BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN

Rocky Flats Plant

U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant
Golden, Colorado

Background Geochemical
Characterization Plan

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FINAL

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN

ROCKY FLATS PLANT
GOLDEN, COLORADO

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EXECUTIVE SUMMARY

This plan describes and establishes a rational program for the characterization of background geochemistry for the Rocky Flats Nuclear Weapons Plant (RFP) The plan describes how data representative of RFP background will be collected and analyzed using a number of statistical and geochemical techniques Background chemistry statistics will provide baseline data for other environmental programs that monitor for potential contaminant releases

The number and location of background samples has been carefully considered in developing the background geotechnical plan Understanding of the local hydrogeology (conceptual model) was paramount in design of the background characterization program Six media (geologic materials, ground water, stream sediment, stream water, seep sediment and seep water) have been sampled at RFP These media can be classified into groupings that may represent subpopulations, e g , geologic materials were sampled by geologic unit Rocky Flats Alluvium, colluvium, and weathered bedrock A background sample made up of geochemically different subpopulations would result in extraneous variability in the background sample, and consequently, a poor characterization of background geochemistry and a lower statistical power to detect downgradient contamination Geochemical and statistical evaluation techniques are presented for determining subpopulations and the potential existence of downgradient contamination

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ACRONYMS

AEC	Atomic Energy Commission
ANOVA	Analysis of Variance
ARAR	Applicable or Relevant and Appropriate Requirement
BDL	Below Detection Limit
CAR	Chemical Analyte Roster
CDH	Colorado Department of Health
CDI	Chronic Daily Intake
CERCLA	Comprehensive Environmental Restoration, Compensation and Liability Act
CHWA	Colorado Hazardous Waste Act
CLP	Contract Laboratory Program
cm/sec	centimeters per second
CSF	Carcinogenic Slope Factor
DI	Daily Intake
DL	Detection Limit
DOE	U S Department of Energy
DQO	Data Quality Objective
EL	Exposure Limit
EMD	Environmental Management Department
EPA	U S Environmental Protection Agency
ER	Environmental Restoration
ERDA	Energy Research and Development Administration
GC	Gas Chromatography
GC/MS	Gas Chromatography/Mass Spectrometry
GRASSP	General Radiochemistry and Routine Analytical Services Protocol
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HQ	Hazard Quotient
IAG	Inter-Agency Agreement
IHSS	Individual Hazardous Substance Site
IM/IRA	Interim Measures/Interim Remedial Action
IRIS	Integrated Risk Information System
MANOVA	Multivariate Analysis of Variance
m/s	meters per second
mg/ℓ	milligram per liter

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ACRONYMS (continued)

mph	miles per hour
ND	Nondetect
NPDES	National Pollutant Discharge Elimination System
OD	Outside Diameter
OU	Operable Unit
PARCC	Precision, Accuracy, Representativeness, Completeness, and Comparability
QA/QC	Quality Assurance/Quality Control
RAS	Routine Analytical Services
RCRA	Resource Conservation and Recovery Act
RfD	Reference Dose
RFEDS	Rocky Flats Environmental Database System
RFI	RCRA Facility Investigation
RFP	Rocky Flats Plant
RI	Remedial Investigation
RPD	Relative Percent Difference
SAS	Special Analytical Services
SOP	Standard Operating Procedure
SWMU	Solid Waste Management Unit
TAL	Target Analyte List
TCL	Target Compound List
TDS	Total Dissolved Solids
$\mu g/\ell$	micrograms per liter

SECTION 1
INTRODUCTION

1.1 PURPOSE

The purpose of this plan is to describe and establish a rational program for the characterization of background geochemistry for the Rocky Flats Nuclear Weapons Plant (RFP), located northwest of Denver, Colorado The plan describes how data representative of RFP background will be collected and analyzed using a number of statistical and geochemical techniques Reasons for implementing the RFP background program are presented below

- Background chemistry statistics will provide baseline data for other environmental programs that monitor for potential contaminant releases
- Background data may be helpful in establishing reasonable cleanup goals and justifying waivers for complying with Applicable or Relevant and Appropriate Requirements (ARAR)
- Background data will help Natural Resource Trustees to identify if a natural resource such as surface water has been damaged at the RFP
- Background data provide a benchmark in assessing human health risks due to contamination at the RFP
- Background ground water data can be used to supplement well data collected locally upgradient of Resource Conservation and Recovery Act (RCRA) regulated units at the RFP (Well chemistry data upgradient and downgradient of RCRA units are regularly compared to monitor the unit for potential contaminant release to ground water)
- Background data will provide a baseline against which RCRA Facility Investigation (RFI)/Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Remedial Investigation (RI) results may be compared for identifying contamination at RFP operable units (OU)
- The background program contributes to the geochemical characterization of the RFP site as mandated by U S Department of Energy (DOE) Order 5400 1
- The background program is a requirement of the Rocky Flats Inter-Agency Agreement (IAG), a legal agreement between the State of Colorado (represented by the Colorado Department of Health [CDH]), U S Environmental Protection Agency (EPA), and DOE

In the context of this plan, "background geochemistry" is defined as the chemistry of geological materials existing at or near RFP, which are believed to be undisturbed, or (at worst) minimally impacted by past RFP operations The chemistry of these materials may be influenced by non-RFP anthropogenic sources such as potential contamination from atmospheric fallout, nearby public highways, industry, and agriculture

The geologic materials considered in this plan will include ground water, surface water and associated sediments, and both consolidated and unconsolidated materials of geological significance at the RFP The characterization of RFP background surficial soils is a major task which at the time of writing is expected to be treated in a separate program Therefore, surficial soils will not be addressed in this plan

1.2 BACKGROUND

The RFP is a government-owned, contractor-operated facility, which is part of the nationwide nuclear weapons production complex The Plant was operated for the U S Atomic Energy Commission (AEC) from its inception in 1951 until the AEC was dissolved in January 1975 At that time, responsibility for the Plant was assigned to the Energy Research and Development Administration (ERDA), which was succeeded by the DOE in 1977 Dow Chemical U S A., an operating unit of the Dow Chemical Company, was the prime operating contractor of the facility from 1951 until June 30, 1975 Rockwell International was the prime contractor responsible for operating the RFP from July 1, 1975, until December 31, 1989 EG&G Rocky Flats, Inc became the prime contractor at the RFP on January 1, 1990, and currently operates the Plant

The primary mission of the RFP is to fabricate nuclear weapons components from plutonium, uranium, and nonradioactive metals (principally beryllium and stainless steel) Parts made at the Plant are shipped elsewhere for assembly In addition, the Plant reprocesses components after they are removed from obsolete weapons for plutonium recovery

Both radioactive and nonradioactive wastes are generated in the production process Current waste handling practices involve on-site and off-site recycling of hazardous materials, on-site

storage of hazardous and radioactive mixed wastes, and off-site disposal of solid radioactive materials at another DOE facility However, both storage and disposal of hazardous and radioactive wastes occurred on site in the past Preliminary assessments under the Environmental Restoration (ER) Program identified some of the past on-site storage and disposal locations as potential sources of environmental contamination

1.3 PREVIOUS INVESTIGATIONS

Various studies have been conducted at the Rocky Flats Plant to characterize environmental media and to assess the extent of radiological and chemical contaminant releases to the environment The investigations performed prior to 1986 are summarized in Rockwell International (1986a) and include

- Detailed descriptions of the regional geology (Malde, 1955, Spencer, 1961, Scott, 1960, 1963, 1965, 1970, 1972 and 1975, Van Horn, 1972 and 1976, DOE, 1980, Dames and Moore, 1981, and Robson, et al , 1981a and 1981b)
- Several drilling programs beginning in 1960 that resulted in the construction of 56 monitor wells by the end of 1982
- An investigation of surface and ground water flow systems by the U S Geological Survey (Hurr, 1976)
- Environmental, ecological, and public health studies that culminated in an environmental impact statement (DOE, 1980)
- A summary report on ground water hydrology using data from 1960 to 1985 (Hydro-Search, Inc , 1985)
- A preliminary electromagnetic survey of the Plant perimeter (Hydro-Search, Inc , 1986)
- A soil gas survey of the Plant perimeter and buffer zone (Tracer Research, Inc , 1986)
- Routine environmental monitoring programs addressing air, surface water, ground water, and soils (Rockwell International, 1975 through 1986a) Additional information on routine environmental programs is also presented in post-1986 annual environmental monitoring reports (Rockwell International, 1987a, 1989a, EG&G, 1990a)

In 1986, two major investigations were completed at the Plant The first was the ER Program Phase 1 installation assessment (DOE, 1986), which included analyses and identification of current operational activities, active and inactive waste sites, current and past waste management practices, and potential environmental pathways through which contaminants could be transported A number of sites were identified that could potentially have adverse impacts on the environment These sites were designated as Solid Waste Management Units (SWMU) by Rockwell International (1987b) and were divided into three categories

1) Hazardous waste management units that will continue to operate and need a RCRA operating permit

2) Hazardous waste management units that will be closed under RCRA interim status

3) Inactive waste management units that will be investigated and cleaned up under Section 3004(u) of RCRA or CERCLA

The IAG (see Appendix A) redefined the SWMUs within the second and third categories as Individual Hazardous Substance Sites (IHSS) This term is used hereinafter, however, no RCRA or CERCLA regulatory distinction in the use of the terms "site," "unit," or "IHSS" is intended in this document The location of the IHSSs at the RFP are shown on Plate 1

The second major investigation completed at the Plant in 1986 involved a hydrogeologic and hydrochemical characterization of the entire Plant site Plans for this study were presented in Rockwell International (1986b, 1986c), and study results were reported in Rockwell International (1986d) Investigation results indicated four areas to be significant contributors to environmental contamination, with each area containing several sites The areas are the 881 Hillside Area, the 903 Pad Area, the Mound Area, and the East Trenches Area

Since 1986 a number of studies and investigations of contamination at the RFP have been conducted In accordance with the IAG, the RFP site is divided into 16 OUs each containing multiple IHSSs The OUs have been ranked and assigned schedules for investigation and cleanup A summary of the waste disposal history at each OU is provided in Appendix A

In terms of site geology, a draft Geologic Characterization Report for the Rocky Flats Plant (EG&G, 1990b) was completed in January 1990 based on re-evaluation of log data and other geologic information This study supersedes all previous geologic investigations with the exception of Hurr (1976)

Lastly, and of greatest relevance to this final background plan, background data for RFP has been collected since 1989 in accordance with the draft Background Hydrogeochemical Characterization and Monitoring Plan (Rockwell, 1989b) The data collected in 1989 were compiled and assessed in the Background Geochemical Characterization Report, Rocky Flats Plant, for 1989 (EG&G, 1990c)

1.4 DATA QUALITY OBJECTIVES

1.4.1 DQO Development Process

Data quality objectives (DQO) are quantitative and qualitative statements specified to ensure that data of known and appropriate quality are obtained during RCRA and CERCLA investigations to support the selection of remedial action alternatives DQOs are determined based on the end uses of the data to be collected DQOs also are developed to provide statements on the level of uncertainty that the DOE and the federal and state regulatory agencies are willing to accept in results derived from environmental data Although the term connotes quality, DQOs also classify program objectives These objectives for the background geochemical characterization are presented in Section 1 1

DQOs for this background characterization plan have been developed through a three-stage process, as illustrated in Figure 1-1 The DQO process has been integrated with development of the background sampling program as outlined in Section 3 of this document

1.4.2 Stage 1 - Identification of Decision Types (Objectives)

Stage 1 of the DQO process is undertaken to identify the individuals responsible for decisions, to identify and involve data users, and to define the types (objectives) of decisions that will be

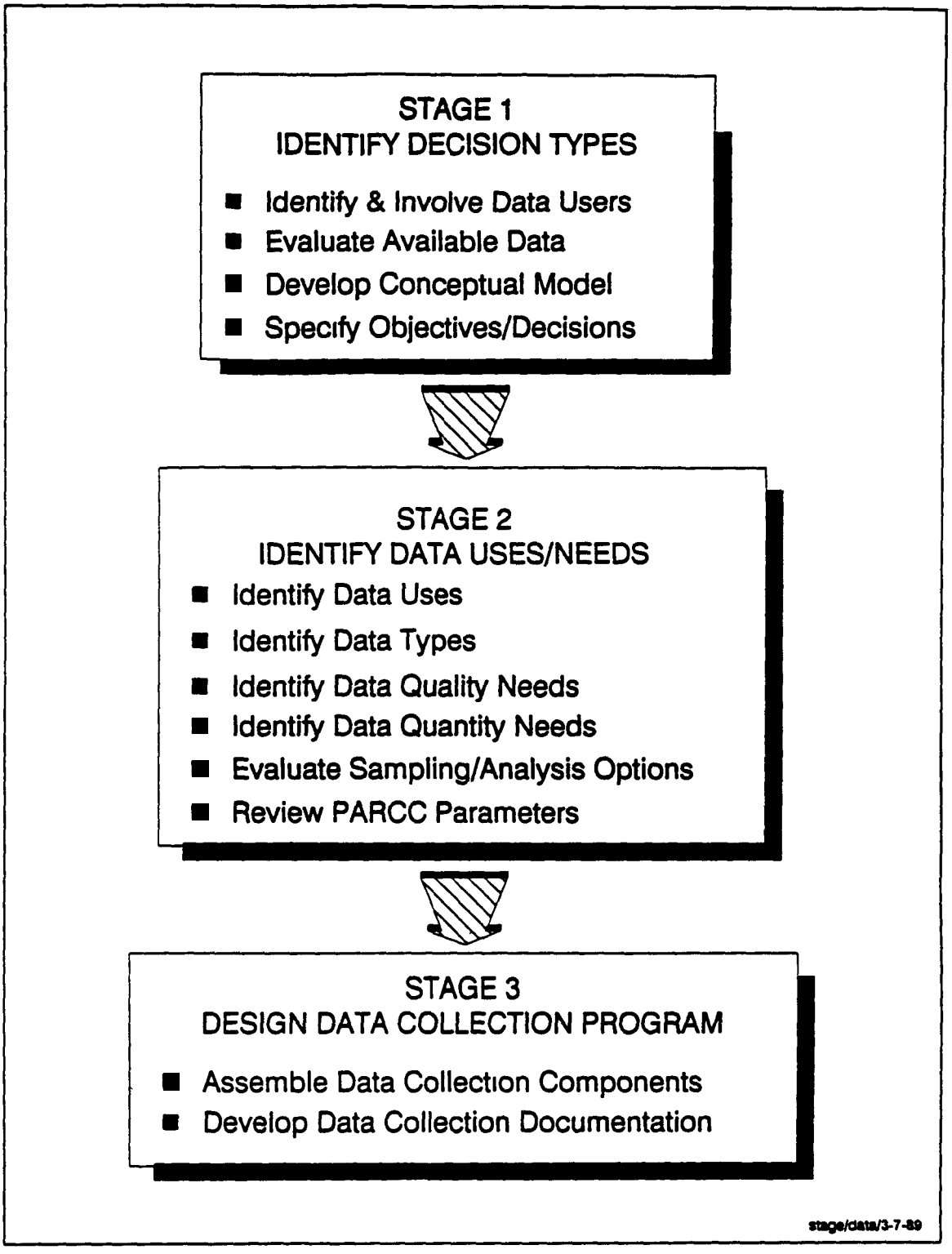


Figure 1-1 DQO Three-Stage Process

made as part of the background characterization program The general decision types that have been identified early in Stage 1 will ensure that the investigative approach will yield data sufficient to support the decision

1.4.2.1 Identification and Involvement of Data Users

The primary data users are those individuals responsible for and involved in the ongoing environmental monitoring and RCRA/CERCLA investigations conducted at the RFP These investigations include RFI/RI planning and implementation, risk assessment Interim Measures/Interim Remedial Action (IM/IRA) planning and implementation, site-wide air, water and sediment quality monitoring, and National Pollutant Discharge Elimination System (NPDES) monitoring The background data are necessary for meaningful interpretation of site-specific data collected for the above noted investigations and monitoring programs

1.4.2.2 Evaluation of Available Information

Several studies discussed in Section 1 3 indicated potentially elevated levels of radionuclides, metals, and chlorinated solvents in soils and water at the site. Furthermore, since establishment of the Plant in 1951, materials defined as hazardous substances, pollutants, and contaminants by CERCLA, and materials defined as hazardous waste and hazardous constituents by RCRA and/or the Colorado Hazardous Waste Act (CHWA), are known to have been produced and disposed or released at various locations at the site These data and historical information provide the rationale for the analytical suite established for the background program and the locations for the background sampling The hydrogeologic characterization of the site based on these previous studies is the foundation for selecting the geologic materials and ground waters to be sampled in the background program

1.4.2.3 Conceptual Models

A conceptual model hypothesizes about the source of contamination, the pathway it may take and the potential receptors of the contamination. Conceptual models have been developed for

many potential sources (IHSSs) that exist at the RFP They are (or will) be presented in the respective RFI/RI Work Plans for the OUs

The basis for these conceptual models (particularly contaminant migration pathways) is the RFP geology, hydrogeology, and meteorology, which is provided in Section 2 The hydrogeologic conceptual model (Section 2.4) for the Plant site is the foundation for the design of the background sampling program Background sampling locations are hydraulically and meteorologically upgradient or sidegradient of all known IHSSs

Conceptual models will be tested, refined and modified throughout the background and OU characterization programs in order to adequately determine all potential sources and migration pathways for contaminants that exist at the RFP

1.4.2.4 Objectives

In general, this background characterization program is designed to characterize background conditions in order to determine if the chemical concentrations detected at an IHSS indicate contamination Section 1 1 defines more specific objectives for the background characterization program

1.4.3 Stage 2 - Identification of Data Uses/Needs

Stage 2 of the DQO process defines data uses and specifies the types of data needed to meet the project objectives The major elements of Stage 2 of the DQO process are.

- Identify data uses
- Identify data types
- Identify data quality needs
- Identify data quantity needs
- Evaluate sampling/analysis options

- Review precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters

Data uses and attendant data quality needs have been established for the overall site and will be refined for components of individual RCRA/CERCLA phases The background characterization program phase 2 of the DQO process is detailed in this section

1.4.3.1 Data Uses

Background geochemical data are needed to determine whether chemical concentrations at IHSSs or RCRA regulated units represent contamination Background data are used to support

- Investigation and Characterization
- Risk Assessment
- RCRA Ground Water Monitoring

Each of these activities is described below

Investigation and Characterization

Investigation and characterization involves conducting technical studies to investigate and determine the nature and extent of contamination at an operable unit Contamination is defined as a statistically significant difference between background and site chemical concentrations Therefore, background conditions must be established (Section 3) and statistical tests performed (Section 4) in order to determine the nature and extent of contamination

Risk Assessment

Risk assessment activities involve examination of the potential risks of contaminants to human health and/or the environment Risk assessments involve multi-media modeling of potential exposure routes and environmental pathways for contaminant migration As discussed under

Investigation and Characterization, background data are necessary to determine the existence of contamination and provide a benchmark to assess the incremental risk posed by the contamination Background data can also be used to support waivers for complying with ARARs when background concentrations exceed ARARs

RCRA Ground Water Monitoring

RCRA ground water monitoring involves periodic sampling and analysis of ground water up- and down-gradient of RCRA regulated units to determine compliance with RCRA ground water protection standards Site-wide ground water quality data (the subject of this plan) can be used to determine whether upgradient ground water may be impacted by another IHSS.

1.4.3.2 Data Types

There are five classes of environmental measurement data needed to support the RFP environmental monitoring programs These five classes are

- Hydrogeology
- Organic Chemistry
- Inorganic (Metals) Chemistry
- Major Ion Chemistry
- Radiochemistry

Specific background/site data needed for each of the five classes is described in Section 3 of this plan The analytical suites are based on the types of wastes known to have been disposed at the RFP, and elements/compounds that previous data suggest are elevated in the various environmental media Analytical methods and required detection limits are also presented in Section 3

1.4.3.3 Data Quality

Three factors have been considered to define the data quality needs of this background characterization program

- Well defined and accepted methodologies for field activities
- Appropriate analytical levels
- Required detection limits

The background characterization program has been implemented using state-of-the-art methodologies for well installation and sampling of geologic materials, ground water, and surface water Initially, the program followed the ER Program Standard Operating Procedures (SOP) (Rockwell International, 1989c) and the ER Program Quality Assurance/Quality Control (QA/QC) Plan (Rockwell International, 1989c), and currently complies with the Environmental Management Department (EMD) SOPs (EG&G, 1991a) and the RFP Site-Wide Quality Assurance Project Plan (QAPjP) (EG&G, 1990d) Differences in these plans and SOPs are minor and do not affect the comparability of "old" and "new" data

The analytical techniques that will be used are identified in Section 3 3 of this report To provide some guidelines, this section defines the analytical levels and indicates the levels appropriate to different generic data uses. The analytical levels are defined as follows

- LEVEL I - Field screening or analysis using portable instruments Some Level I methods are not compound-specific, others are specific and quantitative Results are quickly available This level of analytical techniques is the least costly of the analytical options
- LEVEL II - Field analyses using more sophisticated portable instruments such as setting up instruments in a mobile laboratory on site There is a wide range in the quality of data that can be generated Results can be made available quickly or may take several hours
- LEVEL III - All analyses are performed in an off-site analytical laboratory and may or may not use EPA Contract Laboratory Program (CLP) procedures However, Level III analyses do not usually use the validation or documentation procedures required of CLP Level IV

analysis Level III analyses are also used for non-CLP methods such as radiochemistry analysis

- LEVEL IV - CLP routine analytical services (RAS) All analyses are performed in an off-site CLP analytical laboratory following CLP protocols Level IV is characterized by rigorous QA/QC protocols and documentation

- LEVEL V - Analysis by non-standard methods All analyses are performed in an off-site analytical laboratory which may or may not be a CLP laboratory Method development or method modification may be required for specific constituents or detection limits CLP special analytical services (SAS) are Level V.

Risk assessment typically requires the use of validatable data, i e , Level IV (and V), although Level III data can be used when verified by an adequate percentage of Level IV data The background and site-specific investigations use Level IV analytical techniques for CLP organics and inorganics, and Level III (highest level attainable) for radiochemistry and other non-CLP analytes This assures adequate data quality for risk assessment purposes.

The adequacy of the associated detection limits are evaluated in Section 3 3 of this document Adequacy is determined based on the magnitude of the detection limit relative to a health-based acceptable concentration, i e , detection limits that significantly exceed the health based limits may not be sufficiently accurate to allow meaningful evaluation of human health risk

1.4.3.4 Data Quantity

The number of samples that should be collected can be determined using a variety of approaches In situations where data are available, statistical techniques may be utilized to determine the required number of samples to meet the program objectives The sampling program described in Section 3 provides sampling numbers and locations amenable to rigorous statistical interpretation

1.4.3.5 Evaluate Sampling/Analysis Options

The number and location of background samples has been carefully considered in developing the background geochemical plan Understanding of the local hydrogeology (conceptual model) was paramount in design of the background characterization program The conceptual model is included in Section 2 4, and the background characterization program is presented in Section 3

1.4.3.6 PARCC Parameters

The PARCC (precision, accuracy, representativeness, comparability, and completeness) parameters are overall indicators of data quality PARCC parameters, specifically precision and accuracy, are compound, media and analytical method specific The specific objectives associated with each of these parameters are dependent on the intended use(s) of the data

For the RFP environmental monitoring programs, environmental data collected must conform to the following criteria

1 Data must be of known and documented quality

2 Data must be obtained in accordance with rigorous, documented, quality assurance/quality control (QA/QC) criteria

3 Data obtained from analyses are characterized by low detection limits and method-specific detection limits Where available, CLP methods and protocols are used Methods and associated detection limits are selected such that data may be compared with federal and state ARARs and/or health-based acceptable concentrations

4 Data are reviewed and validated according to validation procedures prescribed by EPA and DOE Review and validation activities are documented Data validity has three classifications 1) Valid, 2) Acceptable for Use with Qualification(s), and 3) Rejected (Unacceptable)

Precision and Accuracy

Precision and accuracy are largely dependent on the analysis methods used and the results of duplicate, blank, and spike analyses Generally, only data that meet the validation criteria of (1) valid or (2) acceptable will achieve the necessary level of precision and accuracy needed to achieve environmental monitoring objectives As a general rule, data validated as rejected (unacceptable) will not be included in statistical or geochemical analyses However, rejected data may be used if rejection is based only on the absence of quality control data, and other relevant valid or acceptable data suggest this data is useable Nevertheless, such data points will be flagged as rejected whenever they are cited Data that have not yet been validated may be used on an interim basis, and the lack of validation will indicate when they are cited

Representativeness

The location and number of background samples has been carefully considered in design of the background characterization program to assure the data are representative of site conditions The site conceptual model was key to assuring representative sampling

Comparability

Comparability is achieved by using standard methods for sample collection and analysis that are applied for all environmental monitoring activities at the RFP (see Section 1 4 3 3)

Completeness

Completeness is determined by comparing the amount of usable data obtained to the amount that was expected to be obtained The objective for completeness is to obtain 90% valid and acceptable data

1.4.4 Stage 3 - Design Data Collection Program

This background geochemical characterization plan represents Stage 3 of the DQO process, and has been undertaken to document the detailed data collection program Section 3 of this document describes the data collection program for background characterization It presents the details of the background samples to be obtained Sections 4 discusses geochemical and statistical evaluation techniques to be applied to the data

SECTION 2
PHYSICAL SETTING

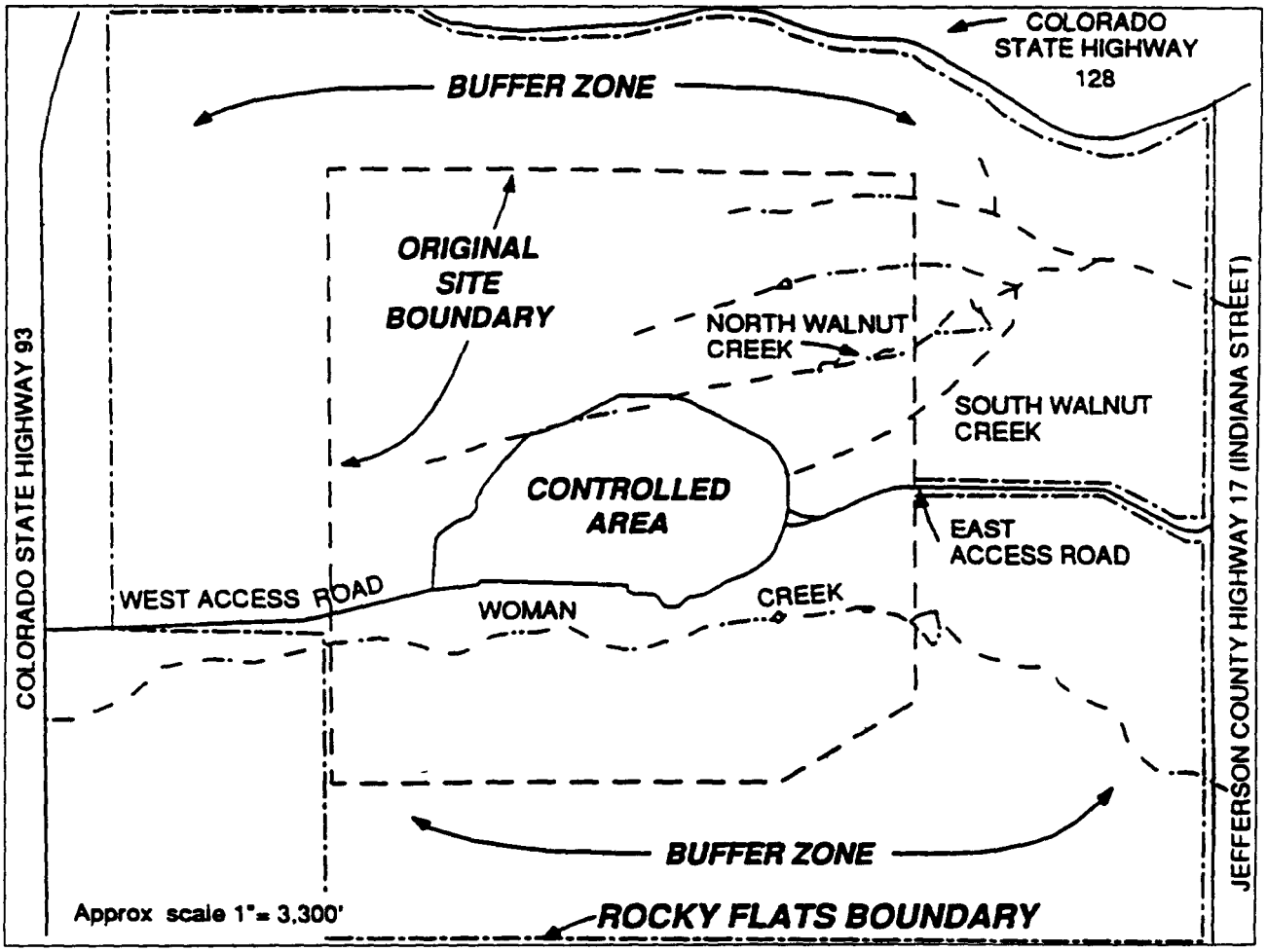
The RFP is located in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 2-1) Other surrounding cities include Arvada, Boulder, and Westminster, which are located less then 10 miles to the southeast, northwest, and east respectively The Plant consists of approximately 6,550 acres of federally owned land in Sections 1 through 4 and 9 through 15 of T2S, R70W, 6th Principal Meridian Major buildings are located within the Plant security area of approximately 400 acres The security area is surrounded by a buffer zone of approximately 6,150 acres (Figure 2-2)

