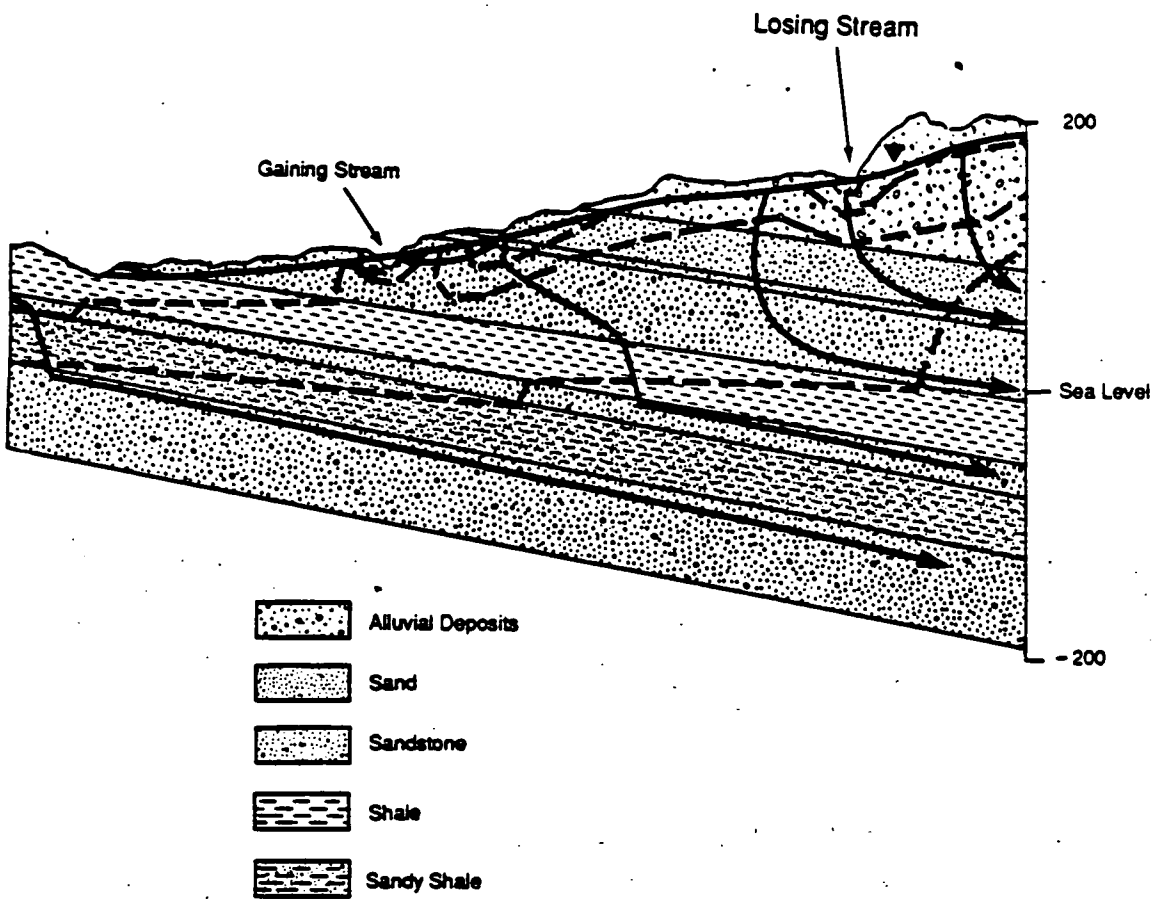


Note: Regional flow based on high recharge in hills which are not shown in this diagram.

Figure 10-12. Atlantic and Gulf Coastal Plain (continued)

Landfill site near the Savannah River in Georgia.

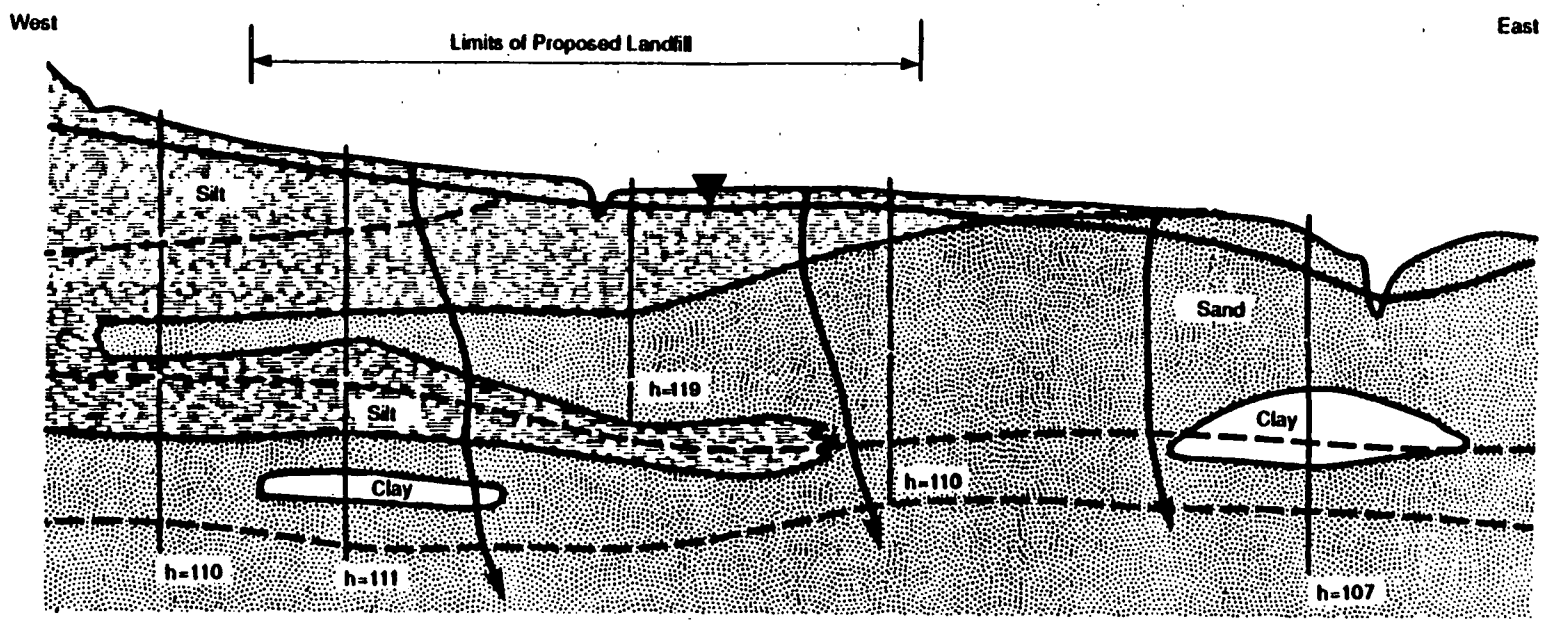
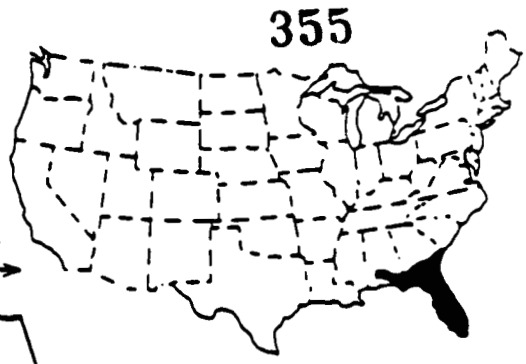
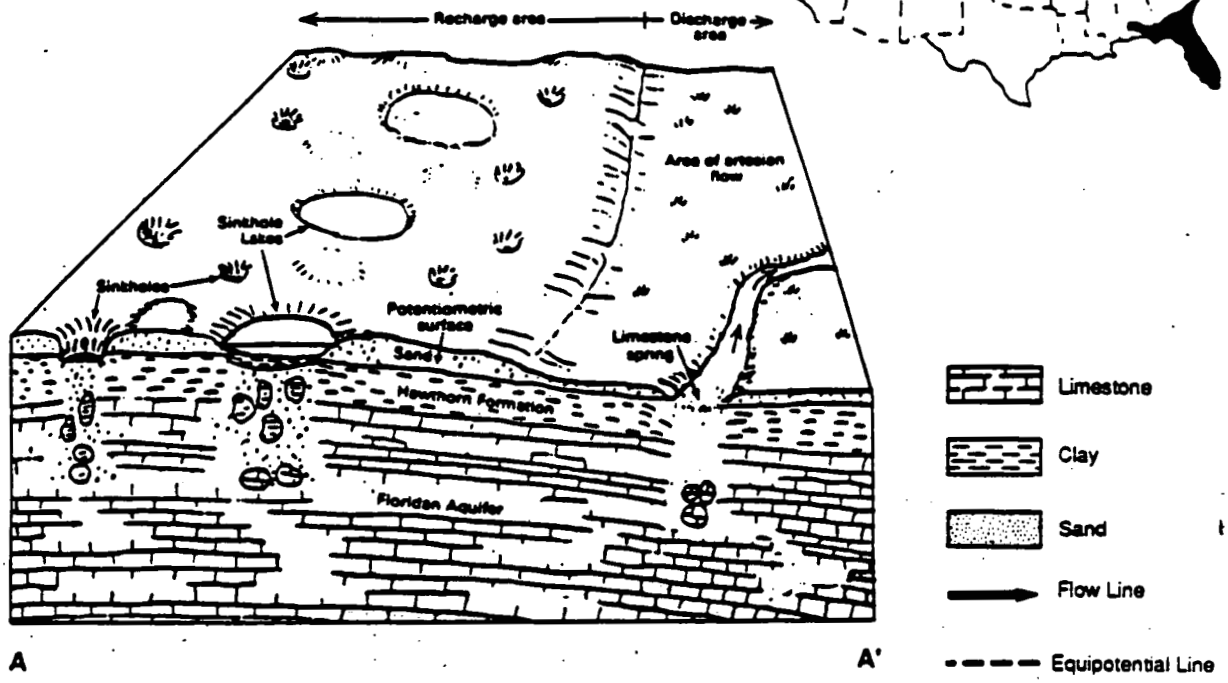


Figure 10-12. Atlantic and Gulf Coastal Plain (continued)

SOUTHEAST COASTAL PLAIN
(Thick layers of sand and clay over semiconsolidated carbonate rocks)





Solution Limestone

Cross-section with highly generalized flow path lines and equipotential lines. Actual condition in Karst terrain may not be definable due to fractures and solution channel flow.

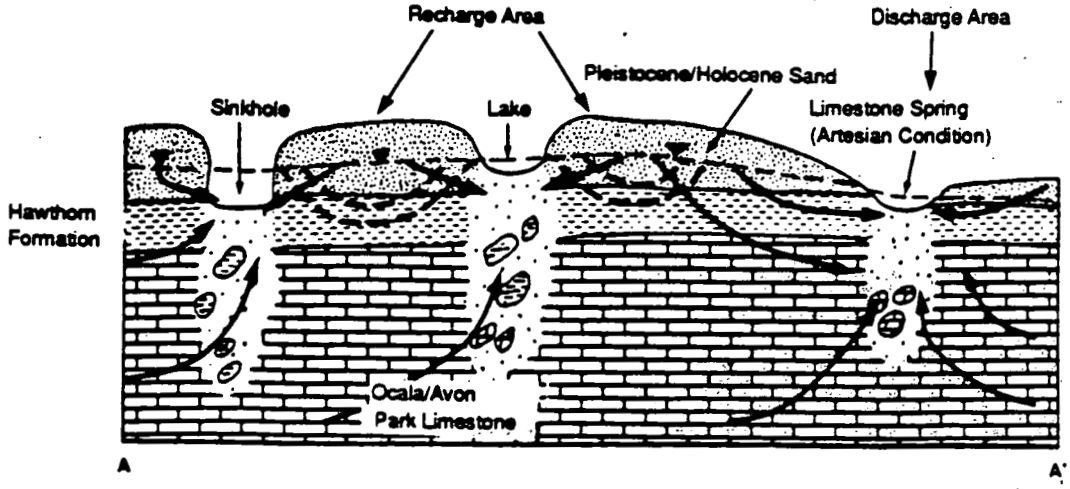
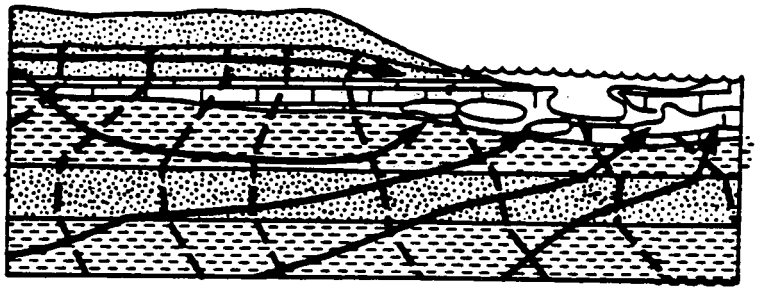
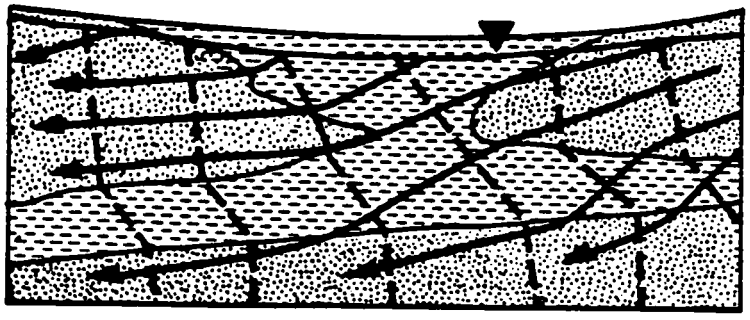


Figure 10-13. Southeast Coastal Plain

Swamp



Beaches and Bars



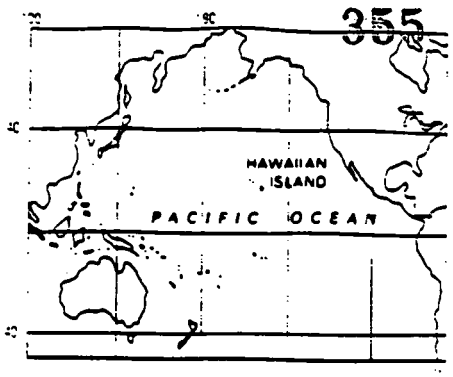
–Highly permeable due to water-washed sands.

–Sand deposits serve as a source of recharge to the underlying unconsolidated coastal deposits.

Figure 10-13. Southeast Coastal Plain (continued)

HAWAIIAN ISLANDS

(Lava flows segmented in part by dikes, interbedded with ash deposits, and partly overlain by alluvium)



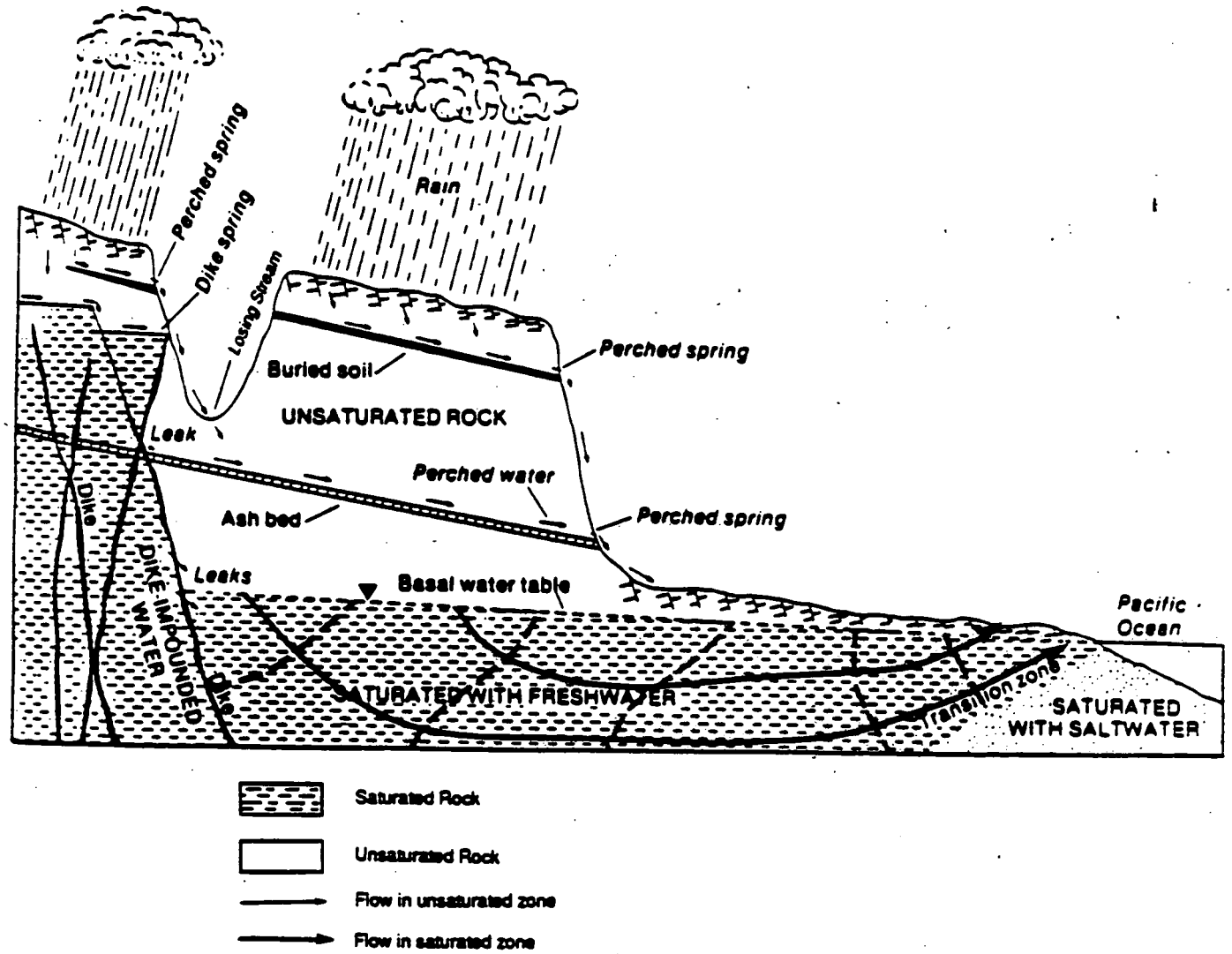
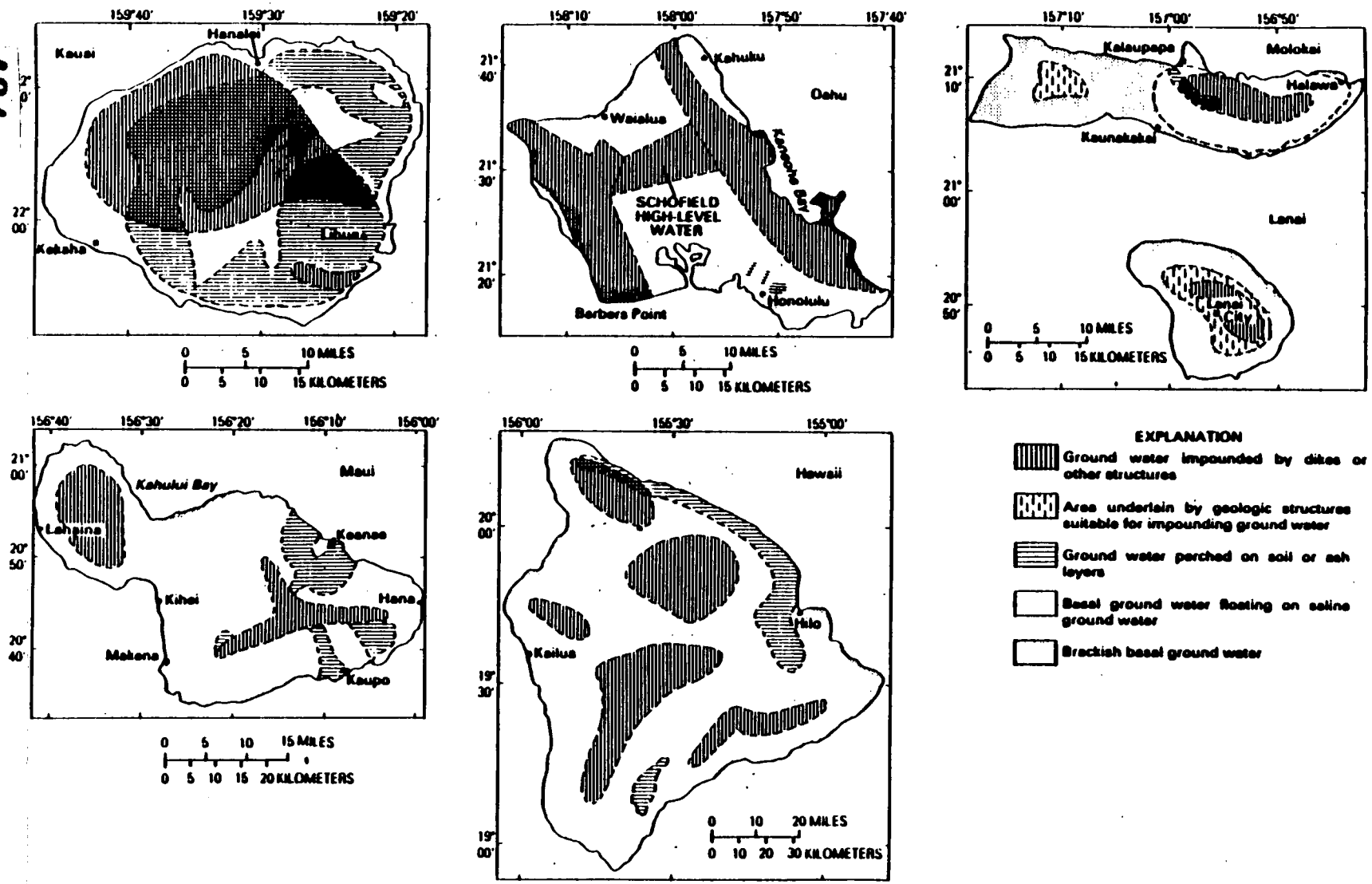


Figure 10-14. Hawaiian Islands



Approximate outline of the different ground-water areas on the principal Hawaiian islands. (From Takasaki, 1977)

Figure 10-14. Hawaiian Islands (Continued)

ALASKA

(Glacial and Alluvial Deposits, Occupied in Part by Permafrost, and Overlying Crystalline, Metamorphic, and Sedimentary Rocks)

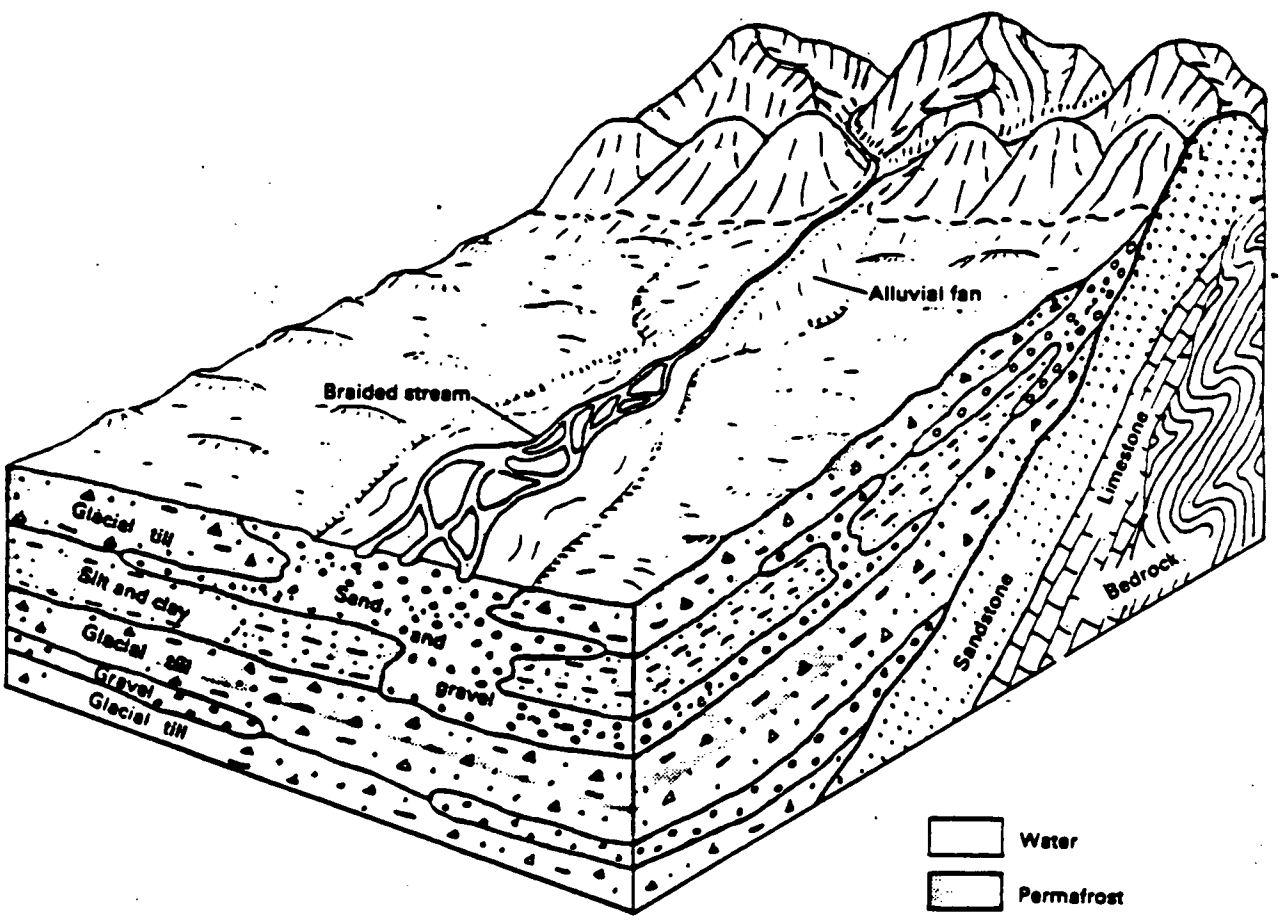
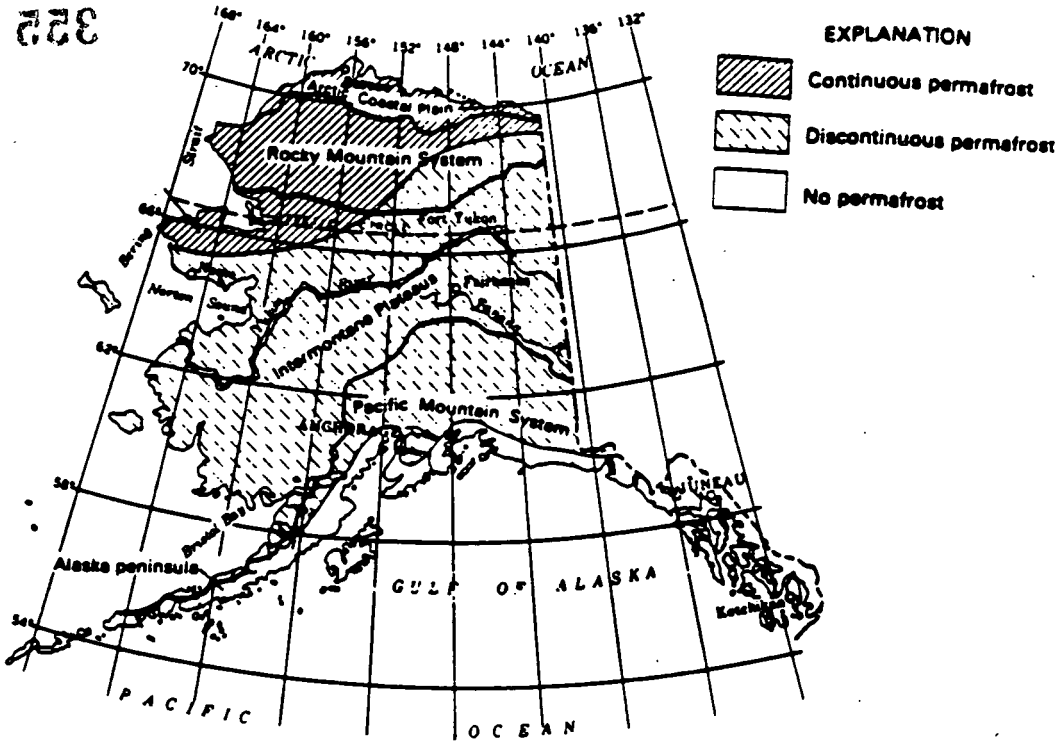


Figure 10-15. Alaska



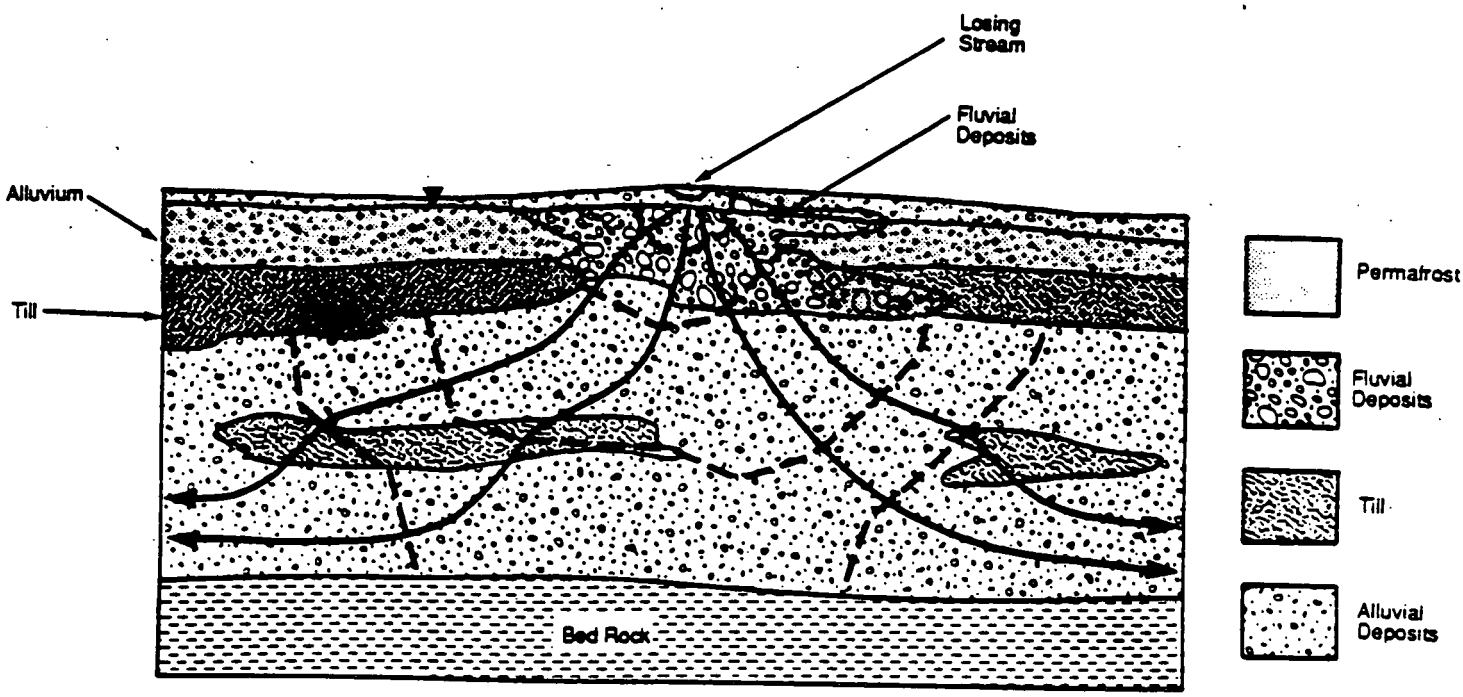
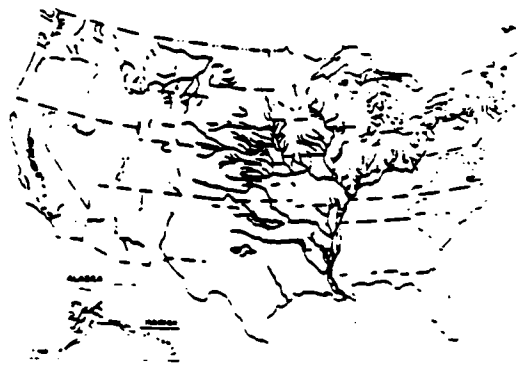


Figure 10-15. Alaska (Continued)

ALLUVIAL VALLEYS

(Thick sand and gravel deposits beneath floodplains and terraces of streams)



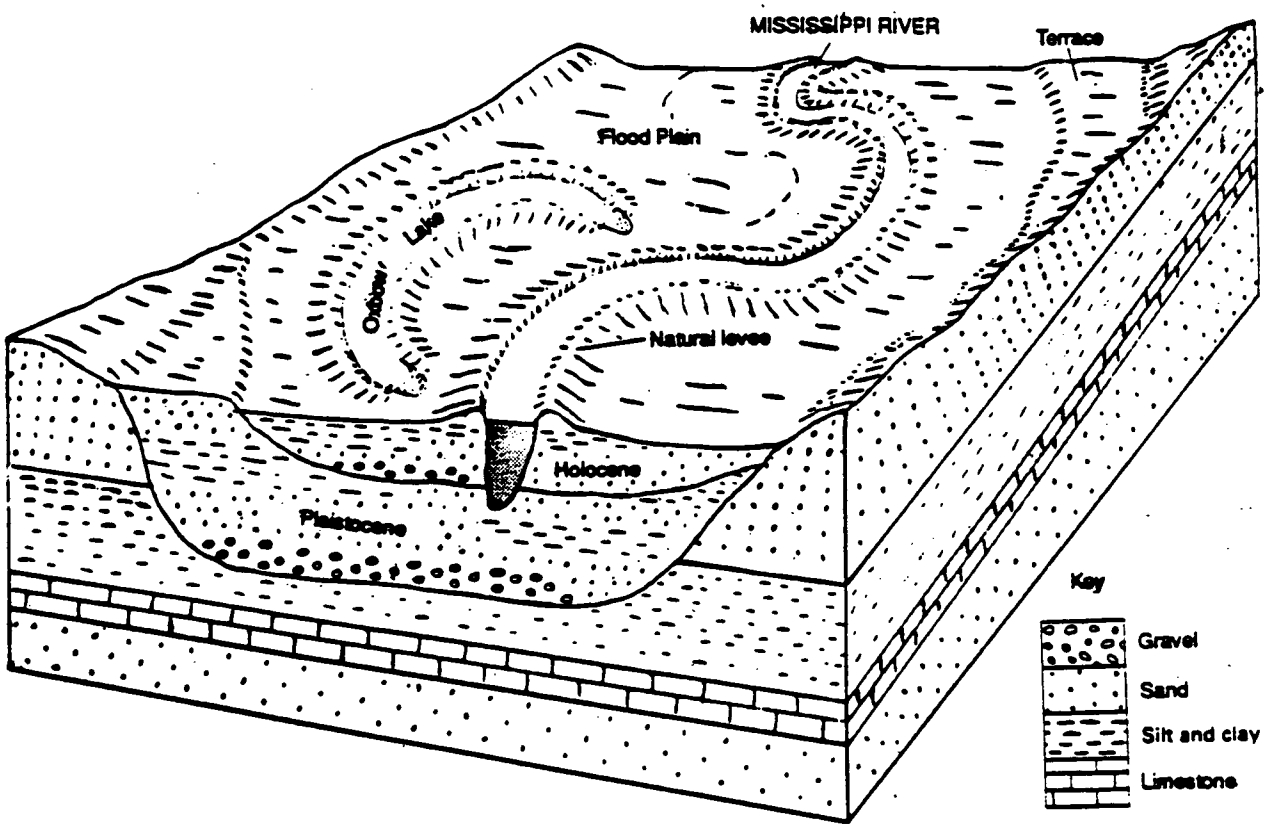


Figure 10-16. Alluvial Valleys

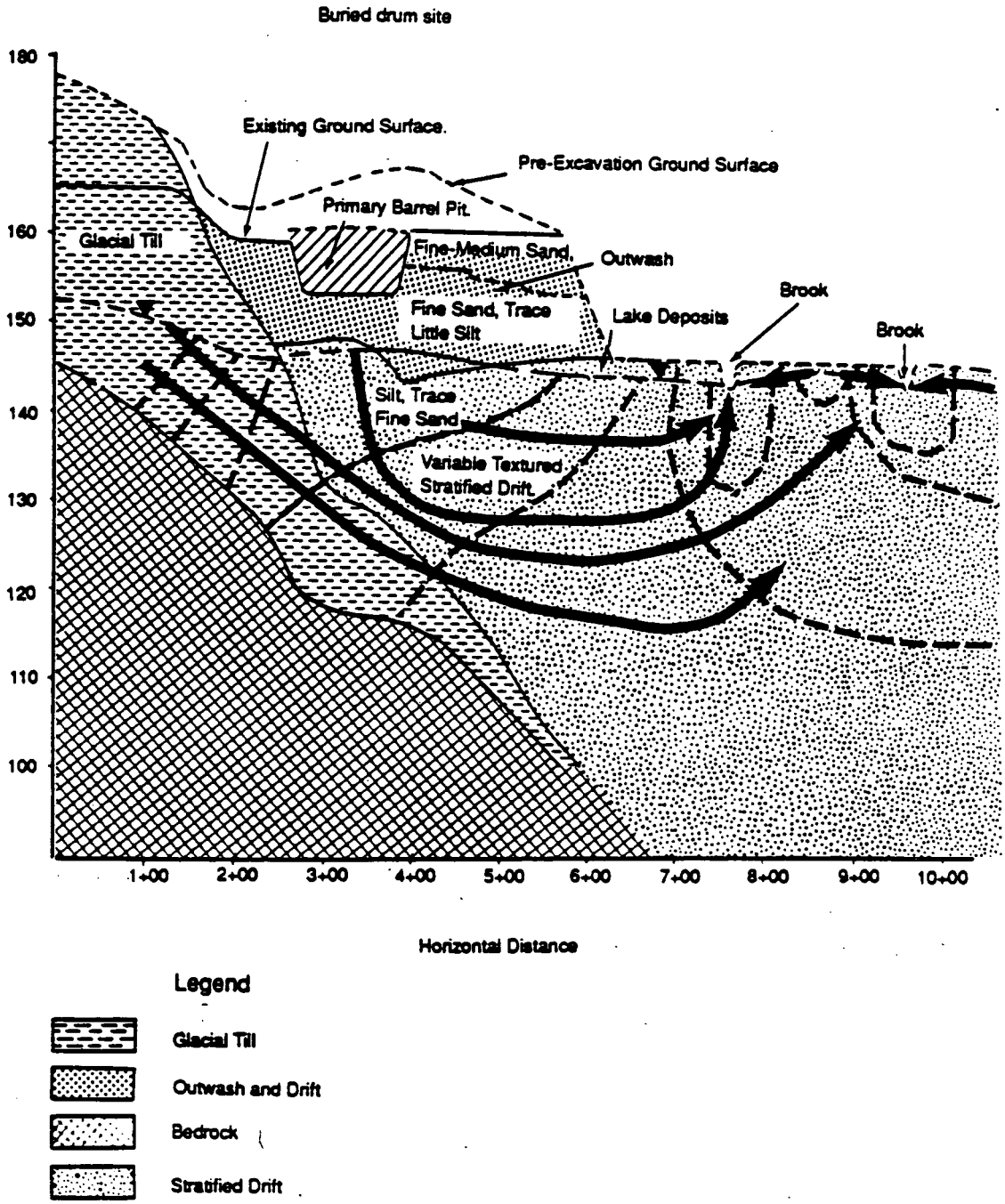


Figure 10-16. Alluvial Valleys (continued)

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Paper No. 2242). Following are descriptions of each of the major ground-water regions illustrated in the Figures (Figures 10-3 through 10-16).

Ground-water flow in the Western Mountain Ranges region is influenced by melting snow and rainfall at higher altitudes. The thin soils and fractures present in the underlying bedrock have a limited storage capacity and are filled quickly with recharging ground water flowing from higher elevations (see Figure 10-3). The remaining surface water runs overland to streams that eventually may recharge other areas. Streams that recharge ground water are referred to as "losing streams." Figure 10-3 also shows local ground-water flow paths influenced by low permeability bedrock located in intermountain valleys throughout the mountain ranges.

The Alluvial Basins region consists of deep, unconsolidated sediments adjacent to mountain ranges. Precipitation often runs rapidly off the mountains and infiltrates into the alluvium at the valley margins. The water moves through the sand and gravel layers toward the centers of the basins (Figure 10-4). The presence of disjointed masses of bedrock in this region is crucial to the hydrogeological regime. Low permeability igneous bedrock often isolates the ground-water regime into individual basins with minimal exchange of ground water. Where the bedrock is composed of limestone or other highly permeable formations, large regional flow systems can develop, encompassing many basins. Recharge areas in this region are located in upland areas; lowland stream beds only carry water when sufficient runoff from the adjoining mountains occurs.

Basaltic bedrock is the major source of ground water within the Columbia Lava Plateau region. Volcanic bedrock yields water mainly from zones at the contacts of separate basalt flows. The permeability and hydraulic conductivity are much higher in these zones at the edges of the flows than in the center of the flows (see Figure 10-5.) This is caused partially by the rapid cooling and consequent fracturing of the top of each basalt flow.

The Colorado Plateau and Wyoming Basin region is a large plateau consisting principally of sandstones, shales, and limestones. These sedimentary rocks are generally horizontal but have been modified by basins and domes in some areas (see Figure 10-6). Sandstones have significant primary porosity and are the major

water-bearing units in this region. Recharge occurs where the sandstones are exposed. Intermittent losing streams created by sudden summer storms provide some recharge, but most recharge is caused by snowmelt.

Generally, ground water is unconfined in the recharge areas and confined in the lower reaches of the aquifers. The storage coefficients and transmissivities in the confined portions of the aquifers are small, causing extensive drawdown during even minor pumping. Saline ground water is characteristic of this region and is caused by the existence of gypsum and halide in the sedimentary deposits.

The High Plains region is underlain by thick alluvial deposits that comprise a productive and extensively developed aquifer system. The source of recharge to the aquifer system is precipitation, except in Western Texas where recharge is centered at playas (see Figure 10-7). In many areas, well discharges far exceed recharge, and water levels are declining. The dominant features influencing ground-water flow in this region include the Ogalalla Aquifer, the Pierre Shale, and the complex interbedding of sand and clay lenses. Figure 10-7 provides generalized flow nets, showing flow patterns through these features.

Thin regolith over fractured sedimentary rocks typifies the nature of the geology in the Nonglaciated Central region (see Figure 10-8). This region extends from the Rocky Mountains to the Appalachian Mountains. Water is transmitted primarily along fractures developed at bedding planes. Interconnected vertical fractures also can store a large portion of the ground water. An example of ground-water flow on a local scale is shown for karst terrain, where ground water moves rapidly through solution cavities and fractures in limestone and where the flow pathways are closely associated with the configuration of fractures. Ground-water flow in the karst regime does not usually follow Darcy's law because most of the flow goes through large channels rather than the pores in the rock. Thus, construction of a flow net may not be appropriate in some cases. An additional example of localized flow in this region is provided, showing a surface impoundment site in Pennsylvania. Notice that ground water discharges to surface water, a phenomenon typical of this region.

