PRELIMINARY DRAFT

PHASE II RFI/RI REPORT
903 PAD, MOUND AND EAST TRENCHES AREA
OPERABLE UNIT NO. 2

VOLUME 1

SECTIONS 1.0, 2.0 AND 3.0
Text, Tables, and Figures

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U.S. Department of Energy
Rocky Flats Plant
Golden, Colorado

ADMIN RECORD

December 1993

OU02-A-001577

(4040-1030-0041-510) (FINAL.CVR) (12/15/93 4:54pm)

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LIST OF ACRONYMS

µCi/l	microcuries per liter
µg/kg	micrograms per kilogram
µg/l	micrograms per liter
1,1-DCE	1,1-dichloroethene
1,1,1-TCA	1,1,1-trichloroethane
1,2-DCA	1,2-dichlorethane
1,2-DCE	1,2-dichloroethene
AGS	above ground surface
Am-241	Americium-241
ANOVA	Analysis of Variance
ARARs	applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
ATD	At time of drilling
Be	beryllium
BGS	below ground surface
BH	borehole
BNA	base neutral acid extractable
Ca	calcium
CCl_4	Carbon tetrachloride
CDH	Colorado Department of Health
CEARP	Comprehensive Environmental Assessment & Response Program
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHC	chlorinated hydrocarbons
$CHCl_3$	chloroform
Cis-1,2-DCE	cis-1,2-dichloroethene
CLP	Contract Laboratory Program
cm/sec	centimeters per second
cm	centimeter
CME	Central Mine Equipment
CMS/FS	Corrective Measures Study/Feasibility Study
COCs	chemicals of concern
COI	chemicals of interest

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cpm	counts per minute
CRDL	contract required detection limit
CRQL	contract required quantitation limit
CS	claystone
CSM	conceptual site model
DCN	document change notice
DF10 qualifier	10x dilution
DF50 qualifier	50x dilution
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DOE	Department of Energy
DQO	Data Quality Objective
DRCOG	Denver-Regional Council of Governments
EE	Environmental Evaluation
EMD	Environmental Management Department
EPA	Environmental Protection Agency
ERDA	Energy Research and Development Admininstration
FDM	Fugitive Dust Model
FIDLER	field instrument for the detection of low-energy radiation
FS	feasibility study
FSP	field sampling plan
ft^2/min	square feet per minute
FWHM	full width half maximum
GC/MS	gas chromatography/mass spectrometry
g/cm^3	gram per cubic centimeter
gpm	gallons per minute
GPR	ground-penetrating radar
GRRASP	General Radiochemistry and Routine Analytical Services Protocol
HASL	Health and Safety Laboratory
HEPA	High Efficiency Particulate Air
HQ	Hazard Quotient
HRR	Historical Release Report
HSL	Hazardous Substances List
HSU	hydrostratigraphic unit
ID	inside diameter
IDL	instrument detection limit

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IHSS	Individual Hazardous Substance Site
K	hydraulic conductivity
Ka	Arapahoe formation
LHSU	lower hydrostratigraphic unit
Li	lithium
MDA	minimal detectable activity
mg/kg	milligrams per kilogram
mg/l	milligrams per liter
Mg	magnesium
mm Hg	millimeters of mercury
MSA	Method of Standard Addition
MW	monitoring well
Na	sodium
NA	not applicable
NAAQS	National Ambient Air Quality Standards
NAPL	Non-aqueous phase liquid
NCP	National Contingency Plan
NE	not encountered
NP	non-plastic
NPDES	National Pollutant Discharge Elimination System
OD	outside diameter
OB	Observation Well
OVM	organic vapor monitor
PA	protected area
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCE	tetrachloroethene
pcf	pounds per cubic foot
pCi/l	picocuries per liter
pCi/ml	picocuries per milliliter
pCi/g	picocuries per gram
pCi/m^3	picocuries per cubic meter
PID	photoionization detector
ppm	parts per million
Pu-239/240	plutonium-239/240
Pu-239	plutonium-239

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PVC	polyvinyl chloride
PW	pumping well
QA/QC	quality assurance/quality control
QAA	Quality Assurance Addendum
Qal	valley fill alluvium
QAPjP	Quality Assurance Project Plan
Qc	colluvium
QC	quality control
Qrf	Rocky Flats Alluvium
R	radius of influence
RAAMP	Radiological Ambient Air Monitoring Program
RAD screen	radiological screen
RBWP	Revised Bedrock Work Plan
RCRA	Resource Conservation and Recovery Act
RDL	required detection limit
RFEDS	Rocky Flats Environmental Database System
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
RI	remedial investigation
ROD	Record of Decision
SAP	sampling and analysis plan
SB	source borehole
SCS	Soil Conservation Service
SEAM	Superfund Exposure Assessment Manual
SID	South Interceptor Ditch
SOP	Standard Operating Procedure
SOW	Statement of Work
SVOC	semivolatile organic compound
SWMS	Soil Water Monitoring System
SWMU	Solid Waste Management Unit
TAL	target analyte list
TCE	trichloroethene
TCL	Target Compound List
TD	total depth
TDR	time domain reflectometry
TDS	total dissolved solids