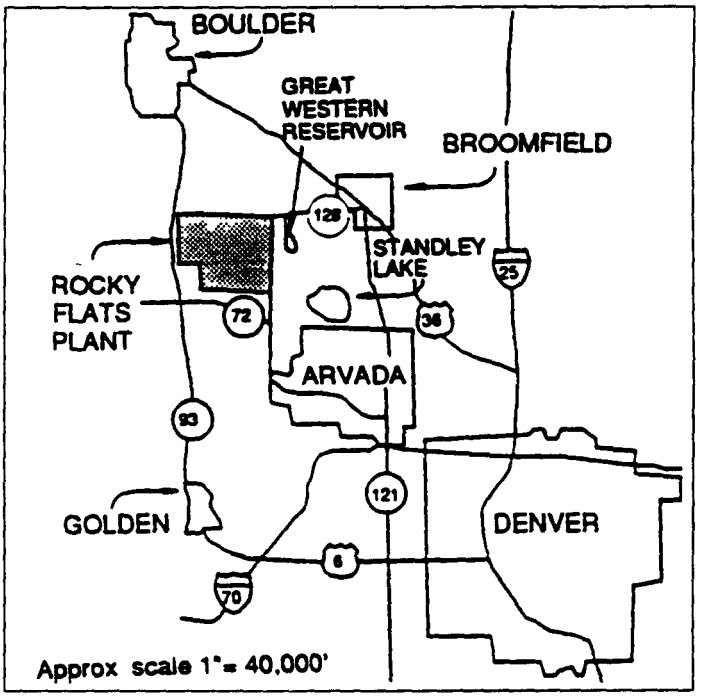
2.1 TOPOGRAPHY

The natural environment of the Plant and vicinity is influenced primarily by its proximity to the Front Range of the Rocky Mountains The Plant is directly east of the north-south trending Front Range, and is located about 16 miles east of the Continental Divide at an elevation of approximately 6,000 feet above mean sea level The RFP is located on a broad, eastward sloping plain of coalescing alluvial fans developed along the Front Range The fans extend about 5 miles in an eastward direction from their origin at Coal Creek Canyon and terminate on the east at a break in slope to low rolling hills The operational area at the Plant is located near the eastern edge of the fans on a terrace between stream-cut valleys (North Walnut Creek and Woman Creek)

2.2 SURFACE WATER HYDROLOGY

Three intermittent streams drain the Rocky Flats Plant with flow generally from west to east These drainages are Rock Creek, Walnut Creek, and Woman Creek (Figure 2-2) Rock Creek drains the northwestern corner of the Plant and flows northeast through the buffer zone to its off-site confluence with Coal Creek An east-west trending interfluve separates the Walnut and Woman Creek drainages North and South Walnut Creeks and an unnamed tributary drain the northern portion of the Plant security area These three forks of Walnut Creek join in the buffer zone and flow toward Great Western Reservoir, which is approximately 1 mile east of the





U.S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	ROCKY FLATS PLANT Golden, Colorado VICINITY MAP	FIGURE 2-1

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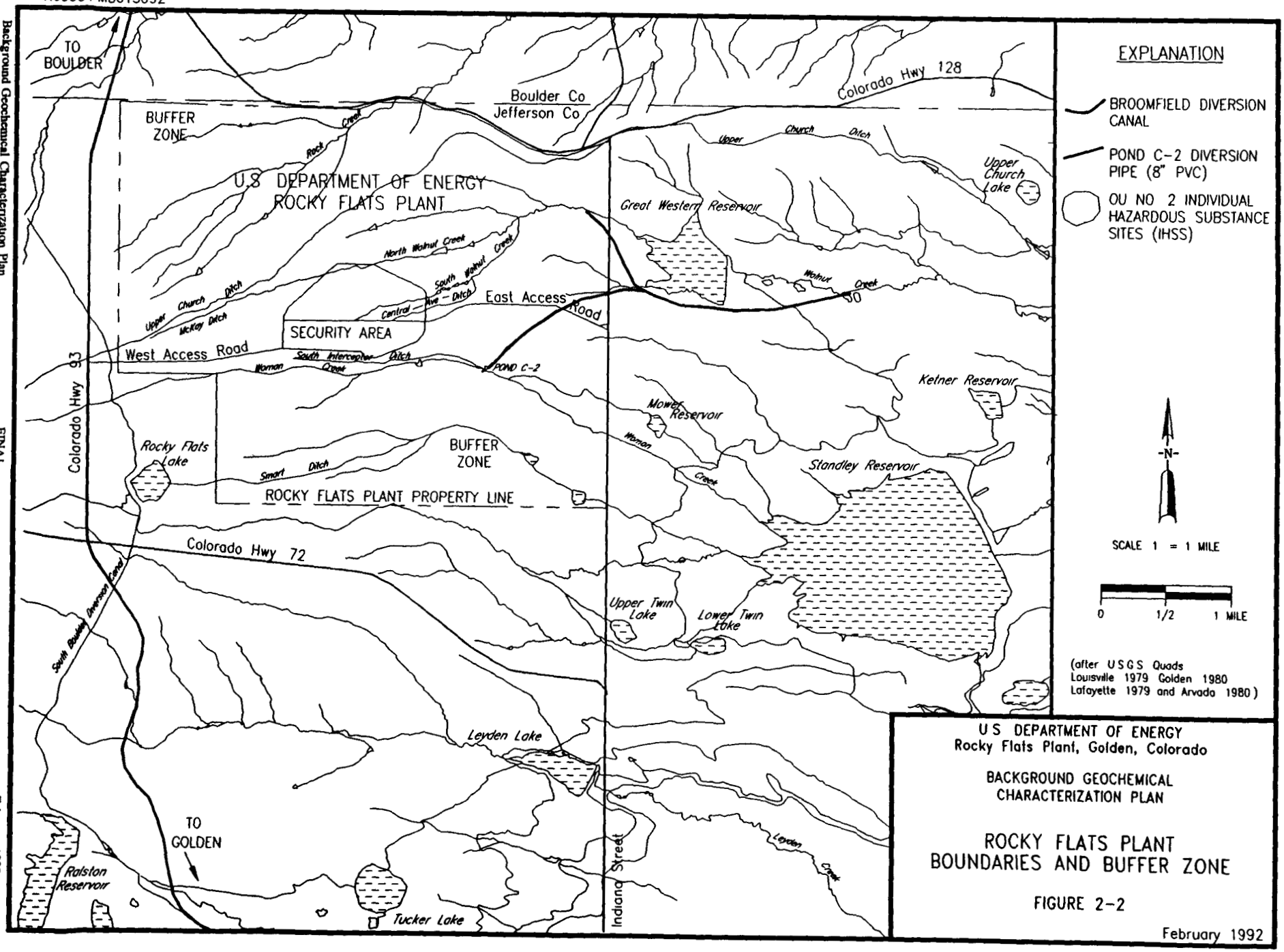

U S DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN

ROCKY FLATS PLANT BOUNDARIES AND BUFFER ZONE

FIGURE 2-2

February 1992

confluence However, this flow is routed around Great Western Reservoir by the Broomfield Diversion Canal, which is operated by the City of Broomfield Woman Creek drains the southern RFP buffer zone flowing eastward The Woman Creek flow is diverted on plant site to Mower Reservoir via the Mower Ditch The South Interceptor Ditch lies between the Plant and Woman Creek The South Interceptor Ditch collects runoff from the southern Plant security area and diverts it to Pond C-2 where it is treated and monitored in accordance with the Plant NPDES permit Treated water from Pond C-2 is then pumped to the Walnut Creek watershed where it is released to the Broomfield Diversion Canal

2.3 REGIONAL AND LOCAL GEOLOGY

Geologic units beneath the Rocky Flats Plant consist of unconsolidated surficial units of Quaternary age (Rocky Flats Alluvium, various terrace alluvia, valley fill alluvium, and colluvium), which unconformably overlie Cretaceous-aged bedrock (Arapahoe Formation, Laramie Formation, and Fox Hills Sandstone) (Figure 2-3) This geologic sequence forms part of a monoclinal fold whose western edge is composed of uplifted strata of Mesozoic age that become younger upsection to the east Figure 2-4 presents a generalized stratigraphic section of the Denver Basin bedrock, and Figure 2-5 shows a stratigraphic section for the RFP including unconsolidated deposits Figure 2-6 shows the surficial geology of the RFP (EG&G, 1992a)

2.3.1 Quaternary-Aged Alluvia

The Quaternary alluvia along the Front Range have been correlated by their height above modern drainages and major streams Each height represents a stable geomorphic level in the Quaternary (Scott, 1965) (Figure 2-7)

The pre-Wisconsin pediment was not a smooth plane, but rather an erosional surface that was cut by a well-developed network of west to east-flowing stream drainages that have probably, to a large part, influenced the current drainage system The pediment surface exhibits as much as 30 feet of relief (EG&G, 1991b) In ravines and drainages the alluvial sediment is breached exposing strata of the Arapahoe and Laramie Formations

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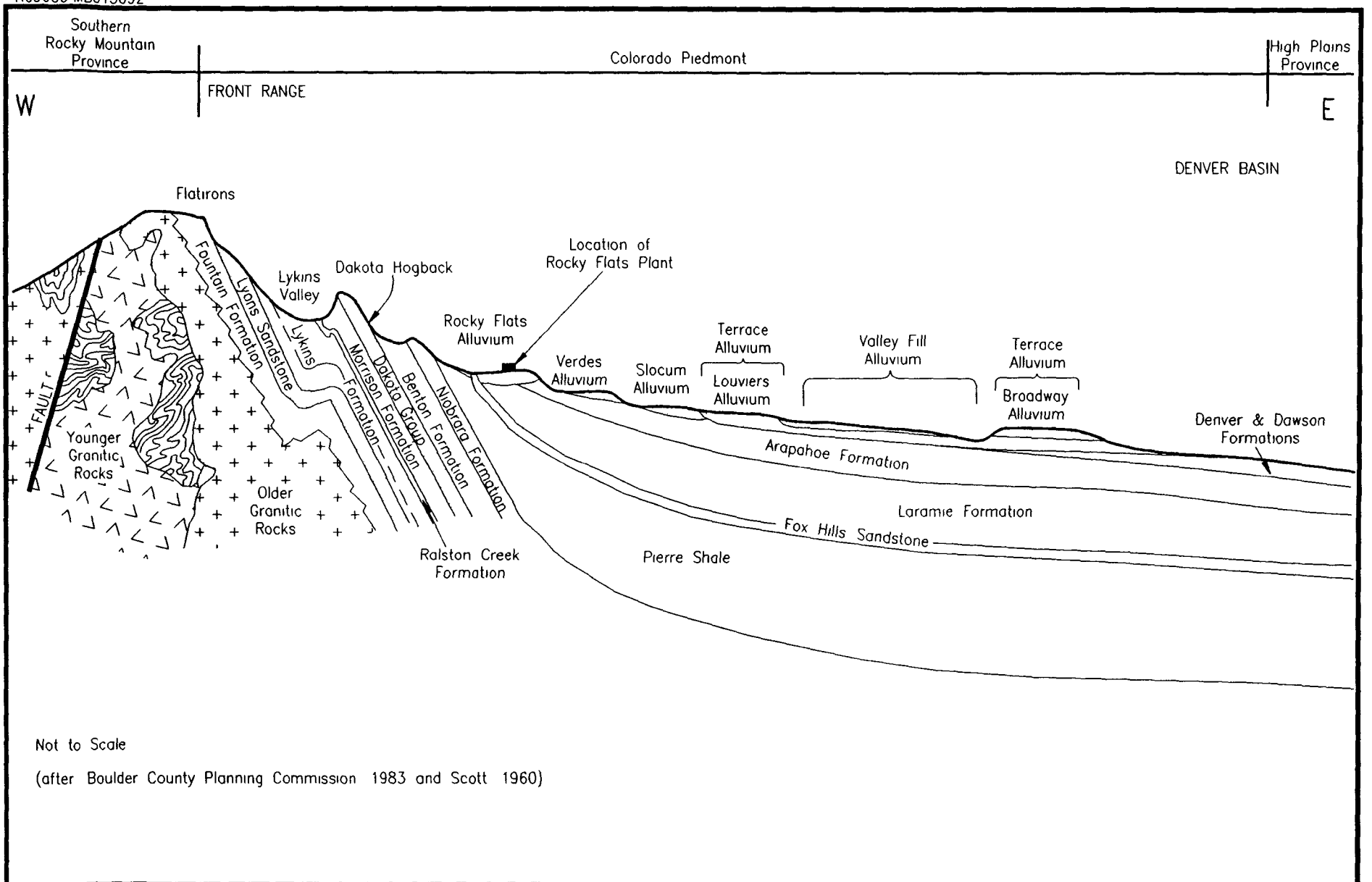
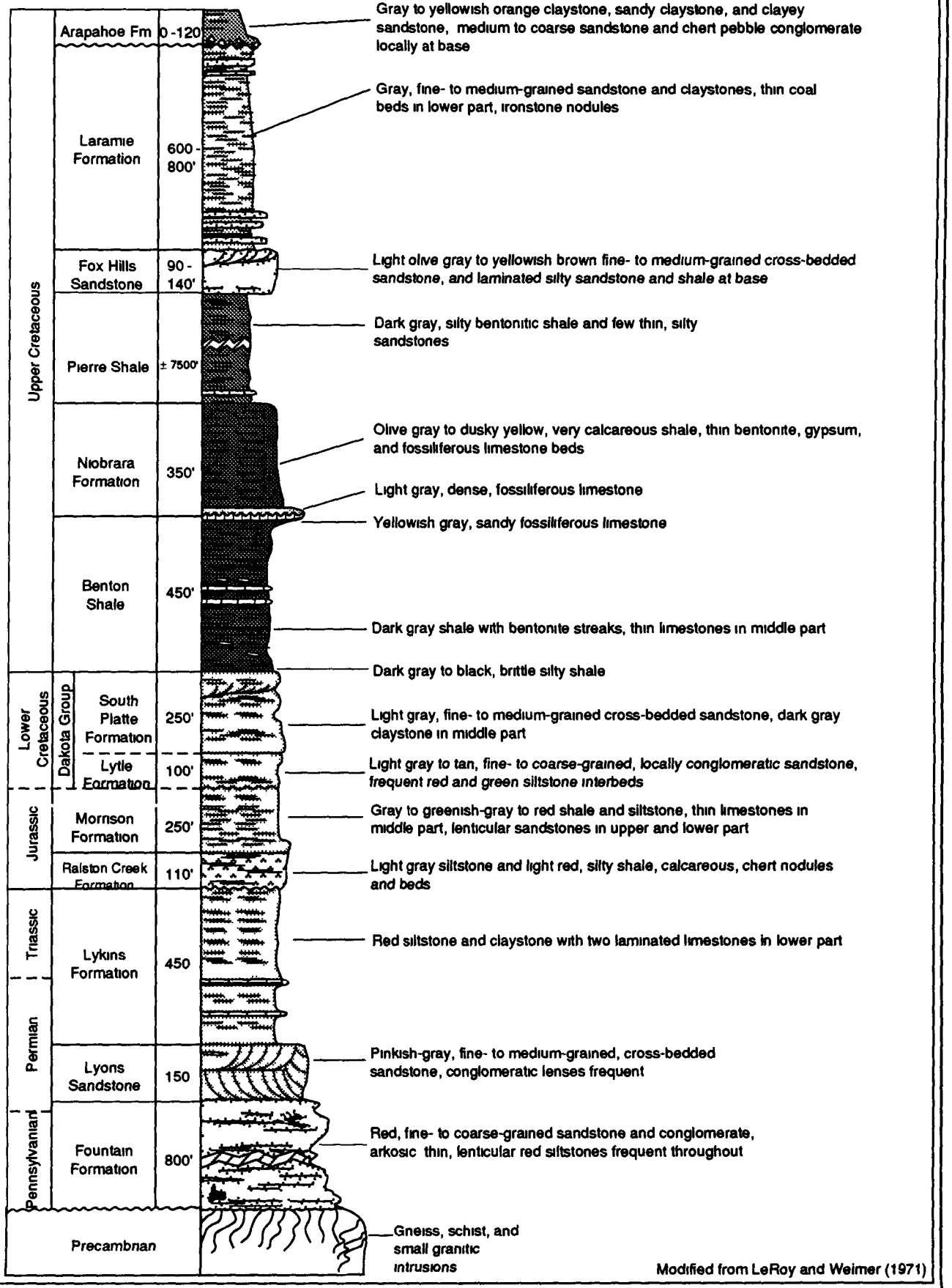
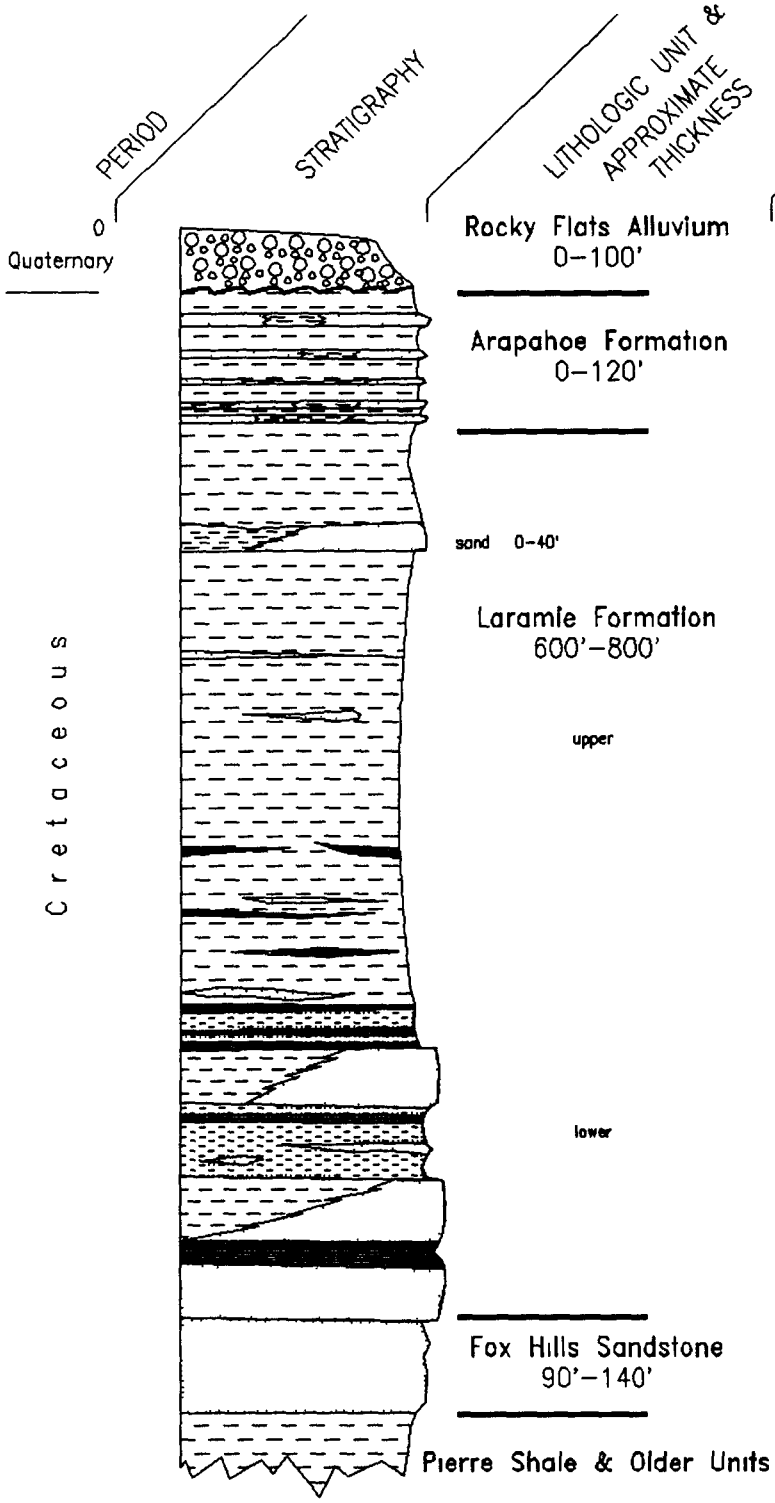


U S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	GENERALIZED EAST-WEST CROSS SECTION FRONT RANGE TO DENVER BASIN	FIGURE 2-3



U S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, CO	GENERALIZED STRATIGRAPHIC SECTION FOR DENVER BASIN	Figure 2-4



Clayey Sandy Gravels–
light brown to yellowish–orange, grayish–orange to dark gray, poorly–sorted angular to subrounded cobbles coarse gravels, coarse sands and gravelly clays; varying amounts of caliche

sand #1 0–27 2
sand #2 0–10
sand #3 0–18'
sand #4 0–15'
sand #5 0–9'+

Claystones, Siltstones, Clayey Sandstones, and Sandstones–
light to medium olive–gray with some dark olive–black claystone and silty claystone, light to olive–gray, fine– to coarse–grained, moderately–sorted fluvial sandstone intervals weathered intervals may be yellowed and basal sand is often conglomeratic

Claystones, Siltstones, Sandstones, and Coal–
kaolinitic light to medium gray claystone and siltstone and some dark gray to black carbonaceous claystone, thin (2') coals and discontinuous very fine to medium grained, moderately sorted sandstone intervals

Sandstones, Claystones, and Coal–
light to medium gray fine– to coarse–grained, poorly– to moderately–sorted silty immature quartzitic sandstone with numerous lenticular, sub–bituminous coal beds and seams that range from 2 thick in the upper lower interval to 8 thick at the base of the lower interval

Sandstones–
grayish–orange to light gray calcareous, fine–grained subrounded glauconitic, friable sandstone

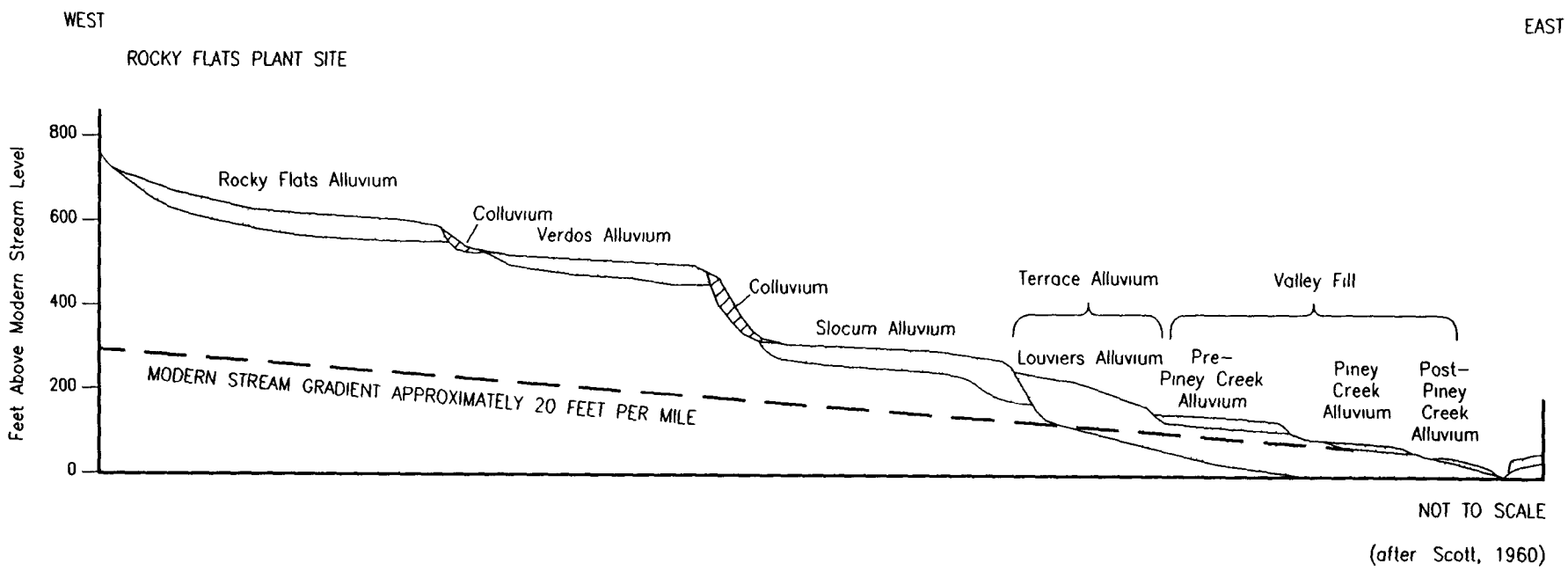
EXPLANATION

Alluvium
Coal
Fine–grained & coarser sandstone
Fine–grained sandstone
Siltstone and claystone
Silty sandstone

(after EG&G, 1991c)

U.S. DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	LOCAL STRATIGRAGHIC SECTION OF THE ROCKY FLATS PLANT	FIGURE 2–5

R69014-PJCW-022192



NOT TO SCALE

(after Scott, 1960)

January 1992

U.S DEPARTMENT OF ENERGY Rocky Flat Plant Golden, Colorado	EROSIONAL SURFACES AND ALLUVIAL DEPOSITS EAST OF THE FRONT RANGE COLORADO	FIGURE 2-7

The Rocky Flats Alluvium comprises the main alluvial cover at RFP Various other surficial deposits occur topographically below the Rocky Flats Alluvium in the Plant drainages Colluvium (slope wash) mantles the valley side slopes between the Rocky Flats Alluvium and the valley bottoms In addition, remnants of younger terrace deposits, including the Verdos, Slocum, and Louviers Alluvia may occur along the valley side slopes Recent valley fill alluvium occurs in the active stream channels (Figure 2-7)

The Quaternary-aged Rocky Flats Alluvium is the oldest (Nebraskan or Aftonian) and topographically highest alluvial deposit at the RFP (Scott, 1965) The alluvium is a series of coalescing alluvial fans deposited by braided streams (Hurr, 1976) It consists of a topsoil layer underlain by orange to dark gray, poorly sorted cobbles, coarse gravel, coarse sand, and gravelly clay Generally the alluvium is coarser-grained west of the Plant and becomes finer grained toward the east Caliche may be present in the interstices of the alluvium in amounts greater than 25 percent over an interval of 1 to 2 feet (EG&G, 1991b) Caliche is most likely to occur where evaporation is high, the water table is close to the surface, the alluvial cover is thin, or the unconsolidated material is underlain by claystones and siltstones which restrict percolation

Because of the uneven surface of the pediment on which the Rocky Flats Alluvium was deposited, the thickness of the alluvium at RFP ranges from 70 to 98 feet just west of the Plant, to less than 10 feet in the central portion of the Plant, and to around 45 feet just east of the Plant (EG&G, 1991b) The erosional surface (pediment) on which the alluvium was deposited slopes gently eastward truncating the Fox Hills Sandstone, the Laramie Formation, and the Arapahoe Formation at RFP The eastward dip of beds within the Rocky Flats Alluvium is apparent from the subsurface elevation of the top of a gravelly sand marker bed observed in boreholes in the East Trenches area

After deposition of the Rocky Flats Alluvium, eastward flowing streams, which may have originated in pre-Wisconsin time, began dissecting the deposit by headward erosion and lateral planation The alluvium was progressively removed by erosion in the Woman Creek drainage south of the plant and in the South Walnut Creek drainage to the north The result is a remnant of Rocky Flats Alluvium extending eastward from the Plant between the two drainages

2.3.2 Cretaceous-Aged Deposits

The Cretaceous-aged formations in the vicinity of RFP were deposited during the Laramie Orogeny Uplifted strata to the west provided the source material for the prograding sequence of Fox Hills delta front sands, Laramie delta plain sands and the Arapahoe fluvial deposits

2.3.2.1 Arapahoe Formation

The Arapahoe Formation is the uppermost bedrock unit in the vicinity of RFP It unconformably underlies surficial materials beneath most of the Plant except in the western portion There, from approximately the middle of the west buffer zone and west to the gravel quarries, the Laramie Formation unconformably underlies the Rocky Flats Alluvium

The Arapahoe Formation is a fluvial deposit composed of overbank and channel deposits It consists predominantly of light to medium olive-gray and some olive-black claystones and silty claystones, and siltstones with some silty sandstones and sandy conglomerates When weathered at the base of the alluvium, the claystones appear dark yellowish-orange, which is a result of iron oxide staining below the alluvial-bedrock unconformity Staining is common at depths of 1 to 20 feet below the alluvium (EG&G, 1991b) Caliche may also be found in this weathered zone in sandstones that occur beneath the Rocky Flats Alluvium and above claystones or siltstones, as a result of reduced percolation and high evaporation

The Arapahoe Formation contains at least five mappable sandstone intervals which are lenticular in nature (EG&G, 1991b) Most of the sandstones are very fine to medium-grained, poorly to moderately sorted, subangular to subrounded, silty, clayey, with frosted quartz grains, although some are coarse-grained or conglomeratic Commonly, the Arapahoe sandstones occurring within 30 to 40 feet of the base of the alluvium are oxidized and are thus pale orange, yellowish-gray and dark yellowish-orange The sandstones that are not in the weathered zone are light gray and olive gray

The formation thickness is 150 feet in the central portion of RFP (EG&G, 1991b) The unit is nearly flat-lying beneath the central and eastern portions of the Plant (EG&G 1990b, 1990e)

2.3.2.2 Laramie Formation

The Laramie Formation underlies the Arapahoe Formation and is composed of two units a thick upper unit composed predominantly of claystone with some siltstones and sandstones, and a lower unit which contains numerous coals and sandstones that increase in thickness at the base of the unit The contact with the overlying Arapahoe Formation is conformable and is defined on the basis of textural and lithologic characteristics, as given in the following description taken from EG&G (1992a)

> "The base of the Arapahoe Formation is defined as the lowest occurrence of lithologically distinct, medium to coarse-grained, well-rounded, frosted, quartz sandstone or conglomeratic sandstone within a continuous vertical section Where no distinct Arapahoe sandstones are present within the vertical sequence, no lithologic break defines that contact and the contact surface is projected from the nearest surface exposures of lithologically distinct Arapahoe sandstones "

The beds dip at approximately 45° to 50° west of the Plant and flatten to less than 2° dip below and east of the Plant (EG&G, 1990b, 1990e)

The upper Laramie is composed of mostly silty claystones, siltstones, and some fine-grained fluvial channel sandstones The basal 150 feet of the upper Laramie interval contains coal beds that range from 1 to 3 feet in thickness The silty claystones are light olive gray to olive black, massive, and may contain sand or carbonaceous material Iron oxide nodules occur in the siltstones (EG&G, 1991b)

The lower Laramie is composed of sandstones and coal beds The sandstones are finer-grained and more laterally continuous than those found in the Arapahoe Formation Coal beds range from 2 to 8 feet in thickness and one sandstone is 50 feet thick (EG&G, 1991b)

The total thickness of the Laramie Formation is about 800 feet, the upper Laramie ranges in thickness from 515 to 690 feet and the lower Laramie ranges from 285 to 115 feet in thickness (Weimer, 1973, EG&G, 1991b)

2.3.2.3 Fox Hills Sandstone

The Fox Hills Sandstone is approximately 75 to 125 feet thick, and is composed chiefly of calcareous, fine-grained feldspathic sandstone with thin beds of siltstone and claystone (EG&G, 1991b) The rocks are grayish-orange to light gray in color The formations is interpreted as a delta-front sandstone in facies relationship with the underlying Pierre Formation and the overlying Laramie Formation (Weimer, 1973)