The topography of the Glaciated Central region is characterized by rolling hills and mountains in the eastern portion of the region and by flat to gently rolling

terrain in the western portion of the region. Glacial deposits vary in thickness within the region and are underlain by bedrock. Ground water occurs in the glacial deposits in pores between the grains and in the bedrock primarily along fractures. Permeability of glacial deposits ranges from extremely transmissive in gravels to low transmissivity in poorly sorted tills. The presence of buried valleys, till, deltas, kames, and other glacial artifacts highly influences the transmission of ground water within the region. Two examples of localized flow are presented in Figure 10-9. The first example shows a flow regime in an area where till has the highest hydraulic conductivity relative to the other formations. In the second example, the till bed has a much lower hydraulic conductivity than the deltaic outwash deposited above it.

Thick regolith overlies fractured crystalline and metamorphic bedrock in most of the Piedmont and Blue Ridge region. The hydraulic conductivities of regolith and fractured bedrock are similar. However, bedrock wells generally have much larger ground-water yields than regolith wells because, being deeper, they have a much larger available drawdown. Fracture-controlled movement of ground water through bedrock is illustrated by generalized flow paths rather than quantitative flow lines used in a flow net in Figure 10-10, as is ground-water movement through saprolite (weathered bedrock) and river alluvium.

The Northeast and Superior Uplands region is characterized by folded and faulted igneous and metamorphic bedrock overlain by glacial deposits. The primary difference in the ground-water environment between this region and the Piedmont and Blue Ridge region is the presence of glacial material rather than regolith. The different types of glacial material have vastly different storage capacities and hydraulic conductivities. Examples of ground-water flow through till, delta, and kame deposits, as well as a generalized ground-water regime with upward gradients, are illustrated in Figure 10-11.

The Atlantic and Gulf Coastal Plain region is underlain by unconsolidated sediments that consist primarily of sand, silt, and clay. The sediments are often interbedded as a result of deposition on floodplains or deltas and of subsequent reworking by ocean currents. Recharge to the ground-water system occurs in the interstream areas; most streams in this region are gaining streams (see Figure 10-12). Encroachment of salt water into well drawdown areas can be a problem in this

area if high rates of ground-water withdrawal occur. An example of a regional flow net based on high recharge in hills shows how regional flow may differ from localized flow based on local topography. Also shown in Figure 10-12 is a landfill located in a recharge area near the Savannah River in Georgia.

Ground water in the Southeast Coastal Plain region lies primarily within semiconsolidated limestone. Sand, gravel, clay, and shell beds overlie the limestone beds. Recharge in this region occurs by precipitation infiltrating directly into exposed limestone and by seepage through the permeable soils that partially mantle the limestone (see Figure 10-13). Coastal environments, such as beaches and bars, and swamp areas have different ground-water regimes, which are shown in Figure 10-13. Flow through solution channels and large fractures in limestone is often rapid, similar to the situation shown in Figure 10-8.

The Hawaiian Islands region consists of many distinct and separate lava flows that repeatedly issued from several eruption centers forming mountainous islands. Lava extruded below sea level is relatively impermeable; lava extruded above sea level is much more permeable, having interconnected cavities, faults, and joints. Ground-water flow in this region is similar to that of the Columbia Plateau region, with the central parts of thick lava flows being less permeable and the major portion of ground-water flow in these thick beds occurring at the edges and contacts of the different lava flows. Alluvium overlies the lava in the valleys and portions of the coastal plains.

Ground water in this region can be characterized by one of three ground-water flow regimes. The first flow regime consists of ground water impounded in vertical compartments by dikes in the higher elevations near the eruption centers. The second flow regime consists of fresh water floating on salt water in the lava deposits that flank the eruption centers. This ground water is referred to as basal ground water and makes up the major aquifers in the region. In some areas of the coastal plain, basal ground water is confined by overlying alluvium, which may restrain seaward migration of fresh water. The third flow regime is where ground water is perched on soils, ash, or thick impermeable lava flows above the basal ground water. Figure 10-14 illustrates examples of ground-water flow in this region.

The Alaska region comprises several distinct flow regimes that can be categorized by ground-water regions in the lower 48 States. For example, Alaska's Pacific Mountain System is similar to the Western Mountain Range and Alluvial Basin regions described previously. The major variable causing Alaska to be classified as a separate region is its climate and the existence of permafrost over most of the region.

Permafrost has a major effect on the hydraulic conductivity of most geologic deposits. Hydraulic conductivity declines as temperatures drop below 0 °C. This effect can be severe, causing a deposit that would be an aquifer in another area to become a low-permeability aquitard in an area of permafrost. In Alaska, ground-water supplies are drawn from deposits that underlie the permafrost or from areas where the permafrost is not continuous. See Figure 10-15.

Most recharge in this region occurs in large alluvial deposits, such as alluvial fans, which streams cross and discharge to. Although the volume of interstream surface water is large during periods of snow melt, these interstream areas do not act as recharge areas because they are usually frozen during the snow melts.

The Alluvial Valley region consists of valleys underlain by sand and gravel deposited by streams carrying sediment-laden melt water from glaciation that occurred during the Pleistocene. These valleys are considered to be a distinct ground-water terrain. They occur throughout the United States and can supply water to wells at moderate to high rates (see Figure 10-16). These valleys have thick sand and gravel deposits that are in a clearly defined band and are in hydraulic contact with a perennial stream. The sand and gravel deposits generally have a transmissivity of 10 or more times greater than that of the adjacent bedrock. Silt and clay commonly are found both above and below the sand and gravel channels in the Alluvial Valley region as a result of overbank flooding of rivers. Ground-water recharge in this region is predominantly by precipitation on the valleys, by ground water moving from the adjacent and underlying aquifers, by overbank flooding of the streams, and, in some glacial valleys, by infiltration from tributary

streams. An example of a flow net illustrating local ground-water movement beneath a waste disposal site in Connecticut also is shown in Figure 10-16.

In addition to determining the directions of ground-water flow, it is essential to determine the approximate rates of ground-water movement to properly design a monitoring program. Hydraulic conductivity, hydraulic gradient, and effective porosity data are required to estimate the average linear velocity of ground water and, therefore, assist in the determination of the rate of contaminant migration. Hydraulic conductivity data can be determined using single well (slug) test data. Several hydraulic conductivity measurements can be made on materials penetrated by individual wells to provide data on the relative heterogeneity of the materials in question. Measurements made in several wells also provide a comparison to check for effects of poor well construction. Hydraulic conductivity can also be determined from multiple-well (pumping) tests. A multiple-well test provides a hydraulic conductivity value for a larger portion of the aquifer. Hydraulic conductivities determined in the laboratory have been shown to vary by orders of magnitude from values determined by field methods and are, therefore, not recommended for use in the RFI.

Porosity can have an important controlling influence on hydraulic conductivity. Materials with high porosity values generally also have high hydraulic conductivities. An exception is clayey geologic materials which, although possessing high porosities, have low hydraulic conductivity values (resulting in low flow rates) due to their molecular structure. All of the pore spaces within geologic materials are not available for water or solute flow. Dead-end pores and the portion of the total porosity occupied by water held to soil particles by surface tension forces, do not contribute to effective porosity. Therefore, to determine average linear velocities, the effective porosity of the materials should be determined. In the absence of measured values, the values provided in Table 10-4 should be used.

Knowledge of the rates of ground-water flow is essential to determine if the locations of the monitoring wells are within reasonable flow distances of the contaminant sources. Flow rate data can also be used to calculate reasonable sampling frequencies. This is particularly important when attempting to monitor the potential migration of a intermittent contaminant release.

TABLE 10-4. DEFAULT VALUES FOR EFFECTIVE POROSITY

Soil Textural Classes	Effective Porosity of Saturation[a]
Unified Soil Classification System	
GC, GP, GM, GS	0.20
SW, SP, SM, SC	(20%)
ML, MH	0.15
	(15%)
CL, OL, CH, OH, PT	0.01
	(1%)[b]
USDA Soil Textural Classes	
Clays, silty clays,	0.01
sandy clays	(1%)[b]
Silts, silt loams,	0.10
Silty clay loams	(10%)
All others	0.20
	(20%)
Rock Units (all)	
Porous media (nonfractured	0.15
rocks such as sandstone and some carbonates)	(15%)
Fractured rocks (most carbonates, shales,	0.0001
granites, etc.)	(0.01%)

a These values are estimates. There may be differences between similar units.

b Assumes de minimus secondary porosity. If fractures or soil structure are present, effective porosity should be 0.001 (0.1%).

Geochemical and biological properties of the aquifer matrix should be evaluated in terms of their potential interference with the goals of the monitoring program. For example, chemical reactions or biological transformations of the monitoring constituents of concern may introduce artifacts into the results. Physical and hydrologic conditions will determine whether or not information on chemical or biological interactions can be collected. If the potential for these reactions or transformations exists, consideration should be given to monitoring for likely intermediate transformation or degradation products.

The monitoring system design is influenced in many ways by a site's hydrogeologic setting. Determination of the items noted in the stratigraphy and flow systems discussions will aid in logical monitoring network configurations and sampling activities. For example:

- Background and downgradient wells should be screened in the same stratigraphic horizon(s) to obtain comparable ground-water quality data. Hydraulic conductivities should be determined to evaluate preferential flowpaths (which will require monitoring) and to establish sampling frequencies.

- The distances between and number of wells (well density) should be a function of the spatial heterogeneity of a site's hydrogeology, as is sampling frequency. For example, formations of unconsolidated deposits with numerous interbedded lenses of varying hydraulic conductivity or consolidated rock with numerous fracture traces will generally require a greater number of sampling locations to ensure that contaminant pathways are intercepted.

- The slope of the potentiometric surface and the slope of the aquitard formation strongly influence the migration rates of light and dense immiscible compounds.

- The hydrogeology will strongly influence the applicability of various geophysical methods (Appendix C), and should be used to establish boundary conditions for any modeling to be performed for the site.

- Analyses for contaminants of concern in the ground-water monitoring program can be influenced by the general water quality present. Naturally-occurring cations and anions can affect contaminant reactivity, solubility, and mobility.

- Sites with complex geology will generally require more hydrogeologic information to provide a reasonable assurance that well placements will intercept contaminant migration pathways. For example, Figure 10-17 illustrates a cross-sectional and plan view of a waste landfill located in a mature Karst environment. This setting is characteristic of carbonate environments encountered in various parts of the country, but especially in the southeastern states. An assessment of the geology of the site through the use of borings, geophysical surveys, aerial photography, tracer studies, and other geological investigatory techniques, identified a mature Karst geologic formation characterized by sinkholes, solution channels and extensive vertical and horizontal fracturing in an interbedded limestone/dolomite. Using potentiometric data, ground-water flow was found to be predominantly in an easterly direction.

  Solution channels are formed by the flow of water through the fractures. The chemical reaction between the carbonate rock and the ground-water flow in the fractures produces solution channels. Through time, these solution channels are enlarged to the point where the weight of the overlaying rock is too great to support; consequently causing a "roof" collapse and the formation of a sinkhole. The location of these solution channels should guide the placement of monitoring wells. Note that in Figure 10-17 the placement of well No. 2 is offset 50 feet from the perimeter of the landfill. The horizontal placement of well No. 2, although not immediately adjacent to the landfill, is necessary in order to monitor all potential contaminant pathways. The discrete nature of these solution channels dictate that each potential pathway be monitored.

  The height of the solution channels ranges from three to six feet directly beneath the sinkhole to one foot under the landfill except for the 40-

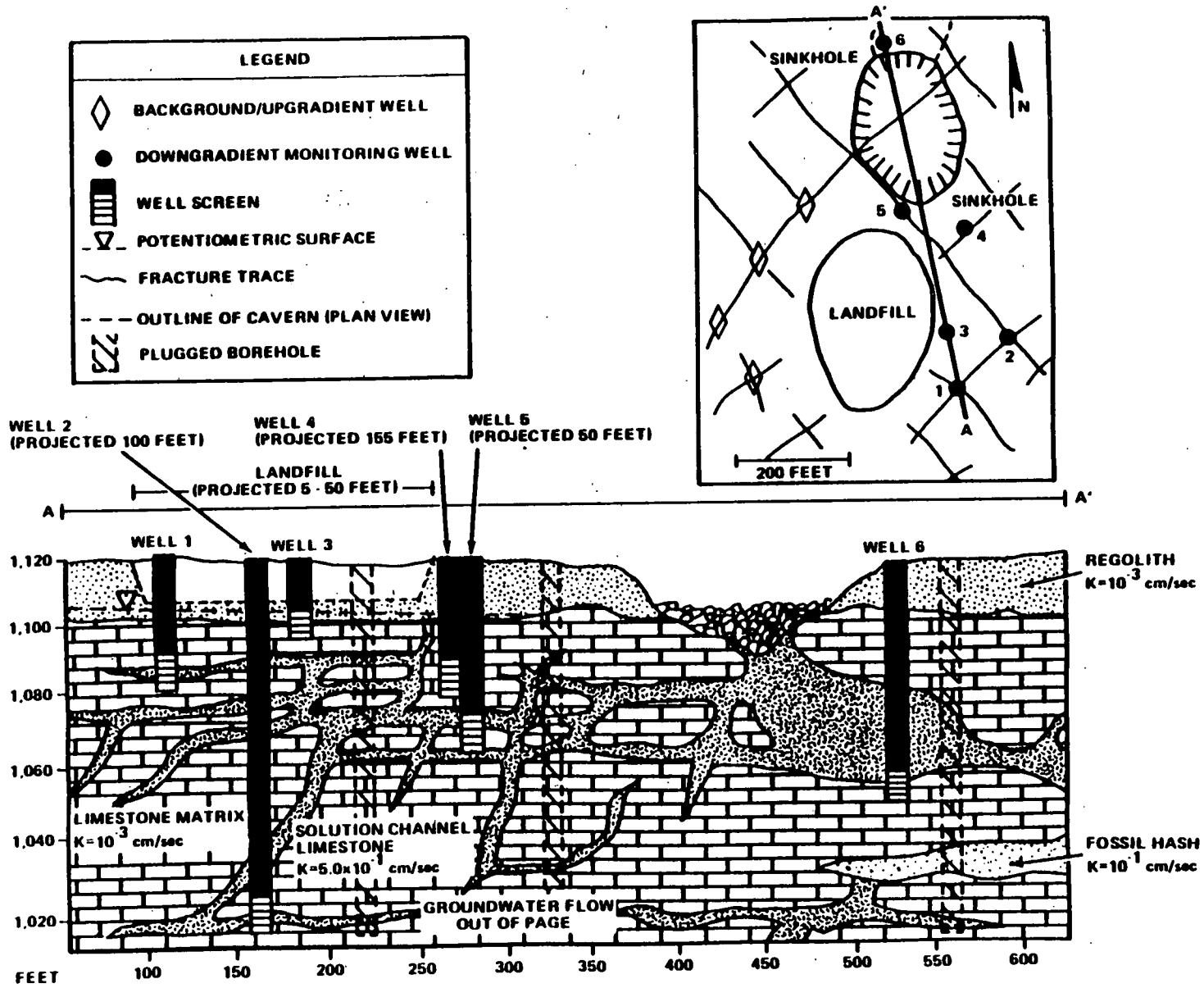


Figure 10-17. Monitoring well placement and screen lengths in a mature karst terrain/fractured bedrock setting.

foot deep cavern. This limited vertical extent of the cavities allows for full screening of the horizontal solution channels. (Note the change in orientation of solution channels due to the presence of the fossil hash layer).

Chapter I of the RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) (U.S. EPA, 1986) provides additional guidance in characterization of site hydrogeology. Various sections of the document will be useful to the facility owner or operator in developing monitoring plans for RCRA Facility Investigations.

In order to further characterize a release to ground water, data should be collected to assess subsurface stratigraphy and ground-water flow systems. These are discussed in the following subsections.

10.3.3.1 Subsurface Geology

In order to adequately characterize the hydrologic setting of a site, an analysis of site geology should first be completed. Geologic site characterization consists of both a characterization of stratigraphy, which includes unconsolidated material analysis, bedrock features such as lithology and structure, and depositional information, which indicates the sequence of events which resulted in the present subsurface configuration.

Information that may be needed to characterize a site's subsurface geology includes:

- Grain size distribution and gradation;
- Hydraulic conductivity;
- Porosity;
- Discontinuities in soil strata; and
- Degree and orientation of subsurface stratification and bedding.

Refer to Section 9 (Soil) for further details.

Grain size distribution and gradation--A measurement of the percentage of sand, silt, and clay should be made for each distinct layer of the soil. Particle size can affect contaminant transport through its impact on adsorption and hydraulic conductivity. Sandy soils generally have low sorptive capacity while clays tend to have a high affinity for heavy metals and some organic contaminants. This is due in part to the fact that small clay particles have a greater surface area in relation to their volume than do the larger sand particles. Greater surface areas allow for increased interactions with contaminant molecules. Clays may also bind contaminants due to the chemical structure of the clay. Methods for determination of sand/silt/clay fractions are available from ASTM, Standard Method No. D422-63 (ASTM, 1984).

Hydraulic conductivity--This property represents the ease with which fluids can flow through a formation, and is dependent on porosity, and grain size, as well as on the viscosity of the fluid. Hydraulic conductivity can be determined by the use of field tests, as discussed in Section 10.6.

Porosity--Soil porosity is the volume percentage of the total volume of the soil not occupied by solid particles (i.e., the volume of the voids). In general, the greater the porosity, the more readily fluids may flow through the soil, with the exception of clays (high porosity), in which fluids are held tightly by capillary forces.

Discontinuities in geological materials--Folds are layers of rock or soil that have been naturally bent over geologic time. The size of a fold may vary from several inches wide to several miles wide. In any case, folding usually results in a complex structural configuration of layers (Billings, 1972).

Faults are ruptures in rock or soil formations along which the opposite walls of the formation have moved past each other. Like folds, faults vary in size. The result of faulting is the disruption of the continuity of structural layers.

Folds and faults may act as either barriers to or pathways for ground-water (and contaminant) flow. Consequently, complex hydrogeologic conditions may be exhibited. The existence of folds or faults can usually be determined by examining

geologic maps or surveys. Aerial photographs can also be used to identify the existence of these features. Where more detailed information is needed, field methods (e.g., borings or geophysical methods) may need to be employed.

Joints are relatively smooth fractures found in bedrock. Joints may be as long as several hundred feet (Billings, 1972). Most joints are tight fractures, but because of weathering, joints may be enlarged to open fissures. Joints result in a secondary porosity in the bedrock which may be the major pathway of ground-water flow through the formation (Sowers, 1981).

Interconnected conduits between grains may form during rock formation (Sowers, 1981). The permeability of a bedrock mass is often defined by the degree of jointing. Ground water may travel preferentially along joints, which usually governs the rate of flow through the bedrock. The degree and orientation of joints and interconnected voids is needed to determine if there will be any vertical or horizontal leakage through the formation. In some cases, bedrock acts as an aquitard, limiting the ground-water flow in an aquifer. In other cases, the bedrock may be much more productive than overlying alluvial aquifers.

Geologic maps available from the USGS (see Section 7) may be useful in obtaining information on the degree and orientation of jointing or interconnected void formation. Rock corings may also be used to identify these characteristics.

Degree and orientation of subsurface stratification and bedding--The owner or operator should develop maps of the subsurface structure for the areas of concern. These maps should identify the thickness and depth of formations, soil types and textures, the locations of saturated regions and other hydrogeological features. For example, the existence of an extensive, continuous, relatively horizontal, shallow strata of low permeability can provide a clue to contaminant routing. In such cases, the contaminants may migrate at shallow depths, which are above the regional aquifer. Such contamination could discharge into nearby, low-lying structures (e.g., seepage into residential basements). This "basement seepage" pathway has been demonstrated to be a significant migration channel in many cases. This pathway may result from migration of vapors in the vadose zone or through lateral migration of contaminated ground water. Basement seepage is more likely to occur in locations with shallow ground water. A method for

estimating basement air contaminant concentrations due to volatile components in ground-water seeped into basements appears in Appendix E.

A variety of direct and indirect methods are available to characterize a site geologically with respect to the above geologic characteristics. Direct methods utilize soil borings and rock core samples and subsequent lab analysis to evaluate grain size, texture, uniformity, mineralogy, soil moisture content, bedrock lithology, porosity, and structure. Combined, these data provide the basis for delineating the geologic nature of the site and, in turn, provide the data necessary to evaluate the hydrologic setting.

Indirect methods of geologic investigation, such as geophysical techniques (See Appendix C) and aerial photography (See Appendix A) can be used to supplement data gathered by direct field methods, through extrapolation and correlation of data on surface and subsurface geologic features. Borehole geophysical techniques can be used to extrapolate direct data from soil borings and bedrock cores. Surface geophysical methods can provide indirect information on depth, thickness, lateral extent, and variation of subsurface features that can be used to extrapolate information gained from direct methods. Applicable surface geophysical methods include seismic refraction, electrical resistivity, electromagnetics, magnetics, and ground penetrating radar.

10.3.3.2 Flow Systems

In addition to characterizing the subsurface geology, the owner or operator should adequately describe the ground-water flow system. To adequately describe the ground-water flow paths, the owner or operator should:

- Establish the direction of ground-water flow (including horizontal and vertical components of flow);

- Establish the seasonal, temporal, and artificially induced (e.g., offsite production well pumping, agricultural use) variations in ground-water flow; and

- Determine the hydraulic conductivities of the hydrogeologic units underlying the site.

Hydrologic and hydraulic properties and other relevant information needed to fully evaluate the ground-water flow system are listed and discussed below:

- Hydraulic conductivity;
- Hydraulic gradient (vertical and horizontal);
- Direction and rate of flow;
- Aquifer type/identification of aquifer boundaries;
- Specific yield (effective porosity)/storage coefficient;
- Depth to ground water;
- Identify uppermost aquifer;
- Identify recharge and discharge areas;
- Use of aquifer; and
- Aquitard type and location.

Hydraulic conductivity--In addition to defining the direction of ground-water flow in the vertical and horizontal directions, the owner or operator should identify the distribution of hydraulic conductivity within each formation. Variations in the hydraulic conductivity of subsurface materials can affect flow rates and alter directions of ground-water flow paths. Areas of high hydraulic conductivity represent areas of greater ground-water flow and zones of potential migration. Therefore, information on hydraulic conductivities is needed to make decisions regarding well placements. Hydraulic conductivity measurement is described in Section 10.6.

Hydraulic gradient--The hydraulic gradient is defined as the change in static head per unit distance in a given direction. The hydraulic gradient defines the direction of flow and may be expressed on maps of water level measurements taken around the site. Ground-water velocity is directly related to hydraulic gradient. Both vertical and horizontal gradients should be characterized.

Direction and rate of flow--A thorough understanding of how ground water flows beneath the facility will aid the owner or operator in locating wells to provide suitable background and/or downgradient samples. Of particular importance is the direction of ground-water flow and the impact that external factors (intermittent well pumping, temporal variations in recharge patterns, tidal effects, etc.) may have on ground-water flow patterns. In order to account for these factors, monitoring procedures should include precise water level measurements in piezometers or observation wells. These measurements should be made in a sufficient number of wells and at a frequency sufficient to adequately gauge both seasonal average flow directions and to show any seasonal or temporal fluctuations in flow directions. Horizontal and vertical components of ground-water flow should be assessed. Methods for determining vertical and horizontal components of flow are described in Subsection 10.5.4.

Identification of aquifer boundaries/aquifer type--Aquifer boundaries define the flow limits and the degree of confinement of an aquifer. There are two major types of aquifers: unconfined and confined. An unconfined aquifer has a free water surface at which the fluid pressure is the same as atmospheric. A confined aquifer is enclosed by retarding geologic formations and is, therefore, under pressure greater than atmospheric. A confining unit consists of consolidated or unconsolidated earth materials that are substantially less permeable than aquifers. Confining units are called aquitards or aquicludes. Aquifer boundaries can be identified by consulting geologic maps and state geologic surveys. Observation wells and piezometers can be used to determine the degree of confinement of an aquifer through analysis of water level data.

Specific yield/storativity--Specific yield and storativity are both terms used to characterize the amount of water an aquifer is capable of yielding. In an unconfined system, the specific yield is the ratio of the drainable volume to the bulk volume of the aquifer medium (some liquid will be retained in pore spaces). The

storativity of a confined aquifer is the volume of water released from a column of unit area and height per unit decline of pressure head. Specific yield or storativity values may be necessary to perform complex ground-water modeling.

Depth to ground water--The depth to ground water is the vertical distance from the land's surface to the top of the saturated zone. A release from a unit not in contact with the water table will first percolate through the unsaturated zone and may, depending upon the nature of the geologic material, disperse horizontally. Thus, a release of this nature may reach a deep water table with limited lateral spreading. Depth to ground water can influence the selection of sampling methods as well as geophysical methods.

A shallow water table can also facilitate releases to other environments via volatilization of some compounds into the unsaturated zone, seepage into basements of buildings in contact with the saturated zone, or the transport of contaminants into wetlands where the water table reaches the level of the ground surface. Sufficient mapping of the water table with particular attention to these features should provide an indication of where these interactions may exist.

Identification of uppermost aquifer--As defined in 40 CFR §260.10, "aquifer" means a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of ground water to wells or springs. "Uppermost aquifer," also defined in 40 CFR §260.10, means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facilitiy's property boundary. Chapter one of the Technical Enforcement Guidance Document (TEGD) (U.S. EPA, 1986) elaborates on the uppermost aquifer definition. It states that the identification of the confining layer or lower boundary is an essential facet of the definition. There should be very limited interconnection, based on pumping tests, between the uppermost and lower aquifers. If zones of saturation capable of yielding significant amounts of water are interconnected, they all comprise the uppermost aquifer. Identification of formations capable of "significant yield" must be made on a case-by-case basis.

There are saturated zones, such as low permeability clay, that may not yield a significant amount of water, yet may act as pathways for contamination that can

migrate horizontally for some distance before reaching a zone which yields a significant amount of water. In other cases, there may be low yielding saturated zones above the aquifer which can provide a pathway for contaminated ground water to reach basements. If there is reason to believe that a potential exists for contamination to escape along such pathways, the owner or operator should monitor such zones.

For further information on the uppermost aquifer definition, including examples illustrating the determination of hydraulic interconnection in various geologic settings, see Chapter One of the TEGD.

Identification of recharge and discharge areas--Ground-water recharge can be defined as the entry into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone. Ground-water discharge can be defined as the removal of water from the saturated zone across the water table surface, together with the associated flow toward the water table within the saturated zone (Freeze and Cherry, 1979). Ground-water recharge and discharge areas also represent areas of potential inter-media transport.

Recharge can be derived from the infiltration of precipitation, inter-aquifer leakage, inflow from streams or lakes, or inadvertently by leakage from lagoons, sewer lines, landfills, etc. Discharge occurs where ground water flows to springs, streams, swamps, or lakes, or is removed by evapotranspiration or pumping wells, etc. Information on the source and location of aquifer recharge and discharge areas may be obtained from state water resource publications, geologic surveys, or existing site information. Comparison of aquifer water levels with nearby surface water levels may also provide an indication of the source and location of aquifer recharge and discharge areas.

Flow nets can also be used to determine areas of aquifer recharge and discharge. Section 10.5.2 describes the use of flow nets to determine ground-water flow patterns.

Use of aquifer--The proximity and extent of local ground-water use (e.g., pumping) may dramatically influence the rate and direction of ground-water flow

possibly causing seasonal or episodic variations. These factors should be considered when designing and implementing a ground-water monitoring system. Information on local aquifer use may be available from the USGS, and state and local water authorities. Aquifer use for drinking water or other purposes may also influence the location of ground-water monitoring wells, as it may be appropriate to monitor at locations pertinent to receptors.

Aquitard type and location--Aquitard type refers to the type of geologic formation that serves to bound ground-water flow for a given aquifer. Such boundaries may be rock or may be an unconsolidated unit such as clay, shale, or glacial till. The identification of such formations and their hydraulic characteristics is essential in determining ground-water flow paths. Aquitard locations can be determined by consulting geologic maps and boring log information. Although aquitards are substantially less permeable than aquifers, they are not totally impermeable and can allow significant quantities of water to pass through them over time. The location of an aquitard should be used in determining monitoring well depths.

10.3.4 Sources of Existing Information

A complete review of relevant existing information on the facility is an essential part of the release characterization. This review can provide valuable knowledge and a basis for developing monitoring procedures. Information that may be available and useful for the investigation includes both site-specific studies and regional surveys available from local, state, and Federal agencies.

Information from the regulatory agency such as the RFA report should be thoroughly reviewed in developing monitoring procedures, and should serve as a primary information source. It may also provide references to other sources of information. In addition, the facility's RCRA Permit Application may contain other relevant information. These reports and all of the facility's RCRA compliance/permit files will provide an understanding of the current level of knowledge about the facility, and will assist in identifying data gaps to be filled during the investigation.

Public information is available from local, state, and Federal governments (see Section 7) concerning the topics discussed below.

10.3.4.1 Geology

Knowledge of local bedrock types and depths is important to the investigation of a site. Sources of geologic information include United States Geological Survey (USGS) reports, maps, and files; State geological survey records; and local well drilling logs. See also Section 9 (Soils).

10.3.4.2 Climate

Climate is also an important factor affecting the potential for contaminant migration from a release source. Mean values for precipitation, evaporation, evapotranspiration, and estimated percolation will help determine the potential for onsite and offsite contaminant transport. The investigator should consult monthly or seasonal precipitation and evaporation (or temperature) records. Climate and weather information can be obtained from:

National Climatic Center
Department of Commerce
Federal Building
Asheville, North Carolina 28801
Tel: (704)258-2850

10.3.4.3 Ground-Water Hydrology

The owner or operator will need to acquire information on the ground-water hydrology of a site and its surrounding environment. Ground-water use in the area of the site should be thoroughly investigated to find the depths of local wells, and their pumping rates. Sources of such information include the USGS, state geological surveys, local well drillers, and State and local water resources boards. A list of all state and local cooperating offices is available from the USGS, Water Resources Division in Reston, Virginia, 22092. This list has also been distributed to EPA Regional Offices. Water quality data, including surface waters, is available through the USGS via their automated NAWDEX system. For further information, telephone (703)860-6031.

10.3.4.4 Aerial Photographs

Aerial reconnaissance can be an effective and economical tool for gathering information on waste management facilities. For this application, aerial reconnaissance includes aerial photography and thermal infrared scanning. See Appendix A for a more detailed discussion of the usefulness of aerial photography in release characterization and availability of aerial photographs.

10.3.4.5 Other Sources

Other sources of information for subsurface and release characterization include:

- U.S. EPA files (e.g., CERCLA-related reports);
- U.S. Geological Survey;
- U.S. Department of Agriculture Soil Conservation Service;
- U.S. Department of Agriculture Agricultural Stabilization and Conservation Service;
- U.S. Department of Interior -Bureau of Reclamation;
- State Environmental Protection or Public Health Agencies;
- State Geological Survey;
- Local Planning Boards;
- County or City Health Departments;
- Local Library;
- Local Well Drillers; and
- Regional Geologic and Hydrologic Publications.

10.4 Design of a Monitoring Program to Characterize Releases

Information on waste, unit and environmental characterization can be used to develop a conceptual model of the release, which can subsequently be used to design a monitoring program to fully characterize the release. The design of a monitoring program is discussed below.

10.4.1 Objectives of the Monitoring Program

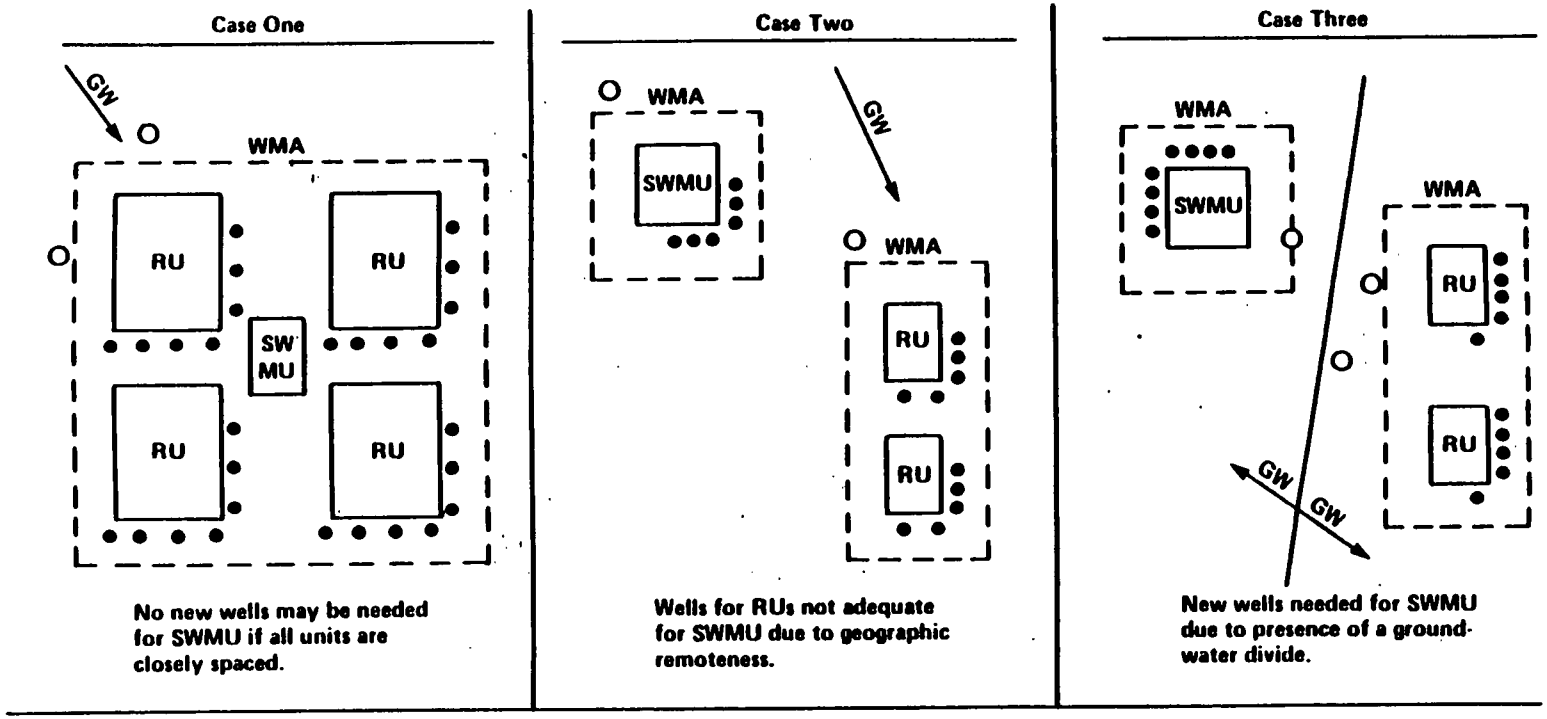
The objective of initial monitoring is to verify or to begin characterizing known or suspected contaminant releases to ground water. To help accomplish this objective, the owner or operator should evaluate any existing monitoring wells to determine if they are capable of providing samples representative of background and downgradient ground-water quality for the unit(s) of concern. Figure 10-18 illustrates three possible cases where existing well systems are evaluated with regard to their horizontal location for use in a ground-water investigation. Adequacy is not only a function of well location but also well construction. Guidance on appropriate well construction materials and methods can be found in the TEGD (EPA, 1986). If the monitoring network is found to be inadequate for all or some of the units of concern, additional monitoring wells should be installed. Further characterization, utilizing both direct and indirect investigative methods, of the site's hydrogeology should be completed to identify appropriate locations for the new monitoring wells.

If initial monitoring verifies a suspected contaminant release, the owner or operator should extend the monitoring program to determine the vertical and horizontal concentrations (i.e., 3-dimensions) of all hazardous constituents in the release. The rate of contaminant migration should also be determined. A variety of investigatory techniques are available for such monitoring programs.

Monitoring procedures should include direct methods of obtaining ground-water quality information (e.g., sampling and analysis of ground water from monitoring wells). Indirect methods of investigation may also be used when appropriate to aid in determining locations for monitoring wells (i.e., through geologic and/or geochemical interpretation of indirect data). For many cases, the use of both direct and indirect methods may be the most efficient approach.

Elements to be addressed in the ground-water monitoring program include:

- Monitoring constituents and indicator parameters;
- Frequency and duration at which samples will be taken;



KEY:

SWMU - Solid Waste Management Unit
RU - Regulated Unit
WMA - Waste Management Area
O - Background Monitoring Well
● - Downgradient Monitoring Well
GW - Ground-Water Flow Direction

Note: Drawings not to scale.

Figure 10-18.
Monitoring well locations

- Sampling and analysis techniques to be used, including appropriate QA/QC procedures; and

- Monitoring locations.

[Note: Permit application regulations in 40 CFR §270.14(c)(2) require applicants to identify the uppermost aquifer and hydraulically interconnected aquifers beneath the facility property if the facility has any "regulated" units. The application must indicate ground-water flow directions and provide the basis for the aquifer identification (e.g., a report written by a qualified hydrogeologist on the hydrogeologic characteristics of the facility property supported by at least the well drilling logs and available professional literature). However, some RCRA permit applications did not require hydrogeologic characterizations (e.g., storage only facilities) prior to the HSWA Amendments of 1984. Now, such characterizations may be required according to RCRA Section 3004(u) when SWMU releases to ground water are suspected or known. The RCRA Ground Water Monitoring Technical Enforcement Guidance Document (TEGD) (U.S. EPA, 1986), and the Permit Applicant's Guidance Manual for Hazardous Waste Land Treatment, Storage, and Disposal Facilities (U.S. EPA, 1984) should be consulted for further information on regulatory requirements.]

10.4.2 Monitoring Constituents and Indicator Parameters

Initial monitoring should be focused on rapid, effective release characterization at the downgradient limit of the waste management area. Monitoring constituents should include waste-specific subsets of hazardous constituents from 40 CFR Part 261, Appendix VIII (see Section 3 and the lists provided in Appendix B). Indicator parameters (e.g., TOX, specific conductance) may also be proposed as indicated in Section 3. Such indicators alone may not be sufficient to characterize a release of hazardous constituents, because the natural background variability of indicator constituents can be quite high. Furthermore, indicator concentrations do not precisely represent hazardous constituent concentrations, and the detection limits for indicator analyses are significantly higher than those for specific constituents.

In developing an initial list of monitoring constituents and indicator parameters, the following items should be considered:

- The nature of the wastes managed at the facility should be reviewed to determine which constituents (and any chemical reaction products, if appropriate) are relatively mobile and persistent;

- The effects of the unsaturated zone (if present) beneath the facility on the mobility, stability and persistence of the waste constituents; and

- The concentrations and related variability of the proposed constituents in background ground water.

In the absence of detailed waste characterization information, the owner or operator should review the guidance presented in Section 3, which discusses the use of the monitoring constituent lists in Appendix B. As discussed in Section 3, the use of these lists is contingent upon the level of detail provided by the waste characterization.

The owner or operator should consider monitoring for additional inorganic indicators that characterize the general quality of water at the site (e.g., chloride, iron, manganese, sodium, sulfate, calcium, magnesium, potassium, nitrate, phosphate, silicate, ammonium, alkalinity and pH). Baseline data on such indicators can be used for subsequent monitoring phases and for selecting corrective measures (e.g., in assessing ground-water treatment alternatives). This is also discussed in Section 3 and Appendix B. Information on the major anions and cations that make up the bulk of dissolved solids in water can be used to determine reactivity and solubility of hazardous constituents and therefore predict their mobility under actual site conditions.

10.4.3 Monitoring Schedule

10.4.3.1 Monitoring Frequency

Monitoring frequency should be based on various factors, including:

- Ground-water flow rate and flow patterns;

- Adequacy of existing monitoring data; and

- Climatological characteristics (e.g., precipitation patterns).

Generally, the greater the rate of ground-water flow, the greater the monitoring frequency needed. For example, monitoring frequency in an intergranular porosity flow aquifer of low permeability materials would likely be less than for a fracture or solution porosity flow aquifer with unpredictable and high flow rates. In the case of a fracture or solution porosity flow aquifer, it is possible that contaminants could migrate past the facility boundary in a matter of days, weeks, or months; thus requiring frequent monitoring.

The adequacy of existing monitoring data can be a factor in determining the monitoring schedule. For example, a facility which has performed adequate monitoring under RCRA interim status requirements may have a good data base which can be helpful in evaluating initial monitoring results. At the other end of the spectrum are facilities lacking hydrogeologic data and monitoring systems. Owners or operators of these facilities will need to design and install an adequate monitoring system for the units of concern. An accelerated monitoring program is recommended at such facilities.

10.4.3.2 Duration of Monitoring

The duration of the initial monitoring phase will vary with facility-specific conditions (e.g., hydrogeology, wastes present) and should be determined through consultation with the regulatory agency. The regulatory agency will evaluate initial monitoring results to determine how long monitoring should continue and to determine the need for adjustments in the monitoring schedule, the list of monitoring constituents, and other aspects of the monitoring effort. If the regulatory agency determines that a release to ground water has not occurred, the investigation process for that release can be terminated at its discretion. If contamination is found during initial monitoring, further monitoring to fully characterize the release will generally be necessary.

10.4.4 Monitoring Locations

If there is no existing monitoring system or if the system is inadequate to effectively characterize ground-water contamination, the owner or operator should design and install a well system capable of intercepting the suspected contaminant plume(s). The system should also be used for obtaining relevant hydrogeologic data. The monitoring well network configuration should be based on the site's hydrogeology, the layout of the facility and the units of concern, the location of receptors, and should reflect a consideration of any information available on the nature and source of the release. It is important to recognize that the potential pathways of contaminant migration are three dimensional. Consequently, the design of a monitoring network which intercepts these potential pathways requires a three dimensional approach.

In many cases, the initial monitoring system will need to be expanded for subsequent phases. Additional downgradient wells will often be needed to determine the extent of the contaminant plume. A greater number of background wells may also be needed to account for spatial variability in ground-water quality.