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TIC	tentatively identified compound
TM1	Technical Memorandum No. 1
TM3	Technical Memorandum No. 3
TOC	total organic carbon
TPH	total petroleum hydrocarbon
TR	trench
TRC	total residual chlorine
TSP	total suspended particulate
TSS	total suspended solids
U	uranium
U-234	uranium-234
U-235	uranium-235
U-238	uranium-238
UHSU	upper hydrostratigraphic unit
USCS	Unified Soil Classification System
USLE	Universal Soil Loss Equation
UTL	upper tolerance limit
VOC	volatile organic compound
WARP	Well Abandonment and Replacement Program

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1.0
INTRODUCTION

The Environmental Restoration (ER) Program for the Rocky Flats Plant (RFP) is designed to investigate and remediate contaminated sites at RFP and involves the following five major activities:

Activity 1	Installation Assessments
Activity 2	Remedial Investigations
Activity 3	Feasibility Studies
Activity 4	Remedial Designs/Remedial Actions
Activity 5	Compliance

This report presents the results of the Operable Unit No. 2 (OU-2) Phase II Resource Conservation and Recovery Act (RCRA) Facility Investigation/Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Remedial Investigation (RFI/RI), which is one component of Activity 2 noted above.

Activity 2 at OU-2 (also known as the 903 Pad, Mound, and East Trenches Areas) includes Phase I and Phase II remedial investigations. A Phase I field program was completed and a draft remedial investigation report (Rockwell International 1987c) prepared in 1987. Based on the results, Phase II RFI/RI Work Plans (DOE 1991a, 1991b, and 1993a) were submitted to U.S. Environmental Protection Agency (EPA) and Colorado Department of Health (CDH) in 1991 and 1993 and Phase II field work performed in 1991 through 1993.

This report summarizes the field activities performed during the Phase II alluvial and bedrock field investigations; characterizes the contaminant sources, defines the nature and extent of contamination in surface soils, subsurface soils, groundwater, surface water, sediments, air, and biota; discusses contaminant fate and transport; characterizes the environmental setting; and includes a Baseline Risk Assessment. These results are used to develop remedial action objectives.

This section provides an introduction and presents the organization of the Phase II RFI/RI report; the investigation objectives, a brief discussion of the background of RFP including plant operations, OU-2 Individual Hazardous Substance Site (IHSS) locations and descriptions, a

summary of previous investigations; and a summary of Phase II RFI/RI work plans and technical memoranda.

1.1 REPORT ORGANIZATION

The OU-2 Phase II RFI/RI Report is organized into ten major sections including references, and appendixes:

- Section 1.0, Introduction, describes the report organization, presents the investigation objectives and background information, and provides detailed summaries of workplans and technical memoranda.

- Section 2.0, OU-2 Field Investigations, presents the scope of the Phase II alluvial and bedrock investigations, describes the field activities performed, sampling procedures and analytical methods, and documents deviations from the workplans*. This section also discusses on-going sitewide investigations that collect air quality, surface water and sediment data from OU-2 that will be used in the site characterization.

- Section 3.0, Physical Characteristics of OU-2, describes the existing physical conditions, meteorology, climatology, soils, geology, hydrogeology, surface water hydrology, and ecology of OU-2.

- Section 4.0, Nature and Extent of Contamination, describes the nature and extent of contamination in surface soil, subsurface soils, groundwater surface water, air, and biota (media). This section begins with a description of the available data and their useability, the data validation process, how data are compared to background data, and how infrequently detected compounds are evaluated. A detailed description of the nature and extent of contamination in each media is presented for the following areas: (1) 903 Pad Area, (2) Mound Area, (3) Northeast Trenches Area, and (4) Southeast Trenches Area. However, the discussion relating to groundwater will be addressed on an OU-2-wide basis and discussed separately.

- Section 5.0, Contaminant Fate and Transport, discusses the factors that affect the movement and persistence of the contaminants identified in Section 4.0. This section also discusses the OU-2 potential routes of contaminant migration, and includes a summary of the fate and transport modeling performed to support the risk assessment.

- Section 6.0, Baseline Health Risk Assessment, presents a summary and the results of the Baseline Health Risk Assessment Report specific to OU-2 (the complete Baseline Health Risk Assessment Report is presented in Appendix H).

- Section 7.0, Environmental Assessment, presents a summary of the evaluation of the nature and extent of contamination in biota, its relationship to abiotic sources, and the extent and type of adverse effects on the ecosystem, community, population and individual levels of biological organizations (the complete Environmental Evaluation report is presented in Appendix I).

- Section 8.0, Summary and Conclusions, presents a brief summary of the findings of the report and recommends remedial action objectives (RAOs).

- Section 9.0 contains the References cited in the report.

- Appendixes

  - Appendixes A, B, and C provide supporting geologic, hydrogeologic, and analytical data, respectively.

  - Appendix D presents the details of the surface soils investigation and results.

  - Appendix E provides the detailed methodology, assumptions and results of the groundwater modeling.

  - Appendix F provides the detailed methodology, assumptions, and results of the surface water modeling.

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- Appendix G provides the detailed methodology, assumptions, and results of the air modeling.

- Appendix H is the Baseline Health Risk Assessment Report.

- Appendix I is the Environmental Evaluation Report.

- Appendix J provides details of the quality assurance procedures implemented for this project.