2.3.3 Structural Features

RFP is situated in an area once tectonically active Structural activity associated with the Laramide Orogeny (approximately 60 to 45 million years ago) was manifested in thrust faults, resulting from compressional stresses After a period of quiescence, the area underwent tensional faulting from the Miocene to the Pliocene period (25 to 5 million years ago), which produced normal and high angle reverse faults associated with the present Front Range

The Plant lies on a monoclinal fold along the eastern margin of the Front Range mountains The axial plane of the fold strikes roughly north-south Just west of the site steeply dipping strata of Pennsylvanian age lie unconformably on Pre-Cambrian granitic rocks

In the vicinity of RFP, two faults exist which are products of the two tectonic events Beneath RFP, a thrust fault is present in the Pierre Shale The thrust has a maximum throw of approximately 80 feet at a depth of 3,600 feet As the more recent structural forces in the area have been extensional in nature, it is not believed that this fault will become active again Approximately 1 5 miles south of the Plant is the northern extension of the Golden Fault In a 1981, study Dames and Moore found "no compelling evidence for current tectonic activity of the Golden Fault " Dames and Moore also found the Golden Fault to be unrelated to other structural features in the area

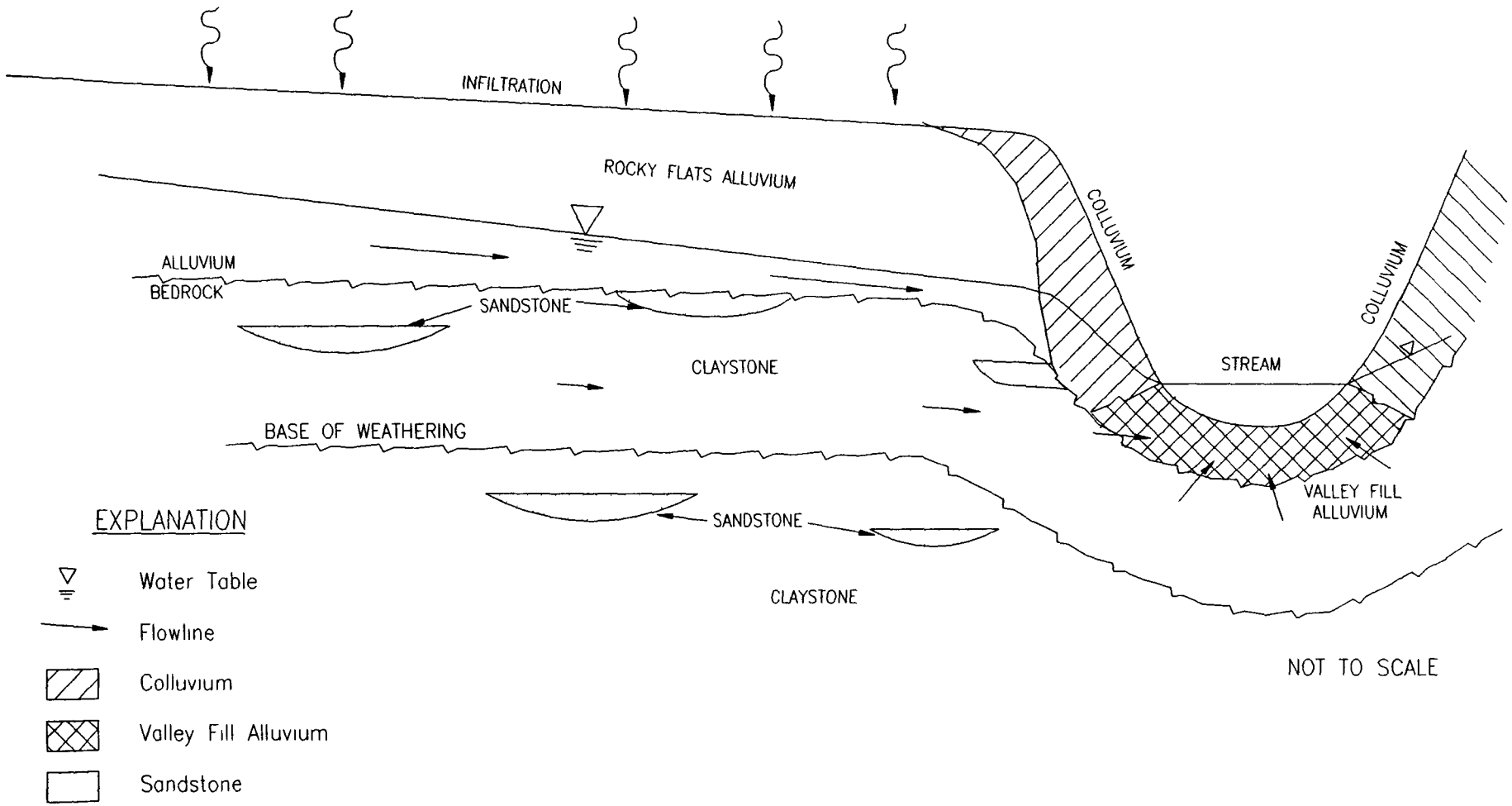
2.4 HYDROGEOLOGY

Unconfined ground water occurs in the Rocky Flats Alluvium which is relatively permeable (Figure 2-8) Recharge to the alluvium is from precipitation, snowmelt, and water losses from ditches, streams, and ponds that are cut into the alluvium Groundwater movement in the Rocky Flats Alluvium is generally from west to east and is controlled by pediment drainages cut into the top of bedrock Flow is downslope through colluvial materials and then along the course of the stream in valley fill materials The Rocky Flats Alluvium terminates approximately 1,500 feet west of the eastern Plant boundary and does not directly supply water to wells located downgradient of the RFP The surficial water table map is presented on Plate 1 Discharge from the alluvium occurs at seeps that may or may not be covered by colluvium at the contact between the alluvium and bedrock along the edges of the valleys Most seeps flow intermittently

Groundwater levels in the Rocky Flats Alluvium rise in response to recharge during the spring and decline during the remainder of the year During periods of high surface water flow, water is lost to bank storage in the valley fill alluvium and returns to the stream after the runoff subsides In the western portion of RFP, where the thickness of the alluvial material is greatest, the depth to the water table is 50 to 70 feet below the surface (EG&G, 1991b) The water table becomes shallower to the east (with local variations) as the alluvial material thins Some mounding occurs under ponds, such as the solar ponds

The Arapahoe sandstones exhibit many of the same hydrological characteristics as the Rocky Flats Alluvium Where the sandstones are in direct contact with the alluvium, ground water exists under unconfined conditions However, saturated sandstones that lie beneath claystones and siltstones are confined water bearing units Where weathered, the claystones themselves may act as unconfined water bearing units, but have much lower hydraulic conductivity than the Rocky Flats Alluvium

The main recharge area for Arapahoe sandstones is under the Rocky Flats Alluvium although some recharge from the colluvium and valley fill alluvium likely occurs along the stream valleys (Figure 2-8) Recharge is greatest during the spring and early summer when rainfall and stream



U S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	SCHEMATIC OF GROUND WATER/SURFACE WATER INTERACTION	FIGURE 2-8

flow are at a maximum and water levels in the Rocky Flats Alluvium are high Discharge occurs at the edges of valleys (Figure 2-8) Ground-water flow in the bedrock is from west to east, although flow within individual sandstones is controlled locally by the channel geometries The Arapahoe sandstones have hydraulic conductivities approximately equivalent to, or less than, those of the overlying Rocky Flats Alluvium (Hydro-Search, 1985, Rockwell International, 1986b)

The lower sandstone unit of the Laramie Formation and the underlying Fox Hills Sandstone comprise a regionally important aquifer in the Denver Basin known as the Laramie-Fox Hills Aquifer (Robson, 1983) Near the center of the basin the aquifer thickness ranges from 200 to 300 feet These units subcrop beneath the Rocky Flats Alluvium west of the Plant and can be seen in clay pits excavated through the Rocky Flats Alluvium (see Figure 2-3) Recharge to the aquifer occurs along the rather limited outcrop area exposed to surface water flow and leakage along the Front Range (Robson, et al , 1981b) Claystones of the Laramie Formation have very low hydraulic conductivities, therefore, the U S Geologic Survey (Hurr, 1976) concludes that Plant operations will not impact any units below the upper claystone unit of the Laramie Formation

In summary, two groundwater flow systems are distinguished in the current conceptual model of the subsurface hydrology of Rocky Flats The upper flow system is unconfined and lies within the Rocky Flats Alluvium, colluvium, valley fill, and weathered bedrock The lower flow system is confined within unweathered bedrock sandstones of the lower Arapahoe and upper Laramie Formations The two flow systems are probably in hydraulic connection whenever bedrock sandstone subcrops under surficial materials (EG&G, 1990c, 1991c)

2.5 METEOROLOGY AND CLIMATOLOGY

The area surrounding the RFP has a semiarid climate characteristic of much of the central Rocky Mountain region Approximately 40 percent of the 15-inch annual precipitation falls during the spring season, much of it as snow Thunderstorms (June to August) account for an additional 30 percent of the annual precipitation Autumn and winter are drier seasons, accounting for 19 and 11 percent of the annual precipitation, respectively Snowfall averages 85 inches per

year, falling from October through May (DOE, 1980) Temperatures are moderate, extremely warm and cold weather is usually of short duration On the average, daily summer temperatures range from 55°F to 85°F, and winter temperatures range from 20°F to 45°F The low average relative humidity (46 percent) is due to the blocking effect of the Rocky Mountains Wind, temperature, and precipitation data are collected on the plant site and summarized annually Table 2-1 presents the 1990 annual summary of the percent frequency of wind directions (16 compass points) divided into 5 speed categories These frequency values are represented graphically in Figure 2-9 Winds at the RFP are predominantly northwesterly Winds greater than 4 18 meters per second (m/s) (9 2 miles per hour [mph]) with easterly components occur with a low frequency

Special attention has been focused on dispersion meteorology surrounding the Plant due to the possibility that significant atmospheric releases might affect the Denver metropolitan area which is located in the predominant downwind direction (southeast) Studies of air flow and dispersion characteristics (e g , Hodgin, 1983, 1984) indicate that drainage flows (winds coming down from the mountains to the west, turn and move toward the north and northeast along the South Platte River valley and pass to the west and north of Brighton, Colorado (DOE, 1980), which is just north of Denver

Table 2-1

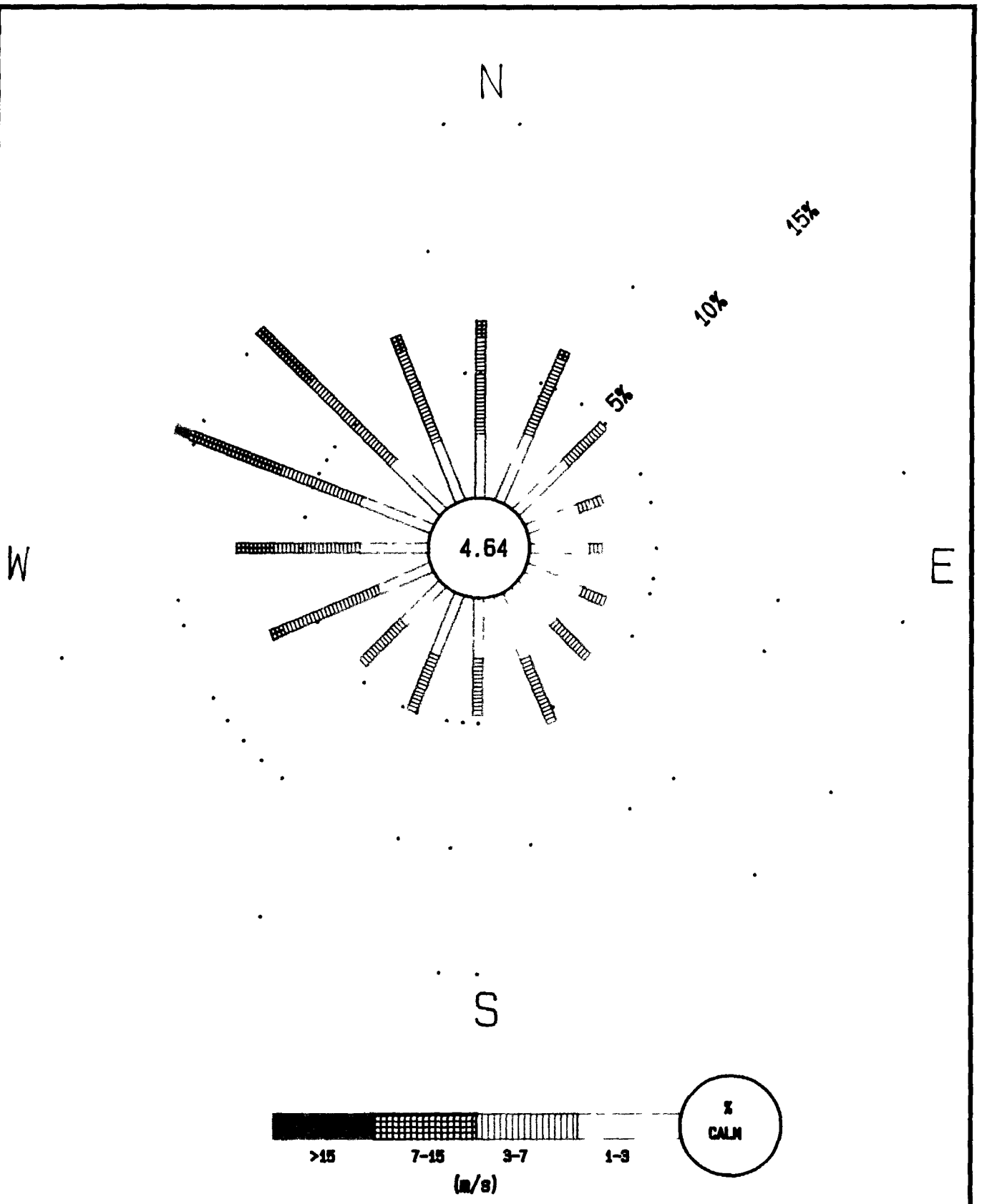
Wind Direction Frequency (Percent) by Five Wind-Speed Classes

Rocky Flats Plant

(Fifteen-Minute Averages 1990 Annual)

	Calm	1-3 (m/s)	3-7 (m/s)	7-15 (m/s)	>15 (m/s)	Total
—	4 64					4 64
N	—	2 59	3 92	0 62	0 01	7 14
NNE	—	2 91	3 25	0 30	0 01	6 47
NE	—	2 91	2 01	0 04	0 00	4 96
ENE	—	2 23	0 95	0 01	0 00	3 19
E	—	2 44	0 41	0 00	0 00	2 85
ESE	—	2 35	0 87	0 00	0 00	3 22
SE	—	2 27	2 08	0 00	0 00	4 35
SSE	—	2 71	2 77	0 08	0 00	5 56
S	—	2 47	2 20	0 15	0 00	4 82
SSW	—	2 58	2 45	0 09	0 00	5 12
SW	—	2 21	2 18	0 11	0 00	4 50
WSW	—	2 25	4 05	0 39	0 00	6 69
W	—	2 82	3 37	1 45	0 11	7 75
WNW	—	3 06	3 44	3 84	0 65	10 99
NW	—	2 88	4 68	2 98	0 15	10 69
NNW	—	2 56	3 92	0 58	0 00	7 06
TOTALS	4 64	41 25	42 54	10 64	0 93	100 00

Reference EG&G, 1992b Rocky Flats Plant Site Environmental Report for 1992



U S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	WIND ROSE FOR THE ROCKY FLATS PLANT 1990 ANNUAL	FIGURE **2-9**

BORDER CW-021992

SECTION 3
BACKGROUND SAMPLING PROGRAM

This section describes the sampling locations and data collection techniques employed during the background borehole, ground water, surface water, and sediment geochemical characterization Surface soils are not considered in this program because it is anticipated that a separate program will be developed by EG&G to characterize surficial soils in background and non-background areas of the RFP

3.1 SAMPLING LOCATIONS

The rationale for selection of background sampling sites consider a number of factors which are listed below

- Plant boundaries - all background sites in the present program are located within the 10 square mile RFP property to establish local background with respect to geology, hydrology, and weather patterns

- Avoidance of contamination - background stations are located to avoid all known IHSSs

- Geology - all key geologic materials are represented Rocky Flats Alluvium, colluvium, valley fill alluvium, and weathered and unweathered Arapahoe and Laramie Formation bedrock

- Hydrology - background sites must be upgradient or sidegradient to the central Plant area and to known IHSSs Sites must be representative of the intermittent streams present at the RFP, associated stream sediments, seep waters, and ground water Both surface and ground water locations are constrained by the limited availability of water due to the semiarid climate at the RFP

- Meteorology - background stations are located west, north, and south of the central Plant area, while the predominant direction of high winds is to the east

- Spatial coverage - an attempt was made to represent all background regions and stream drainages in the RFP buffer zone However, as noted under "hydrology," the limited availability of water has resulted in "clumping" of sites, and lack of representation for some areas

It is recognized that there is the possibility that airborne dispersion of radionuclides from the RFP may extent to background sites Possible sources of radionuclides include the 1957 and 1969 fires, and resuspended soil from the 903 Pad site However, radiation surveys at the RFP (EG&G Energy Measurements, 1982, 1990) do not indicate anomalous readings in the background areas It may be possible to use investigative techniques, such as study of isotopic ratio data, to distinguish potential radionuclide contributions from the RFP, from atmospheric fallout due to nuclear testing, and from natural sources

3.1.1 Geologic Materials/Borehole

As discussed in Section 2, two types of surficial materials occur beneath IHSSs at the RFP Many of the IHSSs are situated on Rocky Flats Alluvium (Plate 1) The second type of surficial material consists of colluvial materials that have accumulated on slopes below the Rocky Flats Alluvium Colluvium is present in the Woman Creek and Walnut Creek drainages IHSSs within these drainages are a part of OUs 5 and 6 Development of background soil data therefore required sampling of both types of materials

In addition to surficial materials, Arapahoe and Laramie Formation claystone and sandstone bedrock geochemistry were characterized for comparison to investigative samples Presented below is a discussion of borehole locations utilized for geologic materials sampled during the background investigation Boreholes were drilled and sampled in 1989 (sampling methods are discussed in Section 3 2)

3.1.1.1 Rocky Flats Alluvium Boreholes

The Rocky Flats Alluvium consists of poorly sorted boulders, cobbles, gravels, sands, silts, and clays deposited in alluvial fans at the base of the Colorado Front Range Mountains (Hurr, 1976) Eight boreholes were drilled to investigate the Rocky Flats Alluvium chemistry (wells B400089, B400289, B400389, B400489, B200589, B200689, B200789, and B200889 [Plate 3]) Boreholes were drilled in both the north buffer zone (boreholes B200589, B200689, B200789 and B200889) and south buffer zone (boreholes B400089, B400289, B400389 and B400489) to characterize the lithology, thickness, and geochemistry of the Rocky Flats Alluvium in different areas of the Plant There are no IHSSs in either of these two areas (see Section 2 and Plate 1)

3.1.1.2 Colluvial Boreholes

Colluvium at the Rocky Flats Plant collects on the sides and at the base of hills and slopes It is the product of mass wasting and downslope creep, commonly observed in and on the valley walls of the Plant buffer zones These deposits consist predominantly of clay with occurrences of sandy clay and gravel Nine boreholes were drilled to characterize the colluvium (boreholes B201089, B201189, B201289, B201489, B201589, B301889, B401989, B302089, and B405989) Boreholes B201089, B201189, B201289, B0201489, and B201589 were drilled in the north buffer zone, and boreholes B301889, B401989, B302089, and B402189 were drilled in the south buffer zone (Plate 3) to investigate spatial variation in colluvial geochemistry

3.1.1.3 Weathered Bedrock Boreholes

The bedrock units underlying the RFP is the Arapahoe Formation This formation consists predominantly of claystone with interbedded sandstone All nine of the boreholes drilled to investigate colluvial materials were extended 12 feet into weathered bedrock of the Arapahoe Formation (Plate 3) Eight boreholes were drilled and sampled in weathered claystone Borehole B402189 encountered weathered non-subcropping sandstone

3.1.2 Ground Water

Ground water at the RFP occurs in Rocky Flats Alluvium, colluvium, valley fill alluvium, and the Arapahoe and upper Laramie Formation Unconfined ground water flow occurs in surficial materials, subcropping sandstone, and surficial bedrock In addition, subcropping claystone may be saturated in some locations Confined ground water occurs in deeper, isolated sandstone hydrostratigraphic units

As can be observed on Plate 2, the background boreholes and monitoring wells in the north buffer zone are not downgradient of the West Spray Field Surface water and ground water flow into a tributary on the upper reaches of Walnut Creek Even if these sampling locations were downgradient of the West Spray Field, travel times would be 42 feet/year (4 0 x 10^{-5} centimeters per second [cm/sec]) based on a conservative hydraulic conductivity of 1 x 10^{-3} cm/sec for the Rocky Flats Alluvium, effective porosity of 0 3, and hydraulic gradient of 0 012 (80 feet/ 6,750 feet) The West Spray Field was used for spray application from April 1982 to October 1985 The sampling locations are 6,750 feet from the eastern edge of the West Spray Field, and it has been 10 years since the initial spraying, therefore, potential contamination has traveled 410 feet

3.1.2.1 Rocky Flats Alluvium Ground Water

Ground water in Rocky Flats Alluvium was investigated by installing, developing, and sampling alluvial wells in eight boreholes used for characterization of the Rocky Flats Alluvium (wells B400189, B400289, B400389, B400489, B200589, B200689, B200789, and B200889) Well 55-86 serves as the ninth background alluvial well (Plate 4) The wells were installed in two different areas of the Plant buffer zone to investigate spatial variability of alluvial ground water quality Wells 55-86, B400189, B400289, B400389, and B400489 were installed in the southwest portion of the buffer zone where there are no IHSSs (Plate 1) This area exhibits lithologies and saturated thicknesses similar to those at the West Spray Field Wells B200589, B200689, B200789, and B200889 were installed in the north buffer zone sidegradient of the Plant where there are also no IHSSs (Plate 1) This area was chosen because the lithologies and

saturated thicknesses are similar to those at the Solar Evaporation Ponds, 903 Pad, Mound, and East Trenches Areas based on a similar topographic position

One well cluster was also installed in the Rocky Flats Alluvium at the location where the greatest saturated thickness was encountered to evaluate geochemical stratification of alluvial ground water quality west of the Plant The alluvium exceeds 90 feet in depth in this area The well cluster consists of three wells constructed on the basis of the static water levels recorded in the area Well B400489 was screened over the entire saturated thickness of the Rocky Flats Alluvium (9 87 to 54 45 feet below ground surface) Well B405789, located approximately 15 feet west of B400489, was screened over the bottom 10 feet of saturated alluvium (43 01 to 52 48 feet below ground surface) Well B405689 was screened from 10 feet above to 10 feet below the water level (3 0 to 22 51 feet below ground surface)

3.1.2.2 Colluvial Ground Water

In order to characterize colluvial ground water quality, 10 wells were installed in colluvial materials They were installed in various areas of the Plant buffer zone to investigate spatial variability Wells B201089, B201189, B201289, B201489, B201589, and B205589 were installed in the north buffer, whereas wells B301889, B401989, B302089, B405989 were installed in the south buffer zone (Plate 4) There are no IHSSs in either of these areas (Plate 1)

3.1.2.3 Valley Fill Alluvial Ground Water

Characterization of valley fill ground water quality was accomplished by installing nine wells in valley fill materials (Plate 4) Wells B102289, B102389, B202489, and B202589 were installed at four locations along the Rock Creek drainage to investigate ground water quality changes along the drainage To investigate spatial variability of ground water quality between drainages, wells B402689, B302789, B302889, B302989, and B303089 were installed in the south buffer zone and completed in Woman Creek Valley fill alluvium None of the above areas have been impacted by IHSSs

3.1.2.4 Bedrock Ground Water

Data for the characterization of background bedrock ground water quality were collected by installing 21 monitor wells screened in bedrock These wells were drilled in various areas of the Plant buffer zone to investigate spatial variability of bedrock ground water quality (Plate 5)

Eleven bedrock wells were completed in the north buffer zone Five of the 11 wells (B203189, B203289, B203489, B203589, and B203689) were installed adjacent to the sidegradient northern alluvial wells and are completed in weathered claystone of the Arapahoe Formation The remaining six wells (B203789, B203889, B203989, B204089, B204189, and B204689) are completed in unweathered sandstones of the Arapahoe Formation Well B204689 was installed for this program but has since become an inactive well because a pump became lodged in the well during sampling The pump was unretrievable, and therefore, the well was sealed and is awaiting abandonment

Ten bedrock wells were installed in the south buffer zone Three of the 10 bedrock wells are completed in unweathered sandstones (B304289, B304989, and B405289), 5 wells are completed in weathered claystone (B304789, B304889, B405189, B305389, and B405489), and 2 wells (B402189 and B405889) are completed in weathered non-subcropping sandstones Well B405489 is installed in weathered claystone of the Laramie Formation

3.1.3 Surface Water

Nine surface water monitoring locations were initially selected as background stations (Plate 6 and Table 3-1) One station (SW-107) is located on the Woman Creek drainage upstream of the Plant, and three stations (SW-41, SW-80, and SW-104) are positioned within tributaries entering Woman Creek from the southwest Station SW-07 is situated in a tributary of Walnut Creek upgradient of any IHSSs (Plate 1), and stations SW-06, SW-05, SW-108, and SW-04 are located along the Rock Creek drainage Surface water stations SW-080, SW-104, and SW-108 are seeps while the rest are instream surface water stations These locations were chosen to collect an array of surface water samples that are representative of background conditions

Table 3-1

Surface Water Stations at Rocky Flats Plant

Station Number	Northing Coordinate (ft) — RFP	Easting Coordinate (ft) — RFP	State Northing Coord (ft)	State Easting Coord (ft)	Ground Surface Elev (ft)
SW004	45162 18	22668 42	75148 42	2085747 15	5721 20
SW005	40095 64	16442 91	753062 65	2079539 99	5973 00
SW006	37119 25	12275 44	750073 29	2075383 44	6129 00
SW007	35270 77	11107 42	746995 12	2074221 82	6184 70
SW041	34024 22	17138 39	748221 44	2080255 33	5980 50
SW080	33104 05	17902 55	746995 12	2081022 32	6042 10
SW104	32376 51	18188 09	746077 71	2081310 19	6062 40
SW107	34187 74	14780 90	747150 81	2077897 92	6054 30
SW108	44323 08	22971 45	757310 54	2086052 87	5838 60

See Plate 6 for station locations

Note Surface water stations SW127, SW130, SW134, SW135, SW136, and SW137 have not been surveyed yet

Six additional surface water stations have been added to the Background Geochemical Monitoring Plan since its inception in 1989 SW-127 is located in the far western part of the Plant on a tributary of Woman Creek SW-130 is located just east and downgradient of Rocky Flats Lake on Smart Ditch in the south buffer zone Surface water stations SW-134, SW-135, SW-136, and SW-137 are located on Rock Creek or unnamed tributaries of Rock Creek

Surface water stations were sampled monthly in 1989, 1990, and 1991, but are now sampled quarterly as of the first quarter of 1992

3.1.4 Stream Sediment

Background stream sediment chemistry is being evaluated by sampling nine sediment monitoring locations for subsequent chemical analyses (Plate 6 and Table 3-2) These stations are paired with nine of the background surface water stations described above Stations SED20, SED21, SED22, and SED23 are located in the Rock Creek drainage, station SED04 is located in Walnut Creek, and stations SED16, SED17, SED18, and SED19 are located in Woman Creek SED18, SED19, and SED21 are located at seeps while the rest and instream sediment stations These sites have been selected as locations representative of lithologies present in the drainages of the Plant site where impacts from management units are not anticipated

3.2 SAMPLING AND DATA COLLECTION

Starting in 1989, field sampling and data collection followed the Rocky Flats ER Program SOPs (Rockwell International, 1989c), and the ER Program QA/QC Plan (Rockwell International, 1989d) These documents have been superceded by the EMD SOPs (EG&G, 1991a), and the Rocky Flats Plant Site-Wide QAPjP (EG&G, 1991d) Presented below are brief discussions of data collection methods that were and/or are utilized for background characterization

Table 3-2

Sediment Water Stations at Rocky Flats Plant

Station Number	Northing Coordinate (ft) — RFP	Easting Coordinate (ft) — RFP	State Northing (ft)	State Easting (ft)	Ground Surface Elev (ft)
SD004	35270 77	11107 42	74822 44	2074221 82	6184 70
SD016	34187 74	14780 90	747150 81	2077897 92	6054 30
SD017	34024 23	17138 39	746995 12	2080255 33	5980 50
SD018	33110 94	17897 74	746084 58	2081017 49	6041 40
SD019	32376 51	18188 09	745351 30	2081310 19	6062 40
SD020	40107 07	16453 06	753074 11	2079550 10	5972 70
SD021	44323 08	22971 45	757310 54	2086052 87	5838 60
SD022	45167 18	22668 42	758148 42	2085747 15	5721 20
SD023	37119 25	12275 44	750073 29	2075383 44	6129 00

See Plate 6 for station locations

3.2.1 Drilling and Logging

All boreholes for soil sampling and monitor well construction were continuously sampled, as drilling permitted, and geologically logged Drilling was performed utilizing auger rigs, rotary coring rigs, and air rotary downhole percussion hammer (ODEX) rigs Hollow stem augers were used to advance the borehole through surficial materials and weathered bedrock where possible, and materials were continuously sampled through the augers with split tube samplers on a wireline

In areas where large cobbles and boulders were encountered such as the south-southwest buffer zone (wells B400189, B400289, B400389, B400489, B305389, B405489, B405689, B405789, and B405889) an air rotary downhole percussion hammer (ODEX) rig was used to advance the boring Casing was simultaneously installed in the borehole as the bit was advanced Cuttings from the borehole were circulated out of the borehole by high pressure air and collected for logging and sampling purposes in 55-gallon drums The cuttings were collected for analytical purposes in boreholes B400289, B400389, B400489, B400589

Protective surface casing was installed prior to a bedrock hole being rotary cored After a deep bedrock borehole was augured 3 to 4 feet into unweathered bedrock, augers were pulled, and 8-⅝ inch outside diameter (OD) threaded casing was lowered into the hole by an auxiliary wireline cable The casing was tremie grouted with Portland Type I and II cement The cement was given 24 hours to set before operations were continued Bedrock boreholes were then continuously cored from the base of the surface casing to total depth using water Continuous core samples were obtained using wireline and split tube samplers