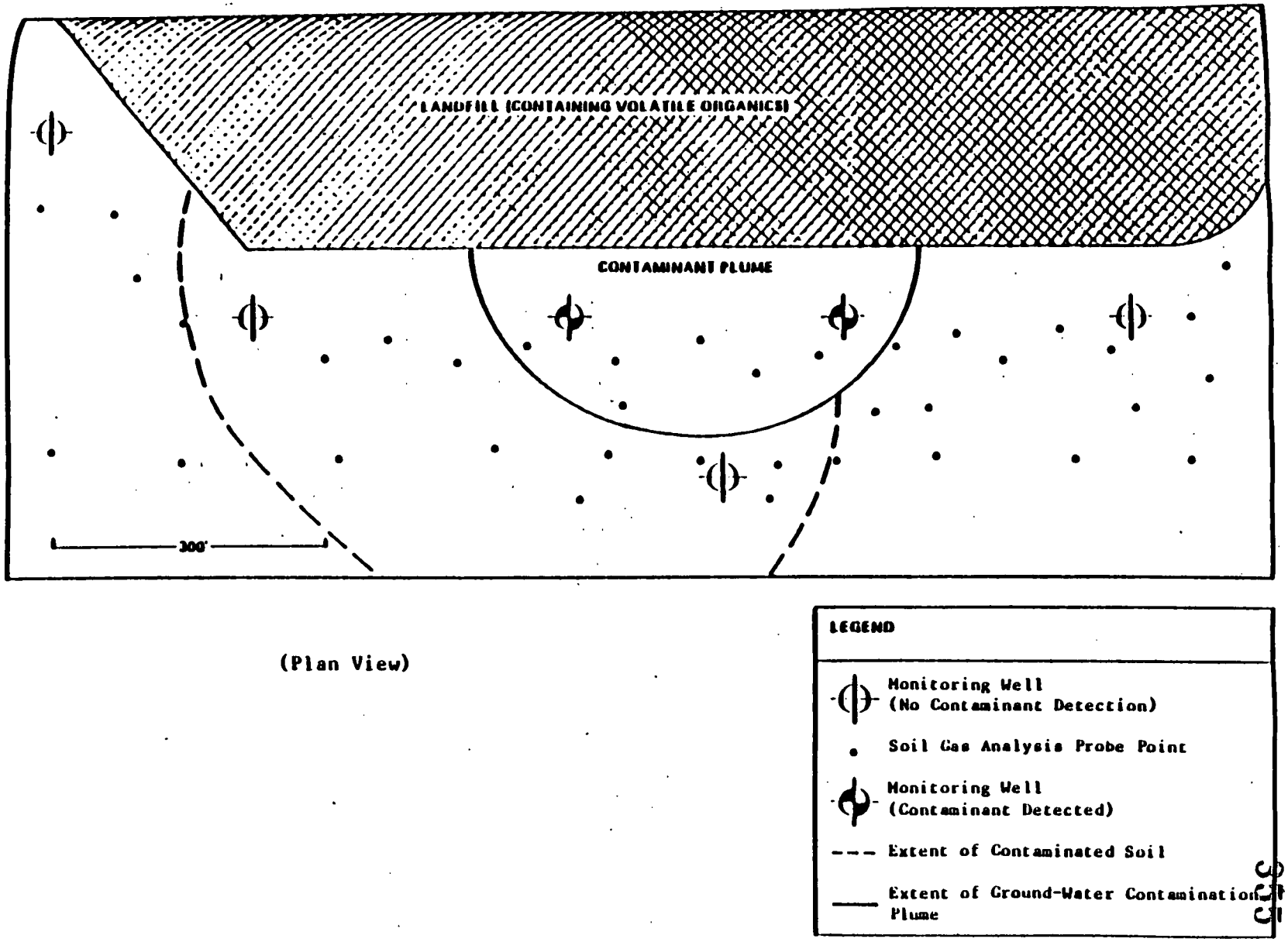
Prior to the installation of additional downgradient monitoring wells, a conceptual model of the release should be made from a review of waste and unit information and current and past site characterization information. Additional hydrogeologic investigations may also be appropriate. For example, piezometer readings surrounding the well(s) showing a release, should be used to determine the current hydraulic gradient(s). These values should be compared to the potentiometric surface map developed for the site hydrogeologic characterization to better describe the direction(s) of release migration. Seasonal (natural or induced) or regional fluctuations should be considered during this comparison. A re-evaluation of the facility's subsurface geologic information should be performed to identify preferential pathways of contaminant migration. In many situations, it may be appropriate to develop ground-water flow nets to show vertical and horizontal components of flow. Guidance on construction of flow nets is provided in Section 10.5.2 and in the Ground Water Flow Net/Flow Line Technical Resource Document, NTIS PB86-224979. (EPA, 1985). The installation of additional piezometers may be necessary to verify the accuracy of the flow nets and assist in

determining whether or not the site hydrogeology has been adequately characterized.

At facilities where it is known or likely that volatile organics have been released to the ground water, organic vapor analysis of soil gas from shallow bore holes may provide an initial indication of the areal extent of the release (Figure 10-19). An organic vapor analyzer (OVA) may be used to measure the volatile organic constituents in shallow hand-augered holes. Alternatively, a sample of soil gas may be extracted from a shallow hole and analyzed in the field using a portable gas chromatograph. These techniques are limited to situations where volatile organics are present. As discussed previously, it is recommended that, where possible, concurrent investigations of more than one contaminated media be conducted. Further, the presence of intervening, saturated, low permeability sediments strongly interferes with the ability to extract a gas sample. Although it is not necessarily a limitation, optimal gas chromatography results are obtained when the analyte is matched with the highest resolution technique, (e.g., electron capture for halogenated species). The effectiveness of this approach should be evaluated by initial OVA sampling in the vicinity of any wells known to be contaminated.

Other direct methods that may be used to define the extent of a release include sampling of seeps and springs. Seeps and springs occur where the local ground-water surface intersects the land surface resulting in ground-water discharge into a stream, lake, or other surface water body. Seeps and springs may be observed near marshes, at road cuts, or near streams. As discharges from seeps and springs reflect the height of the potentiometric surface, they are likely to be most abundant during a wet season.

To minimize the installation of new wells, the use of applicable geophysical and modeling methods may be proposed to describe geologic conditions and contaminant release geometry/characteristics. Such methods can also aid in the placement of new monitoring wells.



(Plan View)

Figure 10-19. Example of using soil gas analysis to define probable location of ground-water release containing volatile organics.

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A variety of indirect geophysical methods are currently available to aid in characterizing geologic conditions and ground-water contamination. Geophysical methods do not provide detailed, constituent-specific data; however, they can be useful in investigating geologic conditions and in estimating the general areal extent of a release. This may reduce speculation involved in determining new well locations. Details on the use of geophysical methods are presented in Section 10.6 and in Appendix C.

Mathematical and/or computer modeling results may be used in conjunction with the results of geophysical investigations to assist in well placement decisions. The owner or operator should not, however, depend solely on such models to determine the placement of new monitoring wells. Because models may not accurately account for the high spatial and temporal variability of conditions encountered in the field, modeling results should be limited to estimating the aerial extent of a release, and in determining placement of new monitoring wells.

In order to estimate the potential extent of a release in the direction of ground-water flow, Darcy's law should be applied, if appropriate, to determine the average linear ground-water velocity (see Section 10.5.3). This velocity should then be multiplied by the age of the unit of concern (assuming the unit began releasing immediately) to estimate the potential distance of contaminant migration. This distance should be used as a "yardstick" in determining well locations. More complex modeling (e.g., solute transport), may be proposed by the owner or operator to assist in locating additional monitoring wells. However, modeling results should not be used in lieu of field monitoring data.

The International Ground Water Modeling Center supported largely by the U.S. Environmental Protection Agency, operates a clearing-house for ground-water modeling software, organizes and conducts short courses and seminars, and carries out a research program supporting the Center's technology transfer and educational activities. Two major functions of the Center are the dissemination of information regarding ground-water models and the distribution of modeling software. The Center maintains computerized data bases, including updated computer codes and test files, and descriptions of a large number of ground-water models. By means of a search and retrieval procedure, this information is easily

accessible and readily available. The Center can be contacted at the following address:

International Ground Water Modeling Center
Holcomb Research Institute
Butler University
Indianapolis, Indiana 46208
Telephone: (317)283-9458

The Center will send, upon request and free of charge, a listing of available publications, and a copy of its Newsletter.

In selecting and applying models, it is important to remember that a model is an artificial representation of a physical system used to characterize a site. A model cannot replace field data, nor can it be more accurate than the available site data. In addition, the use of computer models requires special expertise. Time and experience are needed to select the appropriate code and subsequent calibration. If these resources are not available, modeling should not be attempted. Models are used in conjunction with scientific and engineering judgment; they are an aid to, not a surrogate for, a skilled analyst.

If a model is proposed in the monitoring procedures, the owner or operator should describe all assumptions used in applying the model to the site in question. A sensitivity analysis of the model should be run to determine which input parameters have the most influence on model results, and the model's results should be verified by field sampling. The owner or operator should clear the use of any and all models through the regulatory agency prior to use. Section 3 provides additional information on the use of models.

10.4.4.1 Background and Downgradient Wells

Background wells (preferably upgradient) may be installed to obtain samples that are not affected by the facility, if the owner or operator believes that other sources are contributing to the releases of concern. These wells should be screened at the same stratigraphic horizon(s) as the downgradient wells. Background wells,

if installed, should be sufficient in number to account for any heterogeneity in background ground-water quality.

Downgradient wells should be located and constructed to provide samples of ground water containing any releases of hazardous constituents from the units of concern. Determination of the appropriate number of wells to be included in an initial monitoring system should be based on various factors, including unit size and the complexity of the hydrogeologic setting (e.g., degree of fracturing and variation in hydraulic conductivity). Downgradient monitoring wells should be located at the limit of the waste management area of the units of concern and at other downgradient locations, as appropriate. For example, "old" releases may show higher constituent concentrations at locations downgradient of the unit. In such cases, flow nets may be useful in determining additional downgradient well locations (See Section 10.5.2).

10.4.4.2 Well Spacing

The horizontal spacing between wells should be a design consideration. Site specific factors as listed in Table 10-5 should be considered when determining the horizontal distances between initial monitoring system wells. These factors cover a variety of physical and operational aspects relating to the facility including hydrogeologic setting, dispersivity, ground-water velocity, facility design, and waste characteristics. In the less common homogeneous geologic setting where simple flow patterns are identified, a more regular well spacing pattern may be appropriate. Further guidance on the consideration of site specific conditions to evaluate well spacing is described in Chapter Two of the TEGD (U.S. EPA, 1986).

Subsequent phase monitoring systems should be capable of identifying the full extent of the contaminant release and establishing the concentration of individual constituents throughout the release. Well installation and monitoring should concentrate on defining those areas that have been affected by the release. A well cluster network should be installed in and around the release to define the horizontal and vertical extent of contamination. Networks of monitoring wells will vary from site to site, depending upon hydrogeological complexity and contaminant characteristics. Surface geophysical techniques and modeling may also

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TABLE 10-5. FACTORS INFLUENCING THE INTERVALS BETWEEN INDIVIDUAL MONITORING WELLS WITHIN A POTENTIAL MIGRATION PATHWAY

Wells Intervals May Be Closer If the Site:	Wells Intervals May be Wider If the Site:
• Manages or has managed liquid waste	
• Is very small (i.e., the downgradient perimeter of the site is less than 150 feet)	
• Has waste incompatible with liner materials	
• Has fill material near the waste management units (where preferential flow might occur)	
• Has buried pipes, utility trenches, etc., where a point-source leak might occur	
• Has complicated geology - closely spaced fractures - faults - tight folds - solution channels - discontinuous structures	• Has simple geology - no fractures - no faults - no folds - no solution channels - continuous structures
• Has heterogenous conditions - variable hydraulic conductivity - variable lithology	• Has homogeneous conditions - uniform hydraulic conductivity - uniform lithology
• Is located in or near a recharge zone	
• Has a high (steep) or variable hydraulic gradient	• Has a low (flat) and constant hydraulic gradient
• Low dispersivity	• High dispersivity
• High average linear velocity	• Low average linear velocity

be used, where appropriate, to help facilitate release definition. The well density or amount of sampling undertaken to completely identify the extent of migration should be determined by the variability in subsurface geology present at the site. Formations such as unconsolidated deposits with numerous interbedded lenses of varying permeability, or consolidated rock with numerous fracture traces, will generally require more extensive monitoring to ensure that contamination is appropriately characterized.

Monitoring should be performed to characterize the interior portion(s) of a release. This is important because constituents can migrate at differing rates and may have been released at different times. Monitoring only at the periphery of the release may not identify all the constituents in the release, and the concentration of monitoring constituents measured at the periphery of the release may be significantly less than in the interior portion(s). Patterns in concentrations of individual constituents can be established throughout the release by sampling along several lines that perpendicularly transect the release. The number of transects and the spacing between sampling points should be based on the waste characteristics, the size of the release, and variability in geology observed at the site. Sampling locations should also be selected so as to identify those areas of maximum contamination within the release. In addition to the expected hazardous constituents, the release may contain degradation and reaction products, which may also be hazardous.

Results of geophysical methods may be correlated with data from the monitoring well network. The monitoring program should be flexible so that adjustments can be made to reflect release migration and changes in direction.

The spacing between initial downgradient monitoring wells should ensure the measurement of releases near the unit(s) of concern. However, it is possible that the initial spacings between wells will only provide for measurements in the peripheral portion of a release. This might result in water quality measurements that do not reflect the maximum concentration of contaminants in the release. Therefore, additional downgradient wells may be needed adjacent to the units of concern during subsequent monitoring phases.

A similar effect may be observed, even with a closely spaced initial downgradient monitoring network, if a narrow, localized release migrates past the limit of the waste management area. Such a plume may originate from a small leak in a liner and/or from a leak located close to the downgradient limit of the waste management area, thereby limiting the amount of dispersion occurring in the release prior to its passing the monitoring wells. Consequently, if relatively wide spacing exists between wells or there is reason to expect a narrow, localized release, the installation of additional monitoring wells may be necessary in the immediate vicinity of those wells in which a release has been measured. Such an expansion of the monitoring network is recommended when a release has been measured in only one or two monitoring wells, indicating a localized plume.

10.4.4.3 Depth and Screened Intervals

The depth and screened intervals for initial phase monitoring wells should be based on: (1) geologic factors influencing the potential contaminant pathways of migration to ground water; (2) physical/chemical characteristics of the contaminant controlling its likely movement and distribution in the ground water; and (3) hydrologic factors likely to have an impact on contaminant movement. The consideration of these factors in evaluating the design of monitoring systems is described in the TEGD (U.S. EPA, 1986), including examples of placement in some common geologic environments. Subsection 10.6 provides guidance on borings and monitoring well construction.

In order to establish vertical concentration gradients of hazardous constituents in the release during subsequent monitoring phases, well clusters or multi-depth monitoring wells should be installed. The first well in a cluster (or initial sampling interval in a multi-depth well) should be screened at the horizon in which contamination was initially discovered. Additional wells in a cluster should be screened, where appropriate, above and below the initial well's sampling interval until the margins of the release are established.

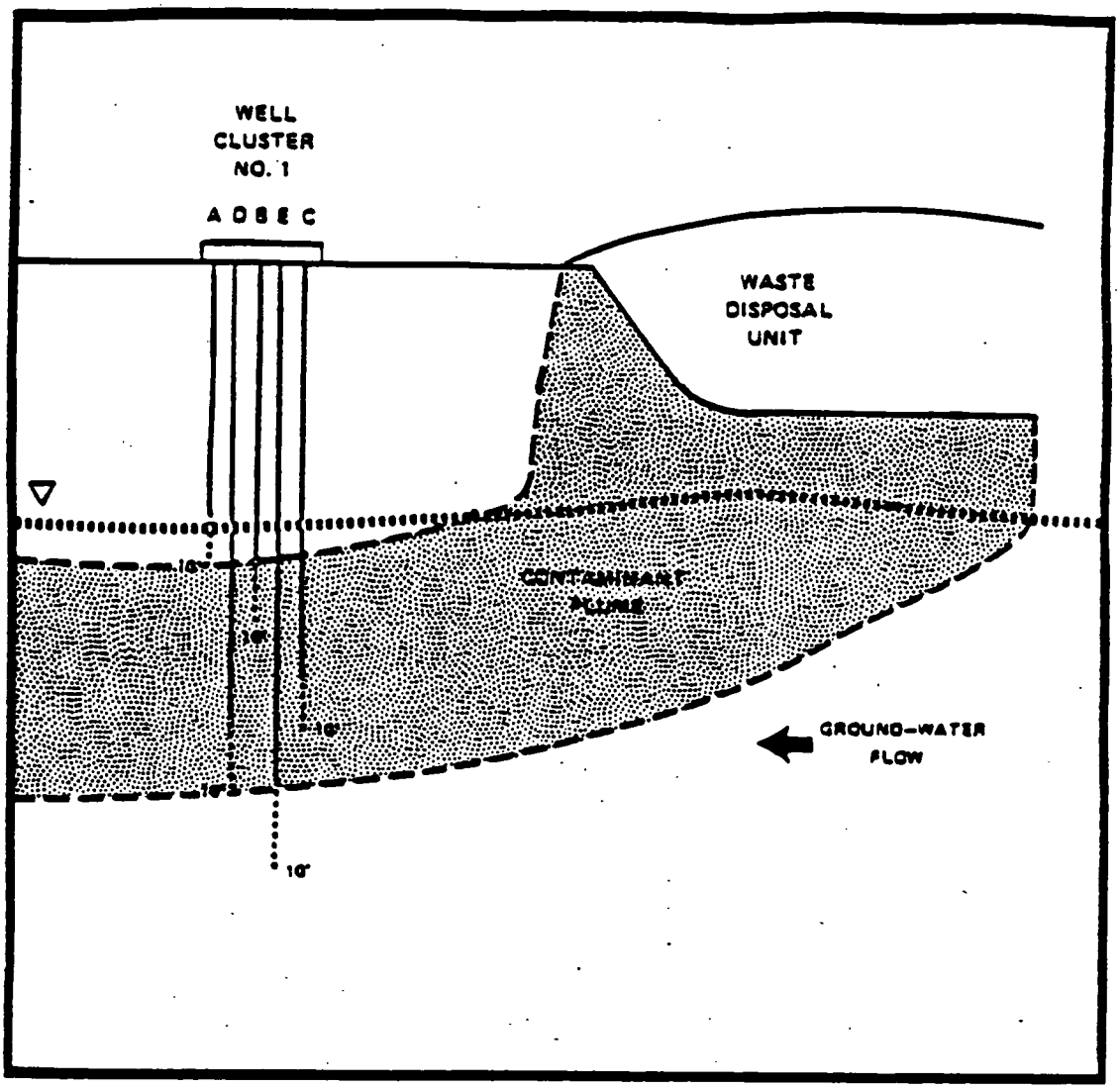
Several wells should be placed at the fringes of the release to define its vertical margins, and several wells should be placed within the release to identify constituents and concentrations. Care must be taken in placing contiguously screened wells close together because one well's drawdown may influence the next

and thus change the horizon from which its samples are drawn. Alternating lower and higher screens should reduce this effect (see Figure 10-20).

The specifications of sampling depths should clearly identify the interval over which each sample will be taken. It is important that these sampling intervals be sufficiently discrete to allow vertical profiling of constituent concentrations in ground water at each sampling location. Sampling will only provide measurements of the average contaminant concentration over the interval from which that sample is taken. Samples taken from wells screened over a large vertical interval may be subject to dilution effects from uncontaminated ground water lying outside the plume limits. The proposed screened interval should reflect the expected vertical concentration gradients within the release.

At those facilities where immiscible contaminants have been released and have migrated as a separate phase (see Figure 10-21), specific techniques will be necessary to evaluate their migration. The detection and sampling of immiscible layers requires specialized equipment that must be used before the well is evacuated for conventional sampling. Chapter 4 of the TEGD (U.S. EPA, 1986) contains a discussion of ground-water monitoring techniques that can be used to sample multi-phased contamination. These sampling techniques vary according to whether the immiscible phase is lighter than water (i.e., floats) or denser than water (i.e., sinks), and is also dependent on the thickness of the layer.

The formation of separate phases of immiscible contaminants in the subsurface is largely controlled by the rate of infiltration of the immiscible contaminant and the solubility of that contaminant in ground water. Immiscible contaminants generally have limited solubility in water. Thus, some amount of the immiscible contaminant released from a unit(s) will dissolve in the ground water and thus migrate in solution. However, if the amount of immiscible contaminant reaching ground water exceeds the ability of ground water to dissolve it (i.e., the constituent water solubility), the ground water in the upper portion of the water table aquifer will become saturated and the contaminant will form a separate immiscible phase. Hence, the contaminant will be present in the ground water at a concentration approaching its water solubility, as well as in a separate immiscible phase. If cosolvents are present, the concentration of the contaminant in the ground water can exceed the contaminant's water solubility, whether or not a separate immiscible phase is present.



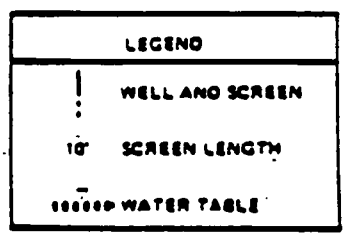


Figure 10-20

Vertical Well Cluster Placement

At this point, the behavior and migration of an immiscible contaminant will be strongly influenced by its density relative to ground water. If the immiscible is less dense than ground water, it will tend to form a separate immiscible layer and migrate on top of the ground water. If the density of the immiscible contaminant is similar to that of ground water, it will tend to mix and flow as a separate phase with the ground water, creating a condition of multiphase flow.

If the density of the immiscible constituent is greater than ground water, it will tend to sink in the aquifer (see Figure 10-21). As the immiscible layer sinks and reaches unaffected ground water in a deeper portion of the aquifer, more of the immiscible contaminant will tend to enter into solution in ground water and begin to migrate as a dissolved constituent. However, if enough of the dense immiscible contaminants are present, some portion of these contaminants will continue to sink as a separate immiscible phase until a geologic formation of reduced permeability is reached. At this point, these dense contaminants will tend to form a layer that migrates along the geologic formation (boundary).

Immiscible phase contaminants may migrate at rates different than that of ground water. In addition, immiscible contaminants may not flow in the same direction as ground water. However, it is important to re-emphasize that some fraction of these contaminants may dissolve in ground water and migrate away from the facility as dissolved constituents.

Light immiscible contaminants tend to migrate downgradient as a floating layer above the saturated zone (see Figure 10-21). The hydraulic gradient is a major factor in the movement of this light immiscible layer. Other important factors involved in the migration rate of a light immiscible phase include the intrinsic permeability of the medium, and the density and viscosity of the contaminants. Oftentimes, an ellipsoidal plume will develop over the saturated zone as depicted in Figure 10-21. While it may be possible to analyze the behavior of a light immiscible layer using analytical or numerical models, the most practical approach for determining the rate and direction of migration of such a layer is to observe its behavior over time with appropriately located monitoring wells.

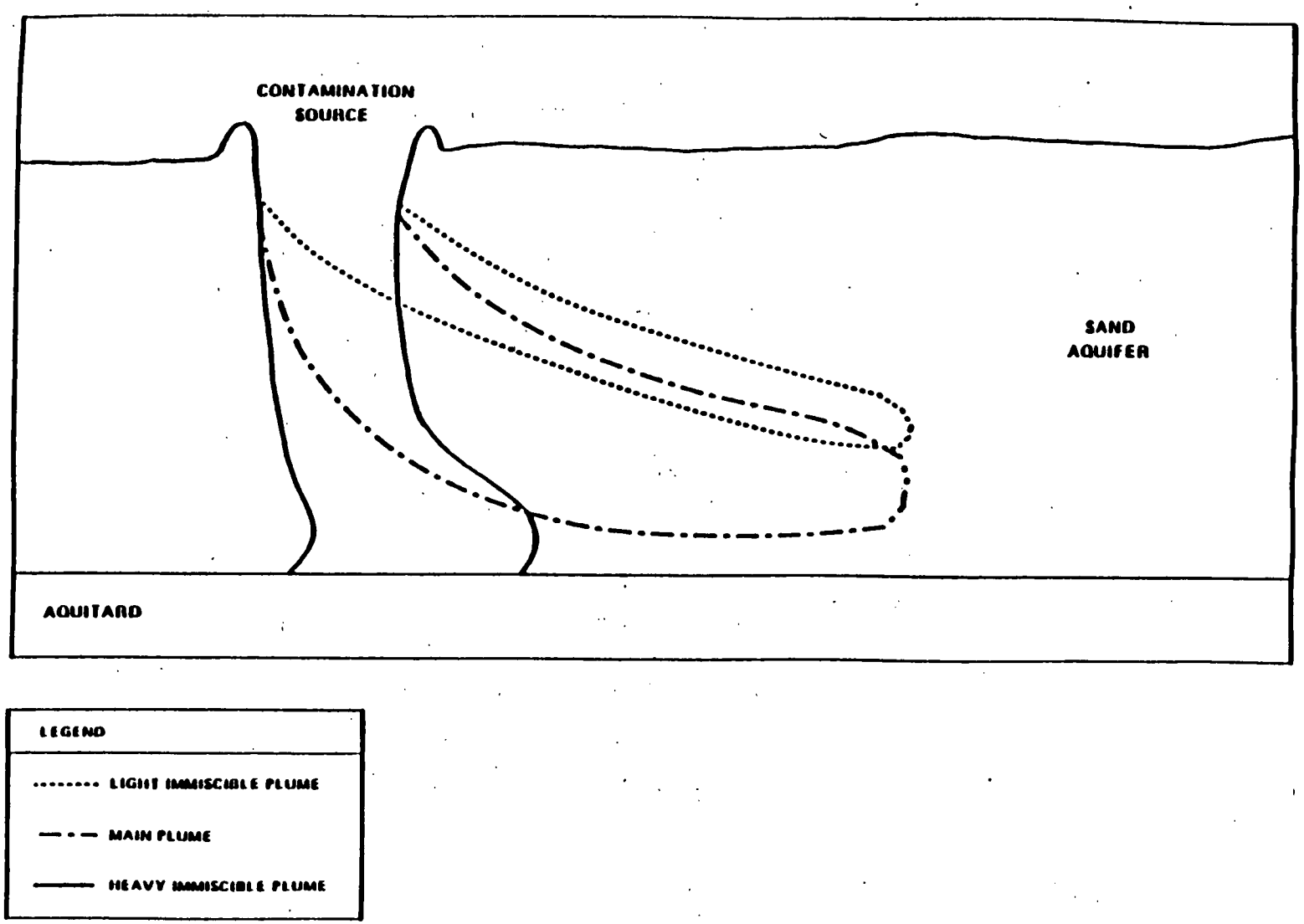


Figure 10-21. General schematic of multiphase contamination in a sand aquifer.

The migration of a layer of dense immiscibles resting on a low permeability geologic formation may be strongly influenced by gravity. Depending on the slope of the retarding formation, the immiscible layer may move with or in a different direction from the flow of the ground water. Consequently, the evaluation of the rate and direction of migration of a dense immiscible layer should include a determination of the configuration of the retarding formation on which the immiscible layer is migrating. The direction of migration and estimates of migration rates of dense immiscibles can then be obtained by including the gravitational forces induced by the slope of the retarding formation in the gradients used to calculate contaminant flow rates. If a dense immiscible layer(s) is expected or known, the monitoring plan should include procedures to verify its direction and rate of flow.

10.5 Data Presentation

Section 5 of this guidance describes data presentation methods with examples. In addition to sorted data tables, the methods described for contaminant isopleth maps, geologic cross-sections, cross-sectional concentration contours, and fence diagrams should be useful for presenting ground-water investigation findings. The following presents specific data presentation methods that may be particularly useful for presenting ground-water investigation data.

10.5.1 Waste and Unit Characterization

Waste and unit characteristics should be presented as:

- Tables of waste constituents and concentrations;
- Tables of relevant physical and chemical properties of waste and constituents;
- Narrative description of unit dimensions, operations etc.; and
- Topographical map and plan drawings of facility and surrounding areas.

10.5.2 Environmental Setting Characterization

Environmental characteristics should be presented as follows:

- Tabular summaries of annual and monthly or seasonal relevant climatic information (e.g., temperature, precipitation);
- Narratives and maps of soil and relevant hydrogeological characteristics such as porosity, organic matter content and depth to ground water;
- Maps showing location of natural or man-made engineering barriers and likely migration routes; and
- Maps of geologic material at the site identifying the thickness, depth, and textures of soils, and the presence of saturated regions and other hydrogeological features.

Flow nets should be particularly useful for presenting environmental setting information for the ground-water medium. A flow net provides a graphical technique for obtaining solutions to steady state ground-water flow. A properly constructed flow net can be used to determine the distribution of heads, discharges, areas of high (or low) velocities, and the general flow pattern (McWhorter and Sunada, 1977).

The Ground Water Flow Net/Flow Line Technical Resource Document (TRD), NTIS PB86-224979. (U. S. EPA, 1985), provides detailed discussion and guidance in the construction of flow nets. Although the focus of this document is on the construction of vertical flow nets, the same data requirements and theoretical assumptions apply to horizontal flow nets. The fundamental difference between vertical and horizontal flow nets is in their application. A flow net in the horizontal plane may be used to identify suitable locations for monitoring wells whereas a flow net in the vertical plane would aid in determining the screened interval of a well.

The following excerpts from the Flow Net Document (U.S. EPA, 1985) explain data needs for flow net construction. Several assumptions must be made to construct a flow net:

- Ground-water flow is steady state, which means flow is constant with time;
- The aquifer is completely saturated;
- No consolidation or expansion of the soil or water occurs;
- The same amount of recharge occurs across the system; and
- Flow is laminar and Darcy's law is valid.

Knowledge of the hydrologic parameters of the ground-water system is required to properly construct a flow net. These parameters include:

- Head distribution, both horizontally and vertically;
- Hydraulic conductivity of the saturated zone;
- Saturated zone thickness; and
- Boundary conditions.

The distribution of head can be determined using time equivalent water level measurements obtained from piezometers and/or wells. Plotting the water level elevations on a base map and contouring these data will provide a potentiometric surface. Contour lines representing equal head are called lines of equipotential. Changes in hydraulic head, both horizontally and vertically within an aquifer, must be known for proper flow-net construction. These changes can be delineated with piezometers or monitoring wells installed at varying depths and spatially distributed. The data must be time equivalent because water levels change over time. Ground-water flow directions can be determined by drawing lines

perpendicular to the equipotential lines. Ground water flows from areas of higher hydraulic head to areas of lower hydraulic head.

The hydraulic conductivity of a material depends on the properties of the fluid and the media. Clayey materials generally have low hydraulic conductivities, whereas sands and gravels have high conductivities (U.S. EPA, 1985). Where flow crosses a boundary between different homogeneous media the ground-water flowlines refract and flow velocity changes due to an abrupt change in hydraulic conductivity. The higher permeability formation serves as a conduit to ground-water flow. This is visually apparent in a properly constructed flow net, because flow tubes are narrower in layers with higher conductivity because less area is necessary to conduct the same volume of ground water. In media of lower conductivity, flow tubes will be wider in order to conduct the same volume of flow (Cedergren, 1977). Construction of flow nets for layered geologic settings (heterogeneous, isotropic systems) are discussed in Section 2 of the flow net document (U.S. EPA, 1985).

The boundary conditions of an aquifer must also be known to properly construct a flow net. These boundary conditions will establish the boundaries of the flow net. The three types of boundaries are: 1) impermeable boundaries; 2) constant head boundaries; and 3) water table boundaries (Freeze and Cherry, 1979). Ground water will not flow across an impermeable boundary; it flows parallel to these boundaries. A boundary where the hydraulic head is constant is termed a constant head boundary. Ground-water flow at a constant head boundary is perpendicular to the boundary. Examples of constant head boundaries are lakes, streams, and ponds. The water table boundary is the upper boundary of an unconfined aquifer, and is a line of known and variable head. Flow can be at any angle in relation to the water table due to recharge and the regional ground-water gradient. The boundary conditions of an aquifer can be determined after a review of the geohydrologic data for a site (U.S. EPA, 1985).

Although a complete understanding of the mathematics of ground-water flow is not necessary for proper flow-net construction by graphical methods, a general understanding of the theory of ground-water flow is required. For a brief discussion of ground-water flow theory as applied to flow nets, refer to Section 1 of the flow net document (U.S. EPA, 1985). Detailed guidance on graphical

construction of flow nets is given in Section 2 of that document. Mathematical techniques can be used to construct flow nets although graphical techniques are the simplest and most commonly used. It is worth noting that flow nets are dimensionless.

When a flow net has been constructed for a site, it is advisable to test the adequacy of the flow net by installing additional piezometers at selected locations. If the site hydrogeology is adequately characterized by the flow net, the head values in the new piezometer(s) will not vary significantly from those predicted by the flow net.

The number of new piezometers needed to check the adequacy of the flow net would vary depending on a number of factors including size of the site, complexity of the site hydrogeology, amount of data used to construct the flow net, and the level of agreement between the site specific flow net and the regional flow regime. For example, at a site with predominantly horizontal flow and well defined stratigraphy, such as illustrated in Figure 10-22, a single new piezometer could test the flow net. For a site with multiple, interconnected aquifers and a significant vertical component of flow, such as illustrated in Figure 10-23, several nested piezometers might be necessary to test the flow net.

In evaluating flow nets and the results of flow net tests, several factors should be kept in mind. The head measurements in a new piezometer may not exactly match the values predicted by the flow net. Some variation is inherent in this type of measurement. The owner or operator should evaluate whether or not the difference between measured and predicted values is significant in the context of flow direction or flow velocity. A new value which reverses the direction of flow or redirects flow towards potential receptors would obviously be significant. A change in flow velocity as indicated by a revised gradient might be significant if the magnitude of the change is substantial or if an increased velocity suggests that the characterization needs to be extended to a greater distance.

There are several situations in which extreme caution is needed in evaluating a flow net test. In many cases, temporal variations will alter the potentiometric surface between the time the flow net is constructed and a test piezometer is installed. Examples of this situation would include locations with large seasonal

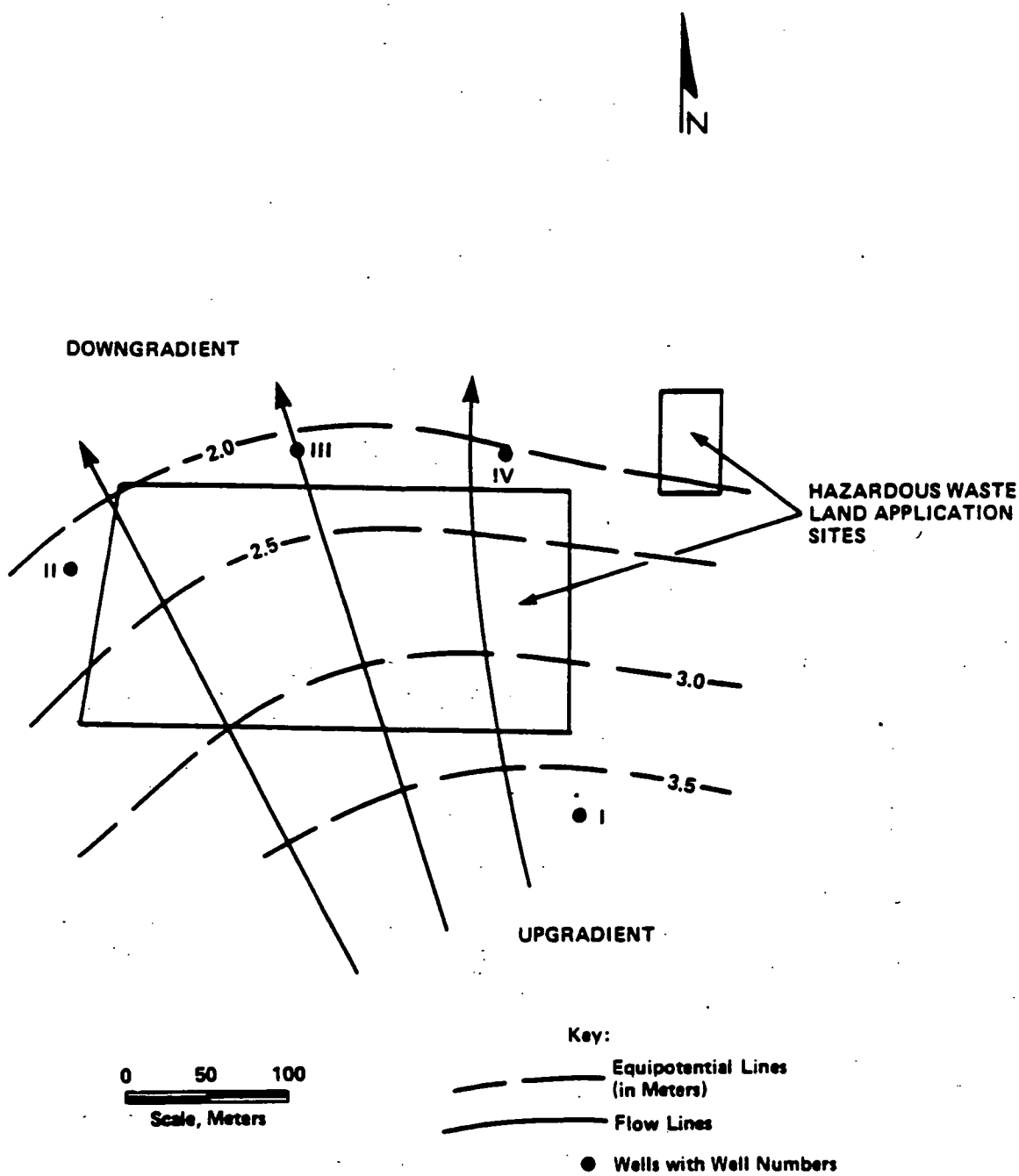


Figure 10-22. Potentiometric surface showing flow direction

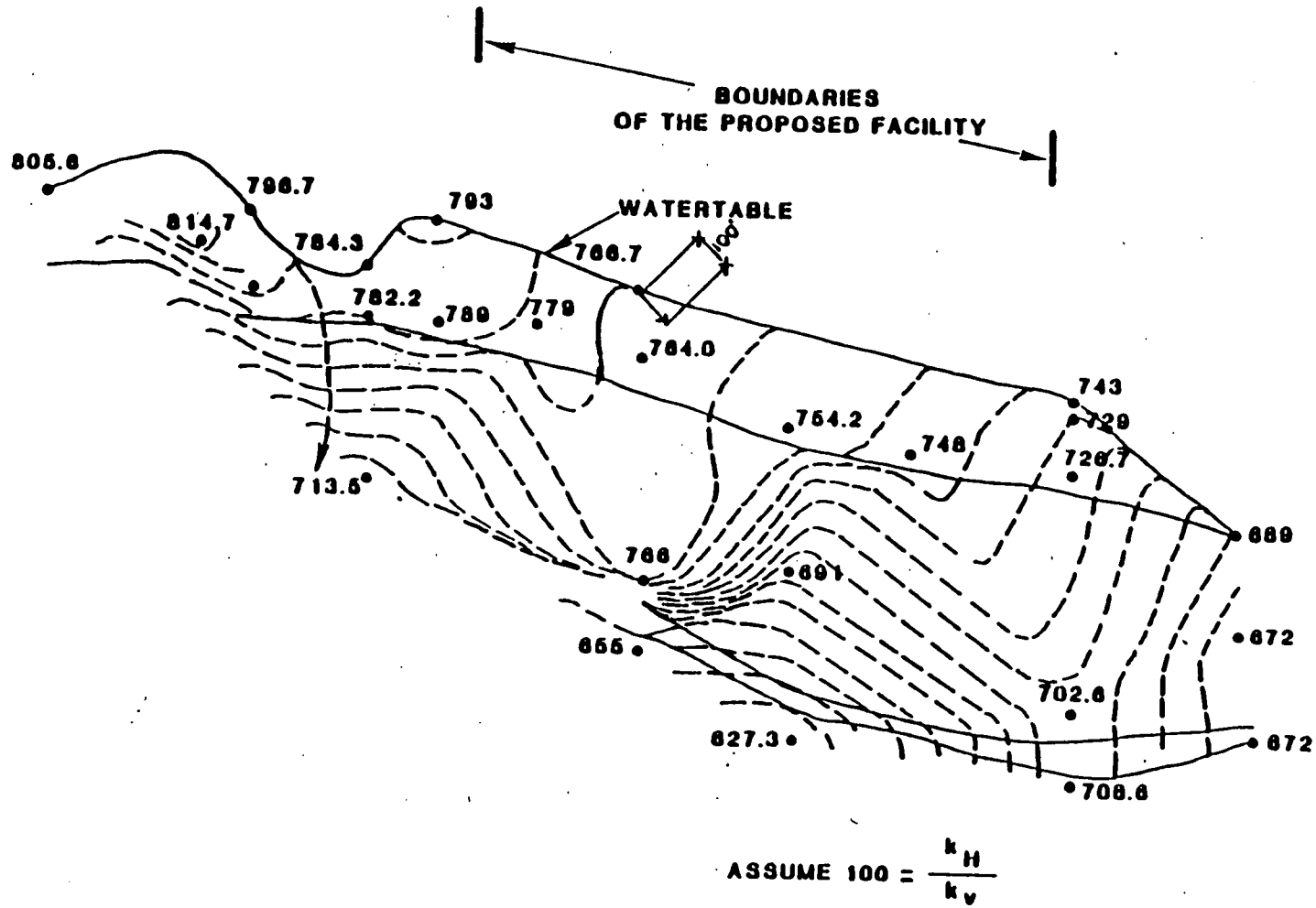


Figure 10-23. Approximate flow net

variations in ground-water levels. Another situation that would introduce problems in interpretation would be a site that is adjacent to tidally influenced surface waters.

Construction of flow nets is not appropriate or valid in certain instances. As discussed in the flow net document (U.S. EPA, 1985), these situations occur when there is a lack of three-dimensional hydrologic data for a ground-water system, and when ground- water flow in a system does not conform to the principles expressed by and assumptions made in Darcy's law. Scaling problems occur when the aquifer and/or geologic layers associated with a particular ground-water system are thin in relation to the length of the flow net. If a flow net is constructed for this situation, the flow net will be made up of squares that are too small to work with unless the scale is exaggerated. For sites where the assumption of steady-state flow is not valid, the construction of flow nets is very difficult. The flow net must be redrawn each time the flow field changes to simulate the transient conditions.

Lack of three-dimensional hydrologic data or hydrologically equivalent data for a ground-water flow system makes proper flow-net construction impossible. Hydrologic testing at various depths within an aquifer and determination of the vertical hydraulic conductivity of an aquifer are essential to provide the necessary data. If these data are not available it will be necessary to obtain them before a flow net can be constructed.

There are three types of ground-water systems in which the principles expressed by Darcy's law do not apply. The first is a system in which the flow is through materials with low hydraulic conductivities under extremely low gradients (Freeze and Cherry, 1979). The second is a system in which a large amount of flow passes through materials with very high hydraulic conductivities. The third is a system in which the porous media assumption is not valid. Darcy's law expresses linear relationships and requires that flow be laminar (flow in which stream lines remain distinct from one another). In a system with high hydraulic conductivity, flow is often turbulent. Turbulent flow is characteristic of karstic limestone and dolomite, cavernous volcanics, and fractured rock systems. Construction of flow nets for areas of turbulent flow would not be valid. The use of Darcy's law also requires the assumption of porous media flow. This assumption may not be valid for many fractured bedrock and karst environments where fractured flow is dominant or large solution features are present.

10.5.3 Characterization of the Release

The objective of monitoring is to estimate the nature, rate, and extent (3-dimensional) of the release. Data are, therefore, collected from a set of monitoring wells that will allow characterization of the dimensions and concentrations of constituents in the plume, as well as the rate of flow.

Subsequent monitoring phases may include the measurement of additional constituents in a more extensive well network than initial monitoring. This will necessitate careful data management. Sections 6.8 and 6.9 of the TEGD (U.S. EPA, 1986) provide useful guidance on organizing, evaluating, and presenting monitoring data. Section 4.7 of the TEGD addresses evaluation of the quality of ground-water data. Specific data presentation and evaluation procedures are presented below.

Migration rates can be determined by using the concentration of monitoring constituents over a period of time in wells aligned in the direction of flow. If these wells are located both at the edge of the release and in the interior of the release, subsequent analysis of the monitoring data can then provide an estimate of the rate of migration both of the contaminant front as a whole and of individual constituents within the release. This approach does not necessarily provide a reliable determination of the migration rates that will occur as the contaminant release moves further away from the facility, due to potential changes in geohydrologic conditions or degradation of the contaminants. More importantly, this approach requires the collection of a time series of data of sufficient duration and frequency to gauge the movement of contaminants. Such a delay is normally inappropriate during initial characterization of ground-water contamination because a relatively quick determination of at least an estimate of migration rates is needed to deduce the impact of ground-water contamination and to formulate an appropriate reaction.

Rapid estimates of migration rates should be made from aquifer properties obtained during the hydrogeologic investigation. The average linear velocity (v) of the ground water should be calculated using the following form of Darcy's law:

$$\bar{v} = \frac{-Ki}{n_e}$$

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where (K) is hydraulic conductivity, (i) is hydraulic gradient, and (n_e) is the effective porosity. This assumes that contaminants flow at the same rate as ground water. This equation can be used to roughly estimate the rate of migration, both of the contaminant front as a whole, and of individual dissolved constituents within the release.