*The alluvial investigation program involved investigation of the Upper Hydrostratigraphic Unit (UHSU) of OU-2 that includes the unconsolidated surficial geologic materials (i.e., the Rocky Flats Alluvium, colluvium, terrace deposits, valley fill alluvium, debris fans, slumps, and man-made deposits), the Arapahoe No. 1 Sandstone, and the weathered claystones of the Arapahoe and/or Laramie Formations. The bedrock investigation program involved investigation of the Lower Hydrostratigraphic Unit (LHSU) that includes the sandstones, siltstones, and unweathered claystones of the Upper Laramie Formation. It should be noted that the objectives of the alluvial and the bedrock programs are different. The alluvial investigation was a broad-based investigative program while the bedrock investigation was a focused program, investigating specific concerns. Therefore, the information presented in Sections 3.0 (Geology and Hydrogeology) and Section 4.0 (Nature and Extent) that pertain to the LHSU will differ in presentation and detail, in some cases, from those presented for the UHSU.

1.2 INVESTIGATION OBJECTIVES

The primary objective of the Phase II RFI/RI is to further characterize the site and provide a baseline risk assessment for OU-2 for developing RAOs. The specific Phase II RFI/RI objectives, as presented in the alluvial work plan (TM1) (DOE 1991a), are presented below:

Characterize Site Physical Features

- Determine the extent of saturation of and groundwater flow directions for the unconfined flow system both spatially and temporally.

- Describe the interaction between the surface water and groundwater pathways.

- Determine the hydraulic connection between surficial deposits and bedrock and quantify material properties.

- Delineate the Arapahoe Formation sandstones.

Characterize Contaminant Sources

- Characterize the nature and distribution of waste materials remaining on site.

- Characterize soils beneath wastes as well as soils at sites where wastes have been removed as potential contaminant sources.

- Identify which sites are sources of groundwater and surface water contamination.

Characterize the Nature and Extent of Contamination

- Determine the horizontal and vertical extent of radionuclide contamination in surficial soils due to wind dispersion.

- Determine the nature and extent of groundwater contamination.

- Characterize surface water and seep quality.

- Describe contaminant fate and transport.

Provide Data for Baseline Risk Assessment

- Assess the threat to public health and the environment from the no action remedial alternative.

Provide Data for Feasibility Study

- Develop RAOs

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Provide Data for Environmental Evaluation

- Assess the bioavailability and toxicity of the contaminants to the flora and fauna.

The specific Phase II RFI/RI objectives for the bedrock program as presented in the Revised Bedrock Work Plan (TM8) (DOE 1993a) are presented below:

- Evaluate the presence or absence of contamination in LHSU units and if present, the source, nature, and vertical extent of contaminants in the LHSU.

- Estimate the permeability of LHSU units containing contamination to evaluate whether viable migration pathways to human receptors exist, or if the LHSU units have sufficient well production capability to supply an on-site resident.

This TM8 field program is a refinement of the program previously described in the Bedrock Work Plan (DOE 1991b) using the "observational approach" methodology.

The TM8 field program focused on gathering data to sufficiently verify that contamination associated with potential LHSU exposure pathways is limited and that the LHSU exposure pathway is an incomplete pathway to human receptors.

1.3 BACKGROUND

The following sections describe in general the plant operations at RFP and summarize the historical activities at each IHSS located within OU-2.

1.3.1 Plant Operations

RFP located northwest of Denver, Colorado, (Figure 1.3-1), is a government-owned, contractor-operated facility, which is part of the nationwide nuclear weapons production complex. RFP 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 RFP was assigned to the Energy Research and Development Administration (ERDA), which was succeeded by the Department of Energy (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 RFP from

July 1, 1975, until December 31, 1989. EG&G, Rocky Flats, Inc., became the prime contractor at RFP on January 1, 1990, and currently operates the facility.

The primary mission of RFP was to fabricate nuclear weapon components from plutonium, uranium, and other non-radioactive metals (principally beryllium and stainless steel). Parts made at RFP were shipped elsewhere for assembly. In addition, RFP reprocessed components after they were removed from obsolete weapons for recovery of plutonium.

Both radioactive and nonradioactive wastes were 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, radioactive mixed wastes occurred on site in the past. Preliminary assessments under the Environmental Restoration Program identified some of the past on-site storage and disposal locations as potential sources of environmental contamination.

1.3.2 OU-2 Individual Hazardous Substance Sites (IHSS) Locations

OU-2 contains the 903 Pad, Mound, and Northeast and Southeast Trenches IHSS Areas located on the east side of the RFP protected area (PA). The boundaries of OU-2 are shown on Figure 1.3-2. Several IHSSs are included in each IHSS area because of their physical proximity to each other. Each IHSS was assigned an IHSS reference number by Rockwell International (1987a) The IHSSs and their respective reference numbers are presented in Table 1.3-1. Figure 1.3-3 shows previously identified IHSS boundaries and revised IHSS boundaries. The IHSS boundaries were revised in the Historical Release Report (HRR) (DOE 1992a) based on reevaluation of areal photographs and other historical records of waste disposal practices in OU-2.

Because the 1991 field investigations were performed prior to revision of the IHSS boundaries in the HRR, the well and borehole locations specified in the alluvial program work plan (DOE 1991a) were based on the previous IHSS boundaries. However, when the wells and boreholes were located in the field, their locations were adjusted, within limits allowed by the work plan, based on visual evidence of trench locations in the field (i.e., depressions or mounding). A comparison of the revised IHSS boundaries relative to the wells and boreholes drilled during the 1991 field program, indicated each identified revised IHSS location was adequately characterized by boreholes and wells, with the following exceptions.