All lithologic samples were described, labeled and packaged by a geologist in the field as described in the SOPs Well construction details are summarized in Table 3-3

Boreholes not completed as monitoring wells were abandoned by backfilling to within 4 to 5 feet of ground surface using Volclay grout, which was tremied downhole and subsequently topped off with Portland Type I and II cement

Table 3-3
Well Data
at
Rocky Flats Plant

Well Number	Well Status	Ground Surface Elev (ft)	Top of Casing Elev (ft)	Depth to Top of Screen	Depth to Bottom of Screen	Total Depth (ft)	Depth to Bedrock (ft)	Bedrock Elevation	Geologic Strata of Complete	Northing Coordinate (ft) - RFP	Easting Coordinate (ft) - RFP	State Northing (ft)	State Easting (ft)
B405586	1	6103 62	6105 81	3 55	36 39	36 39	35 50	6068 12	Qrf	32259 45	15217 16	745260 8365	2078321 1160
B400089	5,6	6121 80	6123 76	28 58	37 95	38 26	48 50	6073 30	Qrf	31599 94	15183 24	744565 0139	2078308 6909
B400189	1	6122 10	6124 15	10 09	49 60	51 35	49 80	6072 30	Qrf	31600 11	15183 13	744565 1830	2078308 5787
B400289	1,5	6105 90	6107 71	20 52	50 00	51 25	49 60	6056 30	Qrf	31676 84	16017 21	744644 6478	2079142 1870
B400389	1,5	6122 00	6124 00	9 50	49 00	50 30	48 50	6073 50	Qrf	30794 80	15266 77	743760 3577	2078394 8564
B400489	1,5	6105 90	6107 07	9 87	54 45	55 70	54 00	6051 90	Qrf	30852 38	16077 58	743820 5973	2079205 2666
B200589	1 5	5968 40	5970 17	11 86	31 57	33 31	30 00	5938 40	Qrf	41857 55	20445 99	754837 3135	2083536 2087
B200689	1 5	5960 10	5961 94	11 58	31 05	32 80	30 60	5929 50	Qrf	42256 66	21069 70	755238 3808	2084158 4352
B200789	1 5	5946 10	5948 08	9 07	28 50	30 47	28 00	5918 10	Qrf	42781 02	21921 46	755765 4125	2085008 2449
B200889	1,5	5936 10	5938 08	8 60	23 12	24 70	22 80	5913 30	Qrf	43199 87	22617 22	756186 4527	2085702 4430
B201089	1 5	5883 10	5885 15	3 48	7 83	9 60	7 50	5875 60	Qc	42275 09	24169 13	755267 0405	2087256 9935
B201189	1,5	5806 50	5808 41	20 36	34 80	36 50	34 00	5772 50	Qc	44655 14	23771 64	757645 1486	2086851 7585
B201289	1,5	5826 10	5827 80	14 73	23 90	26 11	23 40	5802 70	Qc	44616 73	20500 44	757595 9555	2083581 5337
B201489	1 5	5859 40	5861 20	5 58	9 96	11 64	7 00	5852 40	Qc	44092 75	22254 49	757077 9028	2085336 8530
B201589	1 5	5846 00	5847 68	4 38	8 76	10 50	8 20	5837 80	Qc	44426 56	23548 26	757415 8909	2086629 1867
B301889	1 5	5866 80	5868 83	13 16	22 60	24 45	22 30	5844 50	Qc	34321 96	22207 35	747309 5078	2085321 9781
B401989	1 5	6025 60	6027 67	6 55	21 00	22 65	20 50	6005 10	Qc	32873 07	18514 33	745848 8073	2081634 7119
B302089	1 5	5907 50	5909 55	3 85	13 30	15 00	13 50	5894 00	Qc	33804 66	20373 64	746786 2956	2083490 4539
B402189	1 5	6024 60	6026 49	13 50	22 90	24 60	7 50	6017 10	Kss(w)	33364 04	18357 65	746339 1279	2081476 4480
B102289	1	5978 30	5980 06	3 00	12 47	14 22	12 50	5965 80	Qvf	40124 54	16414 83	753091 4539	2079511 8166
B102389	1	5939 50	5941 18	3 74	10 90	12 61	10 40	5929 10	Qvf	40864 32	17161 65	753833 5008	2080256 0041
B202489	1	5770 90	5772 83	3 43	12 90	14 65	12 40	5758 50	Qvf	44414 51	20812 14	757394 8212	2083893 8232
B202589	1	5723 60	5725 45	4 53	11 60	13 40	11 20	5712 40	Qvf	45126 22	22633 57	758112 3563	2085712 4261
B402689	1	6045 40	6047 07	2 55	3 28	5 85	2 80	6042 60	Qvf	34264 35	15145 64	747228 6049	2078262 3035
B302789	1	5832 30	5834 17	4 00	8 55	10 17	8 00	5824 30	Qvf	31715 79	23104 08	744706 9744	2086227 0822
B302889	1	5730 80	5733 16	5 92	10 52	12 10	10 20	5720 60	Qvf	32824 94	26406 34	745826 7435	2089524 8098
B302989	1	5686 20	5688 15	3 46	7 90	9 65	7 40	5678 80	Qvf	32347 94	28146 31	745355 6090	2091265 9007

KEY TO STATUS 1 - Active Well, 2 - Abandoned Borehole 3 - Well Removed/Replaced 4 - Inactive Well, 5 - Borehole Sampled, 6 - Observation Well 7 - Surface Casing Installed Not Cored

KEY TO GEOLOGIC STRATA Qaf-Artificial Fill, Qrf-Rocky Flats Alluvium, Qc-Colluvium, Qvf-Valley Fill Alluvium, Qt - Terrace Alluvium, Kcl-Bedrock Weathered Claystone, Kss(u)-Bedrock Unweathered Sandstone Kss(w)-Bedrock Weathered Sandstone Kst(w) - Bedrock Weathered Siltstone AL-undifferentiated Alluvium

Table 3-3 (Continued)
Well Data
at
Rocky Flats Plant

Well Number	Well Status	Ground Surface Elev (ft)	Top of Casing Elev (ft)	Depth to Top of Screen	Depth to Bottom of Screen	Total Depth (ft)	Depth to Bedrock (ft)	Bedrock Elevation	Geologic Strata of Complete	Northing Coordinate (ft) - RFP	Easting Coordinate (ft) - RFP	State Northing (ft)	State Easting (ft)
B303089	1	5601 20	5602 93	4 61	7 00	8 90	6 60	5594 60	Qvf	29260 92	30864 52	742278 3686	2093993 5910
B203189	1	5968 00	5970 12	35 26	44 70	46 47	30 30	5937 70	Kcl	41868 42	20466 34	754848 2491	2083556 5118
B203289	1	5959 70	5961 59	35 00	44 47	46 00	30 10	5929 60	Kcl	42258 71	21087 88	755240 4851	2084176 6034
B203489	1	5945 70	5947 71	31 00	40 50	41 25	28 60	5917 10	Kcl	42806 76	21964 89	755791 2887	2085051 5736
B203589	1	5935 20	5937 07	29 70	39 16	40 94	24 30	5910 90	Kcl	43221 96	22658 39	756208 6745	2085743 5243
B203689	4	5920 50	5922 45	27 05	36 55	37 30	22 60	5897 90	Kcl	43755 65	23487 29	756744 9537	2086570 4441
B203789	1	5946 20	5948 28	134 15	138 59	140 84	26 70	5919 50	Kss(u)	42792 37	21944 19	755776 8324	2085030 9263
B203889	1	5935 80	5937 69	107 00	111 43	113 90	28 40	5907 40	Kss(u)	43211 47	22635 78	756198 1067	2085720 9611
B203989	1	5920 90	5922 78	125 97	130 42	132 70	23 70	5897 20	Kss(u)	43740 80	23469 07	756730 0555	2086552 2860
B204089	1	5877 60	5879 29	106 50	112 90	115 23	1 60	5876 00	Kss(u)	41904 59	24227 96	754896 8288	2087317 0381
B204189	1	5826 90	5828 86	81 10	95 33	97 62	3 70	5823 20	Kss(u)	42344 56	25382 07	755340 4906	2088469 3930
B304289	1	5833 00	5835 18	84 04	88 49	90 95	10 50	5822 50	Kss(u)	31688 14	23092 28	744679 3015	2086215 3718
B304789	1	5867 50	5869 56	27 90	37 57	39 14	22 90	5844 60	Kcl	34321 35	22184 13	747308 8221	2085298 7662
B304889	1	5730 60	5732 56	14 66	24 14	25 90	9 70	5720 90	Kcl	32815 29	26451 93	745817 2440	2089570 4247
B304989	1	5729 70	5731 85	75 50	82 87	86 25	8 40	5721 30	Kss(u)	32799 24	26481 33	745801 2931	2089599 8741
B405189	1	5967 90	5969 91	13 20	22 69	24 45	8 20	5959 70	Kcl	33804 20	19330 97	746782 3900	2082448 0614
B405289	1	5965 60	5967 31	41 24	45 67	48 00	10 30	5955 30	Kss(u)	33819 62	19347 76	746797 8628	2082464 7930
B305389	1	5832 00	5833 90	15 18	24 58	26 30	10 00	5822 00	Kcl	31726 76	23109 08	744717 9612	2086232 0415
B405489	1	6115 80	6117 67	39 13	48 57	50 05	34 00	6081 80	Kcl	32239 76	15235 37	745204 8392	2078358 6905
B205589	1	5806 40	5808 46	6 87	16 30	18 00	32 30	5774 10	Qc	44664 12	23775 15	757654 1441	2086855 2290
B405689	1	6105 20	6107 25	3 00	22 51	23 75	0 00	0 00	Qrf	30851 28	16062 22	743819 4561	2079189 9129
B405789	1	6104 80	6106 70	43 01	52 48	53 72	52 00	6052 80	Qrf	30853 20	16092 40	743821 4683	2079220 0762
B405889	1	6024 90	6026 87	36 04	45 50	46 75	6 50	6018 40	Kss (w)	33357 04	18357 49	746332 1311	2081476 3079
B405989	1	6023 50	6026 06	2 80	6 70	8 50	6 20	6017 30	Qc	33374 00	18357 88	746349 0917	2081476 6474

KEY TO STATUS 1 - Active Well, 2 - Abandoned Borehole 3 - Well Removed/Replaced 4 - Inactive Well, 5 - Borehole Sampled 6 - Observation Well 7 - Surface Casing Installed Not Cored

KEY TO GEOLOGIC STRATA Qaf-Artificial Fill, Qrf-Rocky Flats Alluvium, Qc-Colluvium, Qvf-Valley Fill Alluvium Qt - Terrace Alluvium, Kcl-Bedrock Weathered Claystone
Kss(u)-Bedrock Unweathered Sandstone Kss(w)-Bedrock Weathered Sandstone Kst(w) - Bedrock Weathered Siltstone, AL-undifferentiated Alluvium

3.2.2 Borehole Sampling

Sampling methods for all boreholes drilled within the background area are described in this section Borehole sample chemical analysis is discussed in Section 3 3

3.2.2.1 Rocky Flats Alluvial Boreholes

Boreholes drilled in the Rocky Flats Alluvium were sampled as follows The top 3 feet of each boring was composited for chemical analyses to characterize the Flatiron Soil Below this depth, 6-foot composites were submitted for chemical analyses to characterize the Rocky Flats Alluvium If a lithologically distinct layer greater than 2 feet in thickness was encountered, a discrete sample was collected for chemical analysis The alluvium within the interval containing the alluvium/bedrock contact was not sampled for chemical analyses unless the total alluvium thickness was less than 5 feet

Samples were collected in glass jars for radionuclides, inorganics, and metals Radionuclides and inorganics were collected in 16-ounce jars, and metals were collected in 8-ounce jars Each container was packed, labeled, and sealed by a geologist in the field Samples were not preserved in the field as defined in the ER Program QA/QC Plan (Rockwell International, 1989d)

3.2.2.2 Colluvium/Bedrock Boreholes

All colluvial boreholes were sampled from the surface to 12 feet below the bedrock contact so weathered bedrock materials could also be sampled for chemical analysis The top 3 feet of the surficial materials were composited for chemical analysis to characterize the Hillslope soil developed on the colluvium All remaining colluvial samples collected followed methods described for Rocky Flats Alluvium sampling

Bedrock contact samples as well as weathered bedrock samples were collected from each colluvium bedrock borehole The bedrock contact sample extended from the contact to 6 feet below the contact A 6-foot composite sample was also collected below this depth If a

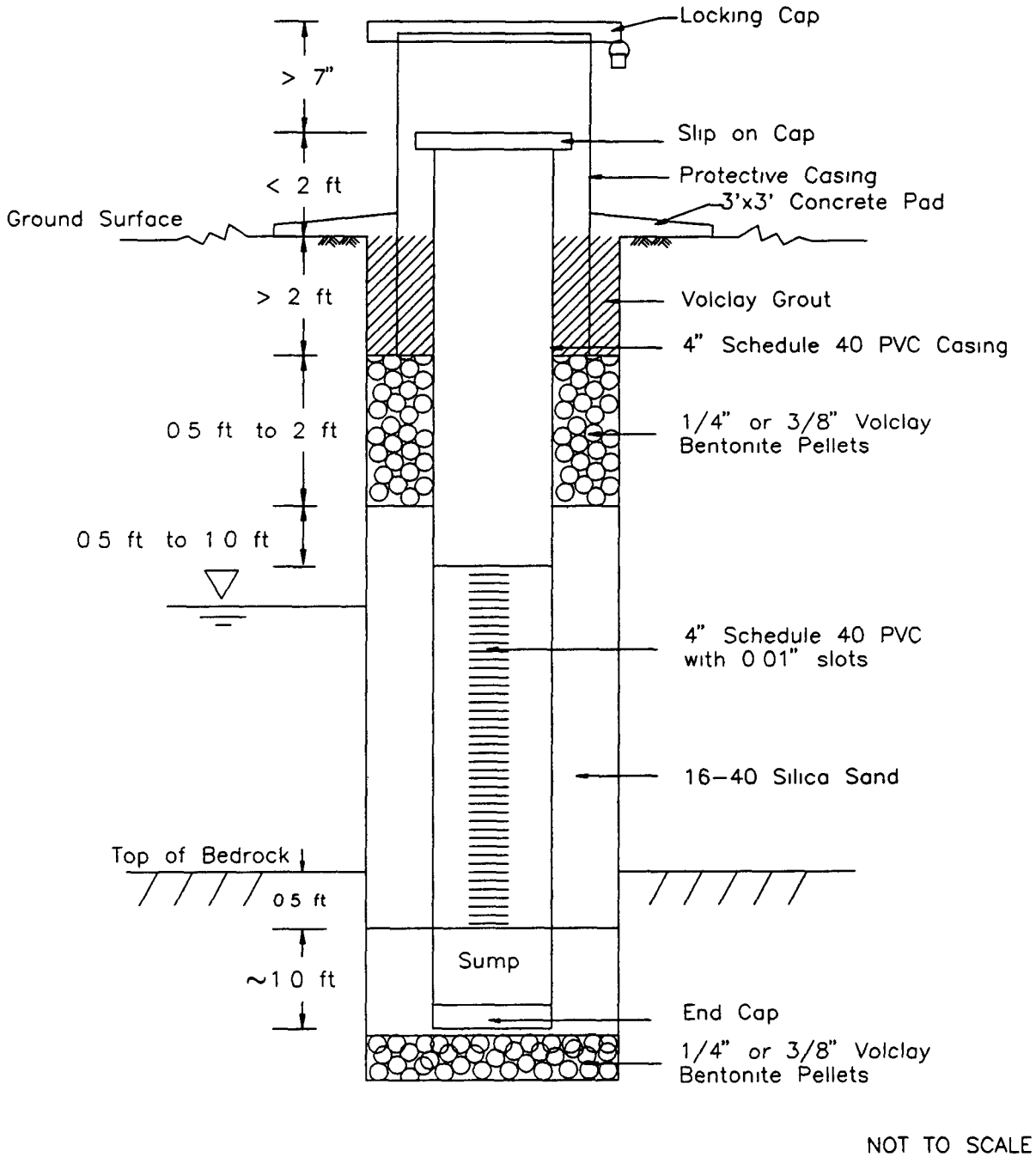
lithologically distinct unit greater than 2 feet in thickness was encountered, a discrete sample was collected Sample containers and parameters were as described for the Rocky Flats Alluvial borehole samples

3.2.3 Monitor Well Installation

All alluvial and colluvial wells were completed with 4-inch diameter, Schedule 40 PVC casing and 0 01 inch slotted Schedule 40 PVC screen with the exception of colluvial well B201289, which was completed with 2-inch Schedule 80 PVC Figure 3-1 illustrates the typical alluvial well design and annulus materials for wells completed in Rocky Flats Alluvium, colluvium, and valley fill alluvium Except for the well cluster completed in Rocky Flats Alluvium discussed previously, all background wells completed in surficial materials were screened over the entire alluvial saturated thickness The screened intervals of these wells extended from 0 5 feet below the bedrock contact to a point above the water level encountered during drilling or observed in nearby wells installed in similar materials

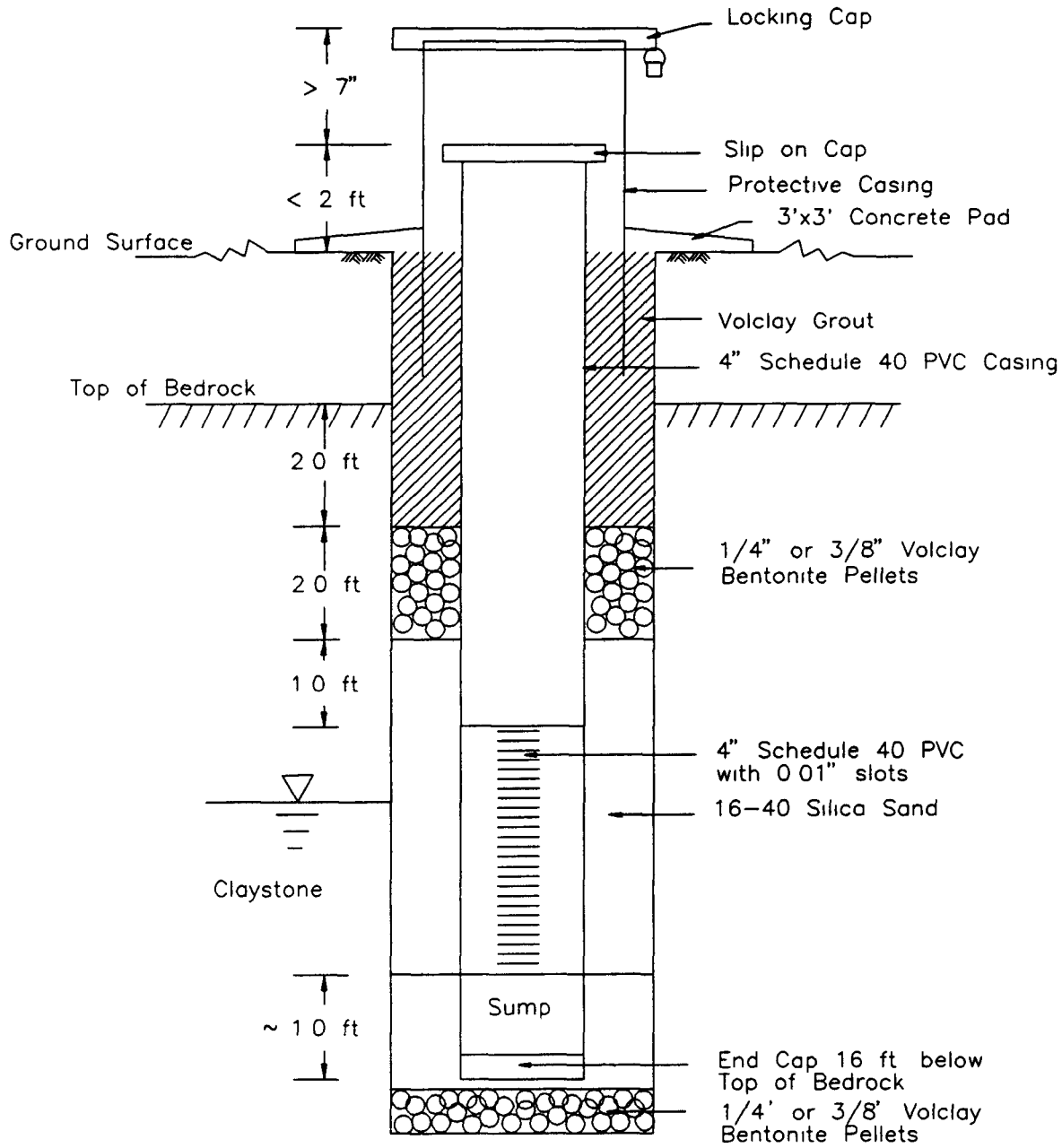
Three different types of bedrock wells were installed during the background characterization Weathered claystone, weathered sandstone, and unweathered sandstone wells were completed to monitor each lithology

Shallow, weathered claystone wells were augured to total depth and constructed in the open borehole Where hole stability was a problem, holes were reamed with large diameter augers to total depth and then the well was constructed inside the augers This occurred at wells B203189, B203489, and B203689 The remainder of the wells were built open hole, using a stainless steel centralizer for downhole stabilization The wells were screened from approximately 5 feet below the bedrock contact to 15 feet below the bedrock contact with the exception of well B203489 in which the screen began 1 4 feet below the contact due to borehole instability during well installation Figure 3-2 presents the typical weathered bedrock well design



U S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	TYPICAL ALLUVIAL MONITOR WELL CONSTRUCTION	FIGURE 3–1

R69010 MB013192



NOT TO SCALE

R69011 MB013192

U.S DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	TYPICAL SHALLOW BEDROCK WELL CONSTRUCTION (Weathered Claystone)	FIGURE 3–2

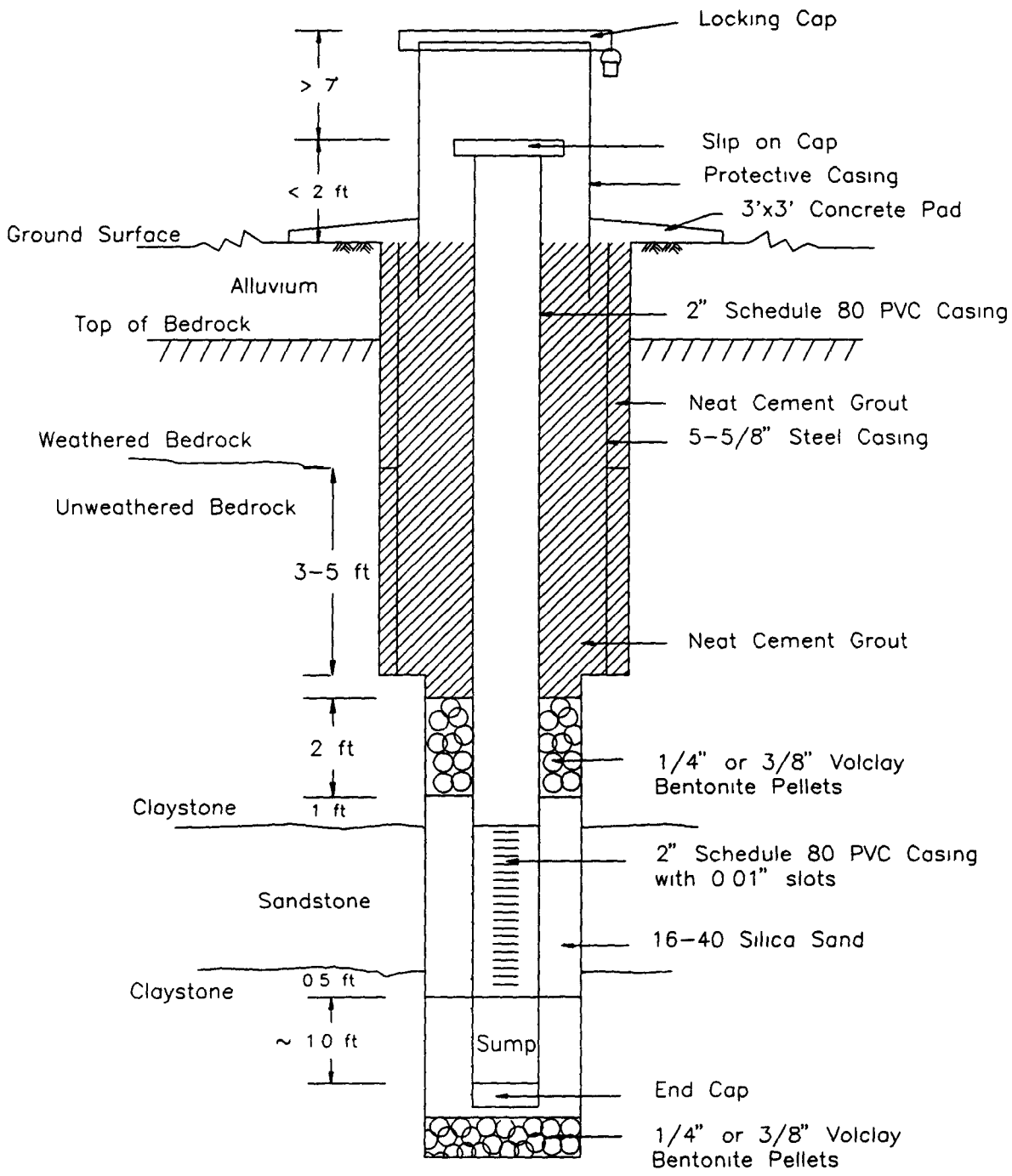
Two weathered sandstone wells were installed during this program Well B402189 was constructed to screen the upper 10 feet of a weathered sandstone encountered at 12 5 feet below ground surface, whereas well B405889 was constructed to monitor the bottom 10 feet of the same sandstone unit In both cases, hole instability warranted constructing the wells within large diameter augers or drill pipe The well construction materials used were the same as those for weathered claystone wells

The third type of bedrock well was completed in unweathered sandstone, these are referred to as deep bedrock wells Each deep bedrock boring was advanced with hollow stem augers through surficial materials into slightly weathered bedrock, and steel surface casing was subsequently installed The remainder of the hole was then rotary cored to total depth All deep bedrock wells were completed with 2-inch diameter Schedule 80 PVC and 0 01 inch slotted Schedule 80 PVC, and 2-foot sumps were placed at the base of the screen The annular materials that were used were the same as those for weathered bedrock wells, except Portland Type I cement was used instead of Volclay grout Figure 3-3 presents the typical unweathered bedrock well design

3.2.4 Well Development

All monitor wells were developed subsequent to well completion and prior to ground water sampling or hydraulic testing The purpose of development is to remove fine materials from the sand pack and the borehole wall to facilitate hydraulic communication between the screened formation and the monitor well

The well development procedures used during the background characterization field activities were consistent with those outlined in the ER Program SOPs (Rockwell International, 1989c) and EMD Standard Operating Procedures (EG&G, 1991a), with two exceptions First, the Geological Society of America Rock Color Chart was used the majority of the time in place of a turbidimeter to gauge turbidity and color of the development water Second, addition of tap water to the top of the sand pack to develop the entire filter pack was not always successful It was apparent in some instances that water added to the wells in the southwest buffer zone was



NOT TO SCALE

U S. DEPARTMENT OF ENERGY Rocky Flats Plant Golden, Colorado	TYPICAL DEEP BEDROCK MONITOR WELL CONSTRUCTION (Unweathered Sandstone)	FIGURE 3-3

R69012 MB013192

lost to the formation almost immediately Several attempts to recover the additional water were made at each location before the procedure was abandoned

3.2.5 Ground Water Sampling

Quarterly sampling of the background wells was initiated subsequent to well development beginning in the second quarter 1989 Three quarterly sampling events were completed in 1989 and four quarterly sampling events occurred in 1990 and 1991

Ground water sampling is performed in accordance with the EMD Standard Operating Procedures (EG&G, 1991a) This includes procedures for equipment decontamination, presample purging, water level measurements, field water quality measurements, sample collection, sample preservation, and sample shipping A well is considered dry if the water level is below the base of the screen prior to the pre-sample purge Chemical analyses for ground water samples are discussed in Section 3 3

Bedrock well B203689 was deleted from the background sampling program because the water level in B203689 corresponded with that of nearby alluvial well B200889 This well is still being sampled, but will not be included in the statistical analysis of background conditions It was believed that both water levels were that of surficial material water bearing zones, and B203689 sampling would not be representative of bedrock ground water chemistry

Procedures initiated during the fourth quarter 1989 for background ground water sampling deviated slightly from second and third quarters Each well was approached for 5 days or until the entire sample was collected If a suite of samples was not finished within the 5-day approach, procedures remained consistent with previous quarters

Prior to presample purging of each well, a water level measurement is obtained and recorded on the water level data sheet This level is measured from the mark present on the north side of the surface casing of each well

3.2.6 Surface Water Sampling

Surface water samples are now collected from 15 background stations Nine locations were used to collect surface water samples starting in first quarter 1989 (SW004, SW005, SW006, SW007, SW041, SW080, SW104, SW107, and SW108) Surface water stations SW127 and SW130 were used as background locations starting in 1990 Surface water stations SW134, SW135, SW136, SW137 will be part of the background program starting in first quarter 1992 Chemical analyses of background surface water samples are discussed in Section 3 3

Stream flow measurements are taken at each sampling location The flow measurements are made as described in the SOP-Discharge Measurement (EG&G, 1991a, Volume IV, Procedure SW 6)

3.2.7 Stream Sediment Sampling

Stream sediment samples are collected from each of the background surface water sampling locations Samples are collected at one point in the stream if the channel width is less than 5 feet If the channel width is greater than 5 feet, but less than 10 feet, two samples are collected within the channel at locations 33% and 67% of the width in from the channel boundary If the width of the channel is greater than 10 feet, but less than 20 feet, three samples are obtained within the channel at locations 25%, 50%, and 75% of the width in from the channel boundary Chemical analyses for the background sediment samples are discussed in Section 3 3 Collection of these samples is consistent with the procedures outlined in the EMD Standard Operating Procedures (EG&G, 1991a, Volume IV, Procedure SW 6)