Rough estimates of migration rates beyond the facility property boundary can be made based on aquifer properties obtained during the site hydrogeologic characterization and knowledge of the physical and chemical properties of contaminants known to be present. By recognizing the various factors which can affect the transport of monitoring constituents, the owner or operator can determine approximate migration rates. Continued monitoring of the release over time should be conducted to verify the rate(s) of migration. Information on rate(s) of migration should be used in determining any additional monitoring well locations.

More refined estimates of contaminant migration rates should consider potential differential transport rates among various monitoring constituents. Differential transport rates are caused by several factors, including:

- Dispersion due to diffusion and mechanical mixing;
- Retardation due to adsorption and electrostatic interactions; and
- Transformation due to physical, chemical, and/or biological processes.

Dispersion results in the overall dilution of the contaminant; however, chromatographic separation of the contaminant constituents and differential dispersion effects can result in a contaminant arriving at a particular location before the arrival time computed solely on the average linear velocity of ground-water flow. Alternately, retardation processes can delay the arrival of contaminants beyond that calculated using average ground-water flow rate(s). Transformation of waste constituents is a complex process which can be difficult to estimate. While some contaminants, such as radionuclides, decay at a constant rate over time, most degradable chemicals are influenced by a variety of factors and the interactions of

these factors can be extremely difficult to predict. Local geologic variations will also affect constituent migration rates. Relating constituent migration rates to ground-water flow rates is a reasonable and relatively quick way to estimate contaminant flow rates. Where possible, contaminant- specific migration rates should also be determined.

Procedures for the evaluation of monitoring data vary in a site-specific manner, but should all result in determinations of the rate of migration, extent, and composition of hazardous constituents of the release. Where the release is obvious and/or chemically simple, it may be possible to characterize it readily from a descriptive presentation of concentrations found in monitoring wells and through geophysical measurements. Where contamination is less obvious or the release is chemically complex, however, the owner or operator may employ a statistical inference approach. The owner or operator should plan initially to take a descriptive approach to data analysis in order to broadly delineate the extent of contamination. Statistical comparisons of monitoring data among wells and/or over time may be necessary, should the descriptive approach provide no clear determination of the rate of migration, extent, and hazardous constituent composition of the release.

10.6 Field Methods

10.6.1 Geophysical Techniques

During the past decade, extensive development of remote sensing geophysical equipment, portable field instrumentation, field methods, analytical techniques and related computer processing have resulted in an improvement in the capability to characterize hydrogeology and contaminant releases. Some of these geophysical methods offer a means of detecting contaminant plumes and flow directions in both the saturated and unsaturated zones. Others offer a way to obtain detailed information about subsurface soil and rock characteristics. This capability to rapidly analyze subsurface conditions without disturbing the site may provide a better overall understanding of complex site conditions, with relatively low risk to the investigative team.

Various geophysical techniques, including electromagnetic, seismic refraction, electrical resistivity, ground penetrating radar, magnetic, and several borehole methods, can be applicable to RCRA Facility Investigations. Table 10-6 suggests appropriate applications for the various geophysical methods. Appendix C provides additional information.

10.6.2 Soil Boring and Monitoring Well Installation

10.6.2.1 Soil Borings

Soil borings should be sufficient to characterize the subsurface geology below the site. Section 1.2 of TEGD (U.S. EPA, 1986) provides criteria for adequate borings. A summary of these criteria is presented below.

- Installation of initial boreholes at a density based on criteria described in Table 10-7 and sufficient to provide initial information upon which to determine the scope of a more detailed evaluation of geology and potential pathways of contaminant migration.

- Initial boreholes should be drilled into the first confining layer beneath the uppermost aquifer. The portion of the borehole extending into the confining layer should be plugged properly after a sample is taken.

- Additional boreholes should be installed in numbers and locations sufficient to characterize the geology beneath the site. The number and locations of additional boreholes should be based on data from initial borings and indirect investigation.

- Collection of samples of every significant stratigraphic contact and formation, especially the confining layer should be taken. Continuous cores should be taken initially to ascertain the presence and distribution of small and large scale permeable layers. Once stratigraphic control is established, samples taken at regular intervals (e.g., five foot) could be substituted for continuous cores.

TABLE 10-6. APPLICATIONS OF GEOPHYSICAL METHODS TO HAZARDOUS WASTE SITES

APPLICATION	RADAR	ELECTROMAGNETICS	RESISTIVITY	SEISMIC	METAL DETECTOR	MAGNETOMETER
Mapping of Geohydrologic Features	1	1	1	1	-	-
Mapping of Conductive Leachates and Contaminant Plumes (e.g., Landfills, Acids, Bases)	2	1	1	-	-	-
Locations and Boundary Definition of Buried Trenches with Metal	1	1	2	2	2	2
Location and Boundary Definition of Buried Trenches without Metal	1	1	2	2	-	-
Location and Definition of Buried Metallic Objects (e.g., Drums, Ordinance)	2	2	-	-	1	1

1. Primary method - Indicates the most effective method
2. Secondary method - Indicates an alternate approach

Source: EPA, 1982, Geophysical Techniques for Sensing Buried Waste and Waste Migration

TABLE 10-7. FACTORS INFLUENCING DENSITY OF INITIAL BOREHOLES

Factors That May Substantiate Reduced Density of Boreholes:	Factors That May Substantiate Increased Density of Boreholes:
• Simple geology (i.e., horizontal, thick, homogeneous geologic strata that are continuous across site that are unfractured and are substantiated by regional geologic information).	• Fracture zones encountered during drilling.
• Use of geophysical data to correlate well log data.	• Suspected pinchout zones (e.g., discontinuous areas across the site).
	• Geologic formations that are tilted or folded.
	• Suspected zones of high permeability that would not be defined by drilling at 300-foot intervals.
	• Laterally transitional geologic units with irregular permeability (e.g., sedimentary facies changes).

- Boreholes in which permanent wells are not constructed should be sealed with materials at least an order of magnitude less permeable than the surrounding soil/sediment/rock in order to reduce the number of potential contaminant pathways.

- Samples should be logged in the field by a qualified professional geologist.

- Sufficient laboratory analysis should be performed to provide information concerning petrologic variation, sorting (for unconsolidated sedimentary units), cementation (for consolidated sedimentary units), moisture content, and hydraulic conductivity of each significant geologic unit or soil zone above the confining layer/unit.

- Sufficient laboratory analysis should be performed to describe the mineralogy (X-ray diffraction), degree of compaction, moisture content, and other pertinent characteristics of any clays or other fine- grained sediments held to be the confining unit/layer. Coupled with the examination of clay mineralogy and structural characteristics should be a preliminary analysis of the reactivity of the confining layer in the presence of the wastes present.

ASTM or equivalent methods should be used for soil classification, specifically:

- ASTM Method D422-63 for the particle size analysis of soils, which describes the quantitative determination of the distribution of particle sizes in soils; and

- ASTM Methods D2488-69, for the identification and description of soils based on visual examination and simple manual tests.

An adequate number of geologic cross-sections should be presented by the owner or operator. These cross-sections should adequately depict major geologic or structural trends and reflect geologic/structural features in relation to groundwater flow. Additionally, an owner or operator should provide a surface topo-

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graphic map and aerial photograph of the site. Details regarding specific means for the presentation of geologic data are presented in Section 5 and in Section 1.2.3 of the TEGD (U.S. EPA, 1986).

10.6.2.2 Monitoring Well Installation

The owner or operator is advised to consult Chapter Three of the TEGD (U.S. EPA, 1986) for guidance on monitoring well installation. This chapter provides information on the following topics:

- Drilling Methods for Installing Wells--Section 3.1 (TEGD) discusses a variety of well drilling methods and corresponding applicability to the installation of RCRA monitoring wells. The selection of the actual drilling method that an owner or operator should use at a particular site is a function of site-specific geologic conditions. Of utmost importance is that the drilling method the owner or operator uses will minimize the disturbance of subsurface materials and will not cause contamination of the ground water.

- Monitoring Well Construction Materials--Section 3.2 (TEGD) discusses the selection of construction materials for RCRA monitoring wells which are durable enough to resist chemical and physical degradation, and do not interfere with the quality of ground-water samples. Specific well components that are of concern include well casings, well screens, filter packs, and annular seals.

- Design of Well Intakes--Section 3.3 (TEGD) discusses the design and construction of the intake of monitoring wells so as to: (1) allow sufficient ground-water flow to the well for sampling; (2) minimize the passage of formation materials (turbidity) into the well; and (3) ensure sufficient structural integrity to prevent the collapse of the intake structure.

- Development of Wells--Section 3.4 (TEGD) discusses the requirements for proper development of the monitoring wells to ensure turbid-free ground water samples.

- Documentation of Well Construction Activity--Section 3.5 (TEGD) lists the information required for the design and construction of wells as follows:

  - date/time of construction;
  - drilling method and drilling fluid used;
  - well location (± 0.5 ft);
  - borehole diameter and well casing diameter;
  - well depth (± 0.1 ft);
  - drilling and lithologic logs;
  - casing materials;
  - screen materials and design;
  - casing and screen joint type;
  - screen slot size/length;
  - filter pack material/size;
  - filter pack volume calculations;
  - filter pack placement method;
  - sealant materials (percent bentonite);
  - sealant volume (lbs/gallon of cement);
  - sealant placement method;
  - surface seal design/construction;
  - well development procedure;
  - type of protective well cap;
  - ground surface elevation (± 0.01 ft);
  - top of casing elevation (± 0.01 ft); and
  - detailed drawing of well (including dimensions).

- Specialized Well Design--Section 3.6 (TEGD) discusses two cases which require special monitoring well design: (1) where dedicated pumps are used to draw ground-water samples; and (2) where light and/or dense phase immiscible layers are present.

- Evaluation of Existing Wells--Section 3.7 (TEGD) discusses how to evaluate the ability of existing wells to produce representative ground-water samples.

Particular attention should be paid to the discussion in Section 3.2.1 regarding well casing materials (TEGD). It is imperative that well materials are nonreactive to contaminants that may be present in the ground water. In cases where the facility has existing monitoring wells which could potentially be used in the RFI, the owner or operator should evaluate whether these wells are capable of producing representative ground-water samples. A demonstration involving the installation of new well(s) near existing wells and the analysis and comparison of samples for the same monitoring constituents from both wells may be necessary if the existing wells' integrity is in question.

10.6.3 Aquifer Characterization

10.6.3.1 Hydraulic Conductivity Tests

In addition to defining the direction of ground-water flow in the vertical and horizontal direction, the owner or operator should identify areas of high and low hydraulic conductivity within each formation. Variations in the hydraulic conductivity of subsurface materials can create irregularities in ground-water flow paths. Areas of high hydraulic conductivity represent areas of greater ground-water flow and, if contaminants are present, zones of potential migration. Therefore, information on hydraulic conductivities is generally required before the owner or operator can make reasoned decisions regarding well placements. It may be beneficial to use analogy or laboratory methods to corroborate results of field tests; however, only field methods provide direct information that is adequate to define the hydraulic conductivity.

Hydraulic conductivity can be determined in the field using single well tests, more commonly referred to as slug tests, which are performed by suddenly adding or removing a slug (known volume) of water from a well or piezometer and observing the recovery of the water surface to its original level. Similar results can be achieved by pressurizing the well casing, depressing the water level, and suddenly releasing the pressure to simulate removal of water from the well. Where slug tests are not appropriate (e.g., in fractured flow aquifers), hydraulic conductivity can be determined by multiple well (pumping) tests.

Slug testing is applied by hydrogeologists in many field situations. Interpretation of the results requires some professional judgement. Slug test accuracy is reduced when dealing with extreme values of hydraulic conductivity. Very low values (e.g., less than 10^{-6} cm/sec) are more accurately measured by a resurg head test after bailing or pumping the well dry. High values (e.g., greater than 10^{-2} cm/sec) generally require fast response electronic measurement equipment. High value cases in fractured rock or karst terrain may be misleading if the slug test is measuring the most permeable fractures or solution channels. In such cases, the test results may be misinterpreted to give an artificially high value for the formation as a whole.

When reviewing information obtained from slug tests, several criteria should be considered. First, slug tests are run on one well and, as such, the information obtained from single well tests is limited in scope to the geologic area directly adjacent to the well. Second, the vertical extent of screening will control the part of the geologic formation that is being tested during the slug test. That part of the column above or below the screened interval that has not been tested during the slug test will not have been adequately tested for hydraulic conductivity. Third, the methods used to collect the information obtained from slug tests should be adequate to measure accurately parameters such as changing static water (prior to initiation, during, and following completion of slug test), the amount of water added to, or removed from the well, and the elapsed time of recovery. This is especially important in highly permeable formations where pressure transducers and high speed recording equipment should be used. Lastly, interpretation of the slug test data should be consistent with the existing geologic information (e.g., boring log data). It is, therefore, important that the program of slug testing ensure that enough tests are run to provide representative measures of hydraulic conductivity, and to document lateral and vertical variation of hydraulic conductivity in the geologic materials below the site.

It is important that hydraulic conductivity measurements define hydraulic conductivity both in a vertical and horizontal manner across a site. In assessing hydraulic conductivity measurements, results from the boring program used to characterize the site geology should be considered. Zones of expected high permeability or fractures identified from drilling logs should generally be included in the determination of hydraulic conductivity. Additionally, information from

coring logs can be used to refine the data generated by slug tests (TEGD, Section 1.3.3).

Techniques for determining hydraulic conductivity are specified in Method 9100, Saturated Hydraulic Conductivity, Saturated Leachate Conductivity, and Intrinsic Permeability; from SW-846, Test Methods for Evaluating Solid Waste, 3rd edition, 1986. Method 9100 includes techniques for:

- Laboratory
  - sample collection;
  - constant head methods; and
  - falling head methods.
- Field
  - well construction;
  - well development;
  - single well tests (slug tests); and
  - references for multiple well (pumping) tests.

Cedergren, 1977 also provides an excellent discussion on aquifer tests, including laboratory methods (constant head and falling head), multiple well (pumping) tests (steady-state and nonsteady-state), and single well tests (open-end, packer, and others).

10.6.3.2 Water Level Measurements

Water level measurements are necessary for determining depth to the water table and mapping ground-water contours to determine hydraulic gradients and flow rates. Depths to water are normally measured with respect to the top of the casing as in well depth determinations. Several methods are available, including the electric sounder and the chalked steel tape.

The electric sounder, although not the most accurate method, is recommended for initial site work because of the minimal potential for equipment

contamination and simplicity of use. Sounders usually consist of a conductivity cell at the end of a graduated wire, and a battery powered buzzer. When the cell contacts the water the increased conductivity completes the circuit and allows current to flow to the alarm buzzer. The depth to water can then be read from the graduations on the wire or the wire can be measured directly. This device may not be suitable for use if a potentially flammable or explosive layer (e.g., due to methane gas) is present in the well, unless it is an intrinsically safe device.

The chalked steel tape is a more accurate device for measuring static water levels. The lower 0.5 to 1.0 meters of a steel measuring tape is coated on either side with either carpenter's chalk or any of the various indicating pastes. A weight is attached to the lower end to keep the tape taut and it is lowered into the center of the well (condensate on the casing wall may prematurely wet the tape). A hollow "plopping" sound occurs when the weight reaches water, then the tape is lowered very slowly for at least another 15 cm, preferably to an even increment on the measuring tape. Next, the tape is carefully withdrawn from the well; water depth is determined by subtracting the wetted length of tape from the total length of tape in the well. In small diameter wells, the volume of the weight may cause the water to rise by displacement. In general, the use of indicating paste or chalk should be discouraged although they may not present a significant problem if water samples are not collected. As with all depth measurement devices, the wetted section of the tape and the weight must be thoroughly cleaned before reuse to avoid cross-contamination.

The following sections of the TEGD (U.S. EPA, 1986) should be consulted for water level measurement requirements, and information on data interpretation:

- Ground-water level measurement (1.3.1.1);
- Interpretation of ground-water level measurements (1.3.1.2);
- Establishing vertical components of ground-water flow (1.3.1.3); and
- Interpretation of flow direction (1.3.1.4).

10.6.3.3 Dye Tracing

Dye tracing is a field method which can be used to measure the velocity of ground water for highly permeable strata (such as karst terrain and highly fractured rock media). When the velocity of flowing water and the hydraulic gradient at a common point are known, the permeability can be estimated. The hydraulic gradient (i) of an existing water table can be estimated from wells in the area. If not, observation wells must be installed (Cedergren, 1977).

The procedure used in dye tracing involves the insertion of a dye, such as fluorescein sodium into a test hole and observation of the time it takes to emerge in a nearby test pit or on a bank from which seepage is emerging. The average linear velocity, v, is determined by dividing the distance traveled, L, by the time of travel, t. The effective porosity, n_e, is determined from test data for the in-place soil; if no tests are available, it is determined using the values in Table 10-4. The hydraulic conductivity is calculated from the equation:

$$K = \frac{\bar{v} n_e}{i}$$

It should be noted that the time required for tracers to move even short distances can be very long unless the formations contain highly permeable strata (Cedergren, 1977). As a result of the limitations of tracer techniques, this type of study is applied only in highly specialized locations. Uncertainties associated with the flow path make interpretation of the results difficult. This technique has been used effectively in conjunction with modeling in complex terrain with the tracer study serving to calibrate the model.

10.6.4 Ground-Water Sample Collection Techniques

The procedure for collecting a ground water sample involves the following steps presented in Chapter 4 of TEGD (U.S. EPA, 1986):

- Measurement of static water level elevation (4.2.1);

- Monitoring of immiscible layers (4.2.2);
- Well evacuation (4.2.3);
- Sample withdrawal (4.2.4);
- In situ or field analyses (4.2.5);
- Sample preservation and handling (4.3); and
- Chain-of-custody procedures (4.4).

Collection of static water level elevations on a continuing basis is important to determine if horizontal and vertical flow gradients have changed since initial site characterization, which could necessitate modification of the ground-water monitoring system. Steps should be taken to monitor for the presence and/or extent of light and/or dense phase immiscible organic layers before the well is evacuated for conventional sampling if wastes of this type are present at the facility.

The water standing in the well prior to sampling may not be representative of in situ ground-water quality. Therefore, the owner or operator should remove the standing water in the well so that water which is representative of the formation can replace the standing water. Purged water should be collected and screened with photoionization or organic vapor analyzers, pH, temperature, and conductivity meters. If these parameters and facility background data suggest that the water may be hazardous, it should be drummed and disposed of properly.

The technique used to withdraw a ground-water sample from a well should be selected based on a consideration of the parameters which will be analyzed in the sample. To ensure the ground-water sample is representative of the formation, it is important to avoid physically altering or chemically contaminating the sample during the withdrawal process. In order to minimize the possibility of sample contamination, the owner or operator should:

(1) Use only polytetrafluoroethylene (PTFE) or stainless steel sampling devices; and

(2) Use dedicated samplers for each well. (If a dedicated sampler is not available for each well, the sampler should be thoroughly cleaned between sampling events, and blanks should be taken and analyzed to ensure that cross contamination has not occurred.)

Section 4.2.4 of TEGD (U.S. EPA, 1986) includes specific factors to take into consideration regarding sample withdrawal.

Some parameters are physically or chemically unstable and must be tested either in the borehole using a probe (in situ) or immediately after collection using a field test kit. Examples of several unstable parameters include pH, redox potential, chlorine, dissolved oxygen, and temperature. Although specific conductivity (analogous to electrical resistance) is relatively stable, it is recommended that this characteristic also be determined in the field. Most conductivity instruments require temperature compensation; therefore, temperatures of the samples should be measured at the time conductivity is determined.

Many of the constituents and parameters that are included in ground-water monitoring programs are not stable and, therefore, sample preservation may be required. Refer to methods from EPA's Test Methods for Evaluating Solid Waste - Physical/Chemical Methods, 1986 (EPA/SW-846 GPO No. 955-001-00000-1) for sample preservation procedures and sample container requirements.

Improper sample handling may lead to sample contamination. Samples should be transferred into their containers in such a way as to minimize any contamination. Handling methods are analyte dependent. Special handling considerations for various analyte types are discussed in Section 4.3.3 of the TEGD (U.S. EPA, 1986).

An adequate chain-of-custody program will allow for the tracing of possession and handling of individual samples from the time of field collection through laboratory analysis. An owner or operator's chain-of-custody program requirements are detailed in Section 4 (Quality Assurance and Quality Control).

Chapter Four of the TEGD (U.S. EPA, 1986) may also be consulted for sample collection techniques as well as for analytical procedures, field and laboratory QA/QC requirements, and suggestions for reporting of ground-water data. Section 4 of this guidance presents a general discussion of QA/QC. In addition, the owner or operator may also find the following publication useful for sampling information:

- U.S. EPA. September, 1987. Practical Guide for Ground Water Sampling. EPA/600/2-85/104. NTIS PB86-137304. Washington, D.C. 20460.

10.7 Site Remediation

Although the RFI Guidance is not intended to provide detailed guidance on site remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated sites that directs users toward technical support, potential data requirements and technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

This guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

In addition to the above described reference, several ground-water computer modeling programs are available to assist in designing ground-water remediation systems, such as the one referenced below. Application of such models should be based on site-specific considerations, as most models are not applicable to all situations.

U.S. EPA. 1987. Zone of Capture for Ground Water Corrective Action. IBM Compatible Computer Program and Users Guide. Federal Computer Products

Center, National Technical Information Service. Springfield, VA 22161.

10.8 Checklist

RFI CHECKLIST- GROUND WATER

Site Name/Location _____

Type of Unit _____

1. Does waste characterization include the following information? (Y/N)
   - Constituents of concern/supporting indicator parameters _____
   - Concentrations of constituents _____
   - Physical form of waste _____
   - Chemical properties of waste (organic, inorganic, acid, base) and constituents _____
   - pH _____
   - pKa _____
   - Viscosity _____
   - Water solubility _____
   - Density _____
   - K_{ow} _____
   - Henry's Law Constant _____
   - Physical and chemical degradation (e.g., hydrolysis) _____

2. Does unit characterization include the following information? (Y/N)
   - Age of unit _____
   - Construction integrity _____
   - Presence of liner (natural or synthetic) _____
   - Location relative to ground-water table or bedrock or other confining barriers _____
   - Unit operation data _____
   - Presence of cover _____
   - Presence of on/offsite buildings _____
   - Depth and dimensions of unit _____
   - Inspection records _____
   - Operation logs _____

RFI CHECKLIST- GROUND WATER (Continued)

- Past fire, explosion, or other complaint reports _____
- Existing ground-water monitoring data _____
- Presence of natural or engineered barriers near unit _____

3. Does environmental setting information include the following information?

(Y/N)

Site Soil Characteristics

- Grain size distribution and gradation _____
- Hydraulic Conductivity _____
- Porosity _____
- Discontinuities in soil strata (e.g., faults) _____
- Degree and orientation of subsurface stratification and bedding _____

Ground-Water Flow System Characterization (Y/N)

- Use of aquifer _____
- Regional flow cells and flow nets _____
- Depth to water table _____
- Direction of flow _____
- Rate of flow _____
- Hydraulic conductivity _____
- Storativity/specific yield (effective porosity) _____
- Aquifer type (confined or unconfined) _____
- Aquifer characteristics (e.g., homogeneous, isotropic, leaky) _____
- Hydraulic gradient _____
- Identification of recharge and discharge areas _____
- Identification of aquifer boundaries (i.e., areal extent) _____
- Aquitard characteristics (depth, permeability degree of jointing, continuity) _____

Ground-Water Quality Characteristics (Y/N)

- Presence of minerals and organics _____
- Background water quality _____
- Monitoring constituents and indicator parameters _____

4. Have the following data on the initial phase of the release characterization been collected? (Y/N)
   - Extent _____
   - Location _____
   - Shape _____
   - Hydraulic gradient across plume _____
   - Depth to plume _____
   - Chemistry and concentration _____
   - Velocity _____
   - Potential receptors _____

5. Have the following data on the subsequent phase(s) of the release characterization been collected? (Y/N)
   - Extent _____
   - Location _____
   - Shape _____
   - Hydraulic gradient across plume _____
   - Depth to plume _____
   - Chemistry and concentration _____
   - Velocity _____
   - Potential receptors _____

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SECTION 11

SUBSURFACE GAS

11.1 Overview

This section applies to units with subsurface gas releases, primarily landfills, leaking underground tanks, and units containing putrescible organic matter, but may include other units.

The objective of an investigation of a subsurface gas release is to verify, if necessary, that subsurface gas migration has occurred and to characterize the nature, extent, and rate of migration of the release of gaseous material or constituents through the soil. Methane gas should be monitored because it poses a hazard due to its explosive properties when it reaches high concentrations, and also because it can serve as an indicator (i.e., carrier gas) for the migration of hazardous constituents. Other gases (e.g., carbon dioxide and sulfur dioxide) may also serve as indicators. This section provides:

- An example strategy for characterizing subsurface gas releases, which includes characterization of the source and the environmental setting of the release, and conducting monitoring to characterize the release itself;
- Formats for data organization and presentation;
- Field methods which may be used in the investigation; and
- A checklist of information that may be needed for release characterization.

The exact type and amount of information required for sufficient release characterization will be site-specific and should be determined through interactions between the regulatory agency and the facility owner or operator during the RFI process. This guidance does not define the specific data required in all instances;

however, it identifies possible information which may be necessary to perform release characterizations and methods for obtaining this information. The RFI Checklist, presented at the end of this section, provides a tool for planning and tracking information for subsurface gas release characterizations. This list is not meant to serve as a list of requirements for all subsurface gas releases to soil. Some releases will involve the collection of only a subset of the items listed.

As indicated in the following sections, subsurface gas migrates along the path of least resistance, and can accumulate in structures (primarily basements) on or off the facility property. If this occurs, it is possible that an immediate hazard may exist (especially if the structures are used or inhabited by people) and that interim corrective measures may be appropriate. Where conditions warrant, the owner or operator should immediately contact the regulatory agency and consider immediate measures (e.g., evacuation of a structure).

Case Study Numbers 23 and 24 in Volume IV (Case Study Examples) provide examples of subsurface gas investigations.

11.2 Approach for Characterizing Subsurface Gas Releases

11.2.1 General Approach

The collection and review of existing information for characterization of the contaminant source and the environmental setting will be the primary basis for development of a conceptual model of the release and subsequent development of monitoring procedures to characterize the release. A conceptual model of the release should be formulated using all available information on the waste, unit characteristics, environmental setting, and any existing monitoring data. This model (not a computer or numerical simulation model) should provide a working hypothesis of the release mechanism, transport pathway/mechanism, and exposure route (if any). The model should be testable/verifiable and flexible enough to be modified as new data become available.

The conceptual model for subsurface gas should consider the ability of the waste to generate gaseous constituents, the conditions which would favor subsurface migration of the gaseous release, and the likelihood of such a release to reach and accumulate within structures (e.g., residential basements) at explosive or toxic concentrations.

Additional data collection to characterize the contaminant source and environmental setting may be necessary prior to implementing the monitoring procedures. The subsurface pathway data collection effort should be coordinated, as appropriate, with similar efforts for other media investigations.

Characterization of subsurface gas releases can be accomplished through a phased monitoring approach. An example of a strategy for characterizing subsurface gas releases is shown in Table 11-1.

Development of monitoring procedures should include determining the specific set of subsurface gas indicators and constituents for monitoring. Methane, carbon dioxide, and site-specific volatile organics (e.g., vinyl chloride), can be used to identify the presence of subsurface gas during initial monitoring. Subsequent monitoring will generally involve these gases, but may also involve various other constituents. Development of the monitoring procedures should also include selection of the appropriate field and analytical methods. Selection of these methods will be dependent on site and unit specific conditions.

An initial monitoring phase should be implemented using screening techniques and appropriate monitoring constituent(s). A subsurface gas migration model can be used, as applicable, as an aid in selection of monitoring locations. Subsequent monitoring will generally be necessary if subsurface gas migration is detected during the initial survey. This additional monitoring may include a wider range of constituents.

Characterization of a subsurface gas release can involve a number of tasks to be completed throughout the course of the investigation. These tasks are listed in Table 11-2 with associated techniques and data outputs.

TABLE 11-1

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES OF SUBSURFACE GAS[1]

INITIAL PHASE

1. Collect and review existing information on:

   - Waste
   - Unit
   - Environmental setting
   - Contaminant releases, including inter-media transport

2. Identify any additional information necessary to fully characterize release:

   - Waste
   - Unit
   - Environmental setting
   - Contaminant releases, including inter-media transport

3. Develop monitoring procedures:

   - Formulate conceptual model of release
   - Determine monitoring program objectives
   - Determine monitoring constituents and indicator parameters
   - Sampling approach selection
   - Sampling schedule
   - Monitoring locations
   - Analytical methods
   - QA/QC procedures

4. Conduct Initial Monitoring:

   - Use subsurface gas migration model to estimate release dimensions (plot 1.0 and 0.25 lower explosion limit isopleths for methane)
   - Monitor ambient air and shallow boreholes around the site using portable survey instruments to detect methane and other indicator parameters
   - Use results of above two steps to refine conceptual model and determine sampling locations and depths; conduct limited well installation program. Monitor well gas and shallow soil boreholes for indicators and constituents
   - Monitor surrounding structures (e.g., buildings and engineered conduits) for other indicator parameters and constituents

5. Collect, evaluate and report results:

   - Compare methane results with lower explosion limit (LEL) and 0.25 LEL and report results immediately to regulatory agency if these values are exceeded

TABLE 11-1 (Continued)

EXAMPLE STRATEGY FOR CHARACTERIZING RELEASES OF SUBSURFACE GAS[1]

- Summarize and present data in appropriate format
- Determine if monitoring program objectives were met
- Determine if data are adequate to describe nature, rate and extent of release
- Report results to regulatory agency

SUBSEQUENT PHASES (If Necessary)

1. Identify additional information necessary to characterize release:

   - Modify conceptual model and identify additional information needs
   - Selection of monitoring constituents for subsequent phase
   - Spatial extent of subsurface gas migration
   - Concentration levels of methane and other indicators and additional monitoring constituents
   - Evaluate potential role of inter-media transport

2. Expand initial monitoring as necessary:

   - Expand subsurface gas well monitoring network
   - Add or delete constituents and parameters
   - Expand number of structures subject to monitoring
   - Increase or decrease monitoring frequency

3. Conduct subsequent monitoring:

   - Perform expanded monitoring of area for methane and other indicator parameters and specific monitoring constituents
   - Further monitoring of surrounding structures if warranted

4. Collect, evaluate and report results/identify additional information necessary to characterize release:

   - Compare monitoring results to health and environmental criteria and identify/respond to emergency situations and identify priority situations that warrant interim corrective measures - notify regulatory agency immediately
   - Summarize and present data in appropriate format
   - Determine if monitoring program objectives were met
   - Determine if data are adequate to describe nature, rate, and extent of release
   - Identify additional information needs
   - Determine need to expand monitoring system
   - Evaluate potential role of inter-media transport
   - Report results to regulatory agency

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1 The possibility for inter-media transport of contamination should be anticipated throughout the investigation.

TABLE 11-2
RELEASE CHARACTERIZATION TASKS FOR SUBSURFACE GAS

Investigatory Tasks	Investigatory Techniques	Data Presentation Formats/Outputs
1. Waste/Unit Characterization		
- Identification of waste constituents of concern	- See Sections 3, 7 and Appendix B	- Listing of potential monitoring constituents
- Identification of unit characteristics which promote a subsurface gas release	- See Section 7	- Description of the unit, if active, and operational conditions concurrent with subsurface gas sampling
2. Environmental Setting Characterization		
- Definition of climate	- Climate summaries for regional National Weather Service stations	- Tabular summaries for parameters of interest
- Definition of site-specific meteorological conditions	- Meteorological data from regional National Weather Service stations	- Tabular listing for parameters of interest concurrent with subsurface gas sampling
- Definition of soil conditions	- See Section 9 (e.g., porosity, moisture content, organic carbon content, etc.)	- Soil physical properties
- Definition of site-specific terrain	- See Sections 7, 9 and Appendix A	- Topographic map of site area
- Identification of subsurface gas migration pathways	- Review of unit design and environmental setting	- Identification of possible migration pathways
	- Review of water level measurements	- Depth to water table
- Identification and location of engineered conduits	- Examination of maps, engineering diagrams, etc.	- Description of the examination
	- Ground penetrating radar (See Appendix C)	- Results of study
- Identification and location of surrounding structures	- Survey of surrounding area	- Map with structures identified
3. Release Characteriziation		
- Model extent of release	- Gas migration model (See Appendix D)	- Estimated methane concentration isopleths for LEL and 0.25 LEL
- Screening evaluation of subsurface gas release	- Shallow borehole monitoring and monitoring in surrounding buildings for indicators and specific constituent(s)	- Listing of concentrations levels
- Measurement for specific constituents	- Selected gas well installation and monitoring	- Tables of concentrations - Detailed assessment of extent and magnitude of releases
	- Monitoring in surrounding buildings	- Tables of concentrations

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As monitoring data become available, both within and at the conclusion of discrete investigation phases, it should be reported to the regulatory agency as directed. The regulatory agency will compare the monitoring data to applicable health and environmental criteria to determine the need for (1) interim corrective measures; and/or (2) a Corrective Measures Study. In addition, the regulatory agency will evaluate the monitoring data with respect to adequacy and completeness to determine the need for any additional monitoring efforts. The health and environmental criteria and a general discussion of how the regulatory agency will apply them are supplied in Section 8. A flow diagram illustrating RFI decision points is provided in Section 3 (See Figure 3-2).

Notwithstanding the above process, the owner or operator has a continuing responsibility to identify and respond to emergency situations and to define priority situations that may warrant interim corrective measures. For these situations, the owner or operator is directed to obtain and follow the RCRA Contingency Plan requirements under 40 CFR Part 264, Subpart D.

11.2.2 Inter-media Transport

Contaminated ground water and contaminated soil can result in releases of gaseous constituents via subsurface migration, primarily due to volatilization of organic constituents. Information collected from ground-water and soil investigations may provide useful input data for the subsurface gas pathway characterization. It may also be more efficient to jointly conduct monitoring programs for such related media (e.g., concurrent ground water and subsurface gas migration monitoring programs).

Subsurface gas migration also has the potential for inter-media transport (e.g., transfer of contamination from subsurface gas to the soil and air media). Therefore, information from the subsurface gas migration investigation will also provide useful input for assessing soil contamination and potential air emissions.

11.3 Characterization of the Contaminant Source and the Environmental Setting

The type of waste managed in the unit will determine the conditions under which the gas can be generated, and the type of unit and characteristics of the

surrounding environment (e.g., soil type and organic content) establishes potential migration pathways. Units which may be of particular concern for subsurface gas releases contain putrescible organic material and generally include below grade landfills, units closed as landfills (e.g., surface impoundments), and underground tanks. These types of units may have waste deposited or stored at such depths as to allow for subsurface gas generation by volatilization or decomposition of organic wastes and subsequent migration (see Figures 11-1 and 11-2).

The nature and extent of contamination are affected by environmental processes such as dispersion, diffusion, and degradation, that can occur before and after the release occurred. Factors that should be considered include soil physical and chemical properties, subsurface geology and hydrology, and in some cases, climatic or meteorologic patterns.

The principle components of "landfill gas" are generally methane and carbon dioxide produced by the anaerobic decomposition of organic materials in wastes. Methane is of particular concern due to its explosive/flammable properties, although other gases of concern could be present. The presence of these other gases in a unit is primarily dependent upon the types of wastes managed, the volatilities of the waste constituents, temperature, and possible chemical interactions within the waste. Previous studies (e.g., Hazardous Pollutants in Class II Landfills, 1986, South Coast Air Quality Management District, El Monte, California and U.S. EPA. 1985. Technical Guidance for Corrective Measures - Subsurface Gas. Washington, D.C. 20460) have indicated that the predominant components of landfill gas are methane and carbon dioxide. Methane is generally of greater concentration, however, carbon dioxide levels are generally also high, especially during the early stages of the methane generation process. Concentrations of subsurface gas constituents which may accompany methane/carbon dioxide are generally several orders of magnitude less than methane. In some cases (e.g., associated with acidic refinery wastes) sulfur dioxide may be the primary subsurface gas.

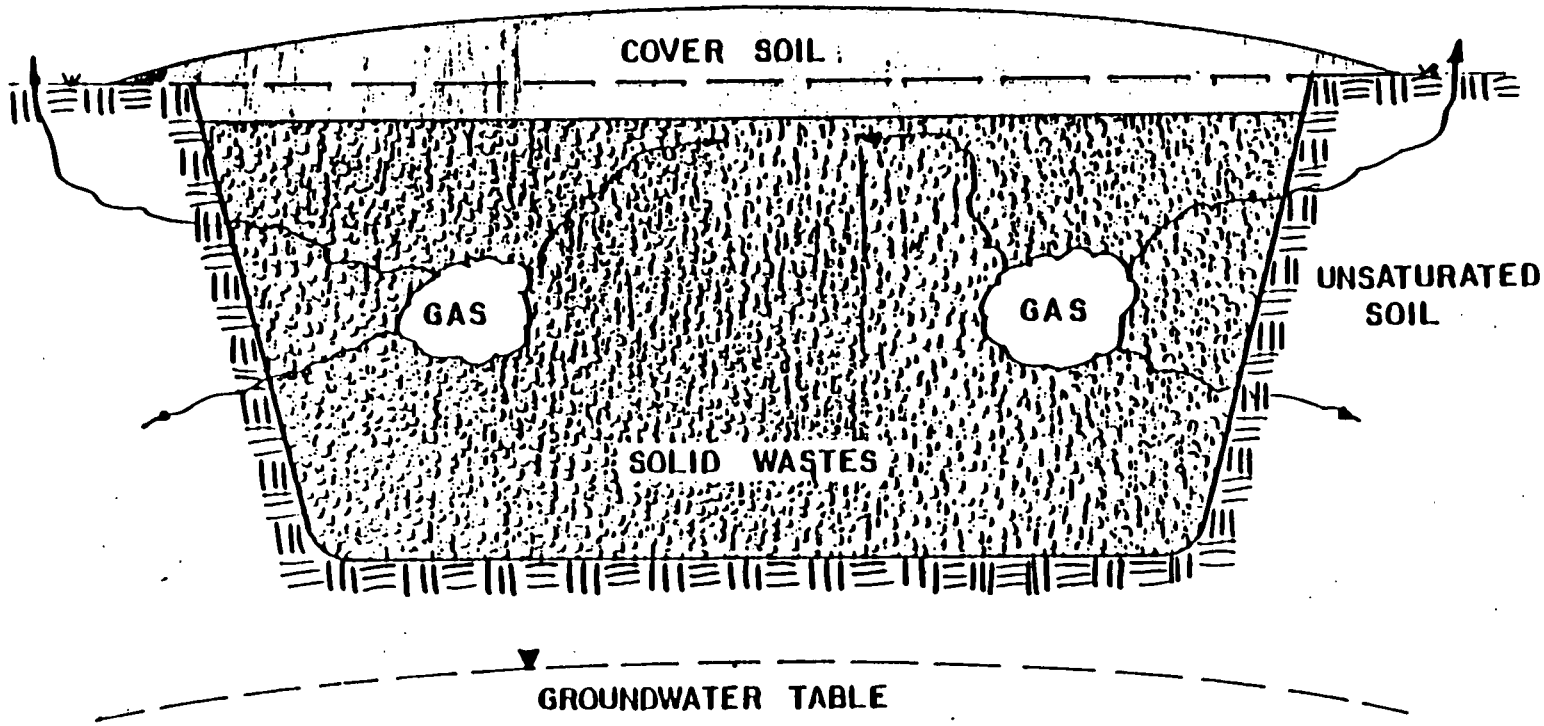
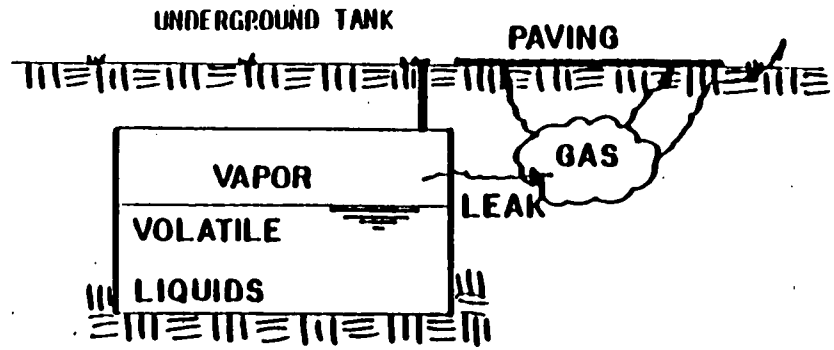


Figure 11-1. Subsurface Gas Generation/Migration in a Landfill
(Note: Gas may also migrate slowly through cover soil.)



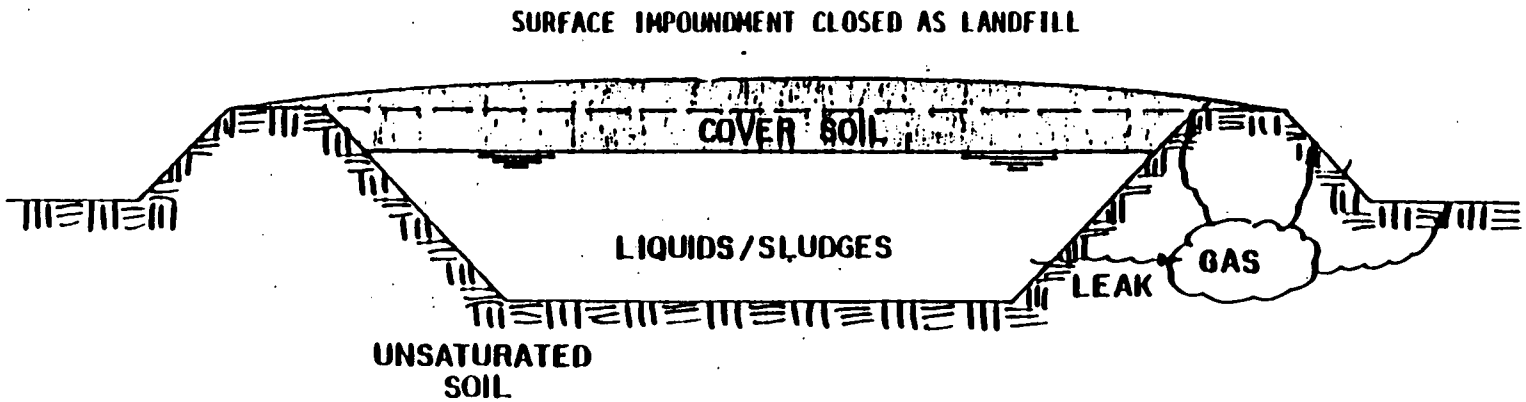


Figure 11-2. Subsurface Gas Generation/Migration from Tanks and Units Closed as Landfills (Note: Gas may also migrate slowly through cover soil.)

11.3.1 Waste Characterization

11.3.1.1 Decomposition Processes

Subsurface gas generation occurs by biological, chemical, and physical decomposition of disposed or stored wastes. Waste characteristics usually affect the rate of decomposition. The owner or operator should review unit-specific information (waste receipts, waste composition surveys, and any other records of wastes managed) to determine waste type, quantities, location, dates of disposal, waste moisture content, organic content, etc.

The three decomposition processes known to occur in the production of subsurface gases are biological decomposition, chemical decomposition, and physical decomposition. These are discussed below:

11.3.1.1.1 Biological Decomposition

The extent of biological decomposition and subsequent gas generation from a given waste is related to the type of unit. Biological decomposition, due primarily to anaerobic microbial degradation, is significant in most landfills and units closed as landfills which contain organic wastes. Generally, the amount of gas generated in a landfill is directly related to the amount of organic matter present.