Additional information reported in the HRR indicates that two previously unidentified trenches and a spray field are located in OU-2 (Figure 1.3-3). One trench is located west of IHSS 111.6 (Trench T-9) in the Southeast Trenches Area, beneath the present East Access Road. This trench has been designated as Trench T-12. The second trench (designated as Trench T-13) is located approximately 500 feet east-northeast of the Inner East Gate guard station and south of IHSS 111.8 (Trench T-11). The spray field is located north of Central Avenue and east of Trenches T-4 and T-10. The spray field has been designated as the East Spray Field (IHSS 216.2). Because these two trenches were identified after completion of the 1991 field investigation, they were not specifically addressed during the investigation. However, a review of borehole data for OU-2 indicates that the Trench T-12 location was drilled and sampled as part of the Well Abandonment and Replacement Program (WARP) in 1992. That program performed soil sampling and analysis activities in the borehole for well 46792 that are similar to those performed for the alluvial field program. Thus, comparable data are available for characterizing Trench T-12 as are available for the other trenches. Those data are included in this Phase II RFI/RI Report and were used in the characterization of nature and extent of contamination (Section 4.3.4.6).

The second trench, Trench T-13, has not been specifically investigated due to its location beneath Central Avenue, which makes it inaccessible for drilling. However, based on information presented in the HRR, it is believed that the waste disposed of in Trench T-13 is similar to that disposed of in the other Northeast Trenches Area IHSSs (i.e., primarily sewage sludge, Section 4.3.3.5). Therefore, the nature and extent of potential contamination in this trench is expected to be similar to that observed for the other trenches. Because this trench is similar to the other trenches in the Northeast Trenches Area, and sufficient groundwater monitoring wells are present in this area to adequately characterize any potential effects to groundwater from this trench, it was judged that specific investigation of this trench is not necessary at this time to meet the needs of the Phase II RFI/RI Report, and, therefore, it was not performed.

The East Spray Field (IHSS 216.2), has not been specifically investigated during the Phase II investigation. However, two plume characterization wells (05391 and 12391) were installed beneath this IHSS and a biased surface soil plot was located within this IHSS. Spray irrigation at IHSS 216.2 was similar to irrigation at IHSS 216.3, therefore the subsurface soil samples collected from beneath IHSS 216.3 will be used to characterize IHSS 216.2.

Site descriptions presented in the following sections are taken from the RFP Comprehensive Environmental Assessment and Response Program (CEARP) Phase 1 Report (DOE 1986a), the RCRA Part B Operating Permit Application (Rockwell International 1987a), and the HRR (DOE 1992a). These descriptions are based on historical records, aerial photography review, and interviews with RFP personnel. Further characterization of each site based on other historical reports and the Phase I RFI/RI results is also included in the following discussions.

1.3.2.1 903 Pad Area

Five sites are located within the 903 Pad Area (Figure 1.3-3). These sites are:

- 903 Drum Storage Site (IHSS 112)
- 903 Lip Site (IHSS 155)
- Trench T-2 Site (IHSS 109)
- Reactive Metal Destruction Site (IHSS 140)
- Gas Detoxification Site (IHSS 183)

Descriptions of each site within the 903 Pad Area are provided in the following sections.

903 Drum Storage Site (IHSS 112)

The 903 Drum Storage Site, also referred to as the 903 Pad, is located southeast of RFP PA. This IHSS was active from the summer of 1958 to January 1967 for storage of drums containing radioactively-contaminated oils and solvents. Presented below is a description of drums stored at the drum storage site from Calkins (1970).

> "Most of the drums transferred to the field were nominal 55-gallon drums, but a significant number were 30-gallon drums. Not all were completely full. Approximately three-fourths of the drums were plutonium-contaminated, while most of the balance contained uranium. Of those containing plutonium, most were lathe coolant consisting of a straight-chain hydrocarbon mineral oil (Shell Vitrea) and carbon tetrachloride in varying proportions. Other liquids were involved, however, including hydraulic oils, vacuum pump oil, trichloroethylene, perchloroethylene, silicone oils, acetone still bottoms, etc. Originally, contents of the drums were indicated on the outside, but these markings were made illegible through weathering and no other good records were kept of the

contents. Leakage of the oil was recognized early, and in 1959 or possibly earlier ethanolamine was added to the oil to reduce the corrosion rate of the steel drums."

Drum leakage was noted at the 903 Drum Storage Site in 1964 during routine handling operations (Dow Chemical 1971). Corrective action consisted of transferring the contents of leaking drums to new drums and fencing the area to restrict access (Dow Chemical 1971). Approximately 420 drums leaked to some degree, and of these, an estimated 50 leaked their entire contents (Dow Chemical 1971). An estimated 5,000 gallons of liquid (Freiberg 1970) containing 86 grams (g) (5.3 curies [Ci]) of plutonium leaked into the soil (Dow Chemical 1971). A heavy rainstorm in August 1967 spread contaminants to a ditch south and southeast of the drum storage site (Dow Chemical 1971); however, the location of the ditch is not provided in this reference. During an investigation conducted by the AEC Health and Safety Laboratory (HASL), it was estimated that approximately 125 grams of Pu-239 were released from the 903 Drum Storage site and redistributed by winds (Krey and Hardy 1970).

Drum storage at the 903 Drum Storage site occurred primarily in the northern and eastern portions of the area. Drums were not stored in the southwest portion where Building 903 was constructed in 1967, and were only briefly stored at the southeast corner. It appears that the drums stored south of the fenced area were placed at this location during cleanup operations because they appear only in the 1968 aerial photos.