3.3 CHEMICAL ANALYSES

3.3.1 Analytical Parameters

Ground water, surface water, sediment, and geologic materials are being analyzed for an extensive list of parameters in order to provide data for investigations, and a complete geochemical characterization The Chemical Analyte Roster (CAR) is presented in Table 3-4,

TABLE 3-4 (Continued)

Background Sediment, Borehole, Surface Water, and Ground Water Sampling Parameters

TOTAL RADIONUCLIDES

Sediment and Boreholes

- Gross Alpha
- Gross Beta
- Uranium -233,234,235, and 238
- Americium -241
- Plutonium -239,240
- Tritium
- Strontium -89,90
- Cesium -137
- Radium -226, 288
- Rad Screen

ANIONS

Ground Water and Surface Water

- Carbonate
- Bicarbonate
- Chloride
- Sulfate
- Nitrate as N
- Cyanide
- Fluoride
- Bromide
- Silica (as Si or SiO_2)
- Ammonium
- Orthophosphate

DISSOLVED RADIONUCLIDES[a]

Ground Water and Surface Water

- Gross Alpha
- Gross Beta
- Uranium -233&234,235, and 238
- Americium -241
- Plutonium -239&240 (surface water only)
- Strontium -89,90
- Cesium 137
- Radium 226,228[b]

TOTAL RADIONUCLIDES[a]

Surface Water

- Gross Alpha
- Gross Beta
- Uranium -233&234,235, and 238
- Plutonium -239&240
- Americium -241
- Cesium -137
- Strontium -89,90
- Radium -226,228[b]
- Tritium

Ground Water

- Plutonium -239&240
- Americium -241
- Tritium

TABLE 3-4 (Continued)

Background Sediment, Borehole, Surface Water, and Ground Water Sampling Parameters

ORGANICS VOLATILES[c]

Target Compound List -
Ground Water and Surface Water

- Chloromethane
- Bromomethane
- Vinyl Chloride
- Chloroethane
- Methylene Chloride
- Acetone
- Carbon Disulfide
- 1,1-Dichloroethene
- 1 1-Dichloroethane
- 1,2-Dichloroethene
- Chloroform
- 1,2-Dichloroethane
- 2-Butanone
- 1 1,1-Trichloroethane
- Carbon Tetrachloride
- Vinyl Acetate
- Bromodichloromethane
- 1,1,2,2-Tetrachloroethane
- 1,2-Dichloropropane
- trans-1,3-Dichloropropene
- Trichloroethene
- Dibromochloromethane
- 1,1,2-Trichloroethane
- Benzene
- cis-1,3-Dichloropropene
- Bromoform
- 2-Hexanone
- 4-Methyl-2-pentanone
- Tetrachloroethene
- Toluene
- Chlorobenzene
- Ethyl Benzene
- Styrene
- Total Xylenes
- Oil and Grease (surface water only)

ORGANICS SEMI-VOLATILES[c]

Target Compound List -

- Phenol
- bis(2-Chloroethyl)ether
- 2-Chlorophenol
- 1,3-Dichlorobenzene
- 1,4-Dichlorobenzene
- Benzyl Alcohol
- 1,2-Dichlorobenzene
- 2-Methylphenol
- bis(2-Chloroisopropyl)ether
- 4-Methylphenol
- N-Nitroso-Dipropylamine
- Hexachloroethane
- Nitrobenzene

ORGANICS SEMI-VOLATILES[c] (continued)

Target Compound List -

- Isophorone
- 2-Nitrophenol
- 2,4-Dimethylphenol
- Benzoic Acid
- bis(2-Chloroethoxy)methane
- 2,4-Dichlorophenol
- 1,2,4-Trichlorobenzene
- Naphthalene
- 4-Chloroaniline
- Hexachlorobutadiene
- 4-Chloro-3-methylphenol(para-chloro-meta-cresol)
- 2-Methylnaphthalene
- Hexachlorocyclopentadiene
- 2,4 6-Trichlorophenol
- 2,4,5-Trichlorophenol
- 2 Chloronaphthalene
- 2-Nitroaniline
- Dimethylphthalate
- Acenaphthylene
- 3-Nitroaniline
- Acenaphthene
- 2,4-Dinitrophenol
- 4-Nitrophenol
- Dibenzofuran
- 2,4-Dinitrotoluene
- 2,6-Dinitrotoluene
- Diethylphthalate
- 4-Chlorophenyl Phenyl ether
- Fluorene
- 4-Nitroaniline
- 4,6-Dinitro-2-methylphenol
- N-nitrosodiphenylamine
- 4-Bromophenyl Phenyl ether
- Hexachlorobenzene
- Pentachlorophenol
- Phenanthrene
- Anthracene
- Di-n-butylphthalate
- Fluoranthene
- Pyrene
- Butyl Benzylphthalate
- 3 3 -Dichlorobenzidine
- Benzo(a)anthracene
- bis(2-ethylhexyl)phthalate
- Chrysene
- Di-n-octyl Phthalate
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Benzo(a)pyrene
- Indeno(1,2,3-cd)pyrene
- Dibenz(a,h)anthracene
- Benzo(g h,i)perylene

TABLE 3-4 (Continued)

Background Sediment, Borehole, Surface Water, and Ground Water Sampling Parameters

ORGANICS PESTICIDES/PCBs[c]

Target Compound List -

Surface Water

- alpha-BHC
- beta-BHC
- delta-BHC
- gamma-BHC (Lindane)
- Heptachlor
- Aldrin
- Heptachlor Epoxide
- Endosulfan I
- Dieldrin
- 4,4'-DDE
- Endrin
- Endosulfan II
- 4,4'-DDD
- Endosulfan Sulfate
- 4,4'-DDT
- Endrin Ketone
- Methoxychlor
- alpha-Chlordane
- gamma-Chlordane
- Toxaphene
- AROCLOR-1016
- AROCLOR-1221
- AROCLOR-1232
- AROCLOR-1242
- AROCLOR-1248
- AROCLOR-1254
- AROCLOR-1260
- Chlordane
- Endrin Aldehyde

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[a] Samples for total radionuclides for ground water will be collected if sufficient water can be evacuated from the well to fill the appropriate containers

[b] Decision tree If Gross Alpha is $\geq$ 5 pCi/ℓ, the sample will be analyzed for Radium-226,228

[c] Volatiles, Semi-volatiles and Pesticide/PCB samples have been collected since 1991

and the rationale for the CAR is discussed in the following paragraphs All parameters on the CAR are analyzed in accordance with the General Radiochemistry and Routine Analytical Services Protocol (GRRASP) (EG&G, 1991e)

3.3.1.1 Radionuclides and Metals

Radionuclides and metals are included on the CAR because Plant records indicate historical releases, and radionuclides and metals have been detected in surface water, ground water, soil boring and sediment samples at the Plant site Radionuclides known to have been released include plutonium, americium, uranium, and tritium Radium is on the CAR because it is a daughter isotope of uranium decay, strontium ^{90} and cesium^{-137} are included because they are fission products Although there is no evidence of a criticality at the RFP, they have been included for completeness and because they exist in the environment as a result of nuclear testing fall out The CLP Target Analyte List (TAL) represent the CAR for metals The TAL is used by the EPA to investigate contamination at abandoned hazardous waste sites, and has been used for characterization of operable units at the RFP Also, the TAL contains several major cations, the data for which is necessary for an adequate geochemical characterization Five non-TAL metals (molybdenum, strontium, cesium, lithium, and tin) are also included on the CAR because they are known to have been released and/or provide a more comprehensive geochemical characterization

3.3.1.2 Other Inorganics and Anions

The other inorganics and anions (see Table 3-4) are on the CAR primarily because they are needed for a complete geochemical characterization Also, high total dissolved solids and nitrate are known to be present in ground water at some of the IHSSs

3.3.1.3 Indicators and Field Parameters

Indicators and field parameters are included on the CAR because they are needed for a complete geochemical characterization and provide useful tools to assess the quality of other chemical analyses

3.3.1.4 Organics

CLP Target Compound List (TCL) organics have been analyzed for the background program in surface water and ground water samples since first quarter 1990 They were not initially analyzed because their presence in background areas of the plant is not likely They have now been included on the CAR for completeness to assure that background data are not influenced by presently unknown IHSSs

3.3.2 Data Quality

3.3.2.1 Analytical Methods

Analytical methods and support levels must be evaluated during the development of site-specific data quality objectives The parameters for which the analytical method are valid, its limitations, and any special considerations that will affect data quality must be understood in order to select appropriate analytical methods for specific uses

The analytical options available to support data collection activities are presented in five general levels (EPA, 1987) These levels are distinguished by the types of technology and documentation used, and their degree of sophistication and were defined in Section 1 4 3 3 of this document

Chemical data derived from the background sampling and analysis program will be used, in part, to evaluate human health risks posed by contamination at operable units Toxicological interpretation of soil chemistry requires validation of analytical data Only LEVEL V and

LEVEL IV analytical reports provide sufficient documentation to allow for data validation Although LEVEL III analytical procedures are similar to LEVEL IV, the documentation provided is not sufficient for data validation, therefore, samples collected as part of this plan will be subjected to LEVEL IV analytical procedures and reporting requirements (TCL and TAL) Other analyses conform to LEVEL III because they are non-CLP analytes All chemical analyses will be performed in accordance with the General Radiochemistry and Routine Analytical Services Protocol (EG&G, 1991e)

3.3.2.2 Detection Limits

In this section, a comparison is made between analytical detection limits for the CAR and the concentration of each analyte which will pose a marginally acceptable health risk This concentration is referred to as an acceptable exposure limit (EL) and is given in milligrams per kilogram for soil and micrograms per liter for water ELs have been calculated for the radionuclides, metals (cadmium, nickel, chromium, beryllium, and mercury), TCL volatiles, and several TCL semivolatiles and pesticides/PCBs that have detected at the RFP The CDH Rocky Flats Health Advisory Panel identified the metals as having the highest potential of being released by the Plant, and are the most toxic (CDH, 1991)[1] Most of these compounds are recognized as having chronic or carcinogenic health effects in humans (i e , an Oral Reference Dose [RfD] or a Carcinogenic Slope Factor [CSF] exists for the substance) If detection limits are adequate for these compounds, they should be adequate for other less toxic metals and chemicals RfDs and CSFs were taken from the Integrated Risk Information System (IRIS) and/or Health Effects Assessment Summary Tables (HEAST) (EPA, 1991a) ELs have been conservatively calculated using exposure scenarios for a future on-site resident Detection limits for analytes are specified in the GRRASP (EG&G, 1991e) The purpose of this exercise is to identify those analytes which may require special analytical procedures to achieve detection limits equal to or less than a calculated EL

[1]Lead was also identified by the Advisory Panel but the element does not have a RfD of CSF

ELs have been compiled based on non-carcinogenic (systemic) and/or carcinogenic properties of the contaminants The basic difference in methodology for assessing non-carcinogenic and carcinogenic risk is the assumption that non-carcinogenic health effects are threshold events, whereas carcinogenic risk is a cumulative effect For non-carcinogens, threshold level intake must be exceeded before potential adverse health effects are expected

The potential for non-carcinogenic health effects are quantified by comparing the daily intake (DI) to a RfD as shown below

$$\text{Non-cancer Hazard Quotient (HQ)} = DI/RfD \quad (1)$$

Where

DI = daily intake (mg/kg-day)

RfD = reference dose (mg/kg-day)

Non-carcinogenic risks from multiple contaminants are conservatively assumed to be additive A noncancer hazard index (HI) is computed by summing HQs for each contaminant

$$HI = DI_1/RfD_1 + DI_2/RfD_2 + \quad DI_i/RfD_i \quad (2)$$

A HI less than 1 implies there will not be systemic health effects from exposure to the contaminants Therefore, for each contaminant, the HQ has been set at 0 1 in computation of the EL to allow for the additive effects of other contaminants

Calculated carcinogenic risks estimate the increased likelihood of an individual contracting cancer during his/her lifetime due to contaminant exposure Carcinogenic risks from multiple contaminants are also assumed to be additive

$$\text{Risk} = CDI \times CSF \quad (3)$$

Where

CDI = Chronic Daily Intake (mg/kg-day) or (pCi)

CSF = Carcinogenic Slope Factor $(mg/kg\text{-}day)^{1}$ or $(pCi)^{-1}$

For each contaminant, the risk has been set at 10^{6} in computation of the EL to allow for the additive effects of the other contaminants This would result in the cumulative risk from all site carcinogens in the range of 10^{-4} to 10^{-6}, which is the target risk range for remediation of the site

The following equation is used to estimate the intake (CDI or DI) resulting from non-radioactive contaminant ingestion

$$\text{Intake (mass contaminant/body mass/time)} = \frac{EL \times IR \times ED \times EF}{BW \times AT} \quad (4)$$

Where

EL	=	Concentration in soil (mass contaminant/mass soil) or water (mass contaminant/volume water)
IR	=	Ingestion Rate (mass soil/time) or volume water/time)
BW	=	Body Weight (mass)
ED	=	Exposure Duration (time)
AT	=	Averaging Time (time)
EF	=	Exposure frequency (unitless)

The following equation is used to estimate the intake (CDI or DI) resulting from radionuclide contaminant ingestion

$$\text{Intake (Mass Contaminant)} = EL \times IR \times ED \times EF \quad (5)$$

Where

EL	=	Concentration in soil (activity/mass soil) or water (activity/volume water)

From these equations, (1) and (4), (3) and (4), or (3) and (5) the EL is calculated using the pre-selected values for HQ and Risk These resulting equations and the parameters used for

calculating the ELs for soil and water, are presented in Tables 3-5 through 3-7 Reference doses and carcinogenic slope factors used in the calculations are provided in Table 3-8

Tables 3-9 and 3-10 compare ELs calculated for soil and water to the detection limits specified by the GRRASP A review of Table 3-9 reveals that, with the exception of beryllium, benzo(b)fluoranthene, benzo(a)pyrene, and Arochlor 1254, the GRRASP-specified detection limits are lower than calculated ELs The detection limit for these compounds exceed the carcinogenic ELs by less than a factor of 6, and does not seriously compromise the risk assessment objectives, i e , the detection limit equates to less than a $6x10^{-6}$ cancer risk, which is well within the acceptable risk range (10^{-4} to 10^{-6}) for remediation Review of Table 3-10 reveals that most of the metals, one-third of the volatile organics, and several of the semivolatile organics and pesticides/PCBs detection limits exceed their respective ELs With the exception beryllium, the detection limits exceed the non-carcinogenic EL for the metals by less than an order of magnitude In these cases, the detection limits represent an HQ of less than 1 (still acceptable) The beryllium detection limit exceeds the carcinogenic EL by a factor of approximately 500 This represents a compromise to the program objectives, however, lower detection limits are difficult to achieve With respect to the organics, most of the detection limit exceedances are relative to the carcinogenic EL, and the exceedance is approximately one order of magnitude Therefore, the detection limits represent a cancer risk of approximately 10^{-5}, which is within the acceptable range (10^{-4} to 10^{-6}) The detection limits exceed the non-carcinogenic ELs for carbon tetrachloride, trans-1,3-dichloropropene (t-1,3-DCP), and cis-1,3-dichloropropene (c-1,3-DCP) by more than an order of magnitude (HQ > 1) An order of magnitude decrease in detection limit can be achieved using the CLP gas chromatography (GC)/electron capture detector method for carbon tetrachloride (GC/mass spectrometry [GC/MS] methods are specified in the GRRASP) Use of the GC method for this compound is not proposed because it is not expected to be present in background surface water or ground water However, adoption of this method may be prudent to demonstrate compliance with cleanup goals at an OU Both t-1,3-DPC and c-1,3-DCP co-elute with other organics using the GC methodology, and therefore, the GC/MS method must be used

Table 3-5

Exposure Limit Calculations For Noncarcinogenic Chemicals

$$EL = \frac{RfD \times HQ \times BW \times AT}{IR \times CF \times ED \times EF}$$

EL	=	exposure limit for soil (mg/kg) or water (mg/ℓ)
RfD	=	oral reference dose (mg/kg-day)
HQ	=	hazard quotient (unitless)
	=	0 1
BW	=	body weight (kg)
	=	70 kg (adult), 15 kg (child)
AT	=	averaging time (period over which exposure is averaged)
	=	ED × 365 days/year
IR	=	ingestion rate
	=	120 mg/day (soil), 2ℓ/day (water)
CF	=	conversion factor (1E-6 kg/mg for soil, 1 for water)
ED	=	exposure duration (years)
	=	30 years (6 years as a child, 24 years as an adult)
EF	=	exposure frequency (days/year)
	=	350 days/year

Table 3-6

Exposure Limit Calculations for Carcinogenic Chemicals

$$EL = \frac{RISK \times BW \times AT}{IR \times CF \times ED \times EF \times CSF}$$

EL	=	exposure limit for soil (mg/kg) or water (mg/ℓ)
RISK	=	1E-6
BW	=	body weight (kg)
	=	70 kg (adult), 15 kg (child)
AT	=	averaging time (period over which exposure is averaged)
	=	70 years × 365 days/year
IR	=	ingestion rate
	=	120 mg/day (soil), 2ℓ/day (water)
CF	=	conversion factor (1E-6 kg/mg for soil), 1 for water
ED	=	exposure duration (years)
	=	30 years (6 years as a child, 24 years as an adult)
EF	=	exposure frequency (days/year)
	=	350 days/year
CSF	=	carcinogenic slope factor (kg-day/mg)

Table 3-7

Exposure Limit Calculations for Radionuclides

$$EL = \frac{RISK}{CSF \times IR \times ED \times EF \times CF}$$

EL	=	exposure limit for soil (pCi/g) or water (pCi/ℓ)
Risk	=	1E-6
CSF	=	carcinogenic slope factor (pCi) [1]
IR	=	ingestion rate 120 mg/day (soil), 2ℓ/day (water)
ED	=	exposure duration (years)
	=	30 years
EF	=	exposure frequency (day/year) 350 days/year
CF	=	conversion factor (10^{-3} g/mg for soil), 1 for water

Table 3-8

Toxicity Values Used to Compute Exposure Limits for Soils and Water

Substance	Chronic Oral RfD (mg/kg-day)	Oral Carcinogenic Slope Factor (kg-day/mg)	Relative Potency
Radionuclides			
U^{233}	NA	1 4E-10	NA
U^{234}	NA	1 4E-10	NA
U^{235}	NA	1 3E-10	NA
U^{238}	NA	1 3E-10	NA
Sr^{89}	NA	3 0E-12	NA
Sr^{90}	NA	3 3E-11	NA
Pu^{239}	NA	3 1E-10	NA
Pu^{240}	NA	3 1E-10	NA
Am^{241}	NA	3 1E-10	NA
Cs^{137}	NA	2 8E-11	NA
H^{3}	NA	5 5E-14	NA
Ra^{226}	NA	1 2E-10	NA
Ra^{228}	NA	1 0E-10	NA
Metals			
Beryllium	5 0E-3	4 3	NA
Cadmium	1E-3	NA	NA
Chromium	5E-3	NA	NA
Mercury	3E-4	NA	NA
Nickel	2E-2	NA	NA
Organics - Volatile			
Chloromethane	NA	1 3 E-2	NA
Bromomethane	1 4 E-3	NA	NA
Vinyl Chloride	NA	1 9 E0	NA
Chloroethane	NA	NA	NA
Methylene Chloride	6 E-2	7 5 E-3	NA
Acetone	1 E-1	NA	NA
Carbon Disulfide	1 E-1	NA	NA
1,1-Dichloroethene	NA	NA	NA
1,1-Dichloroethane	1 E-1	NA	NA

Table 3-8 (Continued)

Toxicity Values Used to Compute Exposure Limits for Soils and Water

Substance	Chronic Oral RfD (mg/kg-day)	Oral Carcinogenic Slope Factor (kg-day/mg)	Relative Potency
Organics – Volatile (continued)			
1,2-Dichloroethene	NA	NA	NA
Chloroform	1 E-2	6 1 E-3	NA
1,2-Dichloroethane	NA	9 1 E-2	NA
2-Butanone	NA	NA	NA
1,1,1-Trichloroethane	9 E-2	NA	NA
Carbon Tetrachloride	7 E-4	1 3 E-1	NA
Vinyl Acetate	1 E0	NA	NA
Bromodichloromethane	2 E-2	1 3 E-1	NA
1,1,2,2-Tetrachloroethane	NA	2 0 E-1	NA
1,2-Dichloropropane	NA	6 8 E-2	NA
trans-1,3-Dichloropropene	3 E-4	1 3 E-1	NA
Trichloroethene	NA	1 1 E-2	NA
Dibromochloromethane	2 E-2	8 4 E-2	NA
1,1,2-Trichloroethane	4 E-3	5 7 E-2	NA
Benzene	NA	2 9 E-2	NA
cis-1,3-Dichloropropene	3 E-4	2 12	NA
Bromoform	2 E-2	7 9 E-3	NA
2-Hexanone	NA	NA	NA
4-Methyl-2-pentanone	NA	NA	NA
Tetrachloroethene	NA	NA	NA
Toluene	2 E-1	NA	NA
Chlorobenzene	2 E-2	NA	NA
Ethyl Benzene	1 E-1	NA	NA
Styrene	2 E-1	3 0 E-2	NA
Total Xylenes	2 E0	NA	NA
Semivolatiles			
Diethylphthalate	8E-1	NA	NA
Acenaphthene	6E-2	NA	NA
Fluorene	4E-2	NA	NA
N-Nitrosodiphenylamine	NA	1 4E-3	NA

Table 3-8 (Continued)

Toxicity Values Used to Compute Exposure Limits for Soils and Water

Substance	Chronic Oral RfD (mg/kg-day)	Oral Carcinogenic Slope Factor (kg-day/mg)	Relative Potency
Semivolatiles (continued)			
Anthracene	3E-1	11 5[a]	0 01
Pyrene	3E-2	NA	NA
Benzo(a)Anthracene	NA	11 5[a]	0 01
Bis(2-Ethylhexyl)Phthalate	2E-2	1 4E-2	NA
Chrysene	NA	11 5[a]	0 01
Benzo(b)Fluoranthene	NA	11 5[a]	1 0
Benzo(k)Fluoranthene	NA	11 5[a]	0 01
Benzo(a)Pyrene	NA	11 5	1 0
Indeno(1,2,3-cd)Pyrene	NA	11 5[a]	0 01
Benzo(g,h,i)Perylene	NA	11 5[a]	0 01
Pesticides/PCBs			
Arochlor 1254	NA	7 7	NA
Beta-BHC	NA	1 8	NA

NA Not available
a The carcinogenic slope factor value for Benzo(a)pyrene has been used for all B2 polycyclic aromatic hydrocarbons (PAHs)

Table 3-9

Exposure Limits for Soil/Geologic Materials

Substance	EL Noncarcinogenic	EL Carcinogenic	Detect Limit
Radionuclides	(pCi/g)	(pCi/g)	(pCi/g)
U^{233}	NA	5 64	0 3
U^{234}	NA	5 64	0 3
U^{235}	NA	6 08	0 3
U^{238}	NA	6 08	0 3
Sr^{89}	NA	263	1 0
Sr^{90}	NA	23 9	1 0
Pu^{239}	NA	2 55	0 3
Pu^{240}	NA	0 09	0 03
Am^{241}	NA	2 55	0 3
Cs^{137}	NA	28 2	0 1
H^{3}	NA	14,363	400
Ra^{226}	NA	6 58	0 5
Ra^{228}	NA	7 9	0 5
Metals	(mg/kg)	(mg/kg)	(mg/kg)
Beryllium	35 4	0 17	**1 0***
Cadmium	7 1	NA	1
Chromium	35 4	NA	2
Mercury	2 1	NA	0 2
Nickel	142	NA	8
Organics - Volatile	(µg/kg)	(µg/kg)	(µg/kg)
Chloromethane	NA	57,700	10
Bromomethane	9,900	NA	10
Vinyl Chloride	NA	400	10
Chloroethane	NA	NA	10
Methylene Chloride	425,000	100,000	5
Acetone	708,000	NA	10
Carbon Disulfide	708,000	NA	5
1,1-Dichloroethene	NA	NA	10
1,1-Dichloroethane	708,000	NA	5
1,2-Dichloroethene	NA	NA	5

Table 3-9 (Continued)

Exposure Limits for Soil/Geologic Materials

Substance	EL Noncarcinogenic	EL Carcinogenic	Detect Limit
Organics - Volatile (continued)			
Chloroform	70,800	123,000	5
1,2-Dichloroethane	NA	8,240	5
2-Butanone	NA	NA	10
1,1,1-Trichloroethane	637,000	NA	5
Carbon Tetrachloride	4,900	5,770	5
Vinyl Acetate	7,080,000	NA	10
Bromodichloromethane	142,000	5,770	5
1,1,2,2-Tetrachloroethane	NA	3,750	5
1,2-Dichloropropane	NA	11,000	5
trans-1,3-Dichloropropene	2,100	5,770	5
Trichloroethene	NA	68,200	5
Dibromochloromethane	142	8,930	5
1,1,2-Trichloroethane	28,000	13,200	5
Benzene	NA	25,900	5
cis-1,3-Dichloropropene	2,100	NA	5
Bromoform	142,000	94,900	5
2-Hexanone	NA	NA	10
4-Methyl-2-pentanone	NA	NA	10
Tetrachloroethene	NA	NA	5
Toluene	1,416,000	NA	5
Chlorobenzene	142,000	NA	5
Ethyl Benzene	708,000	NA	5
Styrene	1,416,000	25,000	5
Total Xylenes	14,160,000	NA	5
Semivolatiles			
Diethylphthalate	5,664,000	NA	330
Acenaphthene	425,000	NA	330
Fluorene	2,832,000	NA	330
N-Nitrosodiphenylamine	NA	536,000	330
Anthracene	2,124,000	7,000	330

Table 3-9 (Continued)

Exposure Limits for Soil/Geologic Materials

Substance	EL Noncarcinogenic	EL Carcinogenic	Detect Limit
Pyrene	212,000	NA	330
Benzo(a)Anthracene	NA	7,000	330
Bis(2-Ethylhexyl)Phthalate	142,000	53,600	330
Chrysene	NA	7,000	330
Benzo(b)Fluoranthene	NA	70	**330***
Benzo(k)Fluoranthene	NA	7,000	330
Benzo(a)Pyrene	NA	70	**330***
Indeno(1,2,3-cd)Pyrene	NA	7,000	330
Benzo(g,h,i)Perylene	NA	7,000	330
Pesticides/PCBs			
Archlor 1254	NA	105	160
Beta-BHC	NA	441	8

NA Not Available

* Detection limits exceed ELs

Table 3-10

Exposure Limits for Water

Substance	EL Noncarcinogenic	EL Carcinogenic	Detection Limit
Radionuclides	(pCi/ℓ)	(pCi/ℓ)	(pCi/ℓ)
U^{233}	NA	343	0 6
U^{234}	NA	343	0 6
U^{235}	NA	369	0 6
U^{238}	NA	369	0 6
Sr^{89}	NA	16,000	1 0
Sr^{90}	NA	1,455	1 0
Pu^{239}	NA	1,548	0 01
Pu^{240}	NA	5 71	0 01
Am^{241}	NA	154 8	0 1
Cs^{137}	NA	1714	1 0
H^{3}	NA	872,000	400
Ra^{226}	NA	400	0 5
Ra^{228}	NA	480	0 5
Metals	(μg/ℓ)	(μg/ℓ)	(μg/ℓ)
Beryllium	3 2	0 011	**5***
Cadmium	0 63	NA	**5***
Chromium	3 2	NA	**10***
Mercury	0 19	NA	0 2
Nickel	12 6	NA	**40***
Organics - Volatile	(μg/ℓ)	(μg/ℓ)	(μg/ℓ)
Chloromethane	NA	3 8	10
Bromomethane	0 9	NA	**10***
Vinyl Chloride	NA	0 026	**10***
Chloroethane	NA	NA	10
Methylene Chloride	37 8	6 5	5
Acetone	63	NA	10
Carbon Disulfide	63	NA	5
1,1-Dichloroethene	NA	NA	5
1,1-Dichloroethane	63	8 0	5
1,2-Dichloroethene	NA	0 54	**5***

Table 3-10 (Continued)

Exposure Limits for Water

Substance	EL Noncarcinogenic	EL Carcinogenic	Detection Limit
Organics – Volatile (continued)			
Chloroform	6 3	8 0	5
1,2-Dichloroethane	NA	0 54	5*
2-Butanone	NA	NA	10
1,1,1-Trichloroethane	56 7	NA	5*
Carbon Tetrachloride	0 44	0 38	5*
Vinyl Acetate	630	NA	10
Bromodichloromethane	12 6	0 38	5*
1,1,2,2-Tetrachloroethane	NA	0 25	5*
1,2-Dichloropropane	NA	0 72	5*
trans-1,3-Dichloropropene	0 19	0 38	5*
Trichloroethene	NA	4 5	5*
Dibromochloromethane	12 6	0 58	5*
1,1,2-Trichloroethane	2 52	0 86	5*
Benzene	NA	1 7	5*
cis-1,3-Dichloropropene	0 19	NA	5*
Bromoform	12 6	6 2	5
2-Hexanone	NA	NA	10
4-Methyl-2-pentanone	NA	NA	10
Tetrachloroethene	NA	NA	5
Toluene	126	NA	5
Chlorobenzene	12 6	NA	5
Ethyl Benzene	63	NA	5
Styrene	126	1 5	5*
Total Xylenes	1,260	NA	5
Semivolatiles	(µg/ℓ)	(µg/ℓ)	(µg/ℓ)
Diethylphthalate	504	NA	10
Acenaphthene	37 8	NA	10
Fluorene	25 2	NA	10
N-Nitrosodiphenylamine	NA	35	10
Anthracene	189	43	10

Table 3-10 (Continued)

Exposure Limits for Water

Substance	EL Noncarcinogenic	EL Carcinogenic	Detection Limit
Semivolatiles (continued)			
Pyrene	18 9	NA	10
Benzo(a)Anthracene	NA	43	10
Bis(2-Ethylhexyl) Phthalate	12 6	3 5	**10***
Chrysene	NA	43	10
Benzo(b)Fluoranthene	NA	0 43	**10***
Benzo(k)Fluoranthene	NA	43	10
Benzo(a)Pyrene	NA	0 43	**10***
Indeno(1,2,3-cd)Pyrene	NA	43	10
Benzo(g,h,i)Perylene	NA	43	10
Pesticides/PCBs			
Arochlor 1254	NA	0 66	**1***
Beta-BHC	NA	2 8	0 05