Organic wastes such as food, sewage sludges, and garden wastes decompose rapidly, resulting in gas generation shortly after burial, with high initial yields. Much slower decomposing organic wastes include paper, cardboard, wood, leather, some textiles and several other organic components. Inorganic and inert materials such as plastics, man-made textiles, glass, ceramics, metals, ash, and rock do not contribute to biological gas production. At units closed as landfills, waste types that undergo biological decomposition might include bulk organic wastes, food processing sludges, treatment plant sludges, and composting waste.

Waste characteristics can increase or decrease the rate of biological decomposition. Factors that enhance anaerobic decomposition include high moisture content, adequate buffer capacity and neutral pH, sufficient nutrients (nitrogen and phosphorus), and moderate temperatures. Characteristics that

generally decrease biological decomposition include the presence of acidic or basic pH, sulfur, soluble metals and other microbial toxicants. The owner or operator should review the waste characteristic information to document if biological decomposition and subsequent gas generation may be occurring.

Under anaerobic conditions, organic wastes are primarily converted by microbial action into carbon dioxide and methane. Trace amounts of hydrogen, ammonia, aromatic hydrocarbons, halogenated organics, and hydrogen sulfide may also be present. With regard to subsurface migration, the primary gases of concern are methane (because of its explosive properties) and constituents that may be present in amounts hazardous to human health or the environment.

11.3.1.1.2 Chemical Decomposition

Gas production by chemical reaction can result from the disposal or storage of incompatible wastes. Reactive or ignitable wastes can produce explosive or heat-producing reactions, resulting in rapid production of gases, and increased pressures and temperatures. Under acidic conditions, a strong oxidizing agent can react with organic wastes to produce carbon dioxide and ammonia which can migrate from the unit, possibly providing a transport mechanism for other gaseous components.

Under typical conditions, gas production from chemical reactions is not expected to occur at landfills or units closed as landfills. However, volatile liquids stored in underground tanks may have a significant potential to create a release by chemical reaction. Good waste management practices, particularly the proper design and operation (e.g., pressure-relief valves and leak detection systems) of underground tanks can minimize the potential for gas release.

11.3.1.1.3 Physical Decomposition

Physical decomposition phenomena include volatilization and combustion. Volatilization can result in subsurface gas generation in underground tanks if there is a leak or puncture. The greater a compound's vapor pressure, the greater will be its potential to volatilize. Maintenance of underground tanks (e.g., pressure-relief valves and leak detection systems) can minimize volatilization.

Combustion processes (e.g., underground fires) sometimes occur at active landfills and result in subsurface gas release. Combustion can convert wastes to byproducts such as carbon dioxide, carbon monoxide, and trace toxic components. Combustion processes can also accelerate chemical reaction rates and biological decomposition, creating greater potential for future subsurface gas generation and subsequent release. The owner or operator should review facility records to determine if combustion has occurred and when.

11.3.1.2 Presence of Constituents

Subsurface gas generation and migration of methane is of concern because of its explosive properties. In addition, methane and other decomposition gases can facilitate the migration of volatile organic constituents that may be of concern because of potential toxic effects. Subsurface gas migration due to leaks from subsurface tanks may also be associated with a variety of volatile organic constituents.

In determining the nature of a release, it may be necessary to determine the specific waste constituents in the unit. Two means of obtaining these data are:

(1) Review of facility records. Review of facility records may not provide adequate information (e.g., constituent concentrations) for RFI purposes. For example, facility records of waste handled in the unit may only indicate generic waste information. Knowledge of individual constituents and concentrations is generally needed for purposes of the RFI.

(2) Conducting waste sampling and analysis. When facility records do not indicate the specific constituents of the waste which are likely to be released and may migrate as subsurface gas, direct waste characterization may be necessary. This effort, aimed at providing compound specific data on the waste, can be focused in terms of the constituents for which analysis should be performed through review of the waste types in the unit. In some cases, however, the generic waste description (e.g., flammable liquids) will not give an indication of the

specific constituents present, and analysis for all of the constituents of concern as gaseous releases (See Appendix B, List 2) may be required.

Additional guidance on identification of monitoring constituents is presented in Section 3.6. Section 7 provides guidance on waste characterization.

11.3.1.3 Concentration

Determination of concentrations of the constituents of concern in the waste may indicate those constituents which are of prime concern for monitoring. The concentration of a constituent in a waste (in conjunction with its physical/chemical properties and total quantity) provides an indication of the gross quantity of material that may be released in the gaseous form.

11.3.1.4 Other Factors

In addition to the factors described above, determination of the potential for volatilization of the waste constituents will help determine if they may be released. The parameters most important when assessing the potential for volatilization of a constituent include the following:

- Water solubility. The solubility in water indicates the maximum concentration at which a constituent can dissolve in water at a given temperature. This value can be used to estimate the distribution of a constituent between the dissolved aqueous phase in the unit and the undissolved solid or immiscible liquid phase. Considered in combination with the constituent's vapor pressure, it can provide a relative assessment of the potential for volatilization.

- Vapor pressure. Vapor pressure refers to the pressure of vapor in equilibrium with a pure liquid. It is best used in a relative sense; constituents with high vapor pressures are more likely to be released in the gaseous form than those with low vapor pressues, depending on other factors such as relative solubility and concentration (i.e., at high concentrations releases can occur even though a constituent's vapor pressure is relatively low).

- Octanol/water partition coefficient. The octanol/water partition coefficient indicates the tendency of an organic constituent to sorb to organic components of the soil or waste matrices of a unit. Constituents with high octanol/water partition coefficients will adsorb readily to organic carbon, rather than volatilizing to the atmosphere. This is particularly important in landfills and land treatment units, where high organic carbon contents in soils or cover material can significantly reduce the release potential of vapor phase constituents.

- Partial pressure. For constituents in a mixture, particularly in a solid matrix, the partial pressure of a constituent will be more significant than the pure vapor pressure. In general, the greater the partial pressure, the greater the potential for release. Partial pressures will be difficult to obtain. However, when waste characterization data is available, partial pressures can be estimated using methods commonly found in engineering and environmental science handbooks.

- Henry's Law constant. Henry's law constant is the ratio of the vapor pressure of a constituent and its aqueous solubility (at equilibrium). It can be used to assess the relative ease with which the compound may be removed from the aqueous phase via vaporization. It is accurate only when used in evaluating low concentration wastes in aqueous solution. Thus it will be most useful when the unit being assessed is a surface impoundment or tank containing dilute wastewaters. As the value increases, the potential for significant vaporization increases, and when it is greater than 0.001, rapid volatilization will generally occur.

- Raoult's Law. Raoult's Law can be used to predict releases from concentrated aqueous solutions (i.e., solutions over 10% solute). This will be most useful when the unit contains concentrated waste streams.

11.3.2 Unit Characterization

Unit design (e.g., waste depth, unit configuration, and cover materials) also affects gas generation. Generally, the amount of gas generated increases with

landfill volume and often with landfill depth. Deeper landfills have a proportionally larger anaerobic zone, greater insulation and compaction, and are more likely to confine gas production. Deeper landfills, such as trench fills or canyon fills, can trap gases along confining sidewalls and bottom bedrock or ground water. Daily, interim, and final cover soils can confine gases within the landfill. This is particularly true for low permeability cover soils (e.g., clays) which impede vertical gas migration. Conversely, mounds or shallow landfills have large surface areas through which gases can vent more easily.

Unit operations, such as methods and procedures used to segregate and isolate inert wastes, to prevent moisture infiltration, to compact and increase the density of the waste, and to minimize or prevent mixing of waste types, can affect resultant releases of subsurface gases. Daily covering of the unit may inhibit decomposition and thus gas generation and subsequent migration.

Certain units have a high potential for allowing the movement of subsurface gas. These units are those that receive and/or store large volumes of decomposable wastes, volatile organic liquids, or highly reactive materials. Subsurface gas migration may occur especially when major portions of a land-based unit are below grade. Gas generated by these units can migrate vertically and laterally from the unit, following the path of least resistance.

Some units are operated above grade or in relatively shallow soils (e.g., surface impoundments, land treatment units). The potential for subsurface gas migration from such units is usually low. Gases generated by such units will generally be vented to the atmosphere unless prevented by a natural barrier (e.g., frozen ground) or an engineered barrier (e.g., soil cover).

Information on unit operations will therefore be important in assessing the potential for subsurface gas migration. Unit operational data may also be required concurrent with any subsurface gas sampling activities. It is particularly important to obtain operational data on any gas collection system in use at the time of sampling. These gas collection systems can significantly affect subsurface gas migration rates, patterns and constituent concentration levels.

Generally, the units that pose the greatest potential for subsurface gas migration include landfills, sites closed as landfills, and underground storage tanks. These are discussed below.

11.3.2.1 Landfills

Gas generated in landfills can vent vertically to the atmosphere and/or migrate horizontally through permeable soil, as shown in Figure 11-1. Closure of the landfill or periodic covering of cells or lifts with impermeable caps may impede the vertical movement of the gases, forcing them to migrate laterally from the unit. Gas migration laterally through the subsurface (e.g., through underground utility line channels or sand lenses) may accumulate in structures on or off the facility property.

11.3.2.2 Units Closed as Landfills

Gas generation and subsequent migration is likely to occur at units closed as landfills containing organic wastes, as previously discussed. Although surface impoundments and waste piles may be closed as landfills, they tend to produce less gas than landfills because they generally contain smaller quantities of decomposable and volatile wastes and are generally at shallow depths. Closure of such units with an impermeable cover will, however, increase the potential for lateral gas movement and accumulation in onsite and offsite structures (see Figure 11-2).

11.3.2.3 Underground Tanks

Subsurface gas release and subsequent migration may occur if an underground tank is leaking. Underground tanks frequently contain volatile liquids that could enter the unsaturated zone should a leak occur (see Figure 11-2).

11.3.3 Characterization of the Environmental Setting

11.3.3.1 Natural and Engineered Barriers

Subsurface conditions at the site should be evaluated to determine likely gas migration routes. Due to the inherent mobility of gases, special attention must be

paid to zones of high permeability created by man-made, biological, and physical weathering action. These zones include backfill around pipes, animal burrows, solution channels, sand and/or gravel lenses, desiccation cracks, and jointing in bedrock. The presence of dead rodents, snakes and other burrowing animals is usually a good indication of a potential subsurface gas pathway.

Natural and engineered barriers can also affect gas migration, generally by inhibiting migration pathways. Natural barriers to gas migration include surface water, ground water, and geologic formations. Engineered barriers include walls, onsite structures, underground structures, caps, liners, and other design features. On the other hand, preferred pathways for subsurface gas migration may result from previous underground construction (e.g., underground utility lines) that can facilitate gas flow. Natural and engineered barriers are discussed in more detail below.

11.3.3.1.1 Natural Barriers

Surface water, ground water, and saturated soils can slow down or control the direction of subsurface gas migration. Gases encountering these barriers will follow the pathway of least resistance, usually through unsaturated porous soil.

Geologic barriers can also impede or control the route of subsurface gas migration. For example, soil type is an important factor in gas migration. Gravels and sands allow gas to migrate readily, particularly sand/gravel lenses, while clayey gravels and sandy and organic clays tend to impede gas movement. Underground utility trenches, backfill with granular materials, filled-in mine shafts, and tunnels or natural caverns can also serve to channel subsurface gas flow. Climatic conditions such as precipitation or freezing can reduce the porosity of surface soils, thereby impeding upward gas movement. Information regarding characterization of soils is provided in Section 9 (Soils).

11.3.3.1.2 Engineered Barriers

Landfills and units closed as landfills may use caps and liners to prevent moisture infiltration and leachate percolation to ground water. Caps can contribute to horizontal gas movement when upward migration to the surface is

restricted (as shown in Figure 11-1). Liners tend to impede lateral migration into the surrounding unsaturated soils. The owner or operator should evaluate cap/liner systems (type, age, location, etc.) to determine potential gas migration pathways. Similar to liners, slurry walls used to border landfill units can retard lateral gas movement. With respect to underground tanks, caps and liners are not typically used. Tanks are often placed into soils with sand or gravel backfill during installation, followed by paving on the surface. Thus, any escaping gases from a leaking underground tank may migrate laterally along the path of least resistance adjacent to the units. The owner or operator should evaluate tank construction, and age, integrity, and location.

11.3.3.2 Climate and Meteorological Conditions

The climate of the site should be defined to provide background information for assessing the potential for subsurface gas migration, identifying migration pathways, and designing the subsurface gas migration monitoring system. Climatic information, on an annual and monthly or seasonal basis, should be collected for the following parameters:

- Temperature means/extremes and frost season (which indicates the potential for impeding the upward migration of the subsurface gas, thus confining the gas within the ground);

- Precipitation means and snowfall (which indicates the potential for "trapping" as well as an indication of soil moisture conditions which affect subsurface gas migration); and

- Atmospheric pressure means (which indicates the potential for gaseous releases to ambient air from a unit of concern).

The primary source of climate information for the Unites States is the National Climatic Data Center (Asheville, NC). The National Climatic Data Center can provide climate summaries for the National Weather Service station nearest to the site of interest. Standard references for climatic information also include the following:

Local Climatological Data - Annual Summaries with Comparative Data, published annually by the National Climatic Data Center;

Climates of the States, National Climatic Data Center; and

Weather Atlas of the United States, National Climatic Data Center.

Meteorological data for the above parameters should also be obtained concurrently with subsurface gas sampling activities. As previously discussed, these meteorological conditions can influence subsurface gas migration rates, patterns and concentration levels. Therefore, these data are necessary to properly interpret subsurface gas sampling data. Concurrent meteorological data for the sampling period can be obtained from the National Climatic Data Center for National Weather Service stations representative of the site area. In some cases, onsite meteorological data will also be available from an existing monitoring program or associated with an RFI characterization of the air media (See Section 12).

11.3.3.3 Receptors

Receptor information needed to assess potential subsurface gas exposures includes the identification and location of surrounding buildings and potential sensitive receptors (e.g., residences, nursing homes, hospitals, schools, etc.). This information should also be considered in developing the monitoring procedures. Additional discussion of potential receptors is provided in Section 2.

11.4 Design of a Monitoring Program to Characterize Releases

Existing data should help to indicate which units have the potential to generate methane or other gases or constituents of concern. Such information can be found in construction or design documents, permit and inspection reports, records of waste disposal, unit design and operation records, and documentation of past releases.

Units of concern should be identified on the facility's topographic map. The location and areal extent of these units can be determined from historical records, aerial photographs, or field surveys. The depths and dimensions of underground

structures, locations of surrounding buildings, and waste-related information should be identified. Waste management records may provide information on waste types, quantities managed, location of waste units, and dates of waste disposal. Waste receipts, waste composition surveys, and records of waste types (e.g., municipal refuse, bulk liquids, sludges, contaminated soils, industrial process wastes or inert materials) should be reviewed. For underground tanks, liquid waste compositions, quantities, and physical properties should be determined.

Review of unit design and operation records may provide background information on units of concern. These records may include engineering design plans, inspection records, operations logs, damage or nuisance litigation, and routine monitorng data. Also, for landfills and units closed as landfills, data may include the presence and thickness of a liner, ground-water elevations, waste moisture contents, type and amount of daily cover, records of subsurface fires, and in-place leachate and/or gas collection systems. Historical information on underground tank integrity may be contained in construction and monitoring records. Records of past releases may provide information on problems, corrective measures, and controls initiated.

The owner or operator should review records of subsurface conditions to determine potential migration pathways. Aerial photographs or field observations should identify surface water locations. Infrared aerial photography or geological surveys from the USGS can be used as preliminary aids to identify subsurface geologic features and ground-water location. In addition to obtaining and reviewing existing information, a field investigation may be necessary to confirm the location of natural barriers. The local soil conservation service will often have information describing soil characteristics (e.g., soil type, permeability, particle size) or a site specific investigation may need to be conducted. (Soil information sources are discussed in Section 9). Climatic summaries (e.g., temperature, rainfall, snowfall) can be obtained from the National Climatic Data Center for the National Weather Service station nearest to the site of interest (Specific climatic data references are cited in Section 12). Historical records of the site (prior use, construction, etc.) should also be reviewed to identify any factors affecting gas migration routes. The monitoring program should also address any engineered structures affecting the migration pathway.

In addition to the above, the owner or operator should examine the units and surrounding area for signs of settlement, erosion, cracking of covers, stressed or dead vegetation, dead rodents, snakes and other burrowing animals, contamination of surface waters, odors, elevated temperatures in any existing monitoring wells, and for venting of smoke or gases. The condition of any existing gas monitoring systems and containment or collection systems should also be examined, as well as any structural defects in tanks or liners. Any overflow/alarm shut off systems, subsurface leak detection systems, secondary containment structures (e.g., concrete pads, dikes or curbs) or other safety systems for early detection of potential gas releases should be checked.

By reviewing all existing information, the owner or operator should be able to develop a conceptual model of the release and design a monitoring program to characterize the release.

11.4.1 Objectives of the Monitoring Program

Characterization of subsurface gas releases can be accomplished through a phased monitoring approach. The objective of initial monitoring should be to verify suspected releases, if necessary, or to begin characterizing known releases. Monitoring should include methane and other indicators such as carbon dioxide, as well as individual constituents if appropriate. If initial monitoring verifies a suspected release, the owner or operator should expand the monitoring program to determine the vertical and horizontal extent of the release, as well as the concentrations of all constituents of concern in the release.

The full extent of the release can be determined through additional shallow borehole and gas monitoring well locations. The goal of this further characterization will be to identify the boundary of gas migration, including the leading edge of the migration.

A great deal of the effort conducted during any subsequent phase may involve investigating anomalous areas where subsurface conditions are non-uniform. In these situations, the gas migration characteristics may differ from surrounding areas. Consequently, non-random sampling techniques are generally most appropriate to monitor these areas. The location of additional gas wells and

shallow boreholes at the sites of subsurface anomalies will provide information regarding the migration pattern around these anomalous areas. Also, because gas well installation may be conducted only to a limited extent under the initial monitoring phase, additional wells may need to be installed.

The monitoring program should also address the selection of constituents of concern, sampling frequency and duration, and the monitoring system design.

11.4.2 Monitoring Constituents and Indicator Parameters

As discussed above, the number and identity of potential subsurface gas constituents will vary on a site-specific basis. Constituents to be included for monitoring depends primarily on the type of wastes received. For example, if an underground storage tank contains specific constituents, they should be considered during subsurface gas monitoring activities. The guidance provided in Section 3 and the lists provided in Appendix B should be used to determine a select set of constituents and indicator parameters for subsurface gas monitoring.

Methane should be used as the primary indicator of subsurface gas migration during the initial and any subsequent monitoring phases. Supplemental indicators (e.g., carbon dioxide and sulfur dioxide) may also be used as appropriate. Field screening equipment should be used to detect the presence of methane in terms of the lower explosive limit (LEL). The LEL for methane is 5 percent by volume, which is equivalent to 50,000 ppm. Individual constituents should also be monitored. In addition, oxygen detectors and nitrogen analyses can be used to confirm the representativeness of all subsurface gas well samples obtained. (The presence of oxygen and nitrogen in well samples indicates the intrusion of ambient air into the well during monitoring. Samples containing ambient air would result in an underestimate of methane and other indicators as well as specific monitoring constituents.)

Methane concentrations observed during the initial monitoring phase which exceed the LEL at the property boundary or 0.25 the LEL within surrounding structures, would warrant initiation of subsequent monitoring phases and, possibly, consideration of interim corrective measures. Similarly, the presence of individual constituents would also trigger the need for subsequent monitoring phases.

Regardless of the degree to which monitoring constituents can be limited by site-specific data, analyses for all constituents identified as applicable in Appendix B (List 2) will generally be necessary for the subsurface gas medium at selected monitoring locations.

11.4.3 Monitoring Schedule

A monitoring schedule should be established and described in the RFI Work Plan. This schedule should describe the sampling frequency, the duration of the sampling effort, and the conditions under which sampling should occur.

During initial monitoring, bar punch probe (See Section 11-6) monitoring for methane and appropriate constituents should be conducted at least twice over the course of one week. Monitoring the wells for methane and constituents should be conducted at least once a week for one month. (Subsurface gas wells should not be monitored for at least 24 hours after installation to allow time for equilibration.) Surrounding buildings should be monitored at least once a week for one month.

During any subsequent monitoring phases, more extensive sampling may be needed to adequately characterize the nature and extent of the release. Monitoring of wells and buildings for methane and constituents should be conducted every other day for a two week period to account for daily fluctuations in gas concentrations.

Conditions for sampling should also be defined. Sampling should generally not be performed if conditions conducive to decreasing gas concentrations are present (e.g., subsurface gas pressure at less than atmospheric pressure). In these cases, sampling should be delayed until such conditions pass. Subsurface gas pressures have a diurnal cycle and are generally at a maximum during the afternoon.

11.4.4 Monitoring Locations

11.4.4.1 Shallow Borehole Monitoring

Areas identified for subsurface gas monitoring as a result of characterization of the contaminant source and the environmental setting should be investigated for concentrations of methane and constituents during the initial monitoring phase. Shallow borehole monitoring using a bar punch probe method or equivalent (See Section 11.6) is recommended. The bar punch is simply a steel or metal bar which is hand-driven or hammered to depths of 6 feet. Once this hole is made it is covered with a stopper or seal to confine the headspace in the hole. The hole should be allowed to equilibrate for up to an hour prior to sampling to provide sufficient time for subsurface gas to replace the air in the hole. The ease of installation of bar punch holes and the ability to obtain real-time direct measurements from field survey instruments combine to make this task a relatively simple operation. It should be recognized, however, that shallow borehole monitoring is a rapid screening method and therefore has its limitations. Two major limitations are that negative findings cannot assure the absence of a release at a greater depth and that air intrusions can dilute the sampling readings. See also Sections 9 (Soil) and 10 (Ground Water) for additional information.

The number of locations to monitor will vary from site to site. However, due to the ease of this operation, it is recommended that many locations be surveyed during the initial monitoring phase. Selection of locations along the perimeter of the unit of concern and at intervals of approximately 100 feet is an adequate initial approach. Individual site conditions and anomalies should be considered to determine whether the number of sampling locations should be increased or decreased. A large site with homogeneous subsurface conditions could require fewer sampling locations by increasing the distance between sampling points. A site with many subsurface anomalies, such as engineered barriers or varying soil strata, would require a greater number of sampling locations. In general, sampling locations should be established where conditions are conducive to gas migration, such as in sands, gravels and porous soils, and near engineered conduits (e.g., underground utility lines). The appropriate precautions should be taken when sampling near engineered conduits so as not to damage such property and to assure the safety of the investigative team and others.

The distance from the unit at which to sample can best be determined through consideration of site-specific characteristics (e.g., soil conditions), and can be aided by the use of the gas concentration contour map generated by the predictive model described in Appendix D. The shallow borehole survey should be fairly extensive, ranging from sampling locations very near the unit to locations at the property boundary and beyond.

11.4.4.2 Gas Monitoring Wells

Gas monitoring wells (See Section 11.6) should be installed to obtain data on subsurface gas concentrations at depths greater than the depth accessible with a bar punch probe. Wells should be installed to a depth equal to that of the unit. Multiple probe depths may be installed at a single location as illustrated in Figure 11-3. Where buried material is fairly shallow (e.g., <10-feet), single depth gas monitoring probes may be sufficient. When buried material exceeds this depth below ground, multiple depth probes should be installed.

The location and depth of gas monitoring wells should be based on the presence of highly permeable zones (e.g., dry sand or gravel), alignment with offsite structures, proximity of the waste deposit, areas where there is dead or unhealthy vegetation (that may be due to gas migration), and any engineered channels which would promote the migration of a subsurface gas release (e.g., utility lines). This information should be gathered during a review of subsurface conditions, as discussed previously. At a minimum, a monitoring well should be installed at the location(s) of expected maximum concentration(s), as determined or estimated during the initial monitoring phase.

Gas monitoring well installation usually requires the use of a drilling rig or power auger. Once a borehole has been drilled to the desired depth, the gas monitoring probes can be installed as illustrated in Figure 11-3. Additional information concerning the installation of subsurface gas monitoring wells is provided in Section 10 (Ground Water) and in Guidance Manual for the Classification of Solid Waste Disposal Facilities NTIS PB81-218505 (U.S. EPA, 1981).

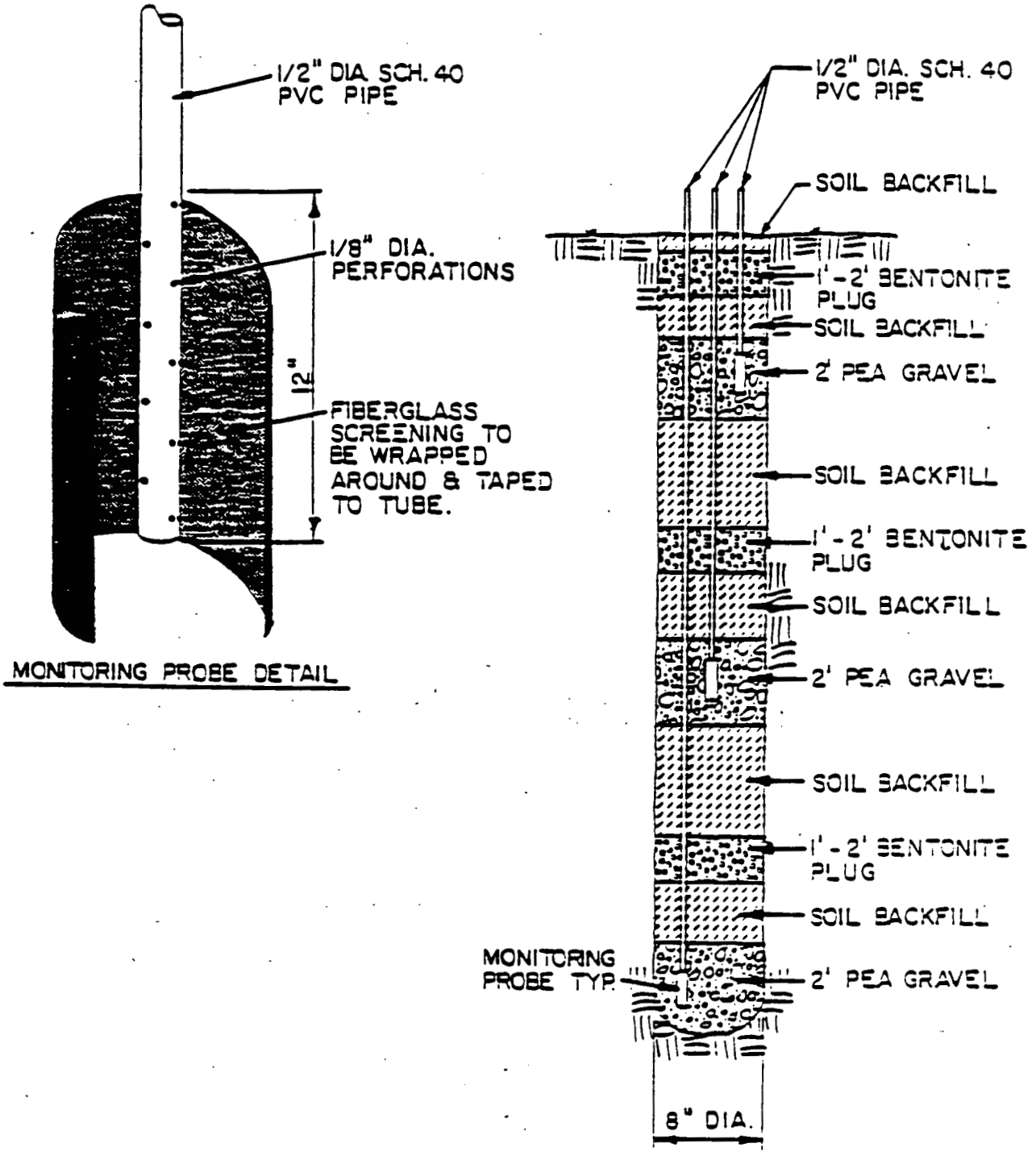


Figure 11-3. Schematic of a Deep Subsurface Gas Monitoring Well

Equilibration times of at least 24 hours should be allowed prior to collection of subsurface gas samples for analysis after well installation and between subsequent collection periods. Individual site characteristics or anomalies which can create significantly different subsurface conditions will require an increased number of wells to sufficiently determine the presence of gas migration. For example, if the predominant soil strata along one side of a unit changes from sandy clay to gravel, a well should be installed in both of these areas. Also, if the amount of gas producing waste buried at the site varies greatly from one area to another, gas monitoring wells should be installed near each area of concern.

Subsurface gas monitoring may be done concurrently with ground-water investigations (Section 10), because results of subsurface gas monitoring may provide useful information for identifying the overall extent of any ground-water contamination.

11.4.4.3 Monitoring in Buildings

Monitoring should also be conducted in surrounding structures near the areas of concern, since methane and other subsurface gas constituents migrating through the soil can accummulate in confined areas. Use of an explosimeter for methane is the recommended monitoring technique (See Section 11.6).

Sampling should be conducted at times when the dilution of the indoor air is minimized and the concentration of soil gas is expected to be at its highest concentration. Optimal sampling conditions would be after the building has been closed for the weekend or overnight and when the soil surface outside the building and over the unit of concern has been wet or frozen for several days. These conditions will maximize the potential for lateral migration of gas into buildings rather than vertically into the ambient air. Recommended sampling locations within the building include basements, crawl spaces, and around subsurface utility lines such as sewer or electrical connections. Access conduits such as manholes or meter boxes are good sampling locations for water, sewer, or gas main connections. Methane and, if appropriate, individual constituents should be monitored for.

The threat of explosion from accumulation of methane within a building makes this monitoring activity important as well as dangerous. The monitoring of

gas concentrations within buildings is a simple process involving a walk through inspection of areas with portable field instruments (e.g., explosimiter). Such measurements should begin during the initial monitoring phase. The importance of identifying potential releases to buildings warrants a complete inspection of all suspect areas. The inherent danger during these investigatons warrants adequate health and safety procedures (See Section 6).

If significant concentrations of methane or constituents are measured in surrounding structures during initial monitoring, subsequent monitoring may need to be expanded to include buildings at greater distances from the unit(s) of concern and to include additional constituents of concern. In addition, interim corrective measures should be considered.

Background indoor air quality levels may be accounted for during the collection and evaluation of the in-building sampling data. Background levels can be accounted for by identifying potential indoor air emission sources (e.g., use of natural gas as a fuel or wood paneling which has the potential for formaldehyde emissions). Further guidance on this subject is presented in the following reference:

U.S. EPA. 1983. Guidelines for Monitoring Indoor Air Quality. EPA- 600/1-4 83-046. NTIS PB83-264465. Office of Research and Development. Washington, D.C. 20460.

11.4.4.4 Use of Predictive Models

In addition to monitoring potential gas releases using portable survey instruments, the owner or operator should consider the use of predictive models to estimate the configuration and concentration of gas releases. A subsurface gas predictive model has been developed by EPA to estimate methane gas migration from sanitary landfills. This model is based on site soil conditions, waste-related data, and other environmental factors.

As part of the initial monitoring phase, the model provided in Appendix D (or another appropriate predictive model after consultation with the regulatory agency), should be used to estimate the extent of subsurface gas migration. Results from this model can be used in determining appropriate monitoring locations. The

methane gas migration model presented in Appendix D yields a methane concentration isopleth map of a release. The LEL and 0.25 LEL isopleths for methane should be mapped for the RFI when appropriate. Because predictive models may not be sensitive to relevant site conditions, however, model results should be used cautiously for the monitoring program design and to supplement actual field data.

11.5 Data Presentation

Subsurface gas data collected during the RFI should be presented in formats that clearly define the composition and extent of the release. The use of tables and graphs is highly recommended. Section 5.2 provides a detailed discussion of data presentation methods.

11.5.1 Waste and Unit Characterization

Waste and unit characteristics should be presented as:

- Tables of waste constitutents and concentrations;
- Tables of relevant physical and chemical properties of waste and potential contaminants;
- Narrative description of unit dimensions, operations, etc.; and
- Topographical map and plan drawings of facility and surrounding areas.

11.5.2 Environmental Setting Characterization

Environmental characteristics should be presented as follows:

- Tabular summaries of annual and monthly or seasonal relevant climatic information (e.g., temperature, precipitation);
- Narratives and maps of soil and relevant hydrogeological characteristics such as porosity, organic matter content, and depth to ground water;

- Maps showing location of natural or man-made engineering barriers and likely migration routes; and

- Maps of geologic material at the site identifying the thickness, depth, and textures of soils, and the presence of saturated regions and other hydrogeological features.

11.5.3 Characterization of the Release

In general, release data should be initially presented in tabular form. To facilitate interpretation, graphs of concentrations of individual constituents plotted against distance from the unit should be used to identify migration pathways and areas of elevated concentrations. Concentration isopleth maps can also be drawn to identify the direction, depths, and distances of gas migration, and concentrations of constituents of concern. Specific examples of these and other data presentation methods are provided in Section 5. Methane concentrations should be presented in terms of the LEL and 0.25 LEL isopleths. Specific monitoring constituent concentrations should also be presented.

11.6 Field Methods

Field methods for subsurface gas investigations involve sample collection and analysis. Sample collection methods are discussed to summarize the monitoring techniques described above. Because subsurface gas monitoring is similar to air monitoring, the available methods for the collection and analysis of subsurface gas samples are presented here only in tabular format with further discussion in the air section of this document (Section 12). Tables 11-3 through 11-5 summarize various methodologies available to collect and analyze air samples. These methodologies range from real-time analyzers (e.g., methane explosimeters) to the collection of organic vapors on sorbents or whole air samples with subsequent laboratory analysis.

A portable gas chromatograph with a flame ionization detector (calibrated with reference to methane) can be used to measure methane concentrations in the field. Methane explosimeters (based on the principle of thermal conductivity) are

TABLE 11-3
SUMMARY OF SELECTED ONSITE ORGANIC SCREENING METHODOLOGIES

Instrument or detector	Measurable parameters	Low range of detection	Comments
Century Series 100 or AID Model 500 (survey mode)	Volatile organic species	Low ppm	Uses Flame Ionization Detector (FID)
GfG Gas Etechonics (Methanometer)	Methane explosion potential	Low ppm	Sensitive to methane
National Mine Service Company	Methane explosion potential	Low ppm	Sensitive to methane
Mine Safety Appliances, Inc.	Methane explosion potential	Low ppm	Sensitive to methane

TABLE 11-4

SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Techniques	Analytical Technique	Applicability[a]	Positive Aspects	Negative Aspects
1. Sorption onto Tenax-GC or carbon molecular sieve packed cartridges using low-volume pump	Thermal Desorption into GC or GC/MS	I	• adequate QA/QC data base • widely used on investigations around uncontrolled waste sites • wide range of applicability • $\mu g/m^3$ detection limits • practicality for field use	• possibility of contamination • artifact formation problems • rigorous cleanup needed • no possibility of multiple analysis • low breakthrough volumes for some compounds
2. Sorption onto charcoal packed cartridges using low-volume pump	Desorption with solvent-analysis by GC or GC/MS	II	• large data base for various compounds • wide use in industrial applications • practical for field use	• problems with irreversible adsorption of some compounds • high (mg/m^3) detection limits • artifact formation problems • high humidity reduces retention efficiency
3. Sorption onto polyurethane foam (PUF) using low-volume or high-volume pump	Solvent extraction of PUF; analysis by GC/MS	I, II, III	• wide range of applicability • easy to preclean and extract • very low blanks • excellent collection and retention efficiencies • reusable up to 10 times	• possibility of contamination • losses of more volatile compounds may occur during storage

TABLE 11-4 (continued)

SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Techniques	Analytical Technique	Applicability[a]	Positive Aspects	Negative Aspects
4. Sorption on passive dosimeters using Tenax or charcoal as adsorbing medium	Analysis by chemical or thermal desorption followed by GC or GC/MS	I or II	• Samplers are small, portable, require no pumps • makes use of analytical procedures of known precision and accuracy for a broad range of compounds • $\mu g/m^3$ detection limits	• problems associated with sampling using sorbents (see #I and II) are present • uncertainty in volume of air sampled makes concentration calculations difficult • requires minimum external air flow rate
5. Cryogenic trapping of analytes in the field	Desorption into GC	II, III	• applicable to a wide range of compounds • artifact formation minimized • low blanks	• requires field use of liquid nitrogen or oxygen • sample is totally used in one analysis-no reanalysis possible • samplers easily clogged with water vapor • no large data base on precision or recoveries
6. Whole air sample taken in glass or stainless steel bottles	Cryogenic trapping or direct injection into GC or GC/MS (onsite or laboratory)	II, III	• useful for grab sampling • large data base • excellent long-term storage • wide applicability • allows multiple analyses	• difficult to obtain integrated samples • low sensitivity if preconcentration is not used
7. Whole air sample taken in Tedlar® Bag	Cryogenic trapping or direct injection into GC or GC/MS (onsite or laboratory)	II, III	• grab or integrated sampling • wide applicability • allows multiple analyses	• long-term stability uncertain • low sensitivity if preconcentration is not used • adequate cleaning of containers between samples may be difficult

TABLE 11-4 (continued)

SUMMARY OF CANDIDATE METHODOLOGIES FOR QUANTIFICATION OF VAPOR PHASE ORGANICS

Collection Techniques	Analytical Technique	Applicability[a]	Positive Aspects	Negative Aspects
8. Dinitropheynlhydrazine liquid Impinger sampling using low-volume pump	HPLC/UV analysis	IV	• specific to aldehydes and ketones • good stability for derivatized compounds • low detection limits	• fragile equipment • sensitivity limited by reagent impurities • problems with solvent evaporation when long-term sampling is performed
9. Direct introduction by probe	Mobile MS/MS	I, II, III, IV	• immediate results • field identification of air contaminants • allows "real-time" monitoring • widest applicability of any analytical method	• high instrument cost • requires highly trained operators • grab samples only • no large data base on precision or accuracy

a Applicability Code

I Volatile, nonpolar organics (e.g., aromatic hydrocarbons, chlorinated hydrocarbons) having boiling points in the range of 80 to 200° C.
II Highly volatile, nonpolar organics (e.g., vinyl chloride, vinylidene chloride, benzene, toluene) having boiling points in the range of -15 to + 120° C.
III Semivolatile organic chemicals (e.g., organochlorine pesticides and PCBs).
IV Aldehydes and ketones.

TABLE 11-5
TYPICAL COMMERCIALLY AVAILABLE SCREENING TECHNIQUES FOR ORGANICS IN AIR

Techniques	Manufacturer	Compounds Detected	Approximate Detection Limit	Comment
Gas Detection Tubes	Draeger Matheson (Kitagawa)	Various organics and inorganics	0.1 to 1 ppmv	Sensitivity and selectivity highly dependend on components of interest.
Continuous Flow Colorimeter	CEA Instruments, Inc.	Acrylonitrile, formaldehyde, phosgene	0.05 to 0.5 ppmv	Sensitivity and selectivity similar to detector tubes.
Colorimetric Tape Monitor	MDA Scientific	Toluene, diisocyanate, dinitro-toluene, phosgene, and various inorganics	0.05-0.5 ppmv	Sensitivity and selectivity similar to detector tubes.
Infrared Analysis	Foxboro/Wilkes	Most organics	1-10 ppmv	Some inorganic gases (H^2, CO) will be detected and therefore are potential interferences.
FID (Total Hydrocarbon Analyzer)	Beckman MSA, Inc. AID, Inc.	Most organics	0.5 ppmv	Responds uniformly to most organic compounds on a carbon basis.
GC/FID (portable)	Foxboro/Century AID, Inc.	Same as above except that polar compounds may not elute from the column	0.5 ppmv	Qualitative as well as quantitative information obtained.
PID and GC/PID (portable)	HNU, Inc. AID, Inc. Photovac, Inc.	Most organic compounds can be detected with the exception of methane	0.1 to 100 ppbv	Selectivity can be adjusted by selections of lamp energy. Aromatics most readily detected.
GC/ECD (portable)	AID, Inc.	Halogenated and nitro substituted compounds	0.1 to 100 ppbv	Response varies widely from compound to compound.
GC/FPD (portable)	AID, Inc.	Sulfur or phosphorus-containing compounds	10-100 ppbv	Both inorganic and organic sulfur or phosphorus compounds will be detected.
Chemiluminescent Nitrogen Detector	Antek, Inc.	Nitrogen-containing compounds	0.1 ppmv (as N)	Inorganic nitrogen compounds will interfere.

also available and provide direct readings of LEL levels and/or percent methane present by volume.

Table 11-3 provides a list of organic screening methodologies suited for detection of methane. Commercial monitoring equipment (direct reading) suitable for screening application are also available specifically for carbon dioxide, and sulfur dioxide. Similar field screening equipment are available for oxygen in order to check for the potential for intrusion of ambient air into the subsurface gas monitoring well. These screening monitors are available from most major industrial hygiene equipment vendors. Direct reading gas detection (e.g., draeger) tubes are also available for methane and other subsurface gas indicators for screening applications.

It is important that all monitoring procedures be fully documented and supported with adequate QA/QC procedures. Information should include: locations and depths of sampling points, methods used (including sketches and photographs), survey instruments used, date and time, atmospheric/soil temperature, analytical methods, and laboratory used, if any. Also see Section 4 (Quality Assurance and Quality Control).

The three basic monitoring techniques available for sampling subsurface gas; above ground air monitoring, shallow borehole monitoring, and gas well monitoring are summarized below.

11.6.1 Above Ground Monitoring

This technique consists of the collection of samples of the subsurface gas after it has migrated out of the soil or into engineered structures (e.g., within buildings or along under-ground utility lines.). Basically, there is no difference in the apparatus from that described for ambient air monitoring (Section 12). The locations at which sampling is conducted, however, are selected to focus on areas where gases might accumulate. Sampling methods can utilize various types and brands of portable direct-reading survey instruments (see Table 11-5). However, because methane gas is frequently the major component of the soil gas, those which are most sensitive to methane, such as explosimeters and FID organic vapor

analyzers, are the preferred instruments. More selective air sampling methods are used, however, for constituent analyses (see Section 12 - Air Methods).

11.6.2 Shallow Borehole Monitoring

Shallow borehole monitoring involves subsurface gas monitoring to depths of up to 6 feet below the ground surface. Bar punches or metal rods which can be hand-driven or hammered into the ground are used to make boreholes from which gas samples are removed. Table 11-6 provides the basic procedure for shallow and deep subsurface monitoring techniques. Sample collection should follow the same methods employed during above ground monitoring.

Shallow borehole monitoring, as previously discussed, is a rapid screening method and, therefore, has its limitations. Two major limitations are that negative findings cannot assure the absence of a release at a greater depth and that air intrusion can dilute the measured concentration levels of the sample. Misleading results can also be obtained if the surface soil layer is contaminated (e.g., due to a spill).

11.6.3 Gas Well Monitoring

Monitoring gas within wells will involve either the lowering of a sampling probe (made of a nonsparking material) through a sealed cap on the top of the well to designated depths, or the use of fixed-depth monitoring probes (see Figure 11-3 and Table 11-6). The probe outlet is usually connected to the desired gas monitoring instrument. More information on gas well monitoring is provided in Sections 9 (Soil) and 10 (Ground Water).

11.7 Site Remediation

Although the RFI Guidance is not intended to provide detailed guidance on sites remediation, it should be recognized that certain data collection activities that may be necessary for a Corrective Measures Study may be collected during the RFI. EPA has developed a practical guide for assessing and remediating contaminated site that directs users toward technical support, potential data requirements and

TABLE 11-6

SUBSURFACE SAMPLING TECHNIQUES

SHALLOW (Up to 6 ft deep)

- Select sampling locations based on soil data and existing monitoring data.