The shipment of drums to the 903 Drum Storage Site ended in January 1967 when drum removal efforts began. Removal of all drums and wastes was completed in June 1968. Presented below is a chronology of the 930 Drum Storage Site remediation as described by Freiberg (1970). Figure 1.3-4 is a facilities map showing locations of the buildings identified below.

- From January 23, 1967, through March 10, 1967, uranium oil drums that were in good condition were transferred to Building 774 and processed.

- On March 10, 1967, Building 903 started processing oil drums. This building was designed to prefilter the oil prior to transferring plutonium-contaminated oil to Building 774 for final processing.

- From March 10, 1967, through May 18, 1967, there were a total of 191 drums of plutonium contaminated oil filtered and shipped to Building 774.

- On May 18, 1967, operations at Building 903 were discontinued due to the amount of time this process was taking.

- Drum-to-drum transfer in the field began May 18, 1967, and the drums were shipped to Building 774 without prior filtration in Building 903.

- From March 17, 1967, through May 10, 1967, in addition to the plutonium transfers, there were 297 drums of uranium-contaminated Alk-Tri waste shipped to Building 774 and processed.

- May 10, 1967, through May 28, 1968, a total of 4,826 drums, containing 50 gallons of oil each, were sent to Building 774 and processed.

- In addition to the oil storage area drums, there were 650 drums from Building 776 current generation sent to Building 774 for processing. A pipeline installed from Building 775 to Building 774 eliminated this additional oil drum generation.

- During transfer operations, it was noted that at the bottom of all drums a deposit of sludge remained after removal of oil. This sludge varied in depth from 1/2 inch to 3 inches and averaged approximately 1 inch. By drum counter results, the sludge within the empty drums contained a total of 5,152 grams of plutonium. These empty drums were later disposed of by adding Oil Dry and MicroCel to absorb the sludge. The drums containing the plutonium sludge and absorbent were then incased in plastic, placed in boxes, and shipped to the burial grounds. The location of the burial grounds is not provided by Freiberg (1970).

There were originally a total of 5,237 drums at the drum storage site when cleanup operations began in 1967. After transfer of the contents to new drums, 4,826 drums were transported to Building 774; of those drums, 3,572 drums contained plutonium-contaminated oil. This leaves unaccounted the contents of 411 drums. The most probable explanation for this discrepancy, according to Freiberg (1970), is a combination of the following factors:

- All of the drums originally sent to the storage site were not completely full.

- Some of the volume was taken up by the sludge which was discarded with the empty barrels.

- Leakage out of the barrels and onto the ground occurred.

Information provided by Freiberg (1970) indicates that an estimated 5,000 gallons of oil leaked from drums onto the ground at the storage site. This estimate was based on the memory and knowledge of those involved in site operations (Freiberg 1970). Based on oil samples taken from barrels, the average plutonium concentration was 4.54×10^{-3} grams per liter (g/l) (9280 microCuries per liter [μCi/l]). Thus, approximately 85 g (5.3 Ci) of plutonium were released to soils at the drum storage site (Freiberg 1970).

In November 1968, site grading began at the 903 Drum Storage Site in preparation for applying an asphalt cap over the area. This work included moving "slightly" contaminated soil from around the fenced area to inside the fenced area (Freiberg 1970). A total of 33 drums of radioactively contaminated rocks were removed from the area in May 1969, and two courses of clean fill material were placed over the site during the late summer of 1969. The disposal location of the 33 drums was not provided by Freiberg (1970) and is unknown. The asphalt was applied in October 1969, and in February 1970, additional road base coarse material was applied to soils directly east and south of the asphalt pad due to soil contamination (Freiberg 1970).

The asphalt containment cover is rectangular and oriented north-south (370 feet) and east-west (395 feet). The pad slopes slightly to the northeast at a drop of one foot per 100 feet. The asphalt cover is approximately eight centimeters (cm) (3.2 inches) thick and it is underlain by approximately fifteen cm (6 inches) of loose gravel and eight cm (3.1 inches) of fill dirt (Navratil et al. 1979).

903 Lip Site (IHSS 155)

During drum removal and cleanup activities associated with the 903 Drum Storage Site, winds and rain redistributed plutonium beyond the pad, primarily to the south and east extending to the southeast perimeter road. Approximately 16 grams of plutonium-239 were redistributed beyond the asphalt pad, in an area exceeding 2,000 acres. The most contaminated area was immediately adjacent to the pad to the south and southeast.

Soil cleanup efforts were undertaken in 1976, 1978, and 1984 to remove plutonium-contaminated soils from three different areas within the 903 Lip Site. The 1976 cleanup consisted of hand-excavating contaminated soils from an area in the vicinity of the Reactive Metal Destruction Site. Approximately 4,000 cubic feet, or 148 cubic yards, of soil were removed from the hot spot within the lip area. Removal of soil took place in a portable building equipped with a HEPA filter. The excavated area was covered with clean top soil and reseeded with native grasses.

The 1976 hand-excavation soil removal technique was inefficient considering the large amount of contaminated soils requiring removal at the 903 Lip Site. In June 1978, a second soil removal project began north of the 1976 removal site, using a front-end loader alone or in conjunction with a bull dozer. All soil that exceeded 2,000 cpm, as determined by a FIDLER survey, was removed. The area of soil removal covered an estimated 43,000 square feet and was approximately 9 inches deep. Cleaned areas were resurveyed and soil removal continued until background readings (approximately 250 cpm by a FIDLER survey) were obtained. Topsoil was then applied to the excavated area, and the site was revegetated with native grasses. During the 1978 soil removal, 1,448 waste crates were removed and shipped off site.