NA Not Available

* Detection limits exceed ELs

In general, use of CLP methods, where appropriate, for the background program helps assure generation of high quality data by adherence to a systematic analytical program It should also be noted that the ELs established in this plan are based on a residential future use scenario (very conservative) whereas the likely future use scenario to be advanced is an ecological reserve, i e , ELs would be higher Lastly, changing analytical methods for those analytes whose current detection limits exceed ELs for organics (particularly chlorinated solvents) is an issue to be resolved in the OU RFI/RIs The issue will be significant in determining the extent of contamination and achieving cleanup goals (during remediation) depending on the final remediation goals that are established for the OU

Detection limits for other parameters (e g , anions, indicators, etc) have been routinely used for geochemical characterization They are of adequate precision and accuracy for the background geochemical characterization

SECTION 4
DATA ANALYSIS

This section describes the statistical and geochemical methods used to characterize the background chemistry at RFP, and how these background data may be compared to non-background or downgradient data It also discusses data validation and quality control data

The overall methodology for computing background statistics is illustrated by the flow chart, Figure 4-1, which is adapted from the initial RFP Background Report (EG&G, 1990c) Figure 4-1 contains a number of explanatory notes Application of many of the more complex procedures is discussed in detail later in Section 4

4.1 PRELIMINARY DATA ANALYSIS

Available chemical data will be carefully reviewed in a multi-step process to establish a reliable set of data upon which conclusions can be drawn, and to identify recurring sampling or analytical problems that can be corrected in the future Chemical data are validated upon receipt from the analytical laboratory These data and validation results are stored in the Rocky Flats Environmental Database System (RFEDS) for later retrieval and use A number of quality control checks are run during the data entry process After background data have been retrieved from RFEDS they will undergo additional quality checks including review and interpretation of field quality control data, and application of a variety of statistical and geochemical methods

4.1.1 Data Validation

Analytical data will be reviewed and validated by an independent contractor not associated with the laboratory generating the data Results will be documented in data validation reports EPA data validation functional guidelines will be used for validating metals data for CLP analytes Non-CLP data will be validated using data validation guidelines that were developed by the EMD because such guidelines have not been published by EPA These non-CLP guidelines are based on EPA validation functional guideline concepts and tailored to non-CLP analytical methods A listing of validation SOPs is available in the QAPjP (EG&G, 1990d)

These are three classes of data quality in the ER Program (1) "V"-Valid and usable without qualification, (2) "A"-Acceptable for Use with Qualification(s), and (3) "R"-Rejected (unacceptable) Valid data meet the following objective standards, where applicable

*1 Analytical methods followed
2 Acceptance criteria achieved
3 Sufficient number and type of QC samples analyzed
*4 QC limits achieved
*5 Compounds and analytes correctly identified
*6 Equipment/instrumentation calibration criteria achieved
7 Sampling holding times met
* Primary validation criteria

Data that are acceptable with qualification meet most, but not all, of the above standards At a minimum, all of the primary validation criteria are achieved within acceptable limits Only data qualified or "valid" or "acceptable" will be used in data analysis Data that have not yet been validated may be used on an interim basis Rejected data that fail to meet primary validation criteria will not be used, except in special circumstances For example the initial Background Geochemical Characterization Report (EG&G, 1990c) included some rejected data in order to compute preliminary statistics for radiochemistry

4.1.2 Field Quality Control

During the background field investigation program, field blank and field duplicate quality control samples are collected in accordance with the RFP ER Program QAPjP (EG&G, 1990d) These samples will be reviewed to evaluate the quality of the ongoing sampling program Field blanks are used to monitor for sample cross-contamination and the effectiveness of the decontamination process The blanks are collected by rinsing decontaminated sampling equipment with distilled/ deionized water, placing it in the appropriate container, and preserving as required

With respect to ground water and surface water samples, the field duplicates are collected following the actual sample collection using the same sampling technique For soil samples, it

is necessary to split the core of the interval being sampled with the sample and duplicate collected from each of the splits using the same technique The data from the sample and duplicate will provide a measure of the sampling precision and sample homogeneity, i e the amount of error in the data attributed to sampling technique or to variability in the analyte concentration in the medium being sampled

Precision is quantified by calculating the relative percent difference (RPD), i e the quotient of the difference between the duplicate analytical results and the average of those results for the given analyte expressed as a percentage

$$\% \text{ RPD} = 100(C1 - C2)/(C1 + C2)/2$$

where

RPD	=	Relative percent difference
C1	=	Concentration of analyte in the sample
C2	=	Concentration of analyte in the duplicate

The QC criterion for laboratory duplicates is a +/-20% RPD for water and+/- 35% RPD for soil Although not directly applicable to field duplicates, these criteria represent benchmarks for evaluating field precision

4.1.3 Treatment of Duplicates

Duplicates will be averaged for all analytes prior to determining univariate statistics (Figure 4-1) If a detected and non-detected value comprise a duplicate pair, one half of the reported detection limit of the non-detected value will be averaged with the detected concentration The resulting averaged value will be evaluated as a detected observation

4.1.4 Replacement of Below Detection Limit Data

The presence of data below the detection limit (nondetects) is a result of both the low levels (or absence) of some analytes within the background areas sampled relative to the magnitude of the analytical detection limits In the case of multiple detection limits and to set an acceptable upper detection limit, all nondetects (ND) greater than 2 times the minimum reporting limit may be omitted (Ganseckı, 1991) For the purposes of exploratory data analysis, all other below detection limit (BDL) data will be replaced with one half the detection limit (DL) Helsel's (1990) method can also be used which fits a distribution to the data (detects), and replaces nondetects with extrapolated values from the fitted distribution (Figure 4-1) The percentage of NDs will be tabulated with calculated descriptive statistics

4.1.5 Geochemical Quality Checks

The following geochemical criteria may be used to assess the general quality of ground water and surface water data

- Calculation of cation-anion balances
- Comparison of total dissolved solids (TDS) measured in the laboratory to TDS calculated from analytical results
- The comparison of field-measured specific conductance to TDS measured in the laboratory
- Comparisons of field-measured pH to laboratory-measured pH

It is recognized that pH is an unstable parameter and is most descriptive of a natural water when measured at the time of sampling However, the comparison of field-measured and laboratory-measured pH data is a useful data check The purpose of these criteria is to further check the consistency of the data, and to help identify transcription errors, field or lab instrument deficiencies, and other potential data problems Another purpose is to explore the data for trends and relationships that indicate incomplete analyses, or geochemical changes between field

measurements and lab measurements Geochemical Methods of data analysis will be discussed in detail later in Section 4

4.1.6 Evaluation of Data Distribution

The data distribution of every analyte with less than 50% NDs and a sample size of at least 10 by sample type will be evaluated in order to facilitate outlier detection, and in preparation for later statistical procedures (Figure 4-1)

Data will be plotted on probability plots, stem-and-leaf diagrams, or box plots, and descriptive statistics such as the coefficient of variation, kurtosis and skewness, and the Shapiro-Wilk statistic (a normality test) will be calculated If the resulting plots, descriptive statistics and test statistics indicate that the data may not be normally distributed, the data may be transformed by computing the natural log of the raw data The distribution of the transformed data will be evaluated in the same manner Alternatively the method of Devore (1987) may be applied to the raw and log transformed data Devore's Method uses the Pearson correlation coefficient to examine the correspondence between ranked data and a Z-score The distribution of data will be assumed to be either normal, or log normal The distribution that best fits the data will be used in subsequent outlier evaluation and statistical tests

4.1.7 Outlier Detection

An outlier is an extreme observation that does not conform to the pattern established by other observations and is unlikely to be a valid member of the population of interest An outlier may be the result of an incorrectly read, recorded, or transcribed measurement, an incorrect calculation, an error in documentation (field or laboratory), or an actual environmental condition

To evaluate the presence of outliers, the following procedure will be applied to each analyte by sample type

1 The data, or log transform of the data will be plotted on normal probability plots or box plots to identify extreme values

2 Extreme values identified from the plots will be statistically tested using the single outlier test defined in ASTM (1975), and described in the RCRA guidance document (EPA, 1989) Alternatively, outlier tests such as those of Dixon (1953), or Rosner (1975) may be applied (Figure 4-1)

3 The identified outlier will be evaluated with respect to the historical data trend, possible irregularities in sampling, and laboratory conditions such as matrix interference in an attempt to determine why the data is aberrant

4 A decision will be made on how to handle the outlier If the outlier resulted from a correctable error, the value will be changed, and the correct value will be included in the data set If an error cannot be identified, the datum may be excluded from subsequent statistical analysis in the professional judgment of the statistician or geochemist However, if one or more data points are excluded, the rationale for the exclusion will be discussed in the text of the report

4.2 EVALUATION OF POPULATIONS

This subsection presents the approach and statistical methods that will be used to establish appropriate populations for background geochemical results

4.2.1 Definitions

Before presenting statistical methods for defining background populations, some statistical definitions are in order A *population* is a well-defined set of all possible observations All ground water at the RFP is a population A *subpopulation* is a well-defined subset of the

population A *sample* is a small subset of the population taken to represent the larger population An *observation* is a measurement on the smallest sampling unit One geochemical analysis or set of analyses is an observation While this observation is based on a ground water sample, a ground water sample is not a statistical term and should not be confused with a statistical sample *Multivariate* is an adjective indicating that there is more than one dependent variable (analytes in the statistical models), *univariate* is an adjective indicating that there is only one dependent variable

A *classification factor* is a criterion by which an observation may be grouped For a ground water observation, the originating water bearing unit is a classification factor The water bearing units that were sampled (Rocky Flats Alluvium, colluvium, valley fill alluvium, weathered bedrock, etc) are *levels* of the classification factor A *one-way* statistical test evaluates the sample with respect to one classification factor (although many levels may be involved), a *n-way* statistical test evaluates the sample with respect to n classification factors

4.2.2 Sample Media

Six media (geologic materials, ground water, stream sediment, stream water, seep sediment, and seep water) have been sampled at RFP Four of these media can be classified into groupings that may represent subpopulations

- Geologic materials were sampled by geologic unit, for example Rocky Flats Alluvium, colluvium, and weathered bedrock
- Ground water was sampled as Rock Flats Alluvial ground water, colluvial ground water, valley fill ground water, weathered bedrock ground water, and unweathered sandstone ground water
- Sediments were sampled as Rock Creek sediment and Woman Creek sediment
- Surface water was sampled as Rock Creek surface water, Woman Creek surface water, and Smart Ditch surface water

Walnut Creek will not be included in the background characterization because most of its drainage basin is downgradient of the RFP facilities and IHSSs such as the West Spray Field

Samples were collected from each of these groups because prior to sampling it was not known if the subpopulations were geochemically distinct A background sample made up of geochemically different subpopulations would result in extraneous variability in the background sample, and consequently, a poor characterization of background geochemistry

Seep sediments and seep surface water were identified as separate media in the process of the data analysis undertaken in the 1989 Background Geochemical Characterization Report (EG&G, 1990c) and subsequent EPA comments (EPA, 1991b)

Other possible sources of variability are location with respect to the main plant for geologic materials and ground water, and seasonality for ground water and surface water (i e , variations over time)

4.2.3 Selection Criteria

Parametric multivariate analysis of variance (MANOVA), parametric and nonparametric analysis of variance (ANOVA), and Chi-squared contingency tables, are proposed to evaluate the effect of the proposed classification factor(s) on the population of each sample type As shown in Figure 4-1, this evaluation is based upon the percentage of detected observations by analyte and the number of observations available If less than 50% of the observations were detected, Chi-squared contingency tables are appropriate If the percentage of detected observations is greater than 50% up to and including 85%, the appropriate test is a nonparametric ANOVA A nonparametric test is better suited to handle the associated percentage (15 to 50%) of nondetects than a parametric test If the percentage of detected observations is greater than 85%, this analyte will be evaluated, with similar analytes, in a parametric MANOVA or parametric ANOVA with other related statistical tests as described below

ANOVA is a statistical procedure for determining if there is a difference between the average values of a variable (i e , the dependent variable) for different levels of a classification factor(s) (i e , the main effects) An ANOVA model with "n" classification factors is called a n-way ANOVA model If the classification factors are specified in the model, the classification factors are termed "fixed " If there is more than one dependent variable in the model, it is called a

MANOVA model For the most part, this study uses 1-way, 2-way and 3-way, fixed-effects, parametric MANOVA and ANOVA models, and 1-way, fixed-effects, nonparametric ANOVA models

4.2.4 ANOVA Designs

Table 3-4 lists the analytes (dependent variables) sampled for as part of the background program As discussed in Section 3, not all analytes were measured in the initial rounds of sampling Dissolved radiochemicals were not analyzed subsequent to the first round of sampling It should be further noted that many radiochemical analyses for geologic materials collected in 1989 were rejected during validation

Fixed effects statistical models are proposed in Table 4-1 where these possible sources of variability are identified as classification factors

Surface water collected at seeps (surface water stations SW080, SW104, and SW108) will be evaluated for seasonality by ANOVA, MANOVA, and by the Seasonal Kendall Test or Mann Kendall Test (Gilbert, 1987) Missing observations due to dry sampling stations are expected Seep water was identified as a separate sample type in the process of data evaluation, agency comment and comment response associated with the 1989 Background Geochemical Characterization Report (EG&G, 1990c)

Stream surface water will be evaluated for two classification factors drainage and seasonality Only two levels of drainage will be evaluated Rock Creek and Woman Creek Observations collected at surface water station SW007, located on a ditch in the Walnut Creek drainage will not be used to represent Walnut Creek in statistical analyses However, data originating from SW007 will be reported in the appendices of future background reports Surface waters from streams have been sampled monthly Future collection will be restricted to a quarterly basis Missing data due to dry sampling stations are expected

Table 4-1

Summary of Statistical Models by Sample Type

Sample Type	Classification Factors	Levels	Max No of Sampling Locations
Seep Surface Water	Seasonality	Winter Spring Summer Fall	3[a]
Stream Surface Water	Drainage	Rock Creek Woman Creek	11[a b]
	Seasonality	Winter Spring Summer Fall	
Ground Water	Aquifer	Rocky Flats Alluvium Colluvium Valley Fill Weathered Bedrock Unweathered Sandstone	51[a]
	Location	Northern Buffer Zone Southern Buffer Zone	
	Seasonality	Winter Spring Summer Fall	
Stream Sediments	Drainage	Rock Creek Woman Creek	6
Geologic Materials	Formation	Rocky Flats Alluvium Colluvium Weathered Bedrock	18
	Location	Northern Buffer Zone Southern Buffer Zone	

a Number of sampling locations available in any one event may be reduced due to insufficient water

b Not all sampling locations were in use at the start of sampling

c Multiple samples taken at various depths at each borehole Colluvium and weathered bedrock samples collected in the same boreholes Total number of samples (excluding field duplicates and redrills) is 119 samples

Ground water will be evaluated for three classification factors water bearing unit, location, and seasonality Ground water is collected quarterly, missing data due to dry sampling stations are expected Seasonality will be evaluated as for surface water

Seep sediments are collected quarterly and will not be evaluated for any classification factors The limited number of background seep locations available for sampling are not adequate for statistical comparisons by location Seasonality effects are sometimes observed as natural waters but are not expected in solids such as sediment and geologic material

Stream sediments will be evaluated for one classification factor — drainage Only two levels of drainage will be evaluated Rock Creek and Woman Creek Observations collected at sediment station SED004 located on a ditch in the Walnut Creek drainage will not be incorporated in the stream sediment statistical analyses However, data originating in SED004 will be reported in the appendices of future background reports

Geologic materials will be evaluated for two classification factors formation and location

4.2.5 Parametric MANOVA and Related Tests

MANOVA and related statistical tests will be applied in the following hierarchical manner

(1) Multivariate test of class(es) (null hypothesis no class effect)

(2) If the null hypotheses of the multivariate tests are rejected, then an n-way (by class) parametric ANOVA test for each analyte will be evaluated (null hypothesis no class effects for an individual analyte) If this test is not significant for a given analyte, no further testing will be done and the sample will not be subdivided for the analyte

(3) If the null hypothesis of one or more classes in the parametric ANOVA is rejected, then multiple comparisons tests (Bonferroni tests) will be conducted to identify which levels of the classes are different from each other (null hypothesis

no differences between levels) The results of these tests will be used to determine how the sample should be subdivided for the calculation of background descriptive statistics

Because use of the parametric MANOVA will provide a more sensitive analysis of the background geochemical data, it will be the preferred statistical test However, in order to reduce the likelihood of Type I errors due to excessive nondetects, MANOVA will only be applied if greater than 50% of the analytes are available, and these analytes each have less than 15% nondetects In order to increase the likelihood that residuals will be normally distributed, raw data may be mathematically transformed (e g , natural log of the raw data) for some analytes

Two assumptions that underlie the use of parametric ANOVA and MANOVA will be evaluated prior to the acceptance of the results

- Residuals are normally distributed
- Residuals have equal variances

A residual is the difference between a measured value and the predicted group mean Residuals that are calculated in the course of the MANOVA will be saved and analyzed for normality and homogeneity of variance

4.2.6 Test of Assumptions for MANOVA/ANOVA

4.2.6.1 Tests of Normality

Normality of the residuals will be evaluated by examining

- Descriptive statistics (e g skewness, kurtosis, coefficient of variation)
- Statistical graphics (e g normal probability plot, box plot)
- Statistical tests (e g , Shapiro-Wilks test, Devore Method)

If the residuals are not normally distributed, it will be determined if the degree of non-normality is sufficient to invalidate the relatively robust ANOVA or MANOVA test

If the departure from normality is substantial and if data transformations cannot achieve normality, then nonparametric statistical methods will be used for evaluating the data instead of the parametric ANOVA or MANOVA

4.2.6.2 Testing Homogeneity of Variance

Variance is a measure of dispersion of a set of observations around the mean of a random variable The F-test will be used to test the equality of variance between residuals from two levels Bartlett's test or Levene's test as outlined by Snedcor and Cochran (1980, p 252-254) will be used to test the homogeneity of variance for residuals from more than two levels

4.2.7 Nonparametric ANOVA

A nonparametric ANOVA evaluates differences in the mean rankings of the data (rather than the raw data or transformations of the raw data) for subsets of the data defined by levels of a classification factor However, the nonparametric tests are less powerful (less sensitive to actual differences in means) than parametric tests especially when the sample size is small (i e , there are relatively few samples)

The nonparametric test used will be the Wilcoxon rank-sum test for a comparison of two levels and the Kruskal-Wallis test, an extension of the Wilcoxon rank sum test, for comparison of more than two levels Both of these tests are outlined in Gilbert (1987, p 247-252) Both tests analyze ranks of data using Wilcoxon scores

The nonparametric ANOVA is a univariate one-way ANOVA Consequently, each variable will be evaluated individually (i e there will be no nonparametric n-way univariate test) Where the statistical models for a given sample type have identified multiple classification factors, the nonparametric ANOVA will be run separately by analyte for each classification factor Multiple comparison tests between levels will not be conducted

4.2.8 Chi-Square Contingency Tables

Contingency tables evaluate univariate count or frequency data assignable to multiple levels of one classification factor Statistical inferences on the validity of the null hypothesis (frequencies of analyte detection and nondetection are equal at all levels) are based upon the comparison using the actual observed frequency of analyte detection and nondetection to the expected frequency of analyte detection and nondetection

For those sample types with more than one classification factor, a contingency table will be used to evaluate each classification factor If the null hypothesis is rejected, an examination of the counts will be used to understand the differences

No chi-square contingency table analysis will be evaluated where any cell size contains less than five observations in more than 20% of the cells in order to retain sensitivity to actual differences between groups

4.3 CALCULATION OF DESCRIPTIVE STATISTICS

Once the appropriate geochemical population has been determined for each analyte, the following procedures will be applied to the respective statistical sample

- The maximum and median concentrations will be identified
- The percentage of NDs will be calculated
- Based on the evaluated data distribution, the mean, variance, and standard deviation will be calculated if the sample contains only detected concentrations, or they will be estimated through the Cohen procedure (see Appendix B) if nondetects are present in the sample
- Tolerance limits will be computed

4.3.1 Cohen Procedure

Cohen (1961) developed a maximum likelihood estimator of mean and standard deviation where greater than 50% of the data has been detected Because this procedure is designed to evaluate

data censored with a single DL, the minimum detection limit will be used when multiple detection limits are present in the data set Cohen's procedure in discussed in detail in Appendix B

4.3.2 Statistical Formulas

For normally distributed samples the following formulas for sample statistics will be used

Median

The median will be estimated by the 50% quantile provided by the SAS™ Univariate Procedure

Mean

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

where	$\bar{x}$	=	arithmetic mean of untransformed results
	n	=	number of observations
	x_i	=	the ith concentration (observation)

Variance

$$s^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}$$

where	s_2	=	variance of untransformed result
	$\bar{x}$	=	sample mean of untransformed results
	n	=	number of observations
	x_i	=	the ith concentration (observation)

Standard Deviation

$$s = \sqrt{s^2}$$

where	s	=	standard deviation of untransformed results
	s^2	=	sample variance of untransformed results

For lognormally distributed samples, the following formulas for sample statistics will be used

Median

The median will be estimated by the antilog$_e$ of the 50% quantile of the log$_e$ transformed data provided by the SAS™ Univariate Procedure

Mean

$$\hat{\mu}_1 = [\exp(\bar{y})]\ \Psi\ (n,t_1)$$

where	$\hat{\mu}_1$	=	minimum variance unbiased (MVU) estimator of the mean of the untransformed data after Sichel (1966)
	$\bar{y}$	=	arithmetic mean of the lognormally transformed data
	t_1	=	$s_y^2/2$
	S_y^2	=	variance of lognormally transformed data
	$\Psi(n,t)$	=	is a function defined by an infinite series

$$\Psi\ (n,t) = 1 + \frac{(n-1)\ t}{n} + \frac{(n-1)^3\ t^2}{2!\ n^2\ (n+1)} + \frac{n-1)^5\ t^3}{3!\ n^3\ (n+1)(n+3)} + \frac{(n-1)^7\ t^4}{4!\ n^4\ (n+1)(n+3)(n+5)} +$$

Variance

$$\hat{\sigma}_t^2 = \exp(2\bar{y}) \{\Psi(n,t_2) - \Psi(n, t_3)\}$$

where	$\hat{\sigma}_t^2$	=	MVU estimator of a two parameter lognormal distribution after Finney (1941)
	$\bar{y}$	=	arithmetic mean of lognormally transformed data
	$\Psi(n,t)$	=	the function given above
	n	=	sample size
	t_2	=	$2\ s_y^2$
	t_3	=	$s_y^2(n-2)/(n-1)$
	s_y^2	=	variance of lognormally transformed data

Equations for mean and variance of lognormally transformed data are discussed in Gilbert (1987, p 165-166) For sets with missing data, $\bar{y}$, s_y, s_y^2 will be estimated with the Cohen procedure

4.3.3 Tolerance Limits

Tolerance limits define a range that contains at least p% of a population with P% probability (level of confidence) A probability (level of confidence) is associated with the tolerance limits since they are estimated from the data set and therefore have some level of uncertainty associated with them For the tolerance limit to be useful in decision making, both "p" and "P" are chosen to be large, in this case p=0 95 and P=0 95 Tolerance limits are either one-sided or two-sided Two-sided tolerance limits are appropriate for pH data where values either larger or smaller than background may be associated with contamination A one-sided tolerance limit is appropriate for all other constituents for which increases over background are indicative of potential contamination

Parametric tolerance limits will be calculated for normally and lognormally distributed background data as appropriate The evaluation of the distribution of background data is addressed in Subsection 4 4 1

The equation for the 95% tolerance limits of normally distributed data is

95% Tolerance Limits

$$L_1 = \bar{x} - Ks \text{ and}$$
$$L_2 = \bar{x} + Ks$$

where	L_1	=	lower 95% tolerance limit
	L_2	=	upper 95% tolerance limit
	$\bar{x}$	=	mean of the sample population of size n
	s	=	standard deviation of the sample population
	K	=	the normal tolerance factor (Dependent on p, P, n and on whether the limit is one sided or two sided)

The equation for the 95% tolerance limits of lognormally distributed data is

Upper 95% Tolerance Limit

$$L_2 = \exp(\bar{y} + Ks_y)$$

where	L_2	=	Upper 95% Tolerance Limit
	$\bar{y}$	=	average of $\log_e$ transforms of raw data
	K	=	the normal tolerance factor (Dependent on p, P, n and on whether the limit is one sided or two sided [Table 4-2])

No lower limit equation is provided because pH is not expected to have a lognormal distribution

The calculation of the background mean and standard deviation for these equations is discussed in Subsection 4 4 3

Table 4-2

Tolerance Factors for Normal Tolerance Limits for 95% Population at 95% Confidence

n	Two-Sided	One-Sided
2	37 67	
3	9 916	7 655
4	6 370	5 145
5	5 079	4 202
6	4 414	3 707
7	4 007	3 399
8	3 732	3 188
9	3 532	3 031
10	3 379	2 911
11	3 259	2 815
12	3 162	2 736
13	3 081	2 670
14	3 012	2 614
15	2 954	2 566
16	2 903	2 523
17	2 858	2 486
18	2 819	2 453
19	2 784	2 423
20	2 752	2 396
21	2 723	2.371
22	2 697	2 350
23	2 673	2 329
24	2 651	2 309
25	2 631	2 292
26	2 612	
27	2 595	
28	2 579	
29	2 554	
30	2 549	2 220
35	2 490	2 166
40	2 445	2 216
45		2 092
50	2 379	2 065
60	2 333	2 022
80	2 272	1 965
100	2 233	1 927
200	2 143	
500	2 070	1 763
1000	2 036	
inf	1 960	1 645

4.4 GEOCHEMICAL EVALUATIONS

Statistical tests can identify a trend or a statistical difference, but geological, chemical, and hydrological principals must be applied to understand the geochemical origin and significance of the statistical results Previous sections of this plan have discussed how background samples will be collected, and chemically and statistically analyzed This section discusses how the background data will be geochemically evaluated

4.4.1 Geochemical Data Review

In addition to statistical screening, the raw background data sets will be examined for "geochemical reasonableness," e g , chemical concentrations are within expected ranges, there is electroneutrality, gravimetrically determined dissolved solids concentrations approximate the sum of the cations and anions, etc If errors are identified in the review, they will be corrected Results that remain "geochemical outliers" after investigation may be excluded from further data analysis based on the professional judgement of the geochemist However, any data that may be excluded from future background reports will be discussed in the text of the report

As an example of the above process, a ground water pH value of 2 0 would be highly anomalous in background regions of RFP and might indicate a new source of contamination However, if earlier and later pH measurements from the same well are consistently several pH units higher, then it is likely that the pH 2 0 value was erroneously measured, possibly on a water sample that had been preserved with acid The value would be omitted from further analysis and discussed in the text

Geochemical data screening may uncover a variety of potential errors such as inconsistencies in concentration units For example, trace element concentrations reported in the 300 milligrams per liter (mg/ℓ) range when they should be in the 300 micrograms per liter (μg/ℓ) range A more subtle data problem is inconsistent stoichiometric units For example, some older nitrate analyses in RFEDS were reported by the laboratory in milligrams per liter as NO_3, while the usual practice today is to report nitrate in milligrams per liter as N Substantial errors can result

from incorrectly mixing nitrate results that have been reported in the two units because equal nitrate concentrations will then differ by a factor of approximately 4 2

Zero values are suspect for most chemical parameters, especially for field parameters specific conductance, dissolved oxygen and pH While dissolved oxygen in ground water can truly have concentrations like 0 0 or 0 1 mg/ℓ, zero has sometimes been used in older data as a missing value flag to indicate "not measured "

Because all water samples are electrically neutral, milliequivalents of cations and anions must balance The background water quality data will be checked by plotting cation versus anion milliequivalents Acceptable analyses should have charge balance errors of less than 15%

Total dissolved solids (TDS) measured in the analytical laboratory will be compared against TDS computed from the analyzed major ion chemistry If the measured TDS is consistently much larger than the computed TDS, it is a good indication that one or more relatively abundant dissolved substances in the water samples were not analyzed for

Another check of data consistency is provided by plotting specific conductance measurements versus TDS (either measured or computed) Linear regression analysis should yield a high correlation coefficient

Because pH data are critical to geochemical modeling, it is useful to plot pH measured at the time of sampling (field-measured pH) versus pH measured later in the analytical laboratory The lab and field values will usually differ because pH is an unstable parameter best measured *in situ*, or at the time of sampling However, if no gross errors have been made, the lab and field-measured pH data should still agree within plus or minus 1 5 pH units

4.4.2 Seasonality Investigations

Natural water chemistry data often vary seasonally as a function of local weather patterns, including the amount of rainfall and snowmelt If background aqueous chemical concentrations vary significantly on a seasonal basis at RFP, it may be necessary to compute separate

background statistics by season If seasonality effects are significant, and seasonality is ignored (obscured) by combining data from all seasons, the larger variance of the combined data set would result in wider tolerance intervals This would make it more difficult to distinguish potential downgradient contamination from background at RFP

As discussed earlier, seasonality will be tested at RFP by comparing quarterly water quality data in analysis of variance procedures and with the Mann-Kendall, or seasonal Kendall statistical tests Because natural chemical concentrations may vary with stream discharge, flow-adjusted concentrations will be generated by regressing analyte concentration versus stream flow, and using the seasonal Kendall test for trend on the residuals from the regression (Gilbert, 1987) This latter test will depend upon the availability of sufficient discharge measurement data for Rock Creek and Woman Creek Several years worth of background monitoring data will be required to start evaluating seasonality

Seasonality may show up in simple "time series plots" of the concentration of selected analytes versus date of sampling at a given station Discharge data could also be used to make a three dimensional plot

Seasonal effects can not be tested in geological materials because boreholes are drilled and sampled only one time at a given location Furthermore, rock materials and seep and stream bed sediments have relatively long residence times compared to natural waters Therefore, although bed sediments are sampled quarterly, basically the same solids are collected each time and seasonality will not be considered for these solids Variability between samples of geologic solids collected from the same site are believed to be the result of natural heterogeneities in the solids and analytical variance

4.4.3 Water Quality Trends

Surface water and ground water data from RFP will be examined using several types of standard geochemical plots Stiff, Trilinear, and Shoeller diagrams While these plots differ in format and number of constituents, they all use major ion chemistry to help classify and compare natural waters from different host rocks or stream drainages For example, plotting 1989 ground

water data on trilinear diagrams indicated similar major ion chemistry in the background alluvial units, and quite different water types in unweathered bedrock units (EG&G, 1990c) Small scale Stiff diagrams can be plotted on an RFP site-wide base map to visually illustrate how the major ion chemistry of ground water changes on a site-wide scale