- Penetrate soil to desired depth. A steel rod 1/2 to 3/4 inch diameter and a heavy hammer are sufficient. A bar punch equipped with insulated handles is better for numerous holes. It is a small, hand operated pile driver with a sliding weight on the top. Hand augers may also be used.

- Insert inert (e.g., Teflon) tubing to bottom of hole. Tubing may be weighted or attached to a small diameter stick to assure that it gets to the bottom of the hole. Tubing should be perforated along bottom few inches to assure gas flow.

- Close top of hole around tubing using a gas impervious seal.

- Before sampling record well head pressure.

- Readings may be taken immediately after making the barhole.

- Attach meter or sampling pump and evacuate hole of air-diluted gases before recording gas concentrations or taking samples.

- When using a portable meter, begin with the most sensitive range (0-100 percent by volume of the lower explosive limit (LEL) for methane). If meter is pegged, change to the next least sensitive range to determine actual gas concentration.

- Tubing shall be marked, sealed, and protected if sampling will be done later.

- If results are erratic the hole should be plugged and further readings taken a few minutes later.

- Monitoring should be repeated a day or two after probe installation to verify readings.

DEEP (More Than 6 ft deep)

- Same general procedures as above.

- Use portable power augers or truck-mounted augers.

- For permanent monitoring points, use rigid tubing (e.g., Teflon) and the general construction techniques shown in Figure 11-4.

CAUTION

- When using hand powered equipment, stop if any unusually high resistance is met. This resistance could be from a gas pipe or an electrical cable.

- Before using powered equipment, confirm that there are no underground utilities in the location(s) selected (see Appendix C - Geophysical Techniques).

- Use non-sparking equipment and procedures and monitor for methane explosive limits.

technologies that may be applicable to EPA programs such as RCRA and CERCLA. The reference for this guide is provided below.

U.S. EPA. 1988. Practical Guide for Assessing and Remediating Contaminated Sites. Office of Solid Waste and Emergency Response. Washington, D.C. 20460.

The guide is designed to address releases to ground water as well as soil, surface water and air. A short description of the guide is provided in Section 1.2 (Overall RCRA Corrective Action Process), under the discussion of Corrective Measures Study.

11.8 Checklist

RFI CHECKLIST - SUBSURFACE GAS

Site Name/Location _____

Type of Unit _____

1. Does waste characterization include the following information? (Y/N)
   - Physical form of waste _____
   - Chemical composition and concentrations _____
   - Presence of biodegradeable waste components _____
   - Quantities managed and dates of receipt _____
   - Location of wastes in unit _____
   - Waste material moisture content and temperature _____
   - Chemical and physical properties of constituents of concern _____

2. Does unit characterization include the following information? (Y/N)
   - Age of unit _____
   - Construction integrity _____
   - Presence of liner (natural or synthetic) _____
   - Location relative to ground-water table or bedrock or other confining barriers _____
   - Unit operation data _____
   - Presence of cover or other surface covering to impede vertical gas migration _____
   - Presence of gas collection system _____
   - Presence of surrounding structures such as buildings and utility conduits _____
   - Depth and dimensions of unit _____
   - Inspection records _____
   - Operation logs _____
   - Past fire, explosion, odor complaint reports _____

RFI CHECKLIST - SUBSURFACE GAS (Continued)

- Existing gas/ground-water monitoring data ____
- Presence of natural or engineered barriers near unit ____
- Evidence of vegetative stress ____

3. Does environmental setting information include the following information? (Y/N)
   - Definition of regional climate ____
   - Definition of site-specific meteorological conditions ____
   - Definition of soil conditions ____
   - Definition of site specific terrain ____
   - Identification of subsurface gas migration routes ____
   - Identification and location of engineered conduits ____
   - Identification of surrounding structures ____

4. Have the following data on the initial phase of the release characterization been collected? (Y/N)
   - Extent and configuration of gas plume ____
   - Measured methane and gaseous constituent concentration levels in subsurface soil and surrounding structures ____
   - Sampling locations and schedule ____

5. Have the following data on the subsequent phase(s) of the release characterization been collected? (Y/N)
   - Extent and configuration of gas plume ____
   - Measured methane and gaseous constituent concentration levels in subsurface soil and surrounding structures ____
   - Sampling locations and schedule ____

11.9 References

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APPENDIX C

GEOPHYSICAL TECHNIQUES

APPENDIX C

GEOPHYSICAL TECHNIQUES

The methods presented in this Appendix have been drawn primarily from two sources. The first, Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982) was written specifically for application at hazardous waste sites, and for an audience with limited technical background. All of the surface geophysical methods discussed below can be found in this document. The second, Geophysical Explorations (U.S. Army Corps of Engineers, Engineering Manual 1110-1-1802, 1979) is a more generic application-oriented manual which contains the borehole methods described in this section.

Caution should be exercised in the use of geophysical methods involving the introduction or generation of an electrical current, particularly when contaminants are known or suspected to be present which have ignitable or explosive properties. The borehole methods are of particular concern due to the possible build up of large amounts of explosive or ignitable gases (e.g., methane).

ELECTROMAGNETIC SURVEYS

The electromagnetic (EM)* method provides a means of measuring the electrical conductivity of subsurface soil, rock, and ground water. Electrical conductivity is a function of the type of soil and rock, its porosity, permeability, and the fluids which fill the pore space. In most cases the conductivity (specific conductance) of the pore fluids will dominate the measurement. Accordingly, the EM method is applicable both to assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. Additionally, trench

*The term "electromagnetic" has been used in contemporary literature as a descriptive term for other geophysical methods, including ground penetrating radar and metal detectors which are based on electromagnetic principles. However, this document will use electromagnetic (EM) to specifically imply the measurement of subsurface conductivities by low frequency electromagnetic induction. This is in keeping with the traditional use of the term in the geophysical industry from which the EM methods originated.

boundaries, buried wastes and drums, as well as metallic utility lines can be located with EM techniques.

Natural variations in subsurface conductivity may be caused by changes in soil moisutre content, ground-water specific conductance, depth of soil cover over rock, and thickness of soil and rock layers. Changes in basic soil or rock types, and structural features such as fractures or voids may also produce changes in conductivity. Localized deposits of natural organics, clay, sand, gravel, or salt- rich zones will also affect subsurface conductivity.

Many contaminants will produce an increase in free ion concentration when introduced into the soil or ground water systems. This increase over background conductivity enables detection and mapping of contaminated soil and ground water at hazardous waste sites. Large amounts of organic fluids such as diesel fuel can displace the normal soil moisture, causing a decrease in conductivity which may also be mapped, although this is not commonly done. The mapping of a plume will usually define the local flow direction of contaminants. Contaminant migration rates can be estimated by comparing measurements taken at different times.

The absolute values of conductivity for geologic materials (and contaminants) are not necessarily diagnostic in themselves, but the variations in conductivity, laterally and with depth, are significant. It is these variations which enable the investigator to rapidly find anomalous conditions (See Figure C-1).

At hazardous waste sites, applications of EM can provide:

- Assessment of natural geohydrologic conditions;
- Locating and mapping of burial trenches and pits containing drums and/or bulk wastes;
- Locating and mapping of plume boundaries;
- Determination of flow direction in both unsaturated and saturated zones;

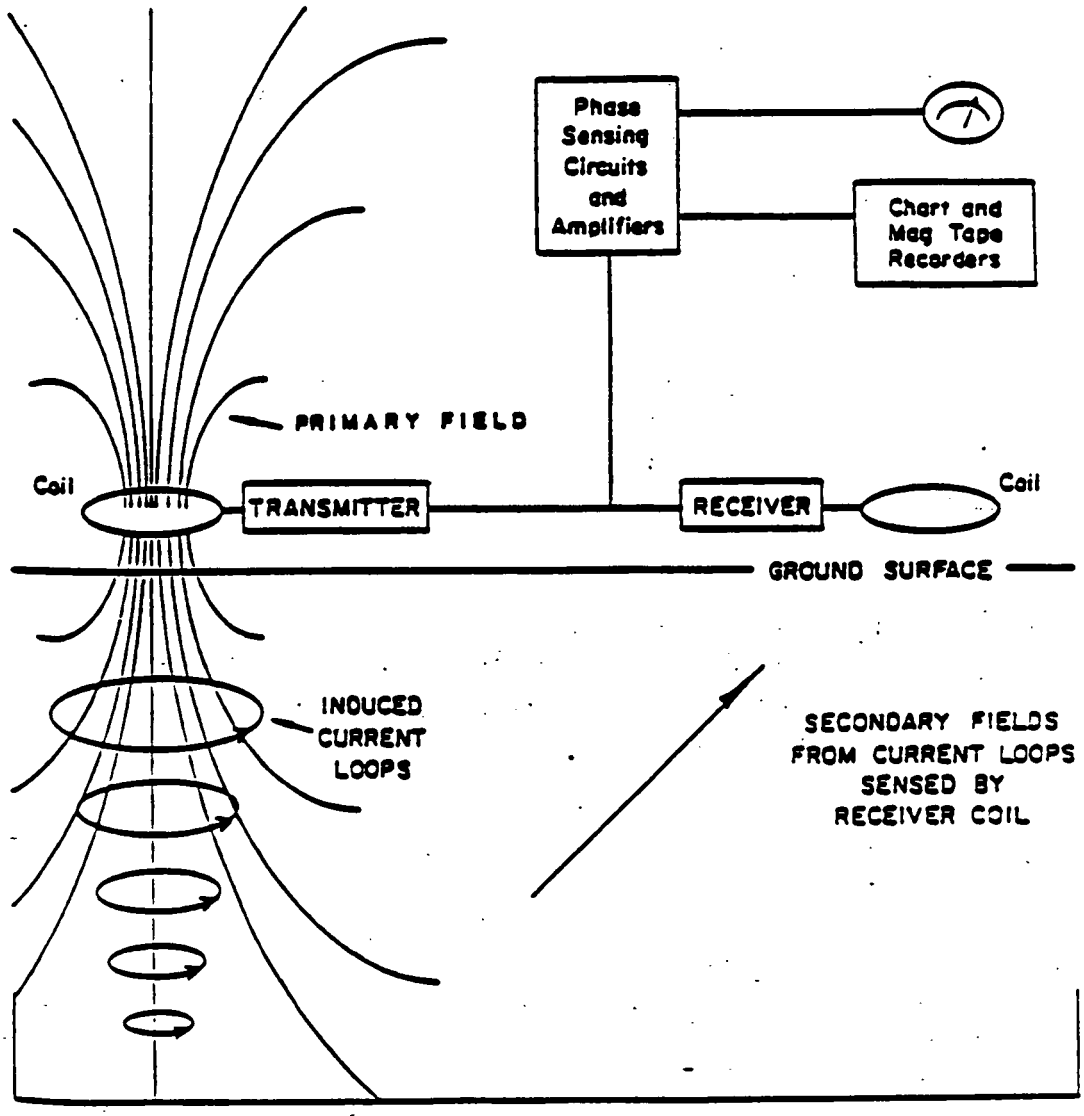

Figure C-1. Block diagram showing EM principle of operations.

- Rate of plume movement by comparing measurements taken at different times; and

- Locating and mapping of utility pipes and cables which may affect other geophysical measurements, or whose trench may provide a pathway for contaminant flow.

Chapter V of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982) should be consulted for further detail regarding use, capabilities, and limitations of electromagnetic surveys.

SEISMIC REFRACTION SURVEYS

Seismic refraction techniques are used to determine the thickness and depth of geologic layers and the travel time or velocity of seismic waves within the layers. Seismic refraction methods are often used to map depths to specific horizons such as bedrock, clay layers, and the water table. In addition to mapping natural features, other secondary applications of the seismic method include the locations and definition of burial pits and trenches.

Seismic waves transmitted into the subsurface travel at different velocities in various types of soil and rock, and are refracted (or bent) at the interfaces between layers. This refraction affects their path of travel. An array of geophones (transducers that respond to the motion of the ground) on the surface measures the travel time of the seismic waves from the source to the geophones at a number of spacings. The time required for the wave to complete this path is measured, permitting a determination to be made of the number of layers, the thicknesses of the layers and their depths, as well as the seismic velocity of each layer. The wave velocity in each layer is directly related to its material properties such as density and hardness. Figure C-2 depicts the seismic refraction technique.

Seismic refraction can be used to define natural geohydrologic conditions, including thickness and depth of soil and rock layers, their composition and physical properties, and depth to bedrock or the water table. It can also be used for the detection and location of anomalous features, such as pits and trenches and for evaluation of the depth of burial sites or landfills.

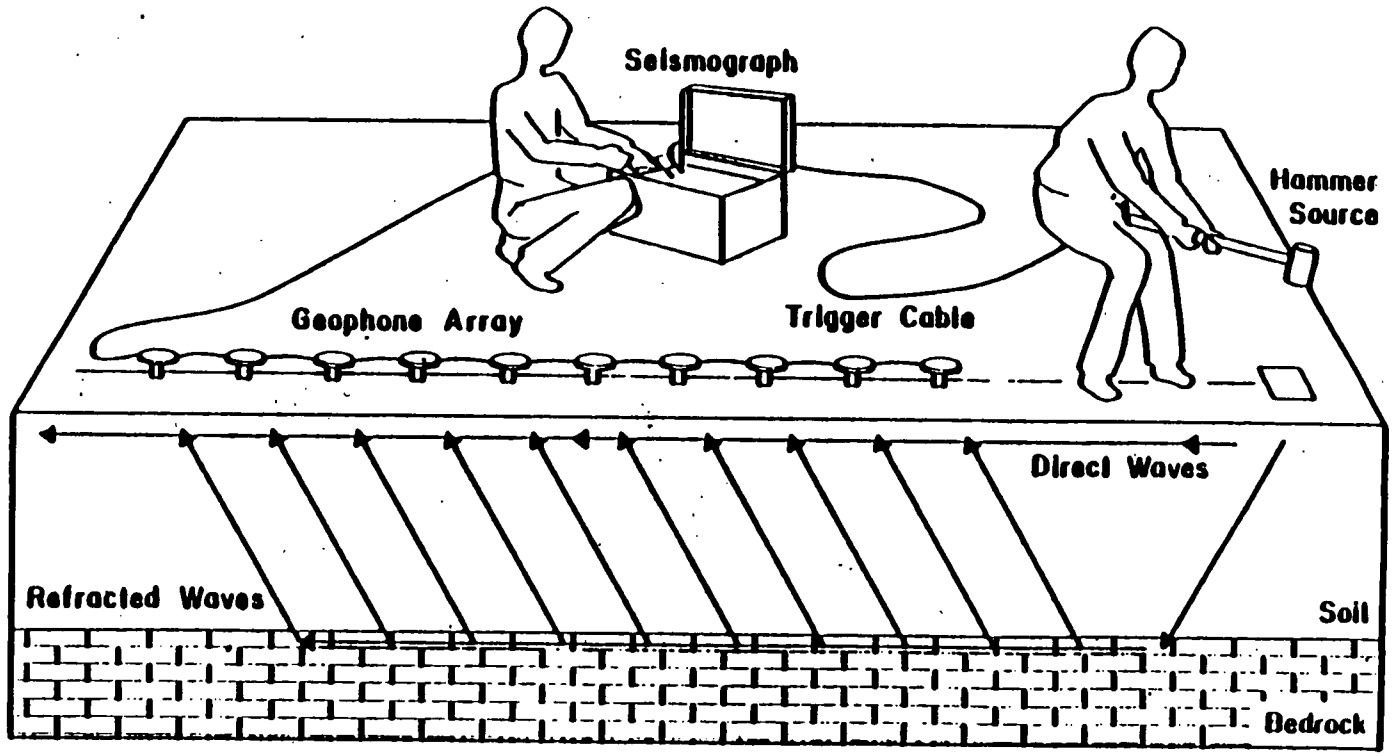

Figure C-2. Filed layout of a 12-channel seismograph showing the path of direct and refracted seismic waves in a two-layer soil/rock system.

Specific details regarding the use of seismic refraction surveys, and the capabilities and limitations of this method can be found in Chapter VII of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982).

RESISTIVITY SURVEYS

The resistivity method is used to measure the electrical resistivity of the geohydrologic section which includes the soil, rock, and ground water. Accordingly, the method may be used to assess lateral changes and vertical cross- sections of the natural geohydrologic settings. In addition, it can be used to evaluate contaminant plumes and locate buried wastes at hazardous waste sites. Figure C-3 is a graphical representation of the concept of a resistivity survey.

Applications of the resistivity method at hazardous waste sites include:

- Locating and mapping contaminant plumes;
- Establishing direction and rate of flow of contaminant plumes;
- Defining burial sites by:
  - locating trenches,
  - defining trench boundaries, and
  - determining the depths of trenches; and
- Defining natural geohydrologic conditions such as:
  - depth to water table or to water-bearing horizons; and
  - depth to bedrock, thickness of soil, etc.

Chapter VI of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982), discusses methods, use, capabilities, and limitations of the resistivity method.

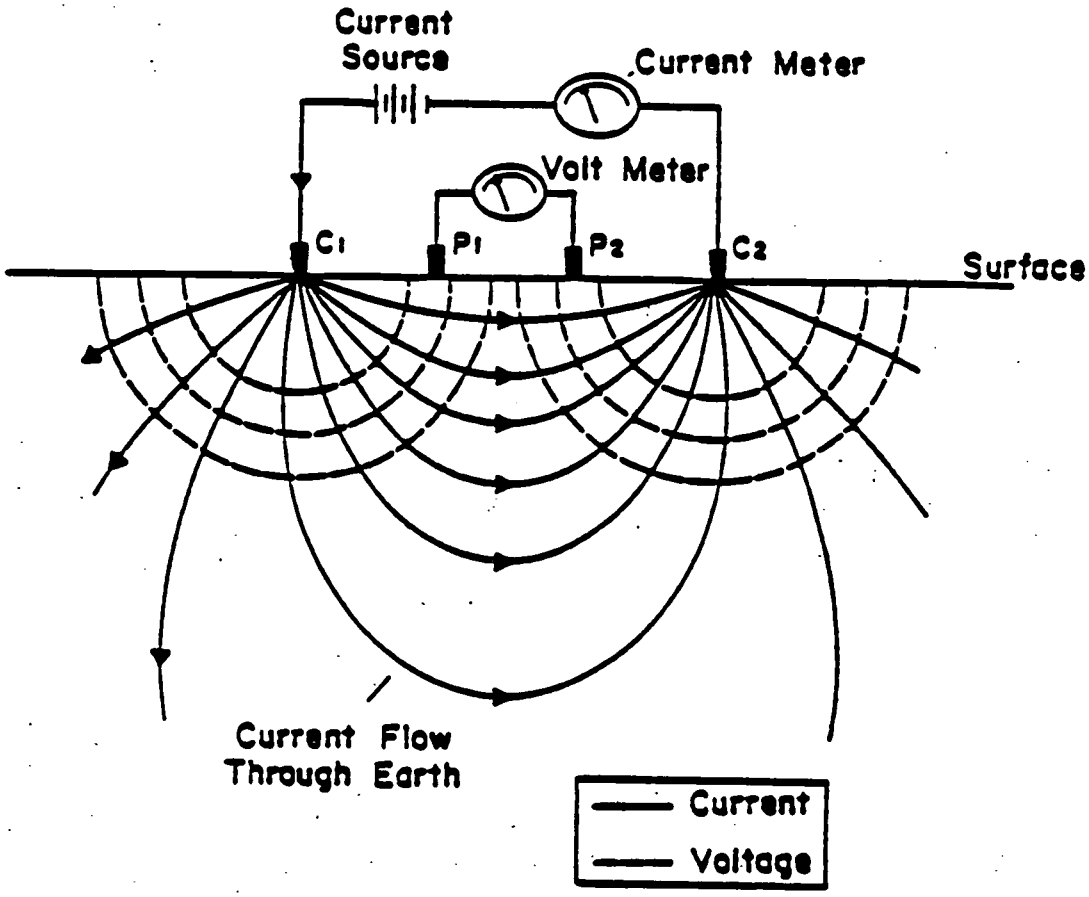

Figure C-3. Diagram showing basic concept of resistivity measurement.

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GROUND PENETRATING RADAR SURVEYS

Ground penetrating radar (GPR)* uses high frequency radio waves to acquire subsurface information. From a small antenna which is moved slowly across the surface of the ground, energy is radiated downward into the subsurface, then reflected back to the receiving antenna, where variations in the return signal are continuously recorded. This produces a continuous cross-sectional "picture" or profile of shallow subsurface conditions. These responses are caused by radar wave reflections from interfaces of materials having different electrical properties. Such reflections are often associated with natural geohydrologic conditions such as bedding, cementation, moisture and clay content, voids, fractures, and intrusions, as well as man-made objects. The radar method has been used at numerous sites to evaluate natural soil and rock conditions, as well as to detect buried wastes. Figure C-4 depicts the ground penetrating radar method.

Radar responds to changes in soil and rock conditions. An interface between two soil or rock layers having sufficiently different electrical properties will show up in the radar profile. Buried pipes and other discrete objects will also be detected.

Radar has effectively mapped soil layers, depth of bedrock, buried stream channels, rock fractures, and cavities in natural settings. Radar applications include:

- Evaluation of the natural soil and geologic conditions;
- Location and delineation of buried waste materials, including both bulk and drummed wastes;

*GPR has been called by various names: ground piercing radar, ground probing radar, and subsurface impulse radar. It is also known as an electromagnetic method (which in fact it is); however, since there are many other methods which are also electromagnetic, the term GPR has come into common use today, and is used herein.

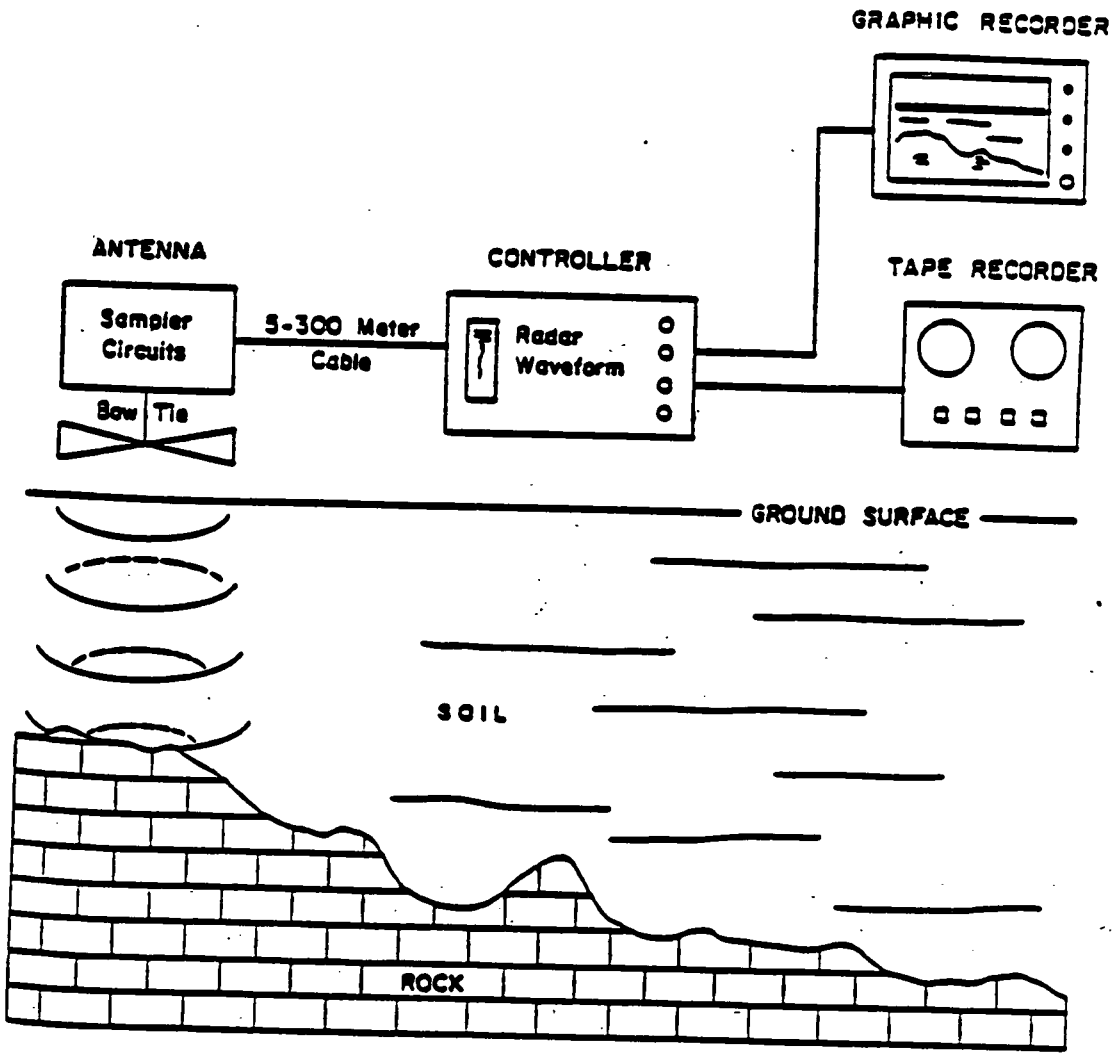

Figure C-4. Block diagram of ground penetrating radar system.Radar waves are relfected from soil/rock interface.

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- Location and delineation of contaminant plume areas; and

- Location and mapping of buried utilities (both metallic and nonmetallic).

In areas where sufficient ground penetration is achieved, the radar method provides a powerful assessment tool. Of the geophysical methods discussed in this document, radar offers the highest resolution. Ground penetrating radar methods are further detailed in Chapter IV of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982), as are this method's capabilities and limitations.

MAGNETOMETER SURVEYS

Magnetic measurements are commonly used to map regional geologic structure and to explore for minerals. They are also used to locate pipes and survey stakes or to map archeological sites. In addition, they are commonly used to locate buried drums and trenches.

A magnetometer measures the intensity of the earth's magnetic field. The presence of ferrous metals creates variations in the local strength of that field, permitting their detection. A magnetometer's response is proportional to the mass of the ferrous target. Typically, a single drum can be detected at distances up to 6 meters, while massive piles of drums can be detected at distances up to 20 meters or more. Figure C-5 shows the use of a magnetometer in detecting a buried drum.

Magnetometers may be used to:

- Locate buried drums;

- Define boundaries of trenches filled with ferrous containers;

- Locate ferrous underground utilities, such as iron pipes or tanks, and the permeable pathways often associated with them; and

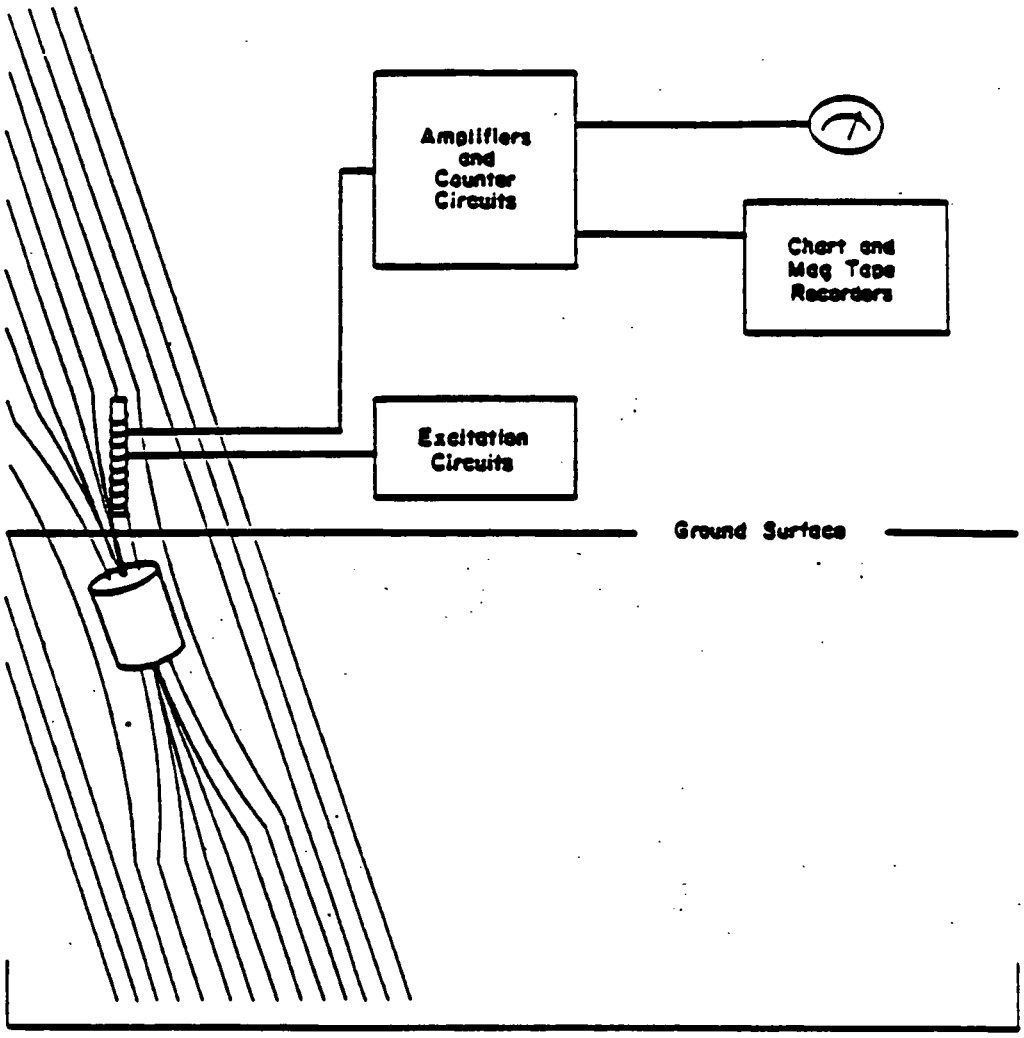

Figure C-5. Simplified block diagram of a magnetometer. A magnetometer senses change in the earth's magnetic field due to buried iron drum.

- Aid in selecting drilling locations that are clear of buried drums, underground utilities, and other obstructions.

The use, capabilities, and limitations of magnetometer surveys at hazardous waste sites are provided in Chapter IX of Geophysical Techniques for Sensing Buried Wastes and Waste Migration (Technos, Inc., 1982).

BOREHOLE GEOPHYSICAL METHODS

There are several different types of borehole geophysical methods used in the evaluation of subsurface lithology, stratigraphy, and structure. Much of the data collected in boreholes is analyzed in conjunction with surface geophysical data to develop a more detailed description of subsurface features. In this section, the major and most applicable types of borehole geophysical methods are identified and briefly discussed. They include:

I. Electrical Surveys
   a. Spontaneous Potential
   b. Resistivity

II. Nuclear Logging
   a. Natural Gamma
   b. Gamma Gamma
   c. Neutron

III. Seismic Surveys
   a. Up and Down Hole
   b. Crosshole Tests
   c. Vertical Seismic Profiling

IV. Sonic Borehole Surveys
   a. Sonic Borehole Imagery
   b. Sonic Velocity

V. Auxiliary Surveys
   a. Temperature
   b. Caliper
   c. Fluid Resistivity

All of the borehole methods presented in this section are detailed in the Army Corps of Engineers Geophysical Explorations Manual (Engineering Manual 1110-1-1802, 1979), with the exception of vertical seismic profiling. This method is relatively new and further information can be found in Balch and Lee, 1984.

Electrical Surveys

The two types of electrical subsurface surveys of geotechnical interest, both of which involve continuous logging with depth of the electrical characteristics of the borehole walls, are the spontaneous potential log and the borehole resistivity log.

The spontaneous potential log (also known as self potential) is a record of the variation with depth of naturally occurring electrical potentials (voltages) between an electrode at the depth in a fluid filled borehole and another at the surface

The known origins for spontaneous potentials arise from the relative mobility and concentrations of the different elemental ions dissolved in the borehole fluid and the fluid in adjacent strata. The electrochemical activities of the minerals in the strata also cause a component of the measured spontaneous potentials (Figure C-6). The relative senses and magnitudes of the several causes from which spontaneous potentials arise are affected by the nature of the borehole fluid, by the mineralogical characteristics of all the strata the borehole penetrates, and by the dissolved solid concentration in the ground water in all potential layers.

The second type of electric survey is the electrical resistivity log. The electrical resistivity of strata is one of the basic parameters that correlates to lithology and hydrology. Direct access to individual layers of the subsurface materials by means of the borehole is the primary advantage of electrical resistivity logging over the more indirect use of apparent electrical resistivity surveys from the surface.

Electrical current can be passed through in situ earth materials between two electrodes. Electric fields created within the three dimensional earth medium are related to the medium's structure and the nature of the aqueous fluid in the medium. Figure C-7 demonstrates the conceptual field configuration for borehole electrical resistivity survey.

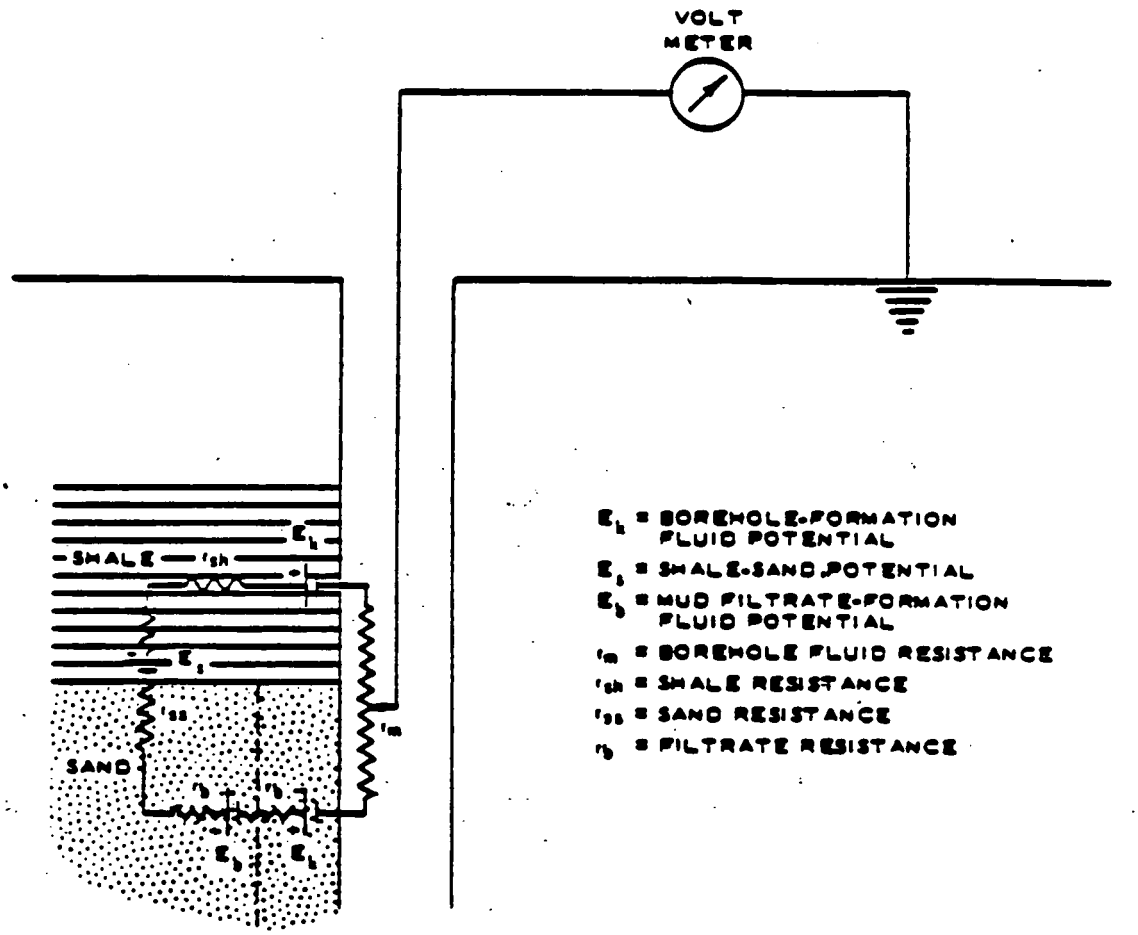

Figure C-6. Conceptual equivalent circuit for self-potential data (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).

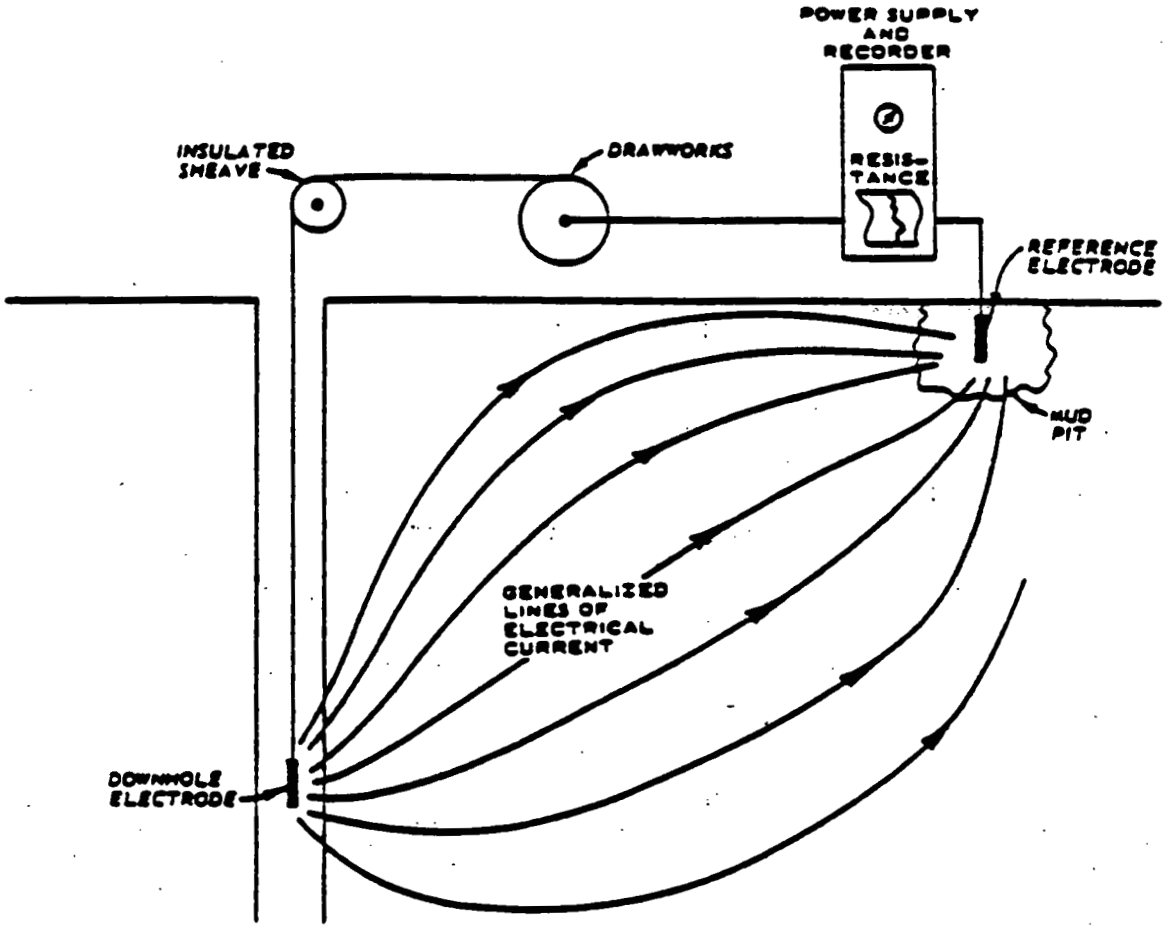

Figure C-7. Single-point resistance log (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).

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Resistivity logging is a valuable tool in correlating beds from borehole to borehole. In addition, they can be used together with knowledge of ground water and rock matrix resistivities (obtained from samples) to calculate porosities and/or water saturations. Also, if porosity is known and a borehole temperature log is available, contaminant concentrations can be inferred by electrical resistivity variations.

Nuclear Logging

Nuclear borehole logging can be used quite effectively for borehole depths ranging from 10 to more than 1,000 feet. At considerable depths, as for large buried structures, nuclear logging is a very effective means of expanding a small number of data points obtained from direct measurements on core samples to continuous records of clay content, bulk density, water content, and/or porosity. The logs are among the simplest to perform and interpret, but the calibrations required for meaningful quantitative interpretations must be meticulously complete in attention to detail and consideration of all factors affecting nuclear radiation in earth materials. Under favorable conditions, nuclear measurements approach the precisions of direct density tests on rock cores. The gamma-gamma density log and the neutron water content log require the use of isotopic sources of nuclear radiation. Potential radiation hazards mandate thorough training of personnel working around these sources. Strict compliance with U.S. NRC Title 10, Part 20, as well as local safety regulations, is required. Additional information on natural gamma, gamma-gamma, and neutron gamma methods is provided below.

The natural gamma radiation tool is a passive device measuring the amount of gamma radiation naturally occurring in the strata being logged. The primary sources of radiation are trace amounts of the potassium isotope K^{40} and isotopes of uranium and thorium. K^{40} is most prevalent, by far, existing as an average of 0.012 percent by weight of all potassium. Because potassium is part of the crystal lattices of illites, micas, montmorillanites, and other clay materials, the engineering gamma log is mainly a qualitative indication of the clay content of the strata.

The natural gamma log is put to its simplest and most frequently used applications in qualitative lithologic interpretation (specifically identification of shale and clay layers) and bed correlations from hole to hole. Since clay fractions

frequently reduce the primary porosity and permeability of sediments, inferences as to those parameters may sometimes be possible from the natural gamma log. Environmentally based surveys may utilize the log for tracing radioactive pollutants. If regulatory restrictions allow the use of radioactive tracers, the natural gamma log can be used to locate ground water flow paths. The natural gamma radiation level is also a correction factor to the gamma-gamma density log.

In the gamma-gamma logging technique, a radioactive source and detector are used to determine density variations in the borehole. An isotopic source of gamma radiation can be placed on the gamma radiation tool and shielded so that direct paths of that radiation from source to detector are blocked. The source radiation then permeates the space and materials near itself. As the gamma photons pass through the matter, they are affected by several factors among which is "Compton scattering." Part of each photon's energy is lost to orbital electrons in the scattering material. The amount of scattering is proportional to the number of electrons present. Therefore, if the portion of radiation able to escape through the logged earth materials without being widely scattered and de-energized is measured, then that is an inverse active measure of electron density. A schematic representation of the borehole gamma-gamma tool is shown in Figure C-8.