Approximately 0.5 Ci (8.2 g) of plutonium were removed from the 903 Lip Site during the first two soil removal projects. This quantity is based on an average soil plutonium concentration of 545 pCi/g (1,200 dpm/g) and a soil density of one gram per cubic centimeter (g/cm^3) (Barker 1982).

A third soil cleanup was performed along the eastern edge of the 903 Lip Site in 1984. A total of 214 tri-wall pallets of contaminated soil were removed from the area; however, the soil disposal location was not provided by Setlock (1984). The excavated area was backfilled with clean topsoil (Setlock 1984).

Trench T-2 Site (IHSS 109)

Trench T-2, as shown on Figure 1.3-3, is located south of the 903 Drum Storage Site and west of the Reactive Metal Destruction Site. It has been stated that the function of T-2 was similar to that of the East Trenches and that prior to 1968, sanitary sewage sludge and flattened empty drums contaminated with uranium and plutonium were disposed of in the trench. However, the HRR states that Trench T-2 was used from approximately 1969 to 1971 for the disposal of nonradioactive liquid chemical wastes and that Trench T-2 was known as "Ryans Pit." It is believed that nonradioactive solvents were dumped in the trench as a method of disposal. The

solvents, disposed of in small quantities, included perchloroethylene, trichloroethylene, and possibly carbon tetrachloride. Other chemicals that were dumped included paint thinner and small quantities of construction-related chemicals. Trench T-2 is believed to measure approximately 10 feet wide by 20 feet long by 5 feet deep and has been backfilled and graded (Rockwell International 1987a and DOE 1992a). Barrels were noted in the western end of Trench T-2 during 1987 investigations.

Reactive Metal Destruction Site (IHSS 140)

The Reactive Metal Destruction Site, also known as the Hazardous Disposal Area, is located on the hillside south of the 903 Drum Storage Site (Figure 1.3-3). This site was used during the 1950s and 1960s primarily for the destruction and disposal of lithium (Li) metal (DOE 1986a). Approximately 400 to 500 pounds of metallic lithium were destroyed on the ground surface in this area and the residues, primarily nontoxic lithium carbonate, were buried (Illsley 1978). Smaller unknown quantities of sodium (Na), calcium (Ca), and magnesium (Mg), solvents, and unknown liquids were also destroyed at this location. Nickel carbonyl and iron carbonyl are believed to have been disposed of in this area in 1969. Historical references do not indicate the method by which constituents were destroyed at the site.

Based on review of historical aerial photography, the Reactive Metal Destruction Site was used from 1968 to 1971. Barrels were noted in the southwestern corner of IHSS 140 during 1987 investigations.

Gas Detoxification Site (IHSS 183)

Building 952, located south of the 903 Drum Storage Site (Figures 1.3-3 and 1.3-4), was used to detoxify various gases from lecture bottles between 1963 and 1983. This building is located within the 903 Lip Area, but not in the area of greatest soil contamination which was remediated in 1978. Each lecture bottle held approximately one liter of compressed gas each. The gases consisted of various types of nitrogen oxides, chlorine, hydrogen sulfide, sulfur tetrafluoride, methane, hydrogen fluoride, and ammonia, which were used in RFP research and development work. Gas detoxification was accomplished by using various commercial neutralization processes available at the time. Neutralization processes included reaction with water, acid, caustic, carbon or air. By-products were disposed of as process wastes. After neutralization, glassware used in the process was triple-rinsed, crushed, and deposited in the

present landfill. The neutralized gases released in the environment during detoxification would no longer be detectable (Rockwell International 1987a).

1.3.2.2 Mound Area

The Mound Area is composed of four sites (Figure 1.3-3):

- Mound Site (IHSS 113)
- Trench T-1 Site (IHSS 108)
- Oil Burn Pit No. 2 Site (IHSS 153)
- Pallet Burn Site (IHSS 154)

These sites are described individually below.

Mound Site (IHSS 113)

The Mound Site, located north of Central Avenue in the eastern RFP PA, was used between April 1954 and September 1958 for drum disposal. Approximately 1,405 drums containing primarily depleted uranium (U) and beryllium (Be) contaminated lathe coolant (a mixture of about 70 percent hydraulic oil and 30 percent carbon tetrachloride) were placed at the Mound Site and covered with soil (Rockwell International 1987a). (Records do not indicate that the barrels were actually buried below ground surface [Calkins 1970].) It is unlikely that some of the coolant also contained enriched uranium and plutonium (Rockwell International 1987a). Some drums also contained Perclene (Smith 1975). Perclene was a brand name of tetrachloroethane (PCE) (Sax and Lewis 1987). Some of the drummed wastes placed in the Mound Site were in solid form (Rockwell International 1987a).

Cleanup activities of the Mound Site were performed in May 1970, and the materials removed were packaged and shipped off site for disposal. Listed below is an inventory of the 1,405 drums removed from the Mound Site in 1970 (Dow Chemical 1971):

No. of Drums	Contents
903	30-gallon drums of depleted uranium solid waste.
21	30-gallon drums of depleted uranium oil waste.