The initial Background Report (EG&G, 1990c) attempted to look at trends in surface water quality in the downstream direction, and evolution of ground water chemistry along the flow path However, these efforts met with limited success for several reasons One of the limiting factors was that background sampling locations are restricted to a relatively small area of the RFP buffer zone upgradient of known IHSSs and buildings Downgradient trends in water chemistry tend to be subtle and are not easily recognized over the short background distances available at RFP

Future background reports will try to detect subtle evolutionary changes in ground water chemistry by including data from selected downgradient (non-background) monitoring wells to obtain a longer flow path Use of both background and non-background wells will allow construction of chemical cross section maps, which should have data that represent most of the breadth and width of the 10 square mile RFP property The concentrations of selected chemicals will be plotted as a function of distance along a flow path on these maps

With respect to surface water, if permission can be obtained from downstream landowners, it may be possible to add off site background stations for surface water sampling on lower Rock Creek Also, the flow path of Woman Creek can be extended on chemical cross sections by including data from existing downgradient stations on RFP property However, surface water quality trends with downstream distance are difficult to establish because surface waters flow rapidly compared to ground water, and surface water quality may be effected by storm events of short duration Therefore, the most meaningful comparisons of surface water quality downgradient require sampling of all of the stations over a very short time period Due to limited availability of water sampling personnel, background stations are sampled along with non-background stations of other monitoring programs at RFP, and surface water stations on a given drainage have historically been sampled over several days or longer An attempt will be made to reprioritize the order in which stations are sampled to reduce this problem Storm event

data must be taken into account when plotting surface water quality against downstream distance, even when samples have been collected on the same day

Besides using geochemical cross sections, background chemical trends in RFP ground water may be mapped in two dimensions by generating "isochemical maps " An isochemical map shows concentration isopleths for a chemical from a particular sampling medium (e g sulfate in Rocky Flats Alluvial ground water) plotted on an RFP base map Obviously, downgradient data will have to be included in these maps if they are extended beyond background areas and used to indicate site-wide chemical trends Inclusion of downgradient data raises the possibility of ground water contamination (from IHSSs) superimposed on the natural site-wide chemical trend If chemical anomalies due to pollution are observed, they will be mentioned in the background report

Geochemical ratio maps plot and contour concentration ratios (of elements or ions), or activity ratios (for radionuclides) on a base map Ratio maps may be particularly helpful in interpreting the sources of radionuclides in various media For example, Krey (1976) used Pu-240/Pu-239 activity ratio data measured in soils to distinguish Pu of RFP origin from Pu from atmospheric fallout in the Denver area This was possible because RFP Pu has a very different Pu-240/Pu-239 ratio than does fallout Other activity ratio maps such as U-235/U-238, or gross alpha/gross beta may be useful in identifying uranium of potential RFP origin from naturally occurring uranium in various background media

Ratio maps like (Ca+Mg)/(Na+K) may be useful for mapping changes in RFP ground water chemistry, which are potentially the result of cation exchange processes

At the time of writing, a pilot study is underway, directed by Dr Jim White of the University of Colorado, to measure and interpret stable isotope (hydrogen and oxygen isotope) and tritium data in ground waters from RFP These stable isotope ratios may be of value in studying mixing of ground waters from different geologic units present at RFP The tritium data may help to age date the ground waters as "prebomb" or "postbomb " If the pilot study is successful, a larger scale study will proceed that will cover both background and non-background areas of RFP Because of this separate study, stable isotope data will not be incorporated into the background

program, except by reference However, background tritium data measured in surface water samples will probably be compared to tritium in underlying sediments

4.4.4 Geochemical Modeling

Geochemical models are computer programs that embody chemical principals in mathematical form These programs can be used to study and help interpret the chemistry of natural waters as well as water and mineral interactions They can be used to study the relative importance of fundamental chemical processes such as dissolution and precipitation, ion exchange, adsorption, and oxidation and reduction

Geochemical modeling will be used as an interpretive tool in studying ground water background chemistry at RFP A number of widely used geochemical models are suitable for this work, including among others PHREEQE, MINTEQA2, and various descendants of the WATEQF model (Parkhurst et al , 1980, Brown and Allison, 1987, Plummer et al 1976, respectively) Each model has particular strengths and weaknesses, and several models may be used for different purposes

The PHREEQE model of Parkhurst, Thorstenson, and Plummer (1980) provides a good example of the utility of geochemical models Input to PHREEQE consists of analyzed ground water chemistry and field measurements such as pH, water temperature, and dissolved oxygen content PHREEQE uses an extensive thermodynamic database to compute the equilibrium distribution of dissolved species in the water The model then computes the state of saturation of the water with respect to a large number of solid phases This helps interpret the processes taking place in the ground water For example, if Rocky Flats alluvial ground water is found to be supersaturated with respect to calcite, then we may assume that caliche or calcium carbonate cement could be precipitating from this water On the other hand, if the water is undersaturated with respect to calcite, caliche should tend to dissolve when in contact with this water PHREEQE can model other types of problems such as predicting the final water chemistry that should result from the mixing of two different ground waters

Geochemical modeling will be limited by the availability of detailed mineralogical data and site-specific adsorption data for RFP Efforts, independent of the Background Program, are underway to attempt to collect these data

4.5 COMPARISON OF BACKGROUND AND NON-BACKGROUND POPULATIONS

Background and non-background data comparisons are not a part of the background study However, these comparison techniques will be of interest to users of the statistics provided by the background program

4.5.1 Selection of Evaluation Methods

Where intra-well comparisons over time are required to ensure continued background status of downgradient wells, control charts are an appropriate procedure Construction of control charts is discussed in many statistics textbooks

Where comparisons of background and non-background areas are required, the following procedures may be implemented

(1) Categorize the non-background observation(s) by classification factors and levels previously identified for that medium in Section 4 3 3 2 For example, a sample of geologic materials might be evaluated for location and formation

(2) Identify the appropriate background samples in which these levels of the classification factors are found Note background samples may change depending on the analyte to be compared For example, the background report for iron may indicate a background sample for Rocky Flats Alluvium and colluvium without regard to location For calcium, the background sample may be Rocky Flats Alluvium, north of the Plant

(3) By analyte, compare the tolerance limit of the background sample, if available, to the non-background concentration

For those analytes where a tolerance limit of the appropriate background population is not available, background/non-background comparisons may be made using the frequency of detected observations This analysis, test of proportions, necessarily requires multiple non-background observations The minimum number of non-background samples increases with lower detection frequencies Procedures for Test of Proportions are outlined by the EPA (1989, p 8-3)

SECTION 5

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APPENDIX A
SUMMARY OF KNOWN OR SUSPECTED ENVIRONMENTAL CONTAMINATION AT RFP

In January 1991, the IAG was signed by the DOE, EPA, and CDH establishing the schedule for environmental restoration activities at RFP The IAG replaced a 1986 Compliance Agreement reflecting new requirements of the Superfund Amendments and Reauthorization Act and helps to clarify cleanup priorities

The IAG organizes the 178 IHSSs (see Plate 1) at the plant into 16 larger areas—termed operable units (OU) The OUs are ranked and assigned schedules according to cleanup priority The schedule provides for interim remedial action at several of the OUs while investigations continue in support of final remedial action The 16 operable units are designated as follows

- OU1 881 Hillside Areas
- OU2 903 Pad, Mound and East Trenches Areas
- OU3 Offsite Releases
- OU4 Solar Ponds
- OU5 Woman Creek
- OU6 Walnut Creek
- OU7 Present Landfill
- OU8 700 Area
- OU9 Original Process Waste Lines
- OU10 Other Outside Closures
- OU11 West Spray Field
- OU12 400/800 Area
- OU13 100 Area
- OU14 Radioactive Sites
- OU15 Inside Building Closures
- OU16 Low-Priority Sites

The IAG provides milestones for the activities and documentation requirements for remediation of the 16 operable units according to the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) The milestone schedules currently extend into August 2001

OU1 - 881 Hillside Area

The main concern at OU1 is the contamination of ground water and soil by volatile compounds (VOCs) Prior to 1972, workers stored drums containing solvents on the ground east of Building 881, subsequently, some of the containers leaked Other IHSSs at OU1 include chemical waste pits, an outfall area, out-of-service fuel tanks, and buried, radionuclide-contaminated soils

OU2 - 903 Pad, Mound, and East Trenches Areas

Former waste storage practices resulted in contamination of soil, surface water, and ground water at OU2 At the 903 Pad, drums containing plutonium-contaminated lathe coolant were stored on the ground, later, these drums were removed and the area was capped with asphalt At the Mound area, similar drums were buried and later removed While the drums existed at these two areas, some leaks occurred, and soil removal may have resulted in wind dispersion of contaminants At the East Trenches Areas, drums containing radioactive waste and sanitary sewer sludge were buried, some of which remain in the trenches Also, sewer plant effluent was spray irrigated on nearby land The variety of contaminants at OU2 includes VOCs, other organics, radionuclides, and metals

OU3 - Off-Site Releases

Some off-site land and reservoirs near the RFP may have been contaminated by releases from the RFP, primarily plutonium and americium Affected areas include the sediments in three reservoirs (Great Western Reservoir, Standley Lake, and Mower Reservoir), plus some land east of Indiana Street, which is east of the RFP boundary Wind resuspended plutonium-contaminated soil from the 903 Pad, and waterborne releases from the plant in the 1950s, 1960s, and 1970s are the potential sources of the off-site contamination

OU4 - Solar Evaporation Ponds

The Solar Evaporation Ponds were used to store low-level radioactive waste, sanitary treatment plant effluent, and contaminated ground water collected downgradient of the ponds Leaks from the ponds contributed radionuclides, metals, nitrates, acids, and bases to the ground water and soil

OU5 - Woman Creek Drainage

OU5 consists of potentially contaminated surface water, stream sediments, and soil in the Woman Creek drainage Radionuclides, metals, and nitrates from OU1 and OU2 may have migrated into OU5 There are several types of IHSSs including an old landfill, ash pits, and retention ponds

OU6 - Walnut Creek Drainage

As with OU5, the surface water, soil, and stream sediments in the Walnut Creek drainage may contain elevated levels of radionuclides, metals, and nitrates IHSSs include a sludge dispersal area, retention ponds, an old outfall, trenches, and spray fields

OU7 - Present Landfill

The soil and ground water in this area may contain various contaminants such as VOCs and metals The landfill is still being used, and only nonhazardous sanitary solid waste currently is disposed in it

OU8 - 700 Area

OU8 consists of 38 IHSSs, that were the sites of numerous spills during early process operations The soil may be contaminated with VOCs and other organics, radionuclides, metals, nitrates, acids, bases, and solvents

OU9 - Original Process Waste Lines

Soils at OU9 may have been affected by leaking pipes or tanks that were used for transporting various types of process wastes Possible contaminants include nitrates, acids, caustics, and radionuclides

OU10 - Other Outside Closures

OU10 consists of a variety of RCRA closure sites hazardous waste storage facilities, tanks, and areas where leaks occurred

OU11 - West Spray Field

From 1982 to 1985, the West Spray Field was spray irrigated with water from solar evaporation ponds that contained elevated levels of nitrates and other wastes This practice may have contaminated the ground water and the vadose zone

OU12 - 400/800 Area

Cooling tower ponds, chemicals from fiberglass operations, leaks, and spills may have contaminated the soil in this area with VOCs and other organics, metals, and acids

OU13 - 100 Area

OU13 comprises chemical storage areas, an underground tank, waste destruction areas, a valve vault, and locations where minor leaks or spills occurred VOCs and other organics, depleted uranium, metals, acids and caustics may have been released to soils from these IHSSs

OU14 - Radioactive Sites

"Radioactive sites" refers to storage areas for radioactive soils removed from the vicinity of radiological operations buildings

OU15 - Inside Building Closures

OU15 includes structures within buildings where hazardous materials were stored or processed

OU16 - Low-Priority Sites

This OU covers miscellaneous leak and waste treatment sites that are considered the least likely to cause health or environmental problems The soils at these sites may have been contaminated by organics, solvents, and nickel carbonyl

COHEN PROCEDURE

A technique for calculation of the mean and standard deviation of a data set containing nondetected data (censored data) was developed by Cohen (1961) and can be used if the data are normally distributed Where data are lognormally distributed, the Cohen procedure can be applied to calculate $\bar{y}$ (mean of the lognormally transformed data) and S_y (standard deviation of the lognormally transformed data) prior to the calculation of the Sitchel mean, Finney variance, and tolerance limits The Cohen procedure is as follows (Doctor, Gilbert, and Kinnison, 1986)

Let

n	=	the total number of observations for a constituent,
k	=	number of actual measurements out of n (not NDs), and
x_o	=	the detection limit of the constituent

Then

1) Compare $h = (n-k)/n$ (the proportion of measurements below the detection limit),

2) Compute x_u = (Sum of x_i for $i = 1$ to k)/k,

3) Compute s^2_u = (Sum of $x_i - x_u)^2$ for $i = 1$ to k)/k,

4) Compute $t = s^2_u/(x_u - x_o)^2$,

5) Obtain an estimate of λ from Table B-1 using h and t ,

6) Estimate the mean and variance of the population from which the censored data set was drawn by computing

$$x = x_u - \lambda (x_u - x_o)$$

and $$s = [s^2_u = \lambda (x_u - x_o)^2]^{1/2}$$

This procedure is restricted to data sets with less than 50% nondetects

Table B-1

Values for λ for Estimating the Mean and Variance of a Normal Distribution when ND Values are Present

t \ h	01	02	03	04	05	06	07	08	09	10	15	20	h \ t
00	010100	020400	030902	041583	052507	063627	074953	086488	09824	11020	17342	24268	00
05	010551	021294	032225	043350	054670	066189	077909	089834	10197	11431	17935	25033	05
10	010950	022082	033398	044902	056596	068483	080568	092852	10534	11804	18479	25741	10
15	011310	022798	034465	046318	058356	070586	083009	095629	10845	12148	18985	26405	15
20	011642	023459	035453	047629	059990	072539	085280	098216	11135	12469	19460	27031	20
25	011952	024076	036377	048858	061522	074372	087413	10065	11408	12772	19910	27626	25
30	012243	024658	037249	050018	062969	076106	089433	110295	11667	13059	20338	28193	30
35	012520	025211	038077	051120	064345	077756	091355	01515	11914	13333	20747	28737	35
40	012784	025738	038866	052173	065660	079332	093193	01725	12150	13595	21139	29260	40
45	013036	026243	039624	053182	066921	080845	094953	01926	12377	13847	21517	29765	45
50	013279	026728	040352	054153	068135	082301	096657	11121	12595	14090	21882	30253	50
55	013513	027196	041054	055089	069306	083708	098298	11308	12806	14325	2235	30725	55
60	013739	027649	021733	055995	070439	085068	099887	11490	13011	14552	22578	31184	60
65	013958	028087	042391	056874	071538	086388	10143	11666	13209	14773	22910	31630	65
70	014171	028513	043030	057726	072605	087670	10292	11837	13402	14987	23234	32065	70
75	104378	028927	043652	058556	073643	88917	10438	12004	13590	15196	23550	32489	75
80	014579	029330	044258	059364	074655	090133	10580	12167	13773	15400	23858	32903	80
85	014775	029723	044848	060153	075642	091319	10719	12325	13952	15599	24158	33307	85
90	014967	030107	045425	060923	076606	092477	10854	12480	14126	15793	24452	33703	90
95	015154	030483	045989	061676	077549	093611	10985	12632	14297	15983	24740	34091	95
1 00	015338	030850	046540	062413	078471	094720	11116	12780	14465	16170	25022	34471	1 00

Table B-1 (Continued)

Values for λ for Estimating the Mean and Variance of a Normal Distribution when ND Values are Present

t \ h	25	30	35	40	45	50	55	60	65	70	80	90	h / t
00	31862	4021	4941	5961	7096	8368	9808	1 145	1 336	1 561	2 176	3 283	00
05	32793	4130	5066	6101	7252	8540	9994	1 165	1 358	1 585	2 203	3 314	05
10	33662	4233	5184	6234	7400	8703	1 017	1 185	1 379	1 608	2 229	3 345	10
15	34480	4330	5296	6361	7542	8860	1 035	1 204	1 400	1 630	2 255	3 376	15
20	35255	4422	5403	6483	7678	9012	1 051	1 222	1 419	1 651	2 280	3 405	20
25	35993	4510	5506	6600	7810	9158	1 067	1 240	1 439	1 672	2 305	3 435	25
30	36700	4595	5604	6713	7937	9300	1 083	1 257	1 457	1 693	2 329	3 464	30
35	37379	4676	5699	6821	8060	9437	1 098	1 274	1 476	1 713	2 353	3 492	35
40	38033	4755	5791	6927	8169	9570	1 113	1 290	1 494	1 732	2 376	3 520	40
45	38665	4831	5880	7029	8295	9700	1 127	1 127	1 511	1 751	2 399	3 547	45
50	39276	4904	5967	7129	8408	9826	1 141	1 321	1 528	1 770	2 421	3 575	50
55	39870	4976	6051	7225	8517	9950	1 155	1 337	1 545	1 788	2 443	3 601	55
60	40447	5045	6133	7320	8625	1 007	1 169	1 351	1 561	1 806	2 465	3 628	60
65	41008	5114	6213	7412	8729	1 019	1 182	1 366	1 557	1 824	2 486	3 654	65
70	41555	5180	6291	7502	8832	1 030	1 195	1 380	1 593	1 841	2 507	3 679	70
75	44592	5245	6367	7590	8932	1 042	1 207	1 394	1 608	1 858	2 528	3 705	75
80	014579	5308	6441	7676	9031	1 053	1 220	1 408	1 624	1 875	2 548	3 730	80
85	014775	5370	6515	7761	9127	1 064	1 232	1 422	1 639	1 892	2 568	3 754	85
90	014967	5430	6586	7844	9222	1 074	1 244	1 435	1 653	1 908	2 588	3 779	90
95	015154	5490	6656	7925	9314	1 085	1 085	1 448	1 668	1 924	2 607	3 803	95
1 00	015338	030850	6724	8005	9406	1 095	1 095	1 461	1 682	1 682	2 626	3 827	1 00

Trend Testing

A Mann-Kendall nonparametric test may be used to determine if there is a decreasing or increasing trend in the quarterly at monthly data The test requires at least 2 years of data If the test is significant at the 0 01 level, i e , a trend is present, then a control chart will be inappropriate for the well A control chart assumes random variations about a constant mean A trend in constituent concentrations in a downgradient well may indicate a release from a site/unit

The Mann-Kendall test requires that the data be adjusted to remove any temporal cycles that may be present This is performed by subtracting from the quarterly constituent concentration the quarterly average concentration and adding back the grand average as follows (Doctor, Gilbert, and Kinnison, 1986)

$$Z_{ij} = X_{ij} - (X_i - X)$$

Where

Z_{ij} = adjusted observation for the ith quarter of the jth year

X_{ij} = unadjusted observation for the ith quarter of the jth year

X_i = arithmetic mean for quarter i over the historical record

$$= \frac{1}{n} \sum_{j=1}^{n} X_{ij}$$

and

X = arithmetic mean of the 4n observations

$$= \frac{1}{4n} \sum_{j=1}^{n} \sum_{i=1}^{4} X_{ij}$$

Note that computing $X_{ij} - X_i$ removes the average effect of quarter i from the data, and that adding X places all the adjusted values Z_{ij} about the same mean, namely X

The next step is to list the adjusted observations in the order they were collected over time, Z_1, Z_2, , Z_n, where Z_i is the observation for quarter i, or month i Then all n(n-1)/2 possible differences $Z_j - Z_k$, where $j > k$ are computed, and the sign of each difference determined

These differences are $Z_2 - Z_1$, $Z_3 - Z_1$, $Z_n - Z_1$, $Z_3 - Z_2$, $Z_4 - Z_3$, $Z_n - Z_{n-2}$, $Z_n - Z_{n-1}$

A convenient way of visualizing the calculations is given in the following table

DIFFERENCES IN DATA VALUES NEEDED
FOR COMPUTING THE MANN-KENDALL STATISTIC S
TO TEST FOR TREND

Observations Listed in Time Order							No of + Signs	No of - Signs
Z_1	Z_2	Z_3	Z_4	•••	Z_{n-1}	Z_n		
	Z_2-Z_1	Z_3-Z_1	Z_4-Z_1	•••	$Z_{n-1}-Z_1$	Z_n-Z_1		
		Z_3-Z_2	Z_4-Z_2	•••	$Z_{n-1}-Z_2$	Z_n-Z_2		
			Z_4-Z_3	•••	$Z_{n-1}-Z_3$	Z_n-Z_3		
					$Z_{n-1}-Z_{n-2}$	Z_n-Z_{n-2}		
						Z_n-Z_{n-1}		
						S =	Sum of + Signs	+ Sum of - Signs

Let sgn $(Z_j - Z_k)$ be an indicator function that takes on the values 1, 0, or -1 according to the sign of $Z_j - Z_k$, as follows

$$\begin{aligned} \text{sgn}\,(Z_j - Z_k) &= 1 && \text{if } Z_j - Z_k > 0 \\ &= 0 && \text{if } Z_j - Z_k = 0 \\ &= -1 && \text{if } Z_j - Z_k < 0 \end{aligned}$$

The statistic

$$S = \sum_{k-1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}\,(Z_j - Z_k)$$

which is the number of positive differences minus the number of negative differences is then computed These positive and negative differences are easily obtained from the last two columns of the previous table If S is a large positive number, this means that measurements taken later in time tend to be larger than those taken earlier Similarly, if S is a large negative number, measurements taken later in time tend to be smaller If n is large, it is impractical to compute S by hand and a computer code is required

The test procedure is to first compute S as described above Then the variance of S is found using the following equation that takes into account the possibility that ties may be present, i e , that two or more quarterly observations may be equal in value

$$VAR(S) = [n (n-1) (2n+5) - \sum_{p=1}^{g} t_p (t_p-1) (2t_p+5)] / 18$$

where g is the number of tied groups and t_p is the number of data in the pth tied group For example, in the sequence of quarterly observations 23, 24, 6, 24, 24, 23, g=2, where $t_1=2$ for the tied value 23 and $t_2=3$ for the tied value 24

Then S and VAR(S) are used to compute the test statistic Z as follows

$$\begin{aligned} Z &= (S - 1)/[VAR(S)]^{1/2} && \text{if } S > 0 \\ &= 0 && \text{if } S = 0 \\ &= (S + 1)/[VAR(S)]^{1/2} && \text{if } S < 0 \end{aligned}$$

The ± 1 added to S is a correction factor that makes the standard normal tables more exact for testing the hypothesis H_o of no trend This correction is not necessary if there are 10 or more data for each quarter ($n_i \geq 10$)

A positive (negative) value of Z indicates an upward (downward) trend If the null hypothesis H_o of no trend is true, the statistic Z has a standard normal distribution Some commonly used critical values from the standard normal tables for evaluating whether the test statistic Z is significantly large are presented by Snedecor and Cochran (1967) To test for either upward or downward trends (a two-tailed test) at the specified (a) level of significance (probability of a false positive), H_o is rejected if the absolute value of Z is greater than $Z_{a/3}$, where $Z_{a/2}$ is obtained from Snedecor and Cochran (1967) or more extensive tables of the standard normal distribution given in most statistical methods books If the alternative hypothesis is for an upward trend (a one-tailed test), H_o is rejected if Z is greater than Z_a H_o is rejected in favor of the alternative hypothesis of a downward trend if Z is negative and the absolute value of Z is greater than Z_a

If $n \leq 40$ and there are not tied observations, the Mann-Kendall test can be computed using the tables of the exact distribution of the Mann-Kendall statistic given in Table A-21 on pages 384-393 of Hollander and Wolfe (1973)

The Sen nonparametric procedure (Doctor, Gilbert, and Kinnison, 1986) may be used to estimate the magnitude of the trend for stations shown to have significant trends by the Mann-Kendall test

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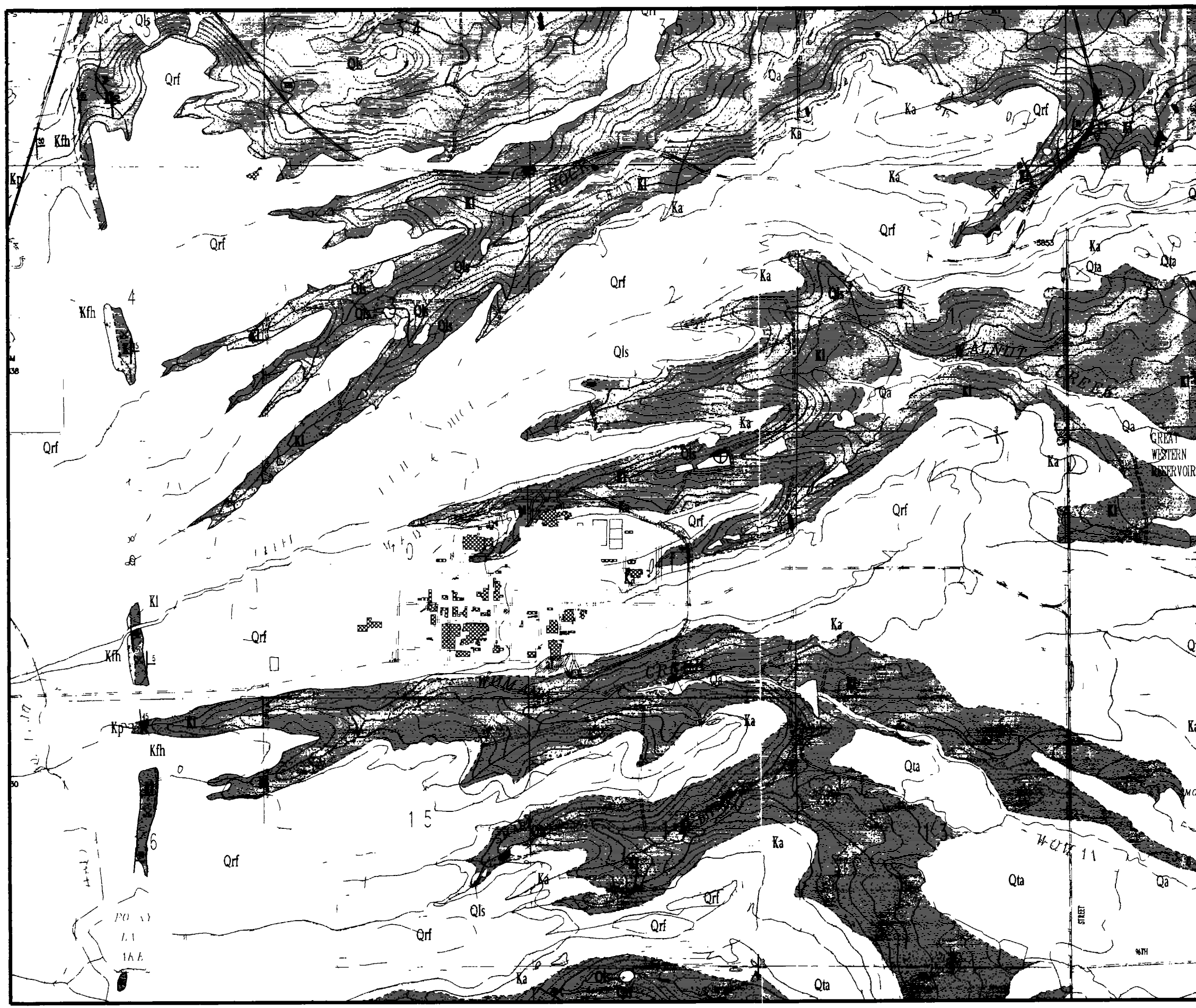
Background Surface Water and Sediment Sampling Stations Plate 6

Fiche location: A-SW-M2



EXPLANATION

- Artificial Fill (RECENT)
- Valley Fill Alluvium (RECENT)
- Landslide Slump (RECENT)
- Undiff. Terrace Alluvium (PLEISTOCENE)
- Rocky Flats Alluvium (PLEISTOCENE)
- Arapahoe Formation (CRETACEOUS)
- Laramie Formation (CRETACEOUS)
- Fox Hills Sandstone (CRETACEOUS)
- Pierre Shale (CRETACEOUS)

Strike and dip of bedding plane in bedrock

inclined — vertical — overturned — horizontal

Gravel and/or clay pit — Benchmark

Area of bedrock exposure

Contact
dashed where approx. located,
dotted where concealed

From EC & G 199

CALE 1 000

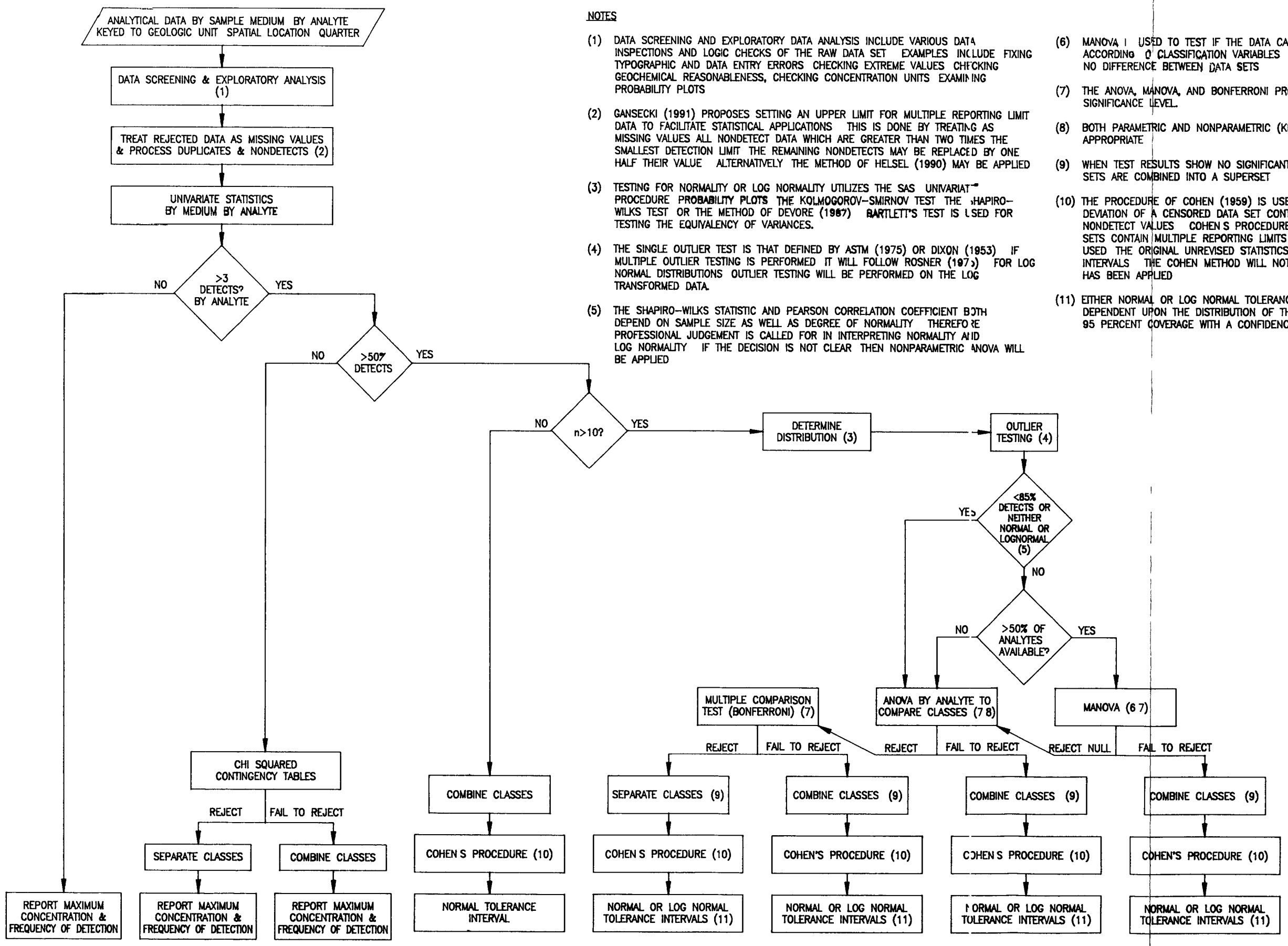
000 0 000

US DEPARTMENT OF ENERGY
Rocky Flats Plant Golden Colorado

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN

SURFICIAL GEOLOGY
FOR THE
ROCKY FLATS PLANT

FIGURE 6 February 199



NOTES

(1) DATA SCREENING AND EXPLORATORY DATA ANALYSIS INCLUDE VARIOUS DATA INSPECTIONS AND LOGIC CHECKS OF THE RAW DATA SET EXAMPLES INCLUDE FIXING TYPOGRAPHIC AND DATA ENTRY ERRORS CHECKING EXTREME VALUES CHECKING GEOCHEMICAL REASONABLENESS, CHECKING CONCENTRATION UNITS EXAMINING PROBABILITY PLOTS

(2) GANSECKI (1991) PROPOSES SETTING AN UPPER LIMIT FOR MULTIPLE REPORTING LIMIT DATA TO FACILITATE STATISTICAL APPLICATIONS THIS IS DONE BY TREATING AS MISSING VALUES ALL NONDETECT DATA WHICH ARE GREATER THAN TWO TIMES THE SMALLEST DETECTION LIMIT THE REMAINING NONDETECTS MAY BE REPLACED BY ONE HALF THEIR VALUE ALTERNATIVELY THE METHOD OF HELSEL (1990) MAY BE APPLIED

(3) TESTING FOR NORMALITY OR LOG NORMALITY UTILIZES THE SAS UNIVARIATE PROCEDURE PROBABILITY PLOTS THE KOLMOGOROV–SMIRNOV TEST THE SHAPIRO–WILKS TEST OR THE METHOD OF DEVORE (1987) BARTLETT'S TEST IS USED FOR TESTING THE EQUIVALENCY OF VARIANCES.