The neutron water detector logging method is much like the gamma-gamma technique in that it uses a radioactive source and detector. The difference is that the neutron log measures water content rather than density of the borehole material. A composite isotopic source of neutron radiation can be placed on a probe together with a neutron detector. A neutron has about the same mass and diameter as a hydrogen nucleus and is much lighter and smaller than any other geochemically common nucleus. Upon collision with a hydrogen nucleus the neutron loses about half its kinetic energy to the nucleus and is slowed down as well as scattered. Collision with one of the larger nuclei scatters the neutron but does not slow it. After a number of collisions with hydrogen nuclei, a neutron is slowed, or it is captured by a hydrogen atom and produces a secondary neutron emission of thermal energy plus a secondary gamma photon. Detectors can be "tuned" to be sensitive to the epithermal (slowed) neutron or to the thermal

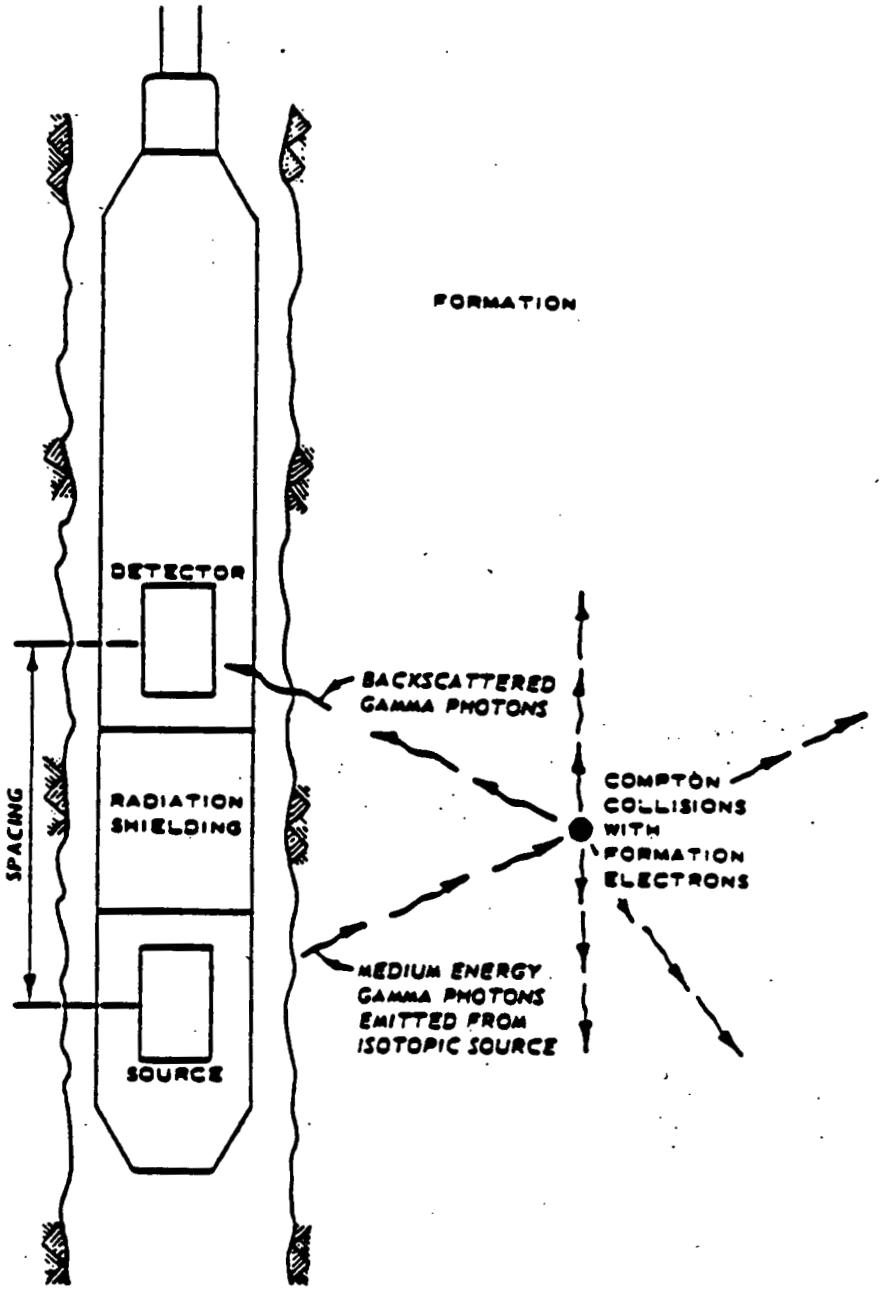

Figure C-8. Schematic of the borehole gamma-gamma density tool (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).

neutron or to the gamma radiation. One of these detectors plus the neutron source is then a device capable of measuring the amount of hydrogen in the vicinity of the tool. In the geologic environment, hydrogen exists most commonly in water (H2O) and in hydrocarbons. If it can be safely assumed that hydrocarbons are not present in appreciable amounts, then the neutron-epithermal neutron, the neutron-thermal neutron, and the neutron-gamma logs are measures of the amount of water present if the tool is calibrated in terms of its response to saturated rocks of various porosities.

The neutron log can be used for hole to hole stratigraphic correlation. Its designed purpose is to measure water quantities in the formation. Therefore, the gamma-gamma density, the neutron water detector, the natural gamma, and the caliper logs together form a "suite" of logs that, when taken together, can produce continuous interpreted values of water content, bulk density, dry density, void ratio, porosity, and pecent of water saturation.

Seismic Surveys

The principles involved in subsurface seismic surveys are the same as those discussed earlier under surface seismic surveys. The travel times for P- and S- waves between source and detector are measured, and wave velocities are determined on the basis of theoretical travel paths. These calculated wave velocities can then be used to complement and supplement other geophysical surveys conducted in the area of investigation.

Three common types of borehole seismic surveys are discussed in this section. They include Uphole and Downhole surveys, Crosshole Tests, and Vertical Seismic Surveys. The applications and limitations are discussed for each of these methods.

In the uphole and downhole seismic survey, a seismic signal travels between a point in a borehole and a point on the ground near the hole. In an uphole survey the energy source is in the borehole, and the detector on the ground surface; in a downhole survey, their positions are reversed. The raw data obtained are the travel times for this signal and distances between the seismic source and the geophones. A plot of travel time versus depth yields, from the slope of the curve, the average

wave propagation velocities at various intervals in the borehole. Figure C-9 depicts a downhole seismic survey technique.

Uphole and downhole surveys are usually performed to complement other seismic tests and provide redundancy in a geophysical test program. However, because these surveys force the seismic signals to traverse all of the strata between the source and detector, they provide a means of detecting features, such as a low velocity layer underlying a higher velocity layer of a "blind" or "hidden" zone (a layer with insufficient thickness and velocity contrast to be detected by surface refraction).

Crosshole tests are conducted to determine the P- and S-wave velocity of each earth material or layer within the depth of interest through the measurement of the arrival time of a seismic signal that has traveled from a source in one borehole to a detector in another. The crosshole test concept is shown in Figure C-10.

In addition to providing true P- and S-wave velocities as a function of depth, their companion purpose is to detect seismic anomalies, such as a lower velocity zone underlying a higher velocity zone or a layer with insufficient thickness and velocity contrast to be detected by surface refraction seismic tests.

The vertical seismic profiling technique involves the recording of seismic waves at regular and closely spaced geophones in the borehole. The surface source can be stationary or it can be moved to evaluate seismic travel times to borehole geophones, calculate velocities, and determine the nature of subsurface features in the vicinity of the borehole.

Vertical seismic profiling surveys are different from downhole surveys in that they provide data on not only direct path seismic signals, but reflected signals as well. By moving the surface source to discrete distances and azimuths from the borehole, this method provides a means of characterizing the nature and configuration of subsurface interfaces (bedding, ground water-table, faults), and anomalous velocity zones around the borehole.

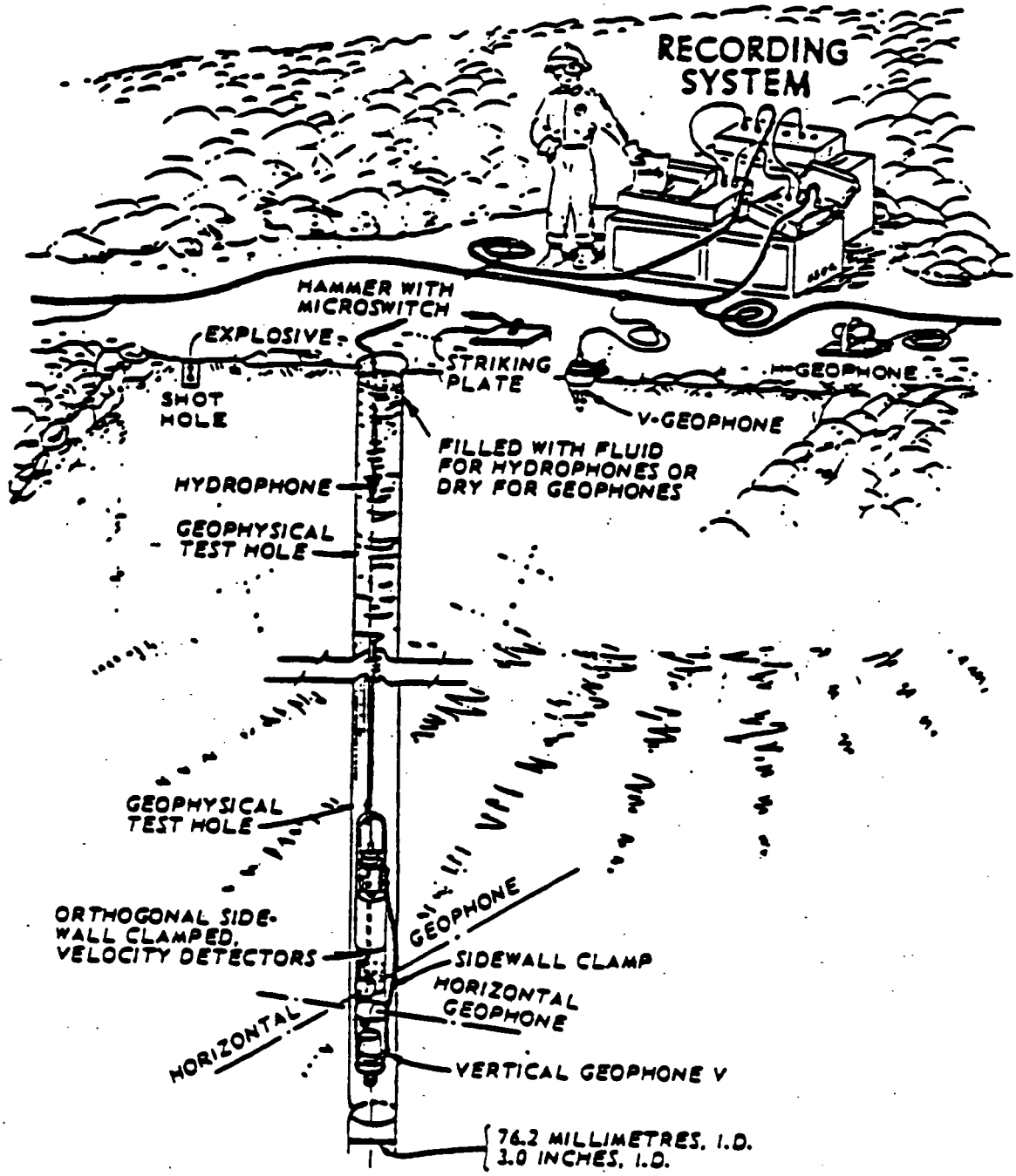

Figure C-9. Downhole survey techniques for P-wave data (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).

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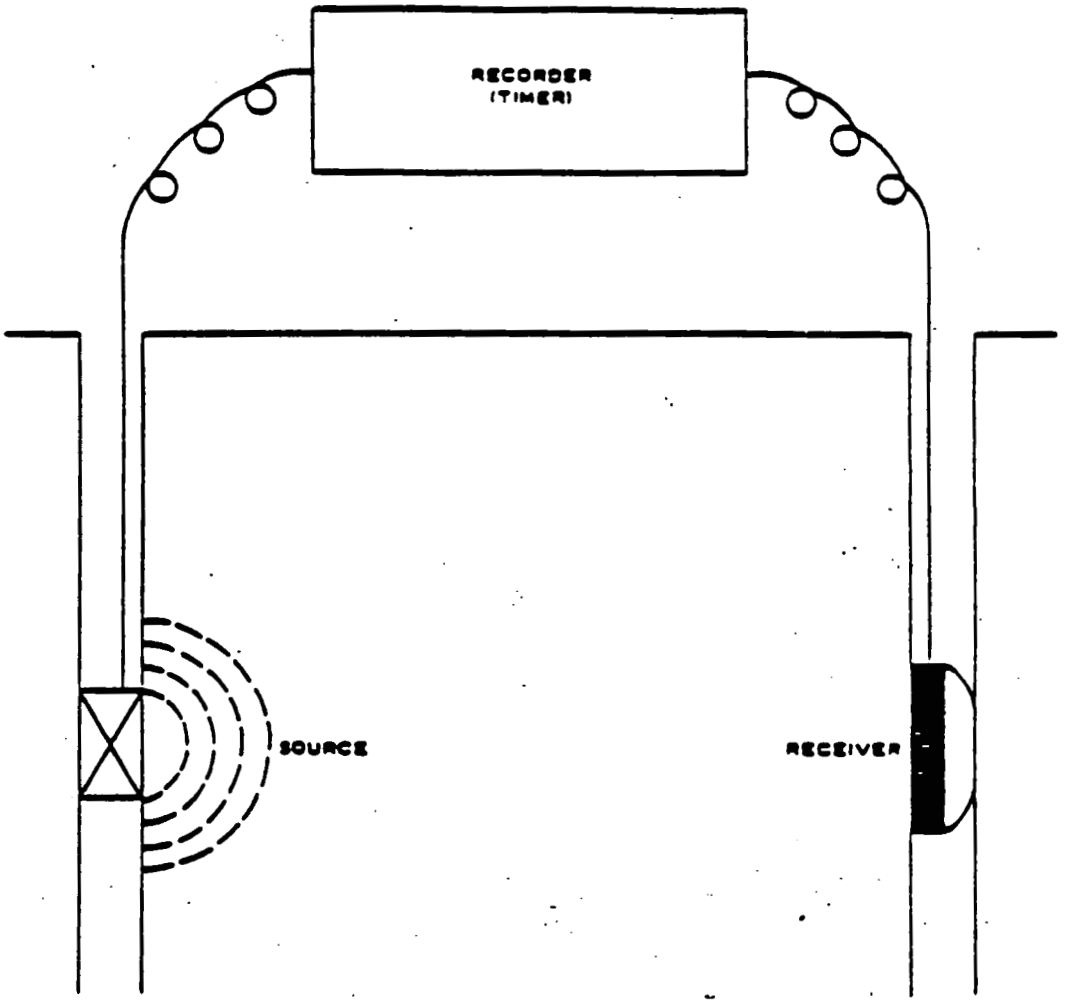

Figure C-10. Basic crosshole test concept (prepared by the Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi).

The interpretation of processed vertical seismic profiling data is used in conjunction with surface seismic surveys as well as other geophysical surveys in the evaluation of subsurface lithology, stratigraphy, and structure. Vertical seismic profiling survey interpretations also provide a basis for correlation between boreholes.

Sonic Borehole Surveys

In this section, two types of continuous borehole surveys involving high frequency sound wave propagation are discussed. Sound waves are physically identical to seismic P-waves. The term sound wave is usually employed when the frequencies include the audible range and the propagating medium is air to water. Ultrasonic waves are also physically the same, except that the frequency range is above the audible range.

The Sonic borehole imagery log provides a record of the surface configuration of the cylindrical wall of the borehole. Pulses of high frequency sound are used in a way similar to marine sonar to probe the wall of the borehole and, through electronic and photographic means, to create a visual image representing the surface configuration of the borehole wall. The physical principle involved is wave reflection from a high impedance surface, the same principle used in reflection seismic surveying and acoustic subbottom profiling. The sonic borehole imagery logging concept is depicted in Figure C-11.

The sonic borehole imagery log can be used to detect discontinuities in competent rock lining the borehole. Varying lithologies, such as shale, sandstone, and limestone, can sometimes be distinguished on high quality records by experienced personnel.

Another method of sonic borehole logging is referred to as the continuous sonic velocity logging technique. The continuous sonic velocity logging device is used to measure and record the transit time of seismic waves along the borehole wall between two transducers as it is moved up or down the hole. A diagram of the continuous sonic velocity logging device is provided in Figure C-12.

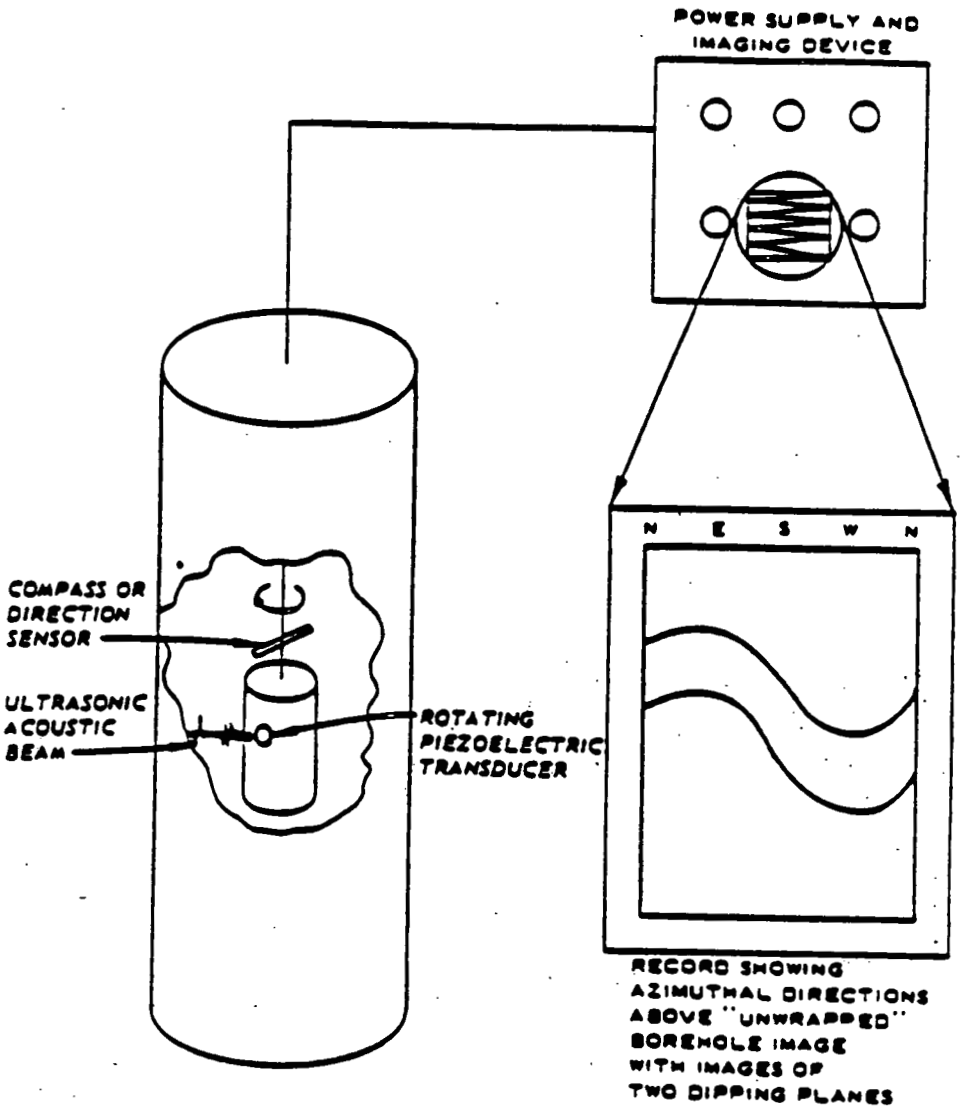

Figure C-11. Sonic imagery logger (prepared by the Waterways Experiment Station, U.S. Army Corp of Engineers, Vicksburg, Mississippi).

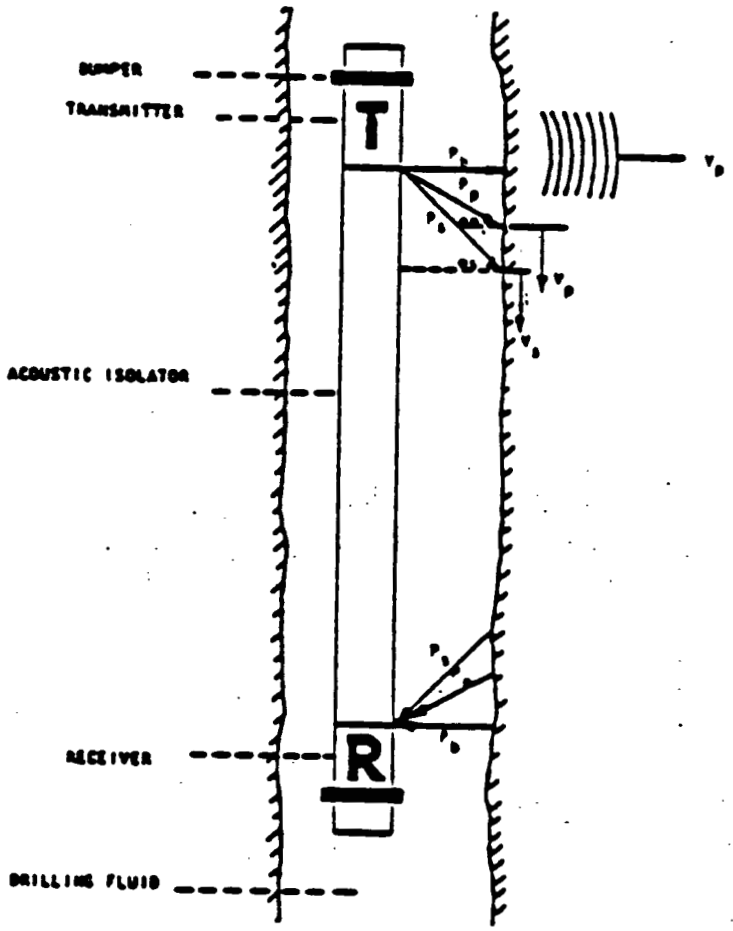

Figure C-12. Diagram of three-dimensional velocity tool (courtesy of Seismograph Service Corporation, Birdwell Division).

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This subsurface logging method provides data on fractures and abrupt lithology changes along the borehole wall that can be effective in characterizing the nature of surrounding material as well as borehole correlation in lithology and structure.

Auxiliary Surveys

An auxiliary survey is the direct measurement of some parameter of the borehole or its contained fluid to provide information that will either permit the efficient evaluation of the lithology penetrated by the boring or aid in the interpretation or reduction of the data from other borehole logging operations. In most instances, auxiliary logs are made where the property recorded is essential to the quantitative evaluation of other geophysical logs. In some instances, however, the auxiliary results can be interpreted and used directly to infer the existence of certain lithologic or hydrologic conditions.

Discussed here are three different auxiliary logs; fluid temperature, caliper, and fluid resistivity, that are especially applicable to the logging methods discussed in this text. A description of each auxiliary log is presented below.

Temperature logs are the continuous records of the temperature encountered at successive elevations in a borehole. The two basic types of temperature logs are standard (gradient) and differential. Both types of logs rely upon a downhole probe, containing one or more temperature sensors (thermistors) and surface electronics to monitor and record the temperature changes encountered in a borehole. The standard temperature log is the result of a single thermistor continuously sensing the thermal gradient of the fluid in the borehole as the sonde is raised or lowered in the hole. The differential temperature log depicts the difference in temperature over a fixed interval of depth in the borehole by employing two thermistors spaced from one to several feet apart or through use of a single thermistor and an electronic memory to compare the temperature at one depth with that of a selected previous depth.

Temperature logs provide useful information in both cased and uncased borings and are necessary for correct interpretation of other geophysical logs (particularly resistivity logs). Temperature logs can also be used directly to indicate the source and movement of water into a borehole, to identify aquifers, to locate zones of potential recharge, to determine areas containing wastes discharged into the ground, and to detect sources of thermal pollution. The thermal conductivity and permeability of rock formations can be inferred from temperature logs as can be the location of grout behind casing by the presence of anomalous zones of heat buildup due to the hydration of the setting cement.

The caliper log is a record of the changes in borehole casing or cavity size as determined by a highly sensitive borehole measuring device. The record may be presented in the form of a continuous vertical profile of the borehole or casing wall, which is obtained with normal or standard caliper logging systems, or as a horizontal cross section at selected depths, used for measuring voids or large subsurface openings. There are two basic methods of obtaining caliper logs. One technique utilizes mechanically activated measuring arms or bown springs, and the other employs piezoelectric transducers for sending and receiving a focused acoustic signal. The acoustic method requires that the hole be filled with water or mud, but the mechanical method operates equally well in water, mud, or air. Reliable mechanically derived caliper logs can be obtained in small (2 in.) diameter exploratory borings as well as large (36 in.) inspection or access calyx-type borings.

Caliper or borehole diameter logs represent one of the most useful and possibly the simplest of all techniques employed in borehole geophysics. They provide a means for determining inhole conditions and should be obtained in all borings in which other geophysical logs are contemplated. Borehole diameter logs provide information on subsurface lithology and rock quality. Borehole diameter varies with the hardness, fracture frequency, and cementation of the various beds penetrated. Borehole diameter logs can be used to accurately identify zones of enlargement (washouts) or construction (swelling), or to aid in the structural evaluation of an area by the accurate location of fractures or solution openings, particularly in borings where core loss has presented a problem. Caliper logs also are a means of identifying the more porous zones in a boring by locating the intervals in which excessive mud filter cake has built up on the walls of the borehole. One of the major uses of standard or borehole caliper logs is to provide

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information by which other geophysically derived raw data logs can be corrected for borehole diameter effects. This is particularly true for such nonfocused logs as those obtained in radiation logging or the quantitative evaluation of flowmeter logs or tracer and water quality work where inhole diameters must be considered. Caliper logs also can be useful to evaluate inhole conditions for placement of water well screens or for the selection of locations of packers for permeability testing.

The fluid resistivity log is a continuous graphical record of the resistivity of the fluid within a borehole. Such records are made by measuring the voltage drop between two closely spaced electrodes enclosed within a downhole probe through which a representative sample of the borehole fluid is channeled. Some systems, rather than recording in units of resistivity, are designed to provide a log of fluid conductivity. As conductivity is merely the reciprocal of resistivity, either system can be used to collect the information on inhole fluid required for the correct interpretation of other downhole logs.

The primary use of fluid resistivity or conductivity logs is to provide information for the correct interpretation of other borehole logs. The evaluation of nuclear and most electrical logs requires corrections for salinity of the inhole fluids, particularly when quantitative parameters are desired for determining porosity from formation resistivity logs.

APPENDIX D

SUBSURFACE GAS MIGRATION MODEL
ADAPTED FROM

GUIDANCE MANUAL FOR THE CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES
U.S. EPA, 1981

APPENDIX D

SUBSURFACE GAS MIGRATION MODEL

METHANE MIGRATION DISTANCE PREDICTION CHARTS

Migration distance charts have been developed to estimate methane distances and to plan the monitoring program. The basic methane migration distance prediction chart and appropriate corrective factor charts were produced by imposing a set of simplifying assumptions on a general methane migration computer model. These charts are based on a number of assumptions that were made to produce them. Case Study Number 24 (Volume IV) illustrates the use of the Subsurface Gas Migration Model.

To illustrate the use of the charts, an example landfill is shown in Figure D-1 along with two cross-sections. Conditions along each side of the waste deposit are typical conditions that could be encountered. A similar sketch or plan of a facility being evaluated should be prepared. The land use within 1/4-mile of the solid waste limits, including offsite and facility structures, should be on the map. The property boundaries and solid waste deposit limits should also be plotted, as has been done in Figure D-1.

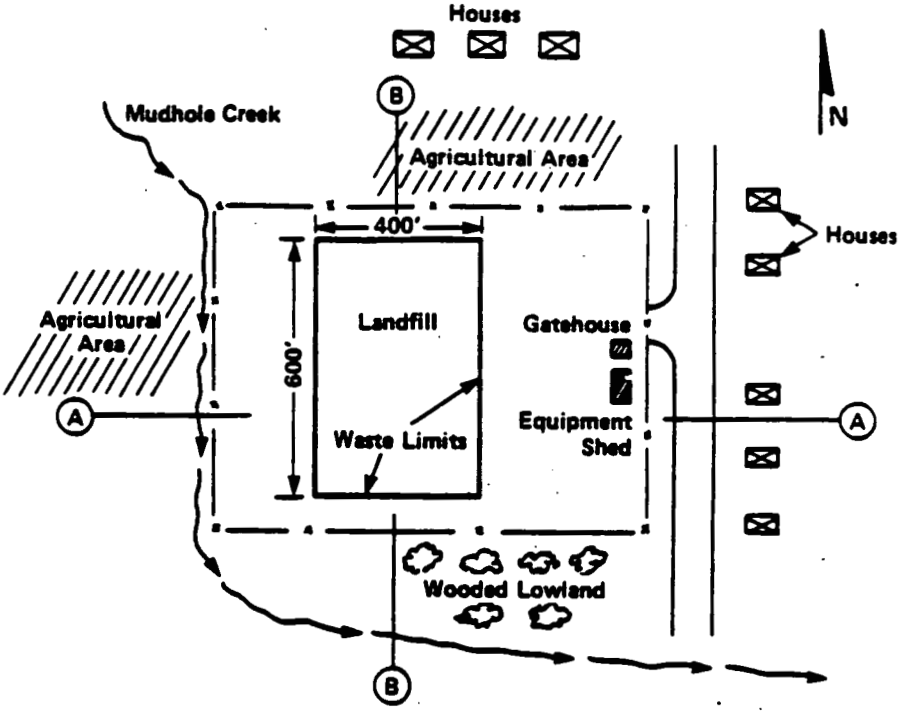
Additional data needs are:

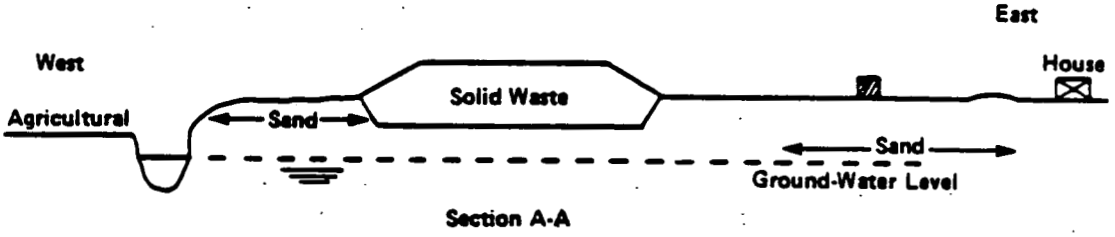
1. The age of the site from the initial deposit of organic waste in years;

2. The average elevation of the bottom of the solid waste;

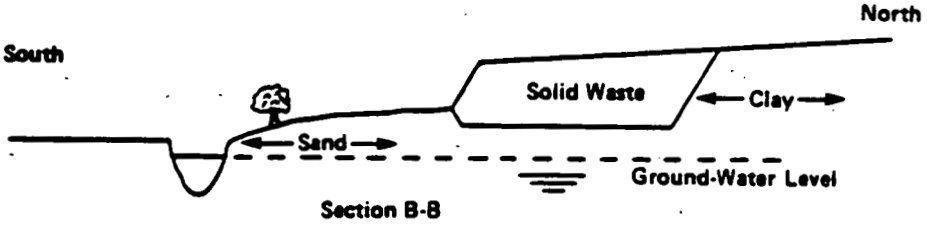
3. Natural boundaries and topography around the site; and

4. The average elevation below the solid waste of a gas impervious boundary such as unfractured rock.





Section A-A



Section B-B

Note: Not to Scale

FIGURE D-1. EXAMPLE LANDFILL

Two calculations of migration distance from the waste boundary are needed for each side of the landfill:

1. The 5 percent (Lower Explosion Limit or LEL) distance for property boundaries.

2. The 1.25 percent (1/4 of the LEL) distance for onsite facility structures.

After preparation of the sketch and cross-sections, the determination of the estimated migration distances begins with the use of Figure D-2 for the 5 percent methane (LEL) migration distance and for the 1.25 percent (1/4 LEL) distance. These distances are then modified, if necessary, with the corrective factors for each depth and surrounding soil surface permeability (Figures D-3 and D-4). The final distances of migration for each side of the landfill can then be plotted on the landfill sketch for comparison to property boundary and structures locations.

UNCORRECTED MIGRATION DISTANCES

The use of Figure D-2 requires the age of the site and the type of soil extending out from each side of the solid waste deposit. The graph is entered with the site age, moving up to the appropriate soil type and methane concentration (1.25 or 5 percent). Interpolations between the sand and clay lines on the graph can be made for other soils, using the following general guidance:

Soil Name	USCS Classification	Chart Use
Clean (no fines) gravels and sands	GW, GP, SW, SP	Sand
Silty gravels and sands, silt, silty and sandy loam, organic silts	GM, SM, ML, OL, MH	Interpolate
Clayey gravels and sands, lean, fat, and organic clays	GC, SC, CL, CH, OH	Clay

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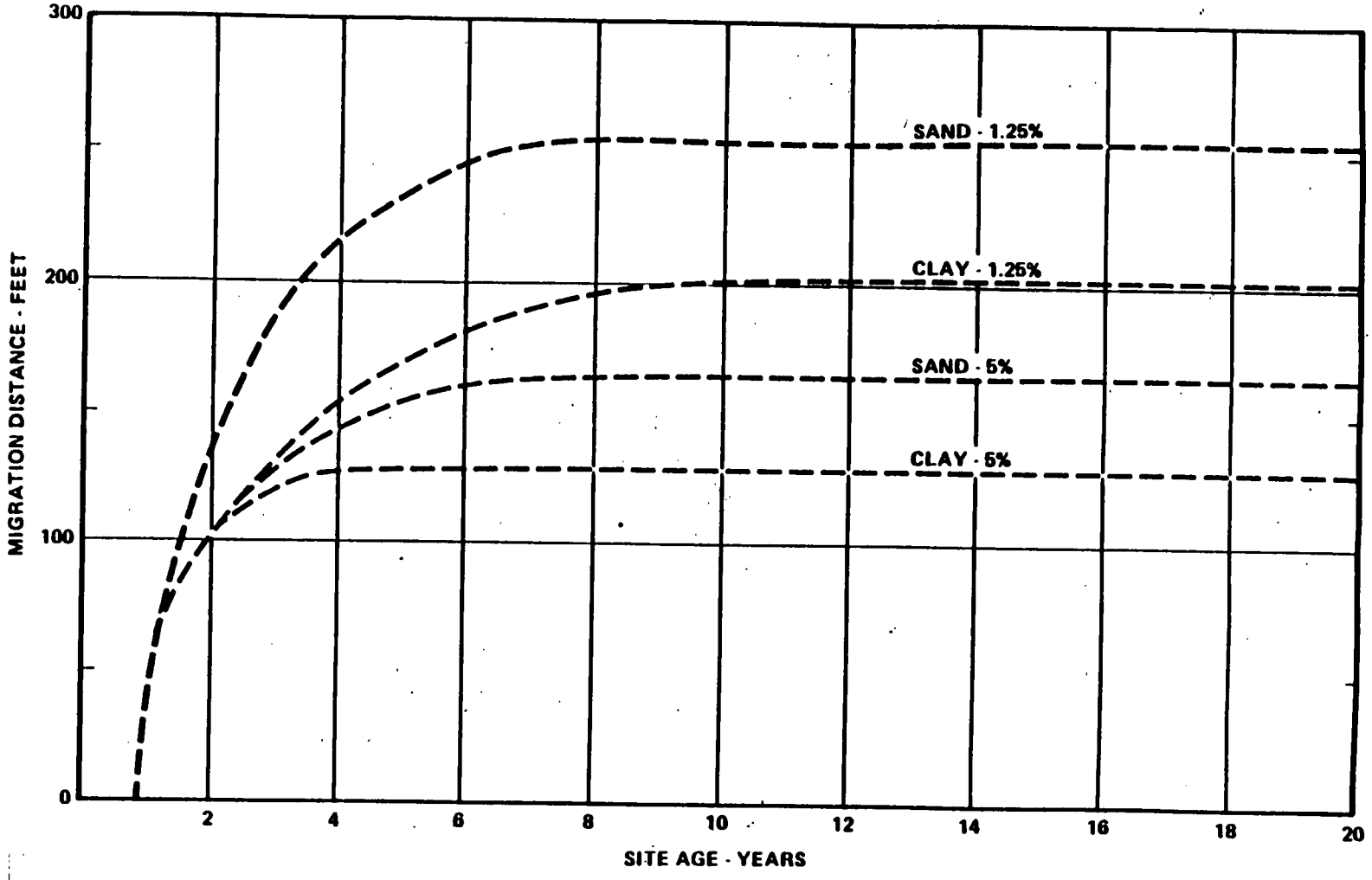


FIGURE D-2. FIVE PERCENT AND 1.25 PERCENT METHANE MIGRATION DISTANCE

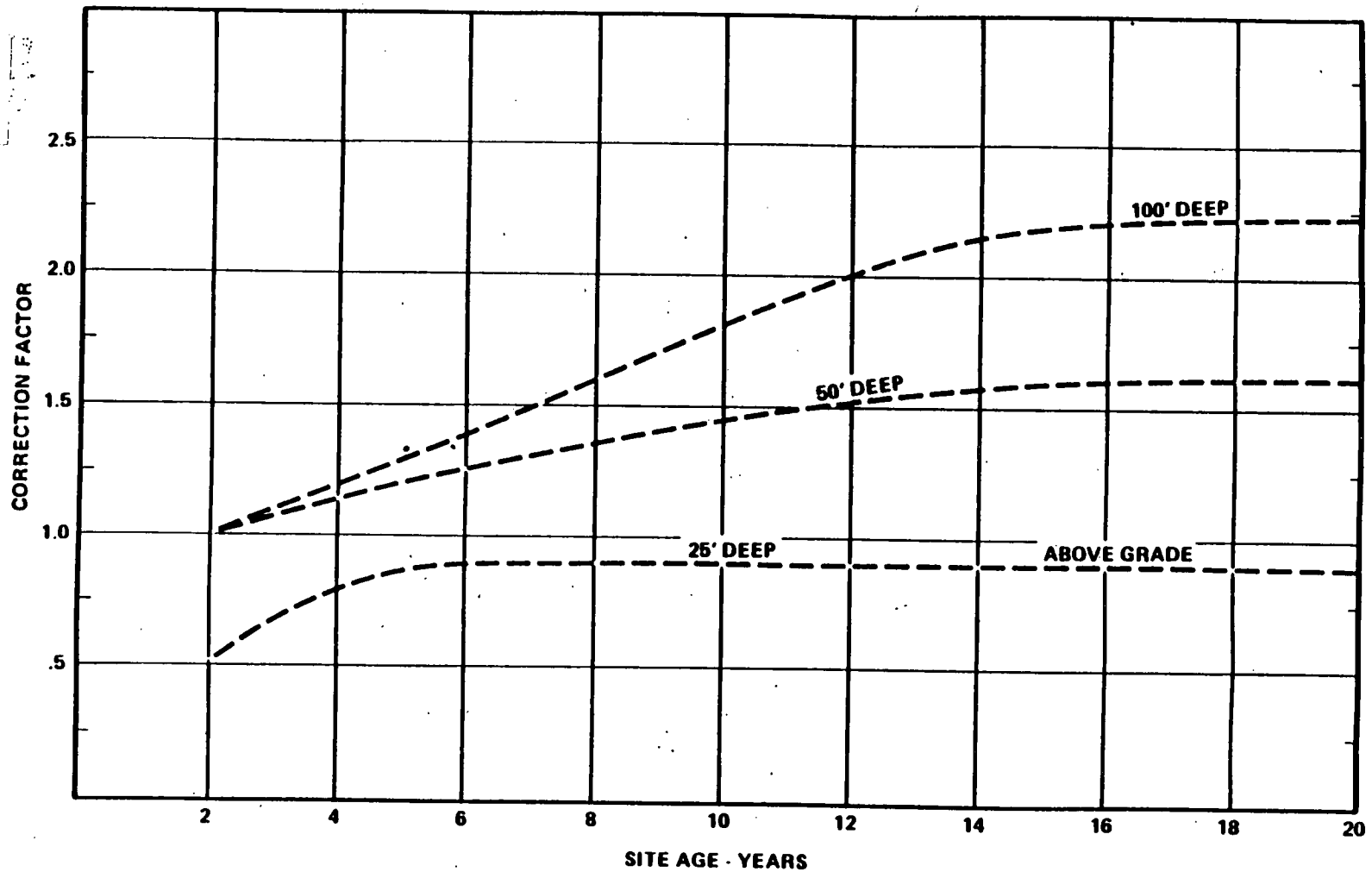


FIGURE D-3. CORRECTION FACTORS FOR LANDFILL DEPTH BEFORE GRADE

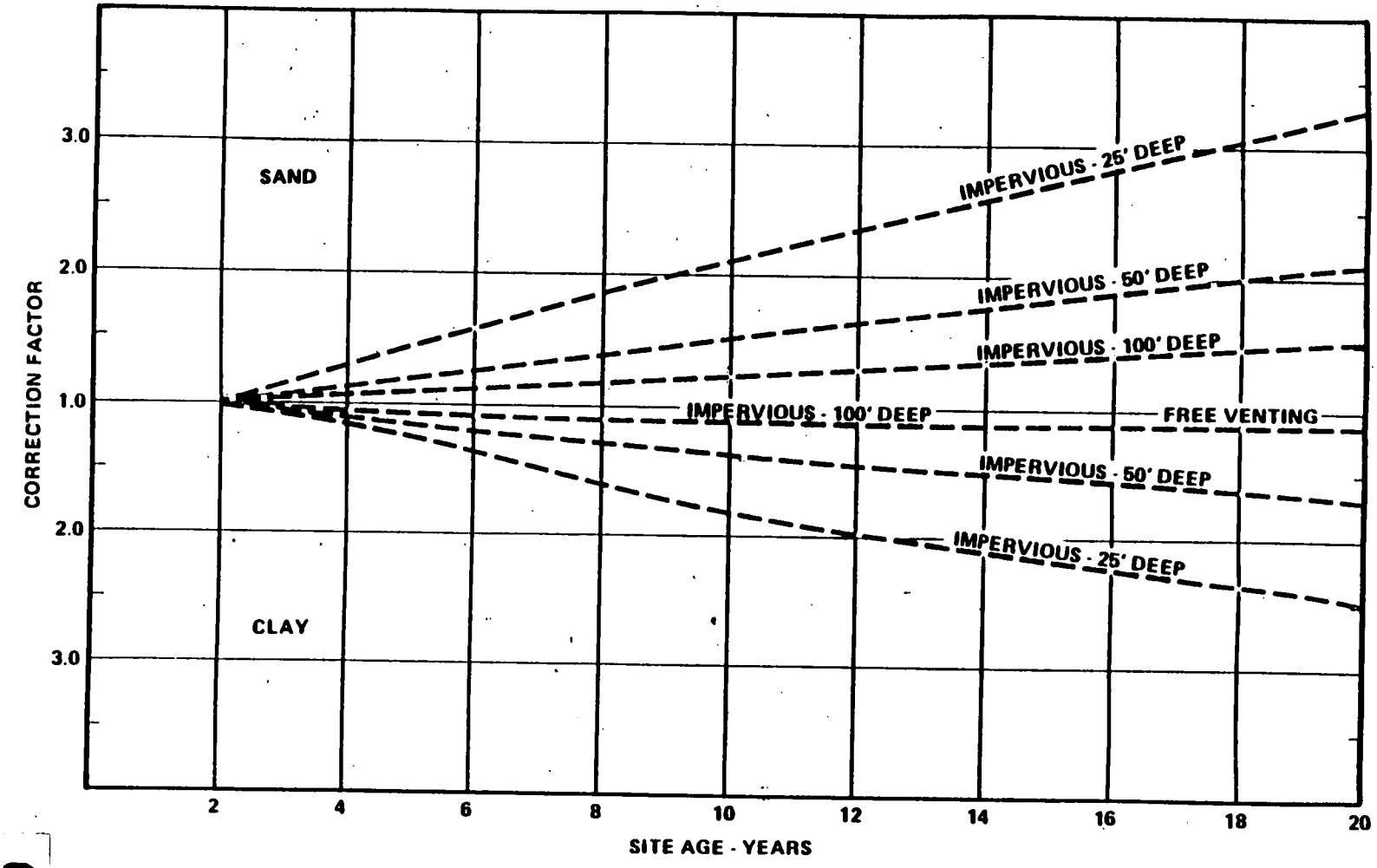


FIGURE D-4. CORRECTION FACTORS FOR SOIL SURFACE VENTING CONDITION AROUND LANDFILL

The uncorrected migration distance from the solid waste limit can then be read on the left for the appropriate site age and soil type.