12	30-gallon drums of plutonium contaminated oil waste. "The plutonium content was so low that it was measurable only by the most sensitive laboratory techniques."
102	55-gallon drums of depleted uranium solid waste.
282	55-gallon drums of depleted uranium oil waste.
85	55-gallon drums of enriched uranium oil waste.
1,405	TOTAL DRUMS

Subsequent surface soil sampling in the vicinity of the excavated Mound Site indicated 0.8 to 112.5 dpm/g (0.4 to 51 pCi/g) activity. This radioactive contamination is thought to have come from the 903 Drum Storage Site via wind dispersion rather than from the Mound Site, because it was limited to the surface (Rockwell International 1987a).

Trench T-1 (IHSS 108)

The trench was used from 1954 until 1962 and contains approximately 125 drums filled with approximately 25,000 kilograms (kg) (55,115 pounds) of depleted uranium chips (Dow Chemical 1971), and small amounts of lathe coolant (hydraulic oil and carbon tetrachloride) (Rockwell International 1987a). Some of the drums contained metal turnings, still bottoms (residue from a distillation process), cemented cyanide waste, and copper alloy. The estimated dimensions of Trench T-1 are 15 feet wide by 200 feet long by 5 feet deep (Rockwell International 1987a). Trench T-1 was covered with about two feet of soil, and the corners were marked (Rockwell International 1987a). Figure 1.3-3 shows the location of Trench T-1.

Routine weed cutting activities in October and November 1982, unearthed two drums inadequately covered with fill material. Both drums were sampled and analyzed for total plutonium and uranium content before they were disposed off site (Illsley 1983). The off-site disposal location was not provided by Illsley (1983). One of the drums sampled contained an oil/water mixture with 55 picoCuries per liter (pCi/l) of plutonium and 2.3 x 10^5 pCi/l of uranium. The other drum contained an oily sludge with 4.3 pCi/g of plutonium and 1.2 microCuries per gram (μCi/g) uranium.

Oil Burn Pit No. 2 Site (IHSS 153)

Oil Burn Pit No. 2 is actually two parallel trenches which were used in 1957 and from 1961 to 1965 to burn approximately 1,082 drums of oil containing uranium (Rockwell International 1987a). According to the HRR, at least 272 drums of oil were burned in addition to the 1,082. The materials contained in the drums were coolant, still bottoms, and waste oil from Building 444 and Building 881. The drums used for the oil burning operations were generally reused; however, 300 empty drums were discarded by flattening and burying them in the burning pits (Dow Chemical 1971). The uranium concentrations of the burned waste oil are unknown. The residues from the burning operations and the flattened drums were covered with backfill. In 1978, the area was excavated to a depth of approximately five feet, and 240 boxes of contaminated soil were removed and shipped off site for disposal.

Pallet Burn Site (IHSS 154)

An area southwest of Oil Burn Pit No. 2 was reportedly used to destroy wooden pallets in 1965. The types of hazardous substances or radionuclides that may have been spilled on these pallets are unknown. This site was remediated and reclaimed in the 1970s (DOE 1986a). Two locations for the Pallet Burn site are shown on Figure 1.3-3. The westernmost location was reported by Owen and Steward (1973). However, based on review of historical aerial photographs, there was no disturbance at this western location. The eastern location was identified from 1963 and 1965 aerial photography of the area.

East Trenches Area

The East Trenches Area consists of nine previously identified burial trenches, two newly identified trenches, and two spray irrigation sites. This area is divided into the Northeast (NE) Trenches and Southeast (SE) Trenches Areas. These areas contain the following sites:

Northeast Trenches Area:

- Trench T-3 (IHSS 110)
- Trench T-4 (IHSS 111.1)
- Trench T-10 (IHSS 111.7)
- Trench T-11 (IHSS 111.8)

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- Trench T-13 (new trench)
- East Spray Field (IHSS 216.2)

Southeast Trenches Area

- Trench T-5 (IHSS 111.2)
- Trench T-6 (IHSS 111.3)
- Trench T-7 (IHSS 111.4)
- Trench T-8 (IHSS 111.5)
- Trench T-9 (IHSS 111.6)
- Trench T-12 (new trench)
- East Spray Field (IHSS 216.3)

Trenches T-3, T-4, T-10, T-11 and T-13 are located north of the East Access Road, and Trenches T-5 through T-9 and Trench T-12 are south of the East Access Road (Central Avenue). The wastes in these trenches have not been disturbed since their burial. The spray fields are located east of Trenches T-5 through T-9 and north and south of the East Access Road (Central Avenue).

Trenches T-3 through T-11 (IHSS 110 and 111.1 to 111.8)

Trenches T-3 through T-11 along with Trench T-2 operated from 1954 to 1968, with Trenches T-9, T-10 and T-11 being differentiated and added to the disposal trench inventory in 1977. These trenches, as well as Trench T-2, were used for disposal of approximately 125,000 kg of sanitary sewage sludge contaminated with uranium and plutonium, and approximately 300 flattened empty drums contaminated with uranium (Illsley 1983). Radiation content of the sewage sludge was reported between 382 pCi/g to 3,590 pCi/g. Older sludge had mostly uranium, with an increasing plutonium fraction in later sludge placed in the trenches. Total alpha radioactivity in Trenches T-2 to T-8 is estimated to be 100 to 150 millicurie (0.1 to 0.15 Ci) (Dow Chemical 1971). Trenches T-4 and T-11 also contain some plutonium- and uranium-contaminated asphalt planking from the solar evaporation ponds, while T-9 also contains some scrap metal and junk. The locations of Trenches T-3 through T-11 are shown in Figure 1.3-3 and are reported to be approximately 10 feet deep with two feet of soil cover. The trenches are variable in length, with the average length being approximately 250 feet.