(4) THE SINGLE OUTLIER TEST IS THAT DEFINED BY ASTM (1975) OR DIXON (1953) IF MULTIPLE OUTLIER TESTING IS PERFORMED IT WILL FOLLOW ROSNER (1975) FOR LOG NORMAL DISTRIBUTIONS OUTLIER TESTING WILL BE PERFORMED ON THE LOG TRANSFORMED DATA.

(5) THE SHAPIRO–WILKS STATISTIC AND PEARSON CORRELATION COEFFICIENT BOTH DEPEND ON SAMPLE SIZE AS WELL AS DEGREE OF NORMALITY THEREFORE PROFESSIONAL JUDGEMENT IS CALLED FOR IN INTERPRETING NORMALITY AND LOG NORMALITY IF THE DECISION IS NOT CLEAR THEN NONPARAMETRIC ANOVA WILL BE APPLIED

(6) MANOVA IS USED TO TEST IF THE DATA CAN BE GROUPED INTO LARGER SETS ACCORDING TO CLASSIFICATION VARIABLES THE NULL HYPOTHESIS IS THAT THERE IS NO DIFFERENCE BETWEEN DATA SETS

(7) THE ANOVA, MANOVA, AND BONFERRONI PROCEDURES ARE USED AT THE .05 SIGNIFICANCE LEVEL.

(8) BOTH PARAMETRIC AND NONPARAMETRIC (KRUSKAL–WALLIS) ANOVAS ARE USED AS APPROPRIATE

(9) WHEN TEST RESULTS SHOW NO SIGNIFICANT DIFFERENCE BETWEEN CLASSES THE DATA SETS ARE COMBINED INTO A SUPERSET

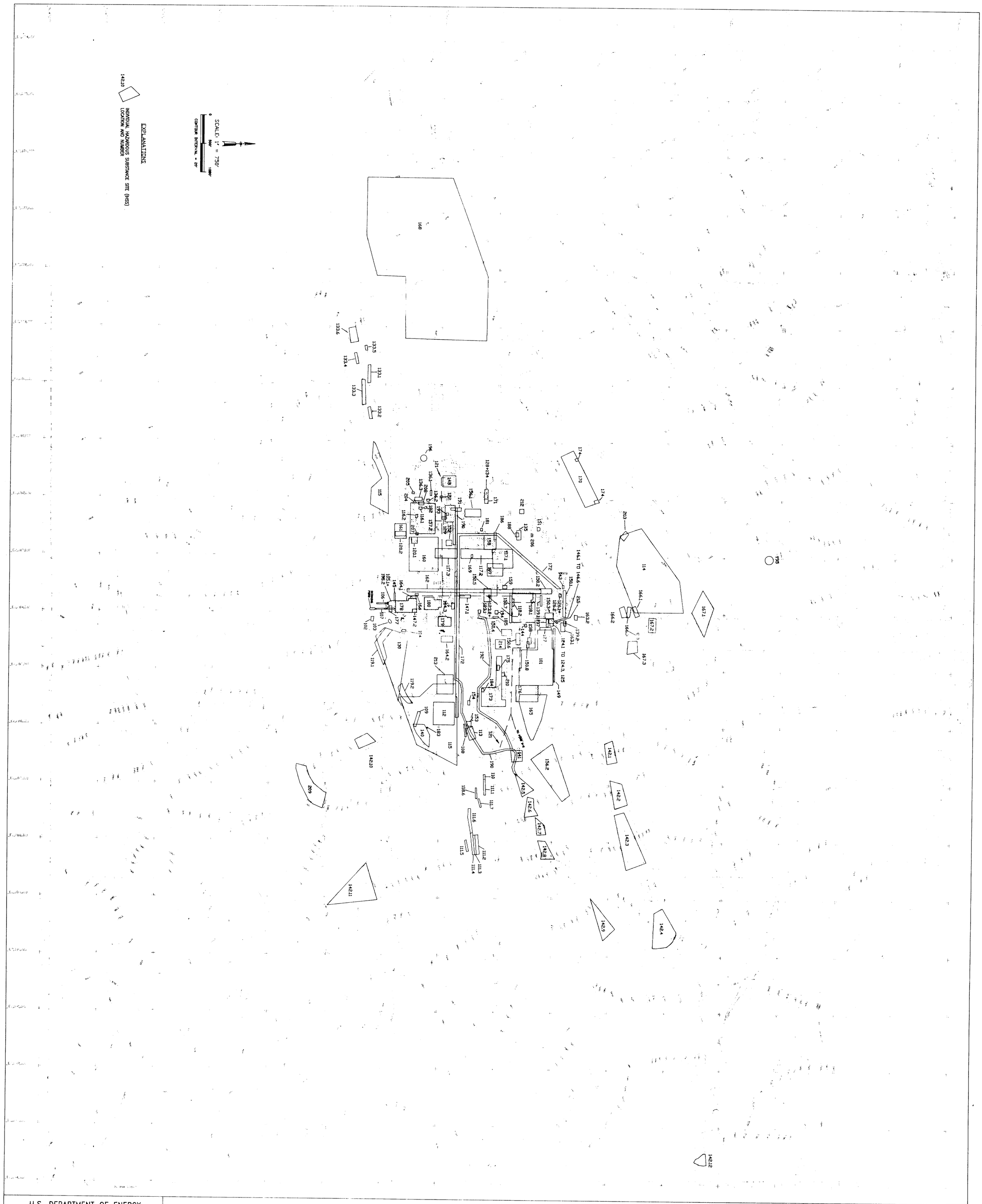
(10) THE PROCEDURE OF COHEN (1959) IS USED TO ESTIMATE THE MEAN AND STANDARD DEVIATION OF A CENSORED DATA SET CONTAINING BETWEEN 15 AND 50 PERCENT NONDETECT VALUES COHEN S PROCEDURE IS NOT ALWAYS SUCCESSFUL WHEN DATA SETS CONTAIN MULTIPLE REPORTING LIMITS WHEN COHEN S PROCEDURE CANNOT BE USED THE ORIGINAL UNREVISED STATISTICS WILL BE USED TO COMPUTE TOLERANCE INTERVALS THE COHEN METHOD WILL NOT BE USED IF THE HELSEL METHOD (1990) HAS BEEN APPLIED

(11) EITHER NORMAL OR LOG NORMAL TOLERANCE INTERVALS ARE CALCULATED DEPENDENT UPON THE DISTRIBUTION OF THE ANALYTE THE INTERVALS HAVE 95 PERCENT COVERAGE WITH A CONFIDENCE LEVEL OF 95 PERCENT

FIGURE 4–1

METHODOLOGY FOR COMPUTATION OF BACKGROUND STATISTICS

R69013 MBCW–022492



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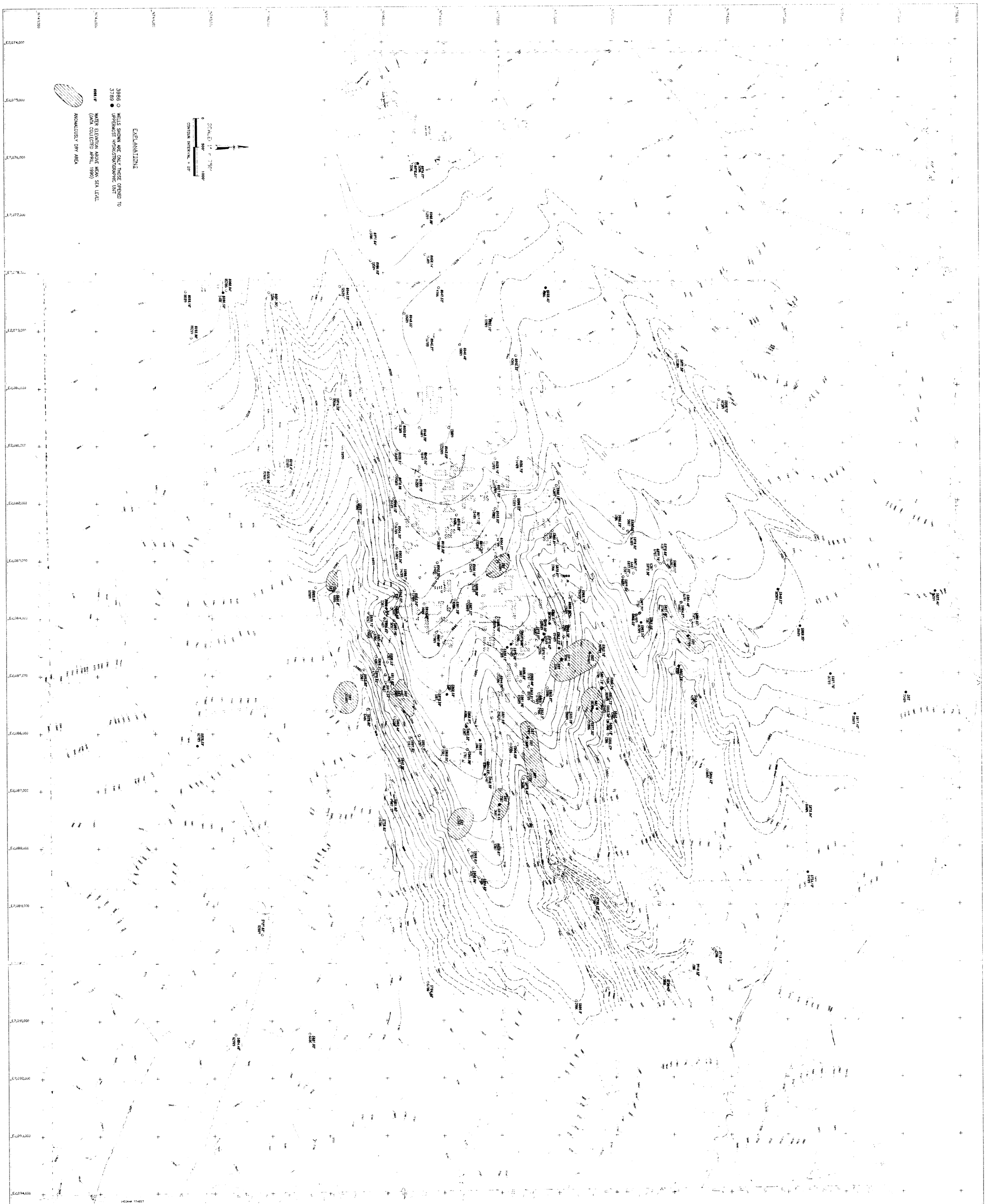
EG&G ROCKY FLATS
ROCKY FLATS PLANT, GOLDEN, COLORADO

PLATE 1

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN
INDIVIDUAL HAZARDOUS SUBSTANCE SITES

NO.	DATE	REVISION

RF9400SCH01259/7/90



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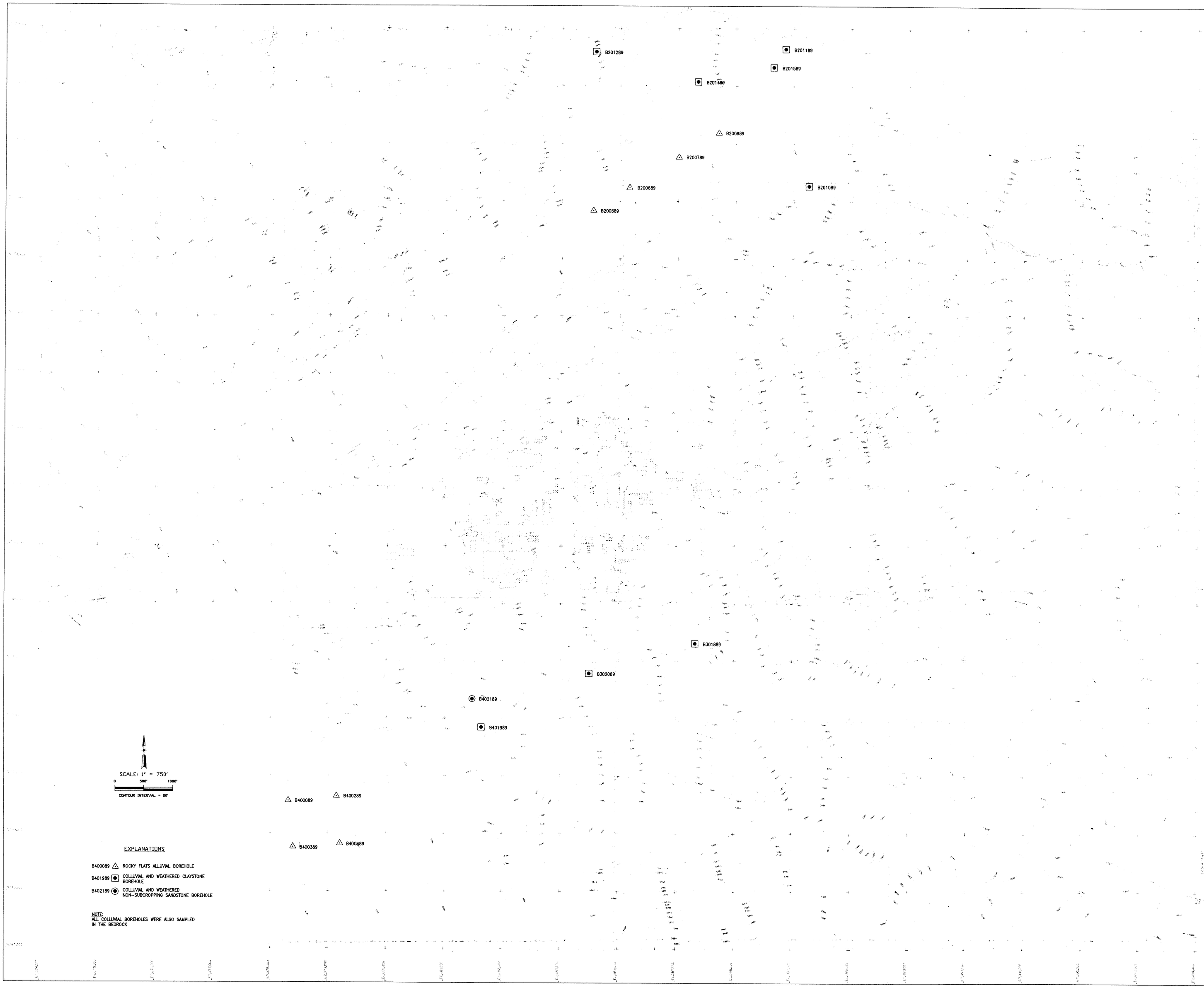
BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN
WATER TABLE ELEVATION OF SURFICIAL MATERIALS

NOTE:
WELL NUMBERS ARE SHOWN WITHOUT THE LEADING LOCATION IDENTIFIER. FOR EXAMPLE WELL B302089 IS SHOWN AS 02089.

NO.	DATE	REVISION

7/90 26022BDMEY90046.DGN



NO.	DATE	REVISION

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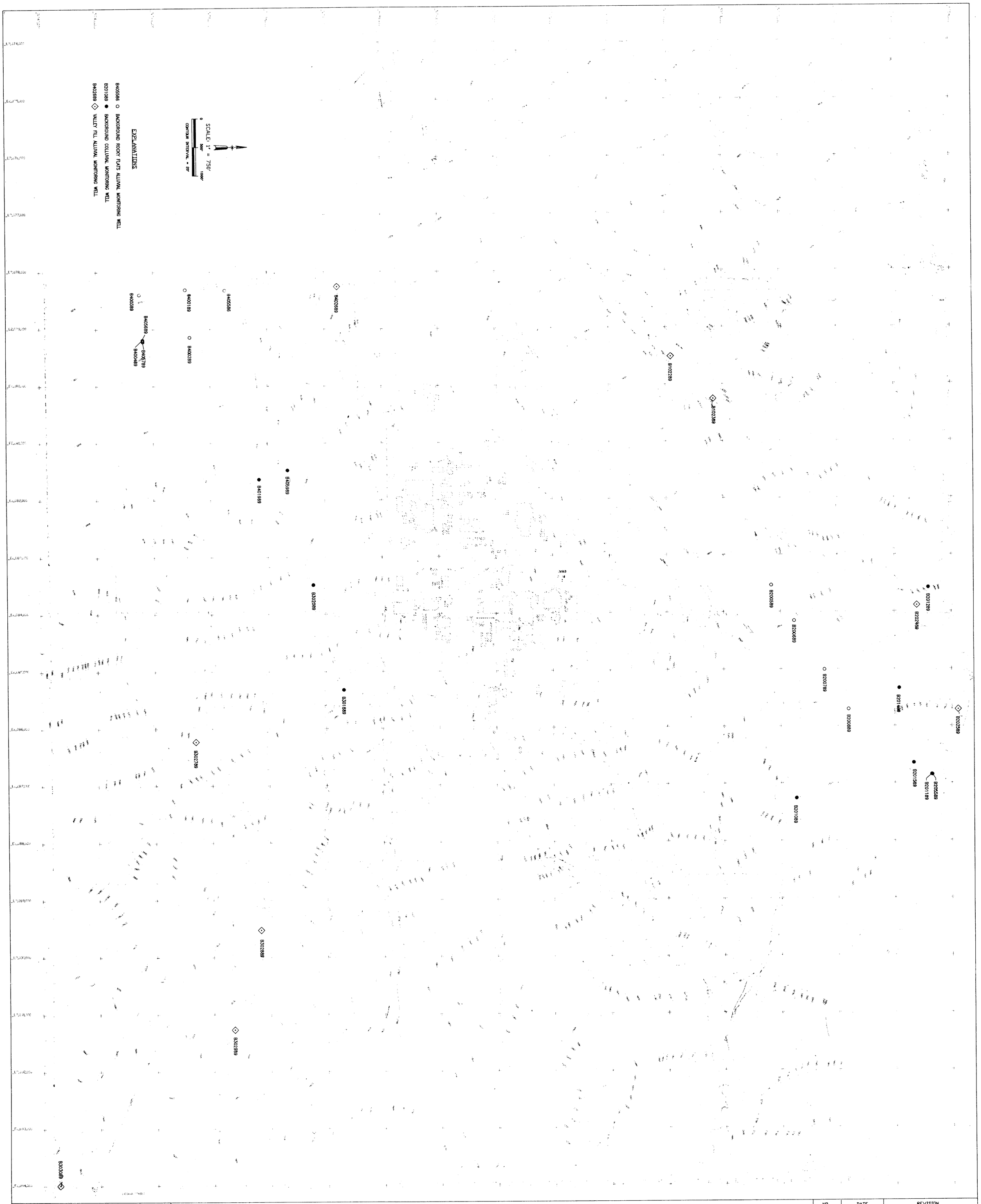
ROCKY FLATS PLANT, GOLDEN, COLORADO

PLATE 3

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN

BACKGROUND BOREHOLES

R69H003JN8012392/750



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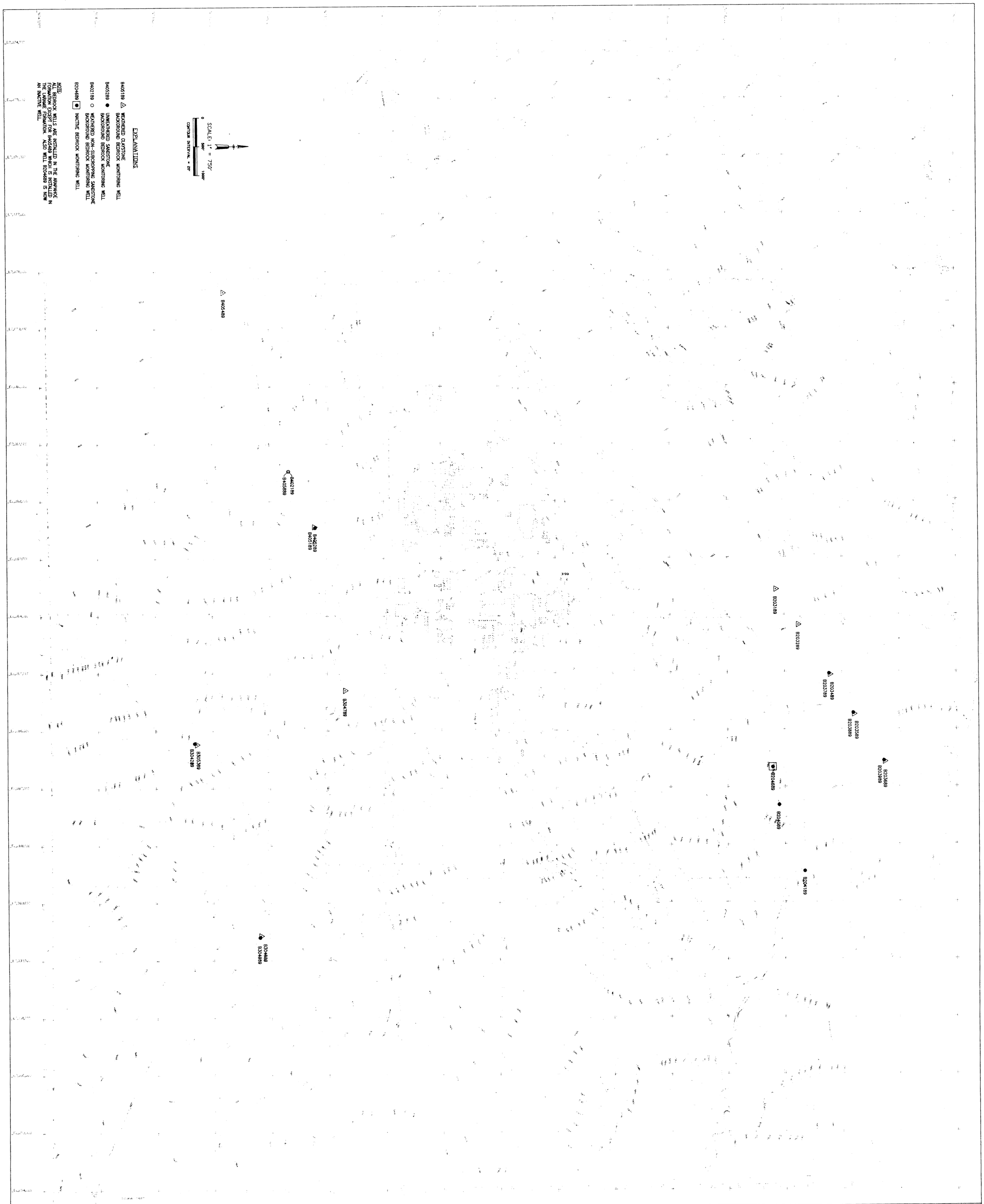
ROCKY FLATS PLANT, GOLDEN, COLORADO

PLATE 4

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN
BACKGROUND ALLUVIAL MONITORING WELLS

NO.	DATE	REVISION



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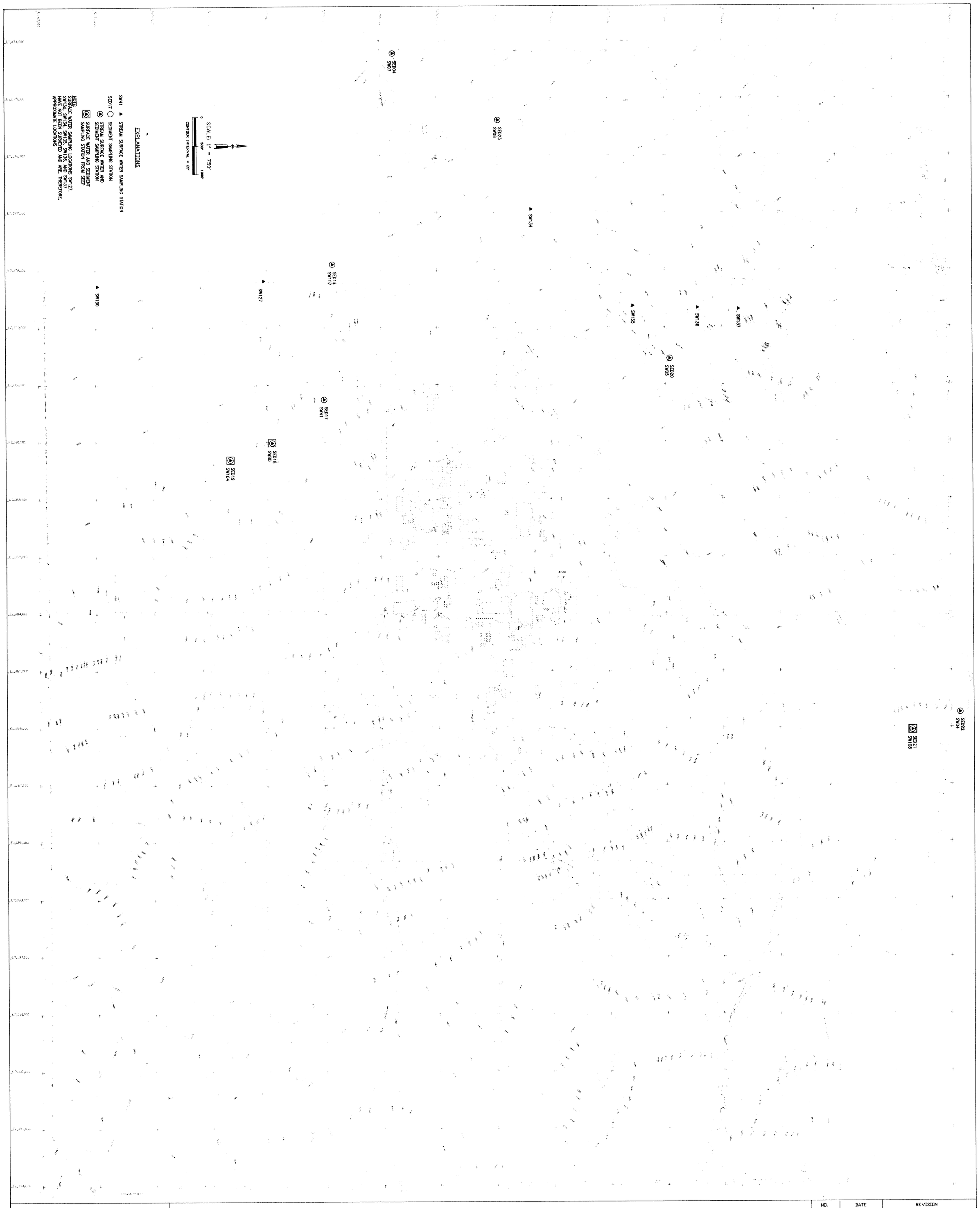
ROCKY FLATS PLANT, GOLDEN, COLORADO

PLATE 5

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN
BACKGROUND BEDROCK MONITORING WELLS

NO.	DATE	REVISION



U.S. DEPARTMENT OF ENERGY

EG&G ROCKY FLATS

ROCKY FLATS PLANT, GOLDEN, COLORADO

PLATE 6

BACKGROUND GEOCHEMICAL CHARACTERIZATION PLAN
BACKGROUND SURFACE WATER AND
SEDIMENT SAMPLING STATIONS

NO.	DATE	REVISION

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