If the soil along a given boundary is stratified and the variability extends from the waste deposit to the property boundary, the most permeable unsaturated thickness should be used in entering the charts. For example, if dry, clean sand underlies surficial silty clays, the uncorrected migration distance should be obtained using the sand line of the chart. If there are questions as to the extent of particular soils along a boundary, helpful information might be obtained from Soil Conservation Services (SCS) Soil Survey Maps or the landfill operator. Field inspection, SCS maps, and permit boring information are sufficient. Additional borings are not necessary as this is only a ranking procedure. Where there is doubt, use the most permeable soil group present.

For the example landfill in Figure D-1, the uncorrected 5 percent methane migration distances for a 10-year old landfill would be (Figure C-2):

Section A-A: East side, 10 years, sand = 165'
West side, 10 years, sand = 165'

Section B-B: South side, 10 years, sand = 165'
North side, 10 years, clay = 130'

The corresponding uncorrected distances for the 1.25 percent methane migration would be:

Section A-A: East side, 10 years, sand = 225'
West side, 10 years, sand = 135'

Section B-B: South side, 10 years, sand = 255'
North side, 10 years, clay = 200'

The depth to corrective mulitpliers for the example sites would be:

Section A-A: East side, 10 years, 20' deep = 1.0
West side, 10 years, 20' deep = 1.0

Section B-B: South side, 10 years, 10' deep = 0.95
North side, 10 years, 50' deep = 1.4

VENTING CONDITIONS CORRECTION

The corrective factors for the surrounding soil venting conditions are obtained using the chart in Figure D-4. This chart is based on the assumption that the surrounding surficial soil is impervious 100 percent of the time. Thus, the value read from the chart must be adjusted, based on the percentage of time the surrounding surficial soil is saturated or frozen and the percentage of land along the path of gas migration from which gas venting to the atmosphere is blocked all year (asphalt or concrete roads or parking lots, shallow perched ground water, surface water bodies not interconnected to ground water). The totally impervious corrective factor is only used when the landfill is entirely surrounded at all times by these conditions. Both time and area adjustments are necessary, and the percentages are additive. Estimates to the nearest 20 percent are sufficient. An adjusted corrective factor is obtained by entering the chart with site age and obtaining the totally impervious corrective factor for the appropriate depth and soil type and then entering this value in the following equation:

Adjusted corrected factor = [(Impervious corrective factor)-1)]
x [5 of impervious time or area] + 1

When free venting conditions are prevalent most of the year, simply use 1.0 (no correction). For depths less than 25 feet deep, use the 25 foot value. For the example site, the adjusted corrective factors for frozen or wet soil conditions 50 percent of the year are:

Section A-A: East side (ignore narrow road, sand 20' deep, 10 years old) = (2.1-1)(0.50) + 1 = 1.55

West side (sand 20' deep, 10 years old) = (2.1-1)(0.50) + 1 = 1.55

Section B-B: South side (sand, 10' deep, = (2.1-1)(0.50) + 1 = 1.55
10 years old)

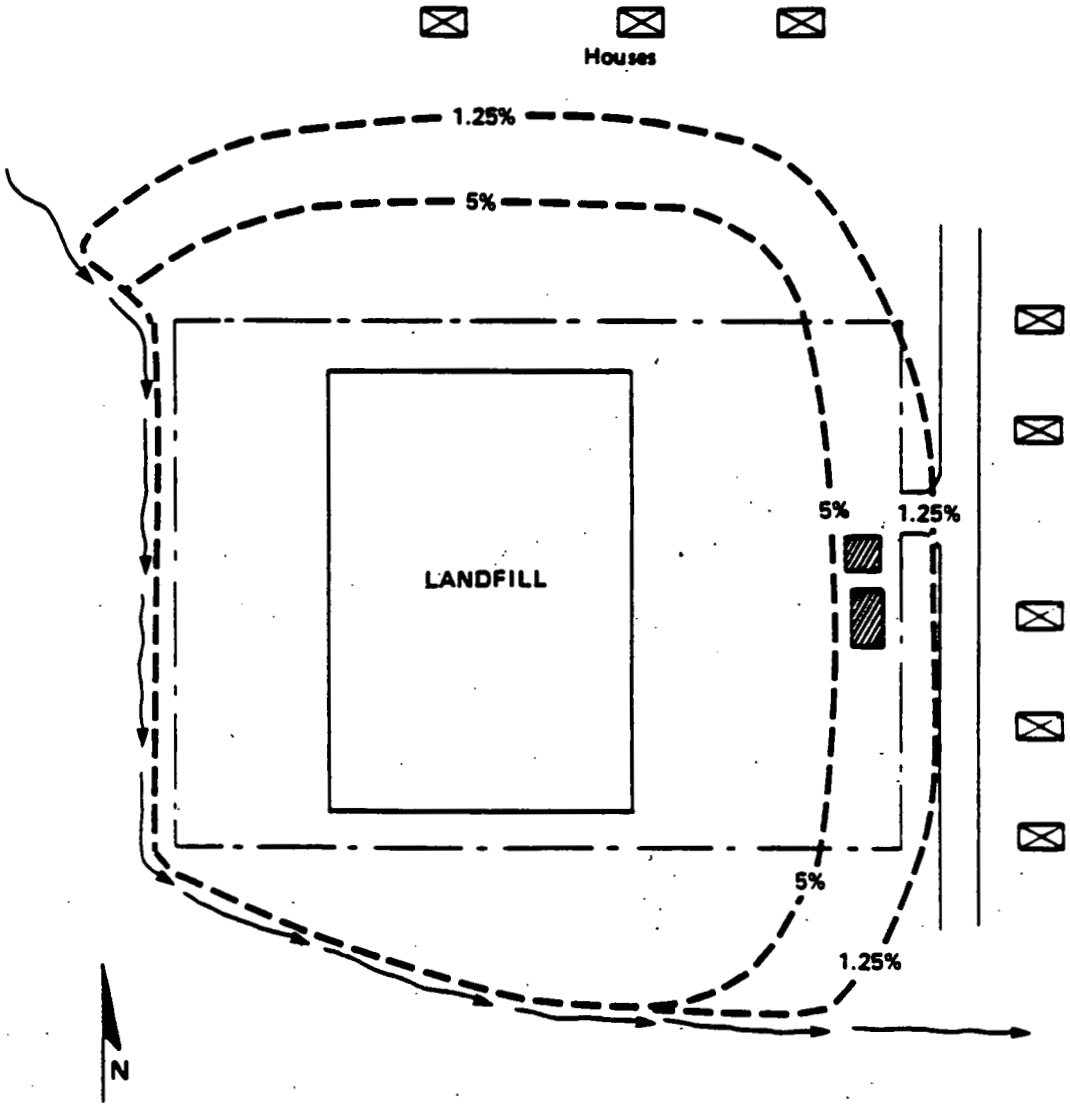
North side (clay, 50' deep, = (1.4-1)(0.50) + 1 = 1.2
10 years old)

Once the surface venting factors have been tabulated as in Table D-1, the corrective distance can be obtained by multiplying across the chart for each side of the landfill. These values can then be plotted on the scale plan to describe contours of the 5 percent and 1.25 percent methane concentrations or simply compared to the distance from the waste deposit to structures of concern (Figure D-5).

Table D-1. METHANE DISTANCE TABULATING FORM

Landfill Side	Methane Concentration	Uncorrected Distance	Correction for Depth	Correction for Venting	Corrected Distance
E	5%	165'	X 1.0	X 1.55	= 256'
	1.25%	255'	X 1.0	X 1.55	= 395'
W	5%	165'	X 1.0	X 1.55	= 256'*(225' max.)
	1.25%	255'	X 1.0	X 1.55	= 395'*(225' max.)
S	5%	165'	X 0.95	X 1.55	= 243'*(225' max.)
	1.25%	255'	X 0.95	X 1.55	= 375'*(225' max.)
N	5%	130'	X 1.4	X 1.2	= 218'
	1.25%	200'	X 1.4	X 1.2	= 336'

* When these distances are plotted on the landfill sketch, they exceed the distance to the creek, which acts as a barrier to the gas migration. Thus the distance to the creek is the maximum migration distance.



NOTE: NOT TO SCALE

FIGURE D-5. EXAMPLE LANDFILL METHANE CONDITIONS

APPENDIX E

ESTIMATION OF BASEMENT AIR CONTAMINANT CONCENTRATIONS DUE TO VOLATILE COMPONENTS IN GROUND WATER SEEPED INTO THE BASEMENT

APPENDIX E

ESTIMATION OF BASEMENT AIR CONTAMINANT CONCENTRATIONS DUE TO VOLATILE COMPONENTS IN GROUND WATER SEEPED INTO THE BASEMENT

Ground water can reach the basement and the walls of a house in several ways. If ground water is contaminated by volatile components, there are several possibilities that the indoor ambient air can be affected by these constituents. There are several methods which can be applied to estimating the ambient air concentrations in the basement into which the contaminants are volatilized from ground water. The manner in which and the extent to which the ground water reaches the basement or the walls will dictate the choice of a method.

Two cases are considered as example scenarios: Case 1) Ground water is seeped inside the basement completely wetting the basement, with a visual indication of water on the floor. Case 2) The basement is partially wetted without a visual indication of liquid on the floor. This latter case can be subdivided into two subcases: Subcase 1) involving a damp floor evident on the surface; Subcase 2) involving a floor without observable dampness on the floor surface but with ground water underneath the concrete floor.

The way the emission rates are estimated will be different for the three cases. If the emission flux rate per unit square area of the exposed surface is denoted by E (g/m^2 day), then in all cases the air concentration, C ($\mu g/m^3$), in the basement can be estimated from:

$$C\ (\mu g/m^3) = E \times 10^6\ A\ t_e/V_B \qquad (1)$$

where A = basement floor and wall area exposed to ground water, m^2

V_B = volume of the basement, m^3, and

t_e = air exchange time for the basement, days.

The air exchange time should be determined on a site-specific or situation-specific basis. The tight room will have a longer time per air exchange in the room, and the room with an exhaust fan will have a shorter time per air exchange. The default value for a typical house could be t_e = 0.05 days.

The emission rates in Eq. (1) can be estimated for the various case scenarios illustrated above.

Case 1. Wet basement with visible liquid.

The volatilization is a mass transfer phenomenon from the liquid phase of ground water on the floor to the basement air. Emission flux rate can be estimated from:

$$E = K_{OL}(C_L - C_L^*) \tag{2}$$

where K_{OL} = overall mass transfer coefficient in the liquid phase unit, m/day, C_L = concentration of contaminant in water, g/m^3, and C_L^* = liquid phase concentration in equilibrium concentration with the basement air, g/m^3. The equilibrium concentration C^* could be assumed to be approaching a small value compared to the ground water contaminant concentration when the air exchange rate is high, or when the time per air exchange is small. But this assumption would not be valid at a low air exchange rate or at a longer time for a room air exchange. In this case, the emission flux rate should be estimated by a trial and error method using Equation (2) in combination with Equation (1), and Henry's Law constant.

It is a well-established scientific principle to use the two-resistance theory to obtain the overall mass transfer coefficient, K_{OL}, as follows:

$$K_{OL} = \frac{1}{k_L} + \frac{1}{H_c k_g} \tag{3}$$

where k_L and k_g = individual mass transfer coefficients in liquid and gas phases, respectively, m/day, and H_C = dimensionless Henry's Law constant obtained from

concentration units for gas and liquid phase concentrations. The numerical value for H_C can be calculated from Henry's Law constant given in atm/g-mol.m^3 by multiplying by 41. Default values for the individual mass transfer coefficients can be estimated from:

$$k_L = 3 \quad \frac{cm}{hr} \left(\frac{44}{MW}\right)^{\frac{1}{2}} \left(\frac{24}{100} \quad \frac{M}{cm} \quad \frac{hr}{day}\right) \qquad (4)$$

$$k_g = 3000 \quad \frac{cm}{hr} \left(\frac{18}{MW}\right)^{\frac{1}{2}} \left(\frac{24}{100} \quad \frac{M}{cm} \quad \frac{hr}{day}\right) \qquad (5)$$

where MW = molecular weight of the contaminant.

Case 2. Basement partially wetted with no visual indication of liquid.

(a) Subcase 1. Dampness evident on the floor or wall surface. The volatilization process can be treated as a diffusional process from the air at the water-air interface through the air pores in the basement floor material and into the basement air. The diffusional process can be solved using the approach described in the EPA report Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup (PB86-232774). The final result needed for emission flux estimation would be:

$$\varepsilon = \frac{2\varepsilon D_{ei}}{\sqrt{\pi \alpha T}} H_c \quad C_L \qquad (6)$$

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where ε = porosity of the floor material, D_{ei} = effective diffusivity in the air pores (= $D_i \varepsilon^{1/3}$), m^2/day, D_i = molecular diffusivity, m^2/day, T = averaging time, days, and $\alpha = D_{ei}\, \varepsilon/(\varepsilon + (1-\varepsilon))/H_c$. If steady state conditions are achieved as a result of a continuous supply of contaminated water to the floor surface, it may be more appropriate to treat the emission rate problem using Eq. (2) rather than Eq. (6).

(b) Subcase 2. No dampness evident on the floor or wall surface but ground water underneath the basement or wall material. Diffusion through the air space of the floor or wall material will result in a slow release of volatile contaminants from ground water to the basement air. The steady state flux rate can be estimated from:

$$\varepsilon = D_i\, \varepsilon^{4/3}\, \frac{H_c C_L - C}{h} \qquad (7)$$

where h = thickness of the barrier between the surface of ground water and the air-basement floor interface, m. When the basement air concentration is small compared to the $H_c C_L$ term in Eq. (7), the C term can be ignored in estimating ε from Eq. (7). Otherwise Eq. (7) should be solved along with Eq. (1) requiring a trial and error solution.

APPENDIX F

METHOD 1312: SYNTHETIC PRECIPITATION LEACH TEST FOR SOILS

SYNTHETIC PRECIPITATION LEACH TEST FOR SOILS

1.0 SCOPE AND APPLICATION

1.1 Method 1312 is designed to determine the mobility of both organic and inorganic contaminants present in soils.

1.2 If a total analysis of the soil demonstrates that individual contaminants are not present in the soil, or that they are present but at such low concentrations that the appropriate regulatory thresholds could not possibly be exceeded, Method 1312 need not be run.

2.0 SUMMARY OF METHOD

2.1 The particle size of the soil is reduced (if necessary) and is extracted with an amount of extraction fluid equal to 20 times the weight of the soil. The extraction fluid employed is a function of the region of the country where the soil site is located. A special extractor vessel is used when testing for volatiles. Following extraction, the liquid extract is separated from the soil by 0.6-0.8 um glass fiber filter.

3.0 INTERFERENCES

3.1 Potential interferences that may be encountered during analysis are discussed in the individual analytical methods.

4.0 APPARATUS AND MATERIALS

4.1 Agitation apparatus - an acceptable agitation apparatus is one which is capable of rotating the extraction vessel in an end-over-end fashion at 30 ± 2 rpm (see Figure 1). Suitable devices known to EPA are identified in Table 2.

4.2 Extraction vessel - acceptable extraction vessels are those that are listed below:

4.2.1 Zero Headspace Extraction Vessel (ZHE) - This device is for use only when the soil is being tested for the mobility of volatile constituents (see Table 1). The ZHE is an extraction vessel that allows for liquid/solid separation within the device and which effectively precludes headspace (as depicted in Figure 3). This type of vessel allows for initial liquid/solid separation, extraction, and final extract filtration without having to open the vessel (see Step 4.3.1). These vessels shall have an internal volume of 500 to 600 mL and be equipped to accommodate a 90-mm filter. Suitable ZHE devices known to EPA are identified in Table 3. These devices contain viton O-rings which should be replaced frequently. For the ZHE to be acceptable for use, the piston within the ZHE should be able to be moved

with approximately 15 psi or less. If it takes more pressure to move the piston, the O-rings in the device should be replaced. If this does not solve the problem, the ZHE is unacceptable for 1312 analyses and the manufacturer should be contacted. The ZHE should be checked after every extraction. If the device contains a built-in pressure gauge, pressurize the device to 50 psi, allow it to stand unattended for 1 hour, and recheck the pressure. If the device does not have a built-in pressure gauge, pressurize the device to 50 psi, submerge it in water and check for the presence of air bubbles escaping from any of the fittings. If pressure is lost, check all fittings and inspect and replace O-rings, if necessary. Retest the device. If leakage problems cannot be solved, the manufacturer should be contacted.

4.2.2 When the soil is being evaluated for other than volatile contaminants, an extraction vessel that does not preclude headspace (e.g. a 2-liter bottle) is used. Suitable extraction vessels include bottles made from various materials, depending on the contaminants to be analyzed and the nature of the waste (see Step 4.3.3). It is recommended that borosilicate glass bottles be used over other types of glass, especially when inorganics are of concern. Plastic bottles may be used only if inorganics are to be investigated. Bottles are available from a number of laboratory suppliers. When this type of extraction vessel is used, the filtration device discussed in Step 4.3.2 is used for initial liquid/solid separation and final extract filtration.

4.2.3 Some ZHEs use gas pressure to actuate the ZHE piston, while others use mechanical pressure (see Table 3). Whereas the volatiles procedure (see Step 7.4) refers to pounds-per-square inch (psi), for the mechanically actuated piston, the pressure applied is measured in torque-inch-pounds. Refer to the manufacturer's instuctions as to the proper conversion.

4.3 Filtration devices - It is recommended that all filtrations be performed in a hood.

4.3.1 Zero-Headspace Extractor Vessel (see Figure 3) - When the waste is being evaluated for volatiles, the zero-headspace extraction vessel is used for filtration. The device shall be capable of supporting and keeping in place the fiber filter, and be able to withstand the pressure needed to accomplish separation (50 psi).

NOTE: When is it suspected that the glass fiber filter has been ruptured, an in-line glass fiber filter may be used to filter the material within the ZHE.

4.3.2 Filter holder - when the soil is being evaluated for other than volatile compounds, a filter holder capable of

supporting a glass fiber filter and able to withstand 50 psi or more of pressure shall be used. These devices shall have a minimum internal volume of 300 mL and be equipped to accomodate a minimum filter size of 47 mm (filter holders having an internal capacity of 1.5 liters or greater are recommended).

4.3.3 Materials of construction - filtration devices shall be made of inert materials which will not leach or absorb soil components. Glass, polytetrafluoroethylene (PTFE) or type 316 stainless steel equipment may be used when evaluating the mobility of both organic and inorganic components. Devices made of high density polyethylene (HDPE), polypropylene, or polyvinyl chloride may be used only when evaluating the mobility of metals. Borosilicate glass bottles are recommended for use over other types of glass bottles, especially when inorganics are constituents of concern.

4.4 Filters - filters shall be made of borosilicate glass fiber, shall have an effective pore size of 0.6 - 0.8 um and shall contain no binder materials. Filters known to EPA to meet these requirements are identified in Table 5. When evaluating the mobility of metals, filters should be acid-washed prior to use by rinsing with 1.0N nitric acid followed by three consecutive rinses with deionized distilled water (a minimum of 1-liter per rinse is recommended). Glass fiber filters are fragile and should be handled with care.

4.5 pH meters - any of the commmonly available pH meters are acceptable.

4.6 ZHE extract collection devices - TEDLAR bags, glass, stainless steel or PTFE gas tight syringes are used to collect the volatile extract.

4.7 Laboratory balance - any laboratory balance accurate to within ± 0.01 g may be used (all weight measurements are to be within ± 0.1 g).

4.8 ZHE extraction fluid transfer devices - any device capable of transferring the extraction fluid into the ZHE without changing the nature of the extraction fluid is recommended.

5.0 REAGENTS

5.1 Reagent water - reagent water is defined as water in which an interferent is not observed at or above the method detection limit of the analyte(s) of interest. For non-volatile extractions, ASTM Type II water, or equivalent meets the definition of reagent water. For volatile extractions, it is recommended that reagent water be generated by any of the following methods. Reagent water should be monitored periodically for impurities.

5.1.1 Reagent water for volatile extractions may be generated by passing tap water through a carbon filter bed containing about 500 g of activated carbon (Calgon Corp., Filtrasorb 300 or equivalent).

5.1.2 A water purification system (Millipore Super-Q or equivalent) may also be used to generate reagent water for volatile extractions.

5.1.3 Reagent water for volatile extractions may also be prepared by boiling water for 15 minutes. Subsequently, while maintaining the water temperature at 90 ± 5°C, bubble a contaminant-free inert gas (e.g. nitrogen) through the water for 1 hour. While still hot, transfer the water to a narrow-mouth screw-cap bottle under zero headspace and seal with a Teflon lined septum and cap.

5.2 Sulfuric acid/nitric acid (60/40 weight percent mixture) H_2SO_4/HNO_3. Cautiously mix 60 g of concentrated sulfuric acid with 40 g of concentrated nitric acid.

5.3 Extraction fluids:

5.3.1 Extraction fluid #1 - this fluid is made by adding the 60/40 weight percent mixture of sulfuric and nitric acids to reagent water until the pH is 4.20 ± 0.05.

5.3.2 Extraction fluid #2 - this fluid is made by adding the 60/40 weight percent mixture of sulfuric and nitric acids to reagent water until the pH is 5.00 ± 0.05.

5.3.3 Extraction fluid #3 - this fluid is reagent water (ASTM Type II water, or equivalent) used to determine cyanide leachability.

Note: It is suggested that these extxraction fluids be monitored frequently for impurities. The pH should be checked prior to use to ensure that these fluids are made up accurately.

5.4 Analytical standards shall be prepared according to the appropriate analytical method.

6.0 SAMPLE COLLECTION, PRESERVATION, AND HANDLING

6.1 All samples shall be collected using an appropriate sampling plan.

6.2 At least two separate representative samples of a soil should be collected. The first sample is used to determine if the soil requires particle-size reduction and, if desired, the percent solids of the soil. The second sample is used for extraction of volatiles and non-volatiles.

6.3 Preservatives shall not be added to samples.

6.4 Samples shall be refrigerated to minimize loss of volatile organics and to retard biological activity.

6.5 When the soil is to be evaluated for volatile contaminants, care should be taken to minimize the loss of volatiles. Samples shall be taken and stored in a manner to prevent the loss of volatile contaminants. If possible, it is recommended that any necessary particle-size reduction be conducted as the sample is being taken.

6.6. 1312 extracts should be prepared for analysis and analyzed as soon as possible following extraction. If they need to be stored, even for a short period of time, storage shall be at 4°C, and samples for volatiles analysis shall not be allowed to come into contact with the atmosphere (i.e. no headspace). See Section 8.0 (Quality Control) for acceptable sample and extract holding times.

7.0 PROCEDURE

7.1 The preliminary 1312 evaluations are performed on a minimum 100 g representative sample of soil that will not actually undergo 1312 extraction (designated as the first sample in Step 6.2).

7.1.1 Determine whether the soil requires particle-size reduction. If the soil passes through a 9.5 mm (0.375-inch) standard sieve, particle-size reduction is not required (proceed to Step 7.2). If portions of the sample do not pass through the sieve, then the oversize portion of the soil will have to be prepared for extraction by crushing the soil to pass the 9.5 mm sieve.

7.1.2 Determine the percent solids if desired.

7.2 Procedure when volatiles are <u>not</u> involved - Enough solids should be generated for extraction such that the volume of 1312 extract will be sufficient to support all of the analyses required. However, a minimum sample size of 100 grams shall be used. If the amount of extract generated by a single 1312 extract will not be sufficient to perform all of the analyses, it is recommended that more than one extraction be performed and the extracts be combined and then aliquoted for analysis.

7.2.1 Weigh out a representative subsample of the soil and transfer to the filter holder extractor vessel.

7.2.2 Determine the appropriate extraction fluid to use. If the soil is from a site that is east of the Mississippi River, extraction fluid #1 should be used. If the soil is from a site that is west of the Mississippi River, extraction fluid #2 should be used. If the soil is to be tested for cyanide leachability, extraction fluid #3 should be used.

Note: Extraction fluid #3 (reagent water) must be used when evaluating cyanide-containing soils because leaching of cyanide-containing soils under acidic conditions may result in the formation of hydrogen cyanide gas.

7.2.3 Determine the amount of extraction fluid to add based on the following formula:

amount of extraction fluid (mL) = 20 x weight of soil (g)

Slowly add the amount of appropriate extraction fluid to the extractor vessel. Close the extractor bottle tightly (it is recommended that Teflon tape be used to ensure a tight seal), secure in rotary extractor device, and rotate at 30 ± 2 rpm for 18 ± 2 hours. Ambient temperature (i.e. temperature of room in which extraction is to take place) shall be maintained at 22 ± 3°C during the extraction period.

Note: As agitation continues, pressure may build up within the extractor bottle for some types of soil (e.g. limed or calcium carbonate containing soil may evolve gases such as carbon dioxide). To relieve excess pressure, the extractor bottle may be periodically opened (e.g. after 15 minutes, 30 minutes, and 1 hour) and vented into a hood.

7.2.4 Following the 18 ± 2 hour extraction, the material in the extractor vessel is separated into its component liquid and solid phases by filtering through a glass fiber filter.

7.2.5 Following collection of the 1312 extract it is recommended that the pH of the extract be recorded. The extract should be immediately aliquoted for analysis and properly preserved (metals aliquots must be acidified with nitric acid to pH < 2; all other aliquots must be stored under refrigeration (4°C) until analyzed). The 1312 extract shall be prepared and analyzed according to appropriate analytical methods. 1312 extracts to be analyzed for metals, other than mercury, shall be acid digested.

7.2.6 The contaminant concentrations in the 1312 extract are compared to thresholds in the clean closure guidance manual. Refer to Section 8.0 for Quality Control requirements.

7.3 Procedure when volatiles are involved:

7.3.1 The ZHE device is used to obtain 1312 extracts for volatile analysis only. Extract resulting from the use of the ZHE shall not be used to evaluate the mobility of non-volatile analytes (e.g. metals, pesticides, etc.). The ZHE device has approximately a 500 mL internal capacity. Although a minimum sample size of 100 g was required in the Step 7.2 procedure, the ZHE can only accommodate a maximum of 25 g of solid , due to the need to add an amount of extraction fluid equal to 20 times the

weight of the soil. The ZHE is charged with sample only once and the device is not opened until the final extract has been collected. Although the following procedure allows for particle-size reduction during the conduct of the procedure, this could result in the loss of volatile compounds. If possible particle-size reduction (see Step 7.1.1) should be conducted on the sample as it is being taken (e.g., particle-size may be reduced by crumbling). If necessary particle-size reduction may be conducted during the procedure. In carrying out the following steps, do not allow the soil to be exposed to the atmosphere for any more time than is absolutely necessary. Any manipulation of these materials should be done when cold (4°C) to minimize the loss of volatiles. Pre-weigh the evaculated container which will receive the filtrate (see Step 4.6), and set aside. If using a TEDLAR® bag, all air must be expressed from the device.

7.3.2 Place the ZHE piston within the body of the ZHE (it may be helpful first to moisten the piston O-rings slightly with extraction fluid). Adjust the piston within the ZHE body to a height that will minimize the distance the piston will have to move once it is charged with sample. Secure the gas inlet/outlet flange (bottom flange) onto the ZHE body in accordance with the manufacturer's instructions. Secure the glass fiber filter between the support screens and set aside. Set liquid inlet/outlet flange (top flange) aside.

7.3.3 Quantitatively transfer 25 g of soil to the ZHE. Secure the filter and support screens into the top flange of the device and secure the top flange to the ZHE body in accordance with the manufacturer's instructions. Tighten all ZHE fittings and place the device in the vertical position (gas inlet/outlet flange on the bottom). Do not attach the extraction collection device to the top plate. Attach a gas line to the gas inlet/outlet valve (bottom flange) and, with the liquid inlet/outlet valve (top flange) open, begin applying gentle pressure of 1-10 psi to a maximum of 50 psi to force most of the headspace out of the device.

7.3.4 With the ZHE in the vertical position, attach a line from the extraction fluid reservoir to the liquid inlet/outlet valve. The line used shall contain fresh extraction fluid and should be preflushed with fluid to eliminate any air pockets in the line. Release gas pressure on the ZHE piston (from the gas inlet/outlet valve), open the liquid inlet/outlet valve, and begin transferring extraction fluid (by pumping or similar means) into the ZHE. Continue pumping extraction fluid into the ZHE until the appropriate amount of fluid has been introduced into the device.

7.3.5 After the extraction fluid has been added, immediately close the inlet/outlet valve and disconnect the extraction fluid line. Check the ZHE to ensure that all valves are in their closed positions. Physically rotate the device in an end-over-end fashion

2 or 3 times. Reposition the ZHE in the vertical position with the liquid inlet/outlet valve on top. Put 5-10 psi behind the piston (if nesessary) and slowly open the liquid inlet/outlet valve to bleed out any headspace (into a hood) that may have been introduced due to the addition of extraction fluid. This bleeding shall be done quickly and shall be stopped at the first appearance of liquid from the valve. Re-pressurize the ZHE with 5-10 psi and check all ZHE fittings to ensure that they are closed.

7.3.6 Place the ZHE in the rotary extractor apparatus (if it is not already there) and rotate the ZHE at 30 ± 2 rpm for 18 ± 2 hours. Ambient temperature (i.e. temperature of the room in which extraction is to occur) shall be maintained at 22 ± 3°C during agitation.

7.3.7 Following the 18 ± 2 hour agitation period, check the pressure behind the ZHE piston by quickly opening and closing the gas inlet/outlet valve and noting the escape of gas. If the pressure has not been maintained (i.e. no gas release observed), the device is leaking. Check the ZHE for leaking and redo the extraction with a new sample of soil. If the pressure within the device has been maintained, the material in the extractor vessel is separated into its component liquid and solid phases.

7.3.8 Attach the evacuated pre-weighed filtrate collection container to the liquid inlet/outlet valve and open the valve. Begin applying gentle pressure of 1-10 psi to force the liquid phase into the filtrate collection container. If no additional liquid has passed through the filter in any 2 minute interval, slowly increase the pressure in 10-psi increments to a maximum of 50 psi. After each incremental increase of 10 psi, if no additional liquid has passed through the filter in any 2 minute interval, proceed to the next 10 psi increment. When liquid flow has ceased such that continued pressure filtration at 50 psi does not result in any additional filtrate within any 2 minute period, filtration is stopped. Close the inlet/outlet valve, discontinue pressure to the piston, and disconnect the filtration collection container.

NOTE: Instantaneous application of high pressure can degrade the glass fiber filter and may cause premature plugging.

7.3.9 Following collection of the 1312 extract, the extract should be immediately aliquoted for analysis and stored with minimal headspace at 4°C until analyzed. The 1312 extract will be prepared and analyzed according to the appropriate analytical methods.

8.0 QUALITY CONTROL

8.1 All data, including quality assurance data, should be

maintained and available for reference or inspection.

8.2 A minimum of one blank (extraction fluid # 1) for every 10 extractions that have been conducted in an extraction vessel shall be employed as a check to determine if any memory effects from the extraction equipment are occurring.

8.3 For each analytical batch (up to twenty samples), it is recommended that a matrix spike be performed. Addition of matrix spikes should occur once the 1312 extract has been generated (i.e. should not occur prior to performance of the 1312 procedure). The purpose of the matrix spike is to monitor the adequacy of the analytical methods used on the 1312 extract and for determining if matrix interferences exist in analyte detection.

8.4 All quality control measures described in the appropriate analytical methods shall be followed.

8.5 The method of standard addition shall be employed for each analyte if: 1) recovery of the compound from the 1312 extract is not between 50 and 150%, or 2) if the concentration of the constituent measured in the extract is within 20% of the appropriate regulatory threshold. If more than one extraction is being run on samples of the same waste (up to twenty samples), the method of standard addition need be applied only once and the percent recoveries applied on the remainder of the extractions.

8.6 Samples must undergo 1312 extraction within the following time period after sample receipt: Volatiles, 14 days; Semi-Volatiles, 40 days; Mercury, 28 days; and other Metals, 180 days. 1312 extracts shall be analyzed after generation and preservation within the following periods: Volatiles, 14 days; Semi-Volatiles, 40 days; Mercury, 28 days; and other Metals, 180 days.

9.0 METHOD PERFORMANCE

9.1 None available.

10.0 REFERENCES

10. 1 None available.

TABLE 1. -- VOLATILE CONTAMINANTS

Compounds	CAS No.
Acetone	67-64-1
Acrylonitrile	107-13-1
Benzene	71-43-2
n-Butyl alcohol	71-36-6
Carbon disulfide	75-15-0
Carbon tetrachloride	56-23-5
Chlorobenzene	108-90-7
Chloroform	67-66-3
1,2-Dichloroethane	107-06-2
1,1-Dichloroethylene	75-35-4
Ethyl acetate	141-78-6
Ethyl benzene	100-41-4
Ethyl ether	60-29-7
Isobutanol	78-83-1
Methanol	67-56-1
Methylene chloride	75-09-2
Methyl ethyl ketone	78-93-3
Methyl isobutyl ketone	108-10-1
1,1,1,2-Tetrachloroethane	630-20-6
1,1,2,2-Tetrachloroethane	79-34-5
Tetrachloroethylene	127-18-4
Tolulene	108-88-3
1,1,1-Trichloroethane	71-55-6
1,1,2-Trichloroethane	79-00-5
Trichloroethylene	79-01-6
Trichlorofluoromethane	75-69-4
1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1
Vinyl chloride	75-01-7
Xylene	1330-20-7

TABLE 2. -- SUITABLE ROTARY AGITATION APPARATUS[1]

Company	Location	Model
Analytical Testing and Consulting Services, Inc.	Warrington, PA (215) 343-4490	4-vessel device
Associated Design and Manufacturing Company	Alexandria, VA (703) 549-5999	4-vessel device, 6-vessel device
Environmental Machine and Design, Inc.	Lynchburg, VA (804) 845-6424	4-vessel device, 6-vessel device
IRA Machine Shop and Laboratory	Santurce, PR (809) 752-4004	16-vessel device
Lars Lande Manufacturing	Whitmore Lake, MI (313) 449-4116	10-vessel device 5-vessel device
Millipore Corp.	Bedford, MA (800) 225-3384	4-vessel ZHE device or 4-one litter bottle extractor device
REXNORD	Milwaukee, WI (414) 643-2850	6-vessel device

[1]Any device that rotates the extraction vessel in an end-over-end fashion at 30 ± 2 rpm is acceptable.

TABLE 3. -- SUITABLE ZERO-HEADSPACE EXTRACTOR VESSELS

Company	Location	Model No.
Analytical Testing & Consulting Services, Inc.	Warrington, PA, (215) 343-4490	C102, Mechanical Pressure Device
Associated Design & Manufacturing Co.	Alexandria, VA (703) 549-5999	3740-ZHB, Gas Pressure Device
Lars Lande Mfg.	Whitmore Lake, MI (313) 449-4116	Gas Pressure Device
Millipore Corp.	Bedford, MA, (800) 225-3384	SD1 P581 C5, Gas Pressure Device

TABLE 4. -- SUITABLE ZHE FILTER HOLDERS[1]

Company	Location	Model	Size
Micro Filtration Systems	Dublin, CA (415) 828-6010	302400	142 mm
Millipore Corp.	Bedford, MA (800) 225-3384	YT30142HW	142 mm
		XX1004700	47 mm
Nucleopore Corp.	Pleasanton, CA (800) 882-7711	425910	142 mm
		410400	47 mm

[1]Any device capable of separating the liquid from the solid phase of the soil is suitable, providing that it is chemically compatible with the soil and the constitutents to be analyzed. Plastic devices (not listed above) may be used when only inorganic contaminants are of concern. The 142 mm size filter holder is recommended.

TABLE 5. -- SUITABLE FILTER MEDIA

Company	Location	Model	Size[1]
Millipore Corp.	Bedford, MA (800) 225-3384	AP40	0.7
Nucleopore Corp.	Pleasanton, CA (415) 463-2530	211625	0.7
Whatman Laboratory Products, Inc.	Clifton, NJ (201) 773-5800	GFF	0.7

[1]Nominal pore size

Figure 1. Rotary Agitation

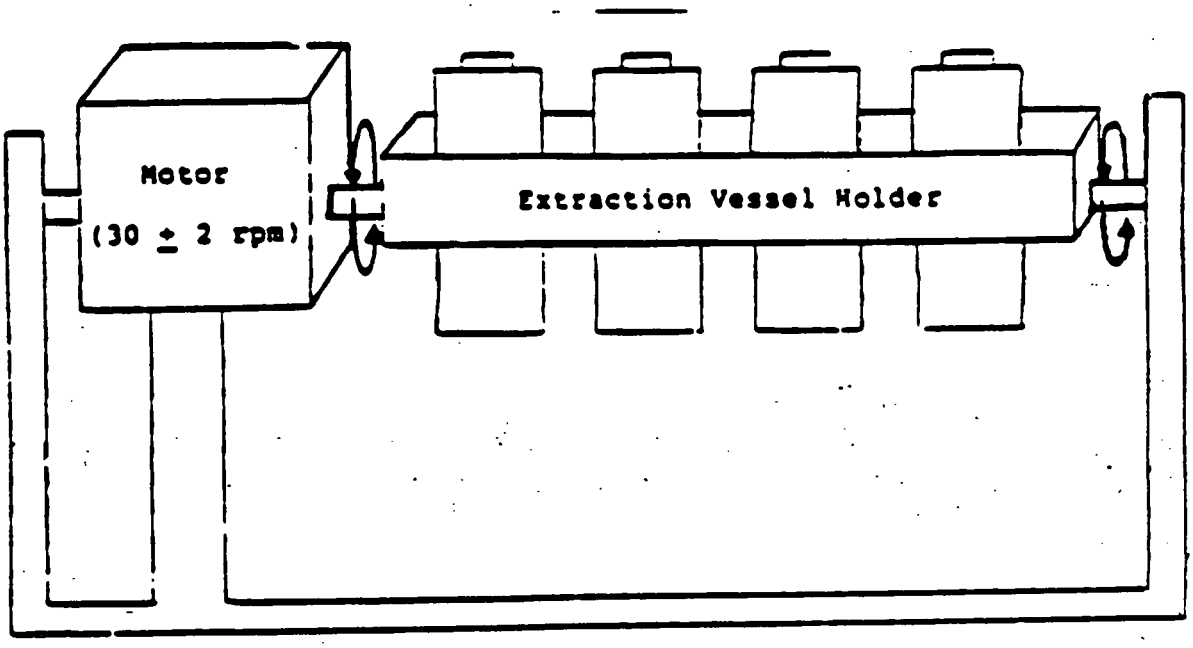

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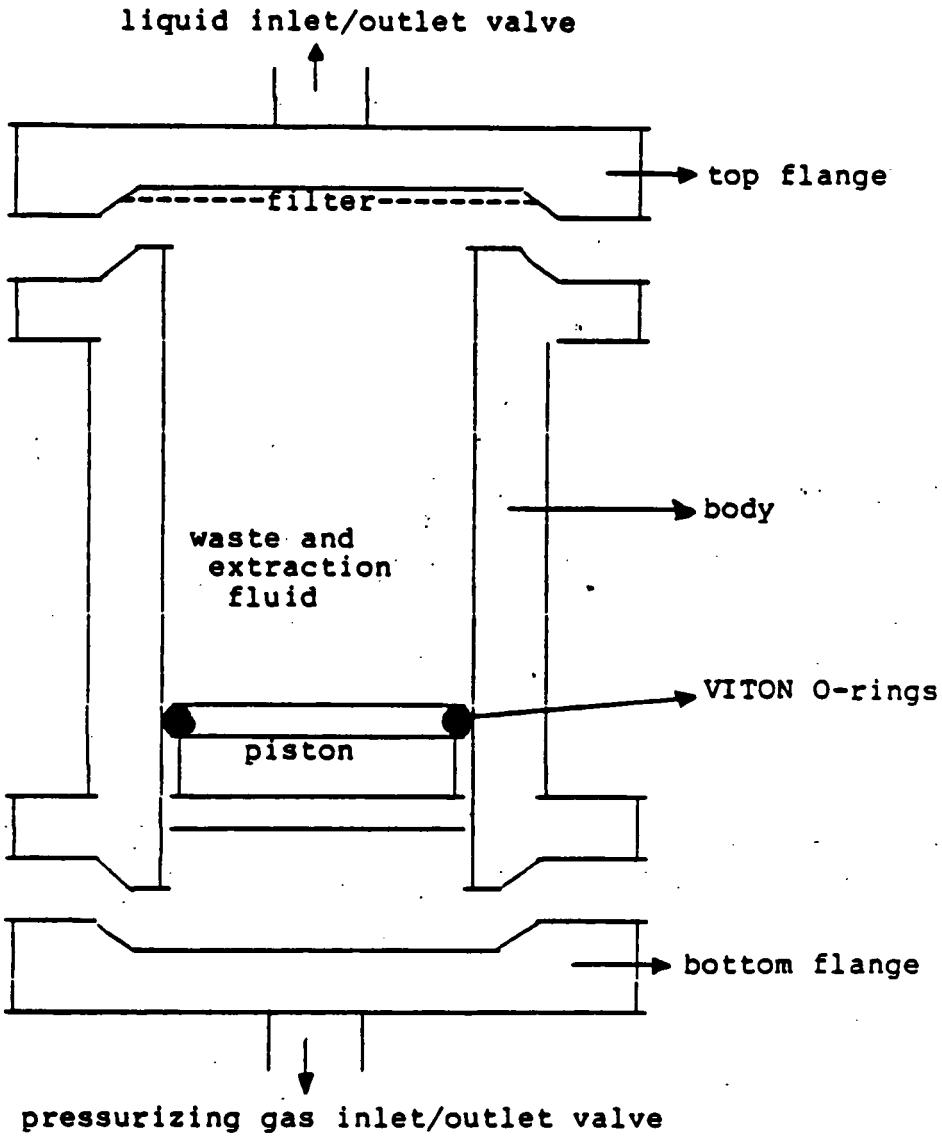
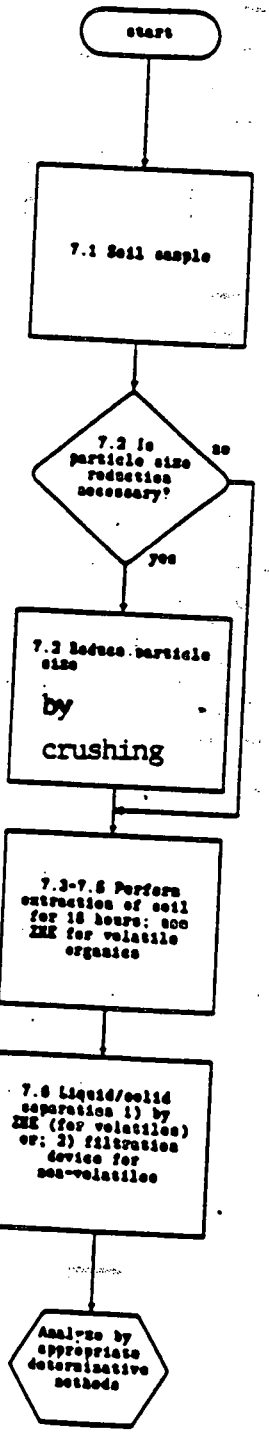
Figure 2. Zero-Headspace Extraction Vessel




start
7.1 Soil sample
7.2 Is particle size reduction necessary?
no
yes
7.2 Reduce particle size
by
crushing
7.3-7.5 Perform extraction of soil for 18 hours; use ZHE for volatile organics
7.6 Liquid/solid separation 1) by ZHE (for volatiles) or; 2) filtration device for non-volatiles
Analyze by appropriate determinative methods