Soil samples were collected from the three newer trenches (T-9, T-10. and T-11) during 1977 to 1983. Soil from T-9 was found to vary from 0.40 to 68 pCi/g in plutonium activity, and from 2.4 to 450 pCi/g in uranium activity. Trench T-10 was found to contain from 0.18 to 14 pCi/g in plutonium activity and from 40 to 126 pCi/g in uranium activity. Trench T-11 was found to contain 4.5 to 50 pCi/g in plutonium activity and 0.9 to 158 pCi/g in uranium activity.

The sampling dates and collection methods of these samples are unknown.

Trench T-12

Trench T-12 has recently been identified and is shown to be located primarily beneath the present East Access Road (Central Avenue) (DOE 1993a). Further investigation has ascertained that the trench is a western continuation of T-9 (IHSS 111.6) and the series of trenches described above. The HRR states that Trenches T-4 through T-11 were active sometime between 1954 and 1968. The actual dates per trench are unknown. However, T-12 must predate completion of the main East Access Road in 1965 since it is 80 percent covered by the road.

The HRR states that all of these trenches are thought to be about ten feet deep and primarily contain sewage sludge. This sewage sludge is believed to contain some uranium and plutonium contamination. Flattened drums may also be present in any of these trenches. At least 2,400 gallons of water and lathe coolant were disposed of in one of the trenches (unknown). This may or may not have been in drums. Therefore, it was concluded and agreed to that Trench T-12 would be characteristically the same as Trench T-9.

Trench T-13

During the investigation into the above trench extension, an additional trench (T-13) was located approximately 500 feet east northeast of the inner east guard station and south of IHSS 111.8 (DOE 1993a). Aerial photographs indicate that it was open between 1966 and 1967. It is now entirely covered by asphalt or base material as part of the northern extension of the East Access Road (Central Avenue), which was built in 1968. Total length of the trench is approximately 250 feet. The aerial photos indicate that is was filled with dark gray material which may be sewage sludge.

This newly located trench was filled at approximately the same time as the trenches described above and is probably very similar to the other trenches in construction and type of materials contained.

East Spray Field Sites (IHSS 216.2 and 216.3)

The Center area (216.2) and South area (216.3) of the East Spray Field are located on top of a hillside to the north and south, respectively, of the East Access Road (Central Avenue).

These spray fields were used for spray irrigation of treated sanitary waste water from Pond B-3. They have been designated as IHSSs because effluent containing low concentrations of chromium (Cr) was inadvertently sprayed in the area in February and March 1989. The chromium entered the sanitary sewage treatment plant subsequent to a spill of chromic acid in Building 444.

As shown on Figure 1.3-3, IHSS 216.2 is considered as part of the Northeast Trenches Area and 216.3 as part of the Southeast Trenches Area.

1.3.3 Previous Investigations

1.3.3.1 Regional and Plantwide Studies

Various studies have been conducted at RFP to characterize environmental media and to assess the extent of radiological and chemical contaminant releases to the environment. These have included geological studies, surface water and groundwater studies, and geophysical and radiometric surveys. Several environmental, ecological and public health studies culminated in the Final Sitewide Environmental Impact Statement. These investigations performed prior to 1986 included:

- Detailed descriptions of the regional geology (Malde 1955; Spencer 1961; Scott 1960, 1963, 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 approximately 60 monitor wells by 1982.

- An investigation of surface and groundwater flow systems by the U.S. Geological Survey (Hurr 1976).

- Environmental, ecological, and public health studies which culminated in an environmental impact statement (DOE 1980).

- A summary report on groundwater hydrology using data from 1960 to 1985 (Hydro-Search, Inc. 1985).

- A preliminary electromagnetic survey of the RFP perimeter (Hydro-Search, Inc. 1986).

- A soil gas survey of the RFP perimeter and buffer zone (Tracer Research, Inc. 1986).

- Routine environmental monitoring programs addressing air, surface water, groundwater, and soils. These programs are summarized in the annual environmental monitoring reports (Rockwell International 1975 through 1983, 1984, 1985, and 1986). Additional information on routine environmental programs is also presented in post-1986 annual environmental monitoring reports (Rockwell International 1987b and 1989, and EG&G 1990a).

In 1986, two major environmental investigations were completed at RFP. The first was the CEARP Installation Assessment (DOE 1986a), 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 that could potentially have adverse impacts on the environment were identified. These sites were designated as Solid Waste Management Units (SWMUs) (DOE 1987) 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 remediated under Section 3004(u) of RCRA or under CERCLA

SWMUs were later renamed to IHSSs. The term IHSS will be used throughout this report.

The second major environmental investigation completed at RFP in 1986 involved a hydrogeologic and hydrochemical characterization of the entire RFP site. Results of these investigations were reported by Rockwell International in 1986. 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. Due to their proximity, the 903 Pad, Mound and East Trenches Areas were grouped together and designated OU-2. The 881 Hillside was designated as OU-1.

In 1989 and 1990, two radiological surveys were conducted at RFP (DOE 1990a, 1991c). The aerial radiological survey in 1989 consisted of airborne measurements of both natural and man-made gamma radiation from the terrain surface in and around RFP. These measurements allowed an estimate of the distribution of isotope concentrations in the survey area that covered 48 square miles.

In 1990, in situ radiological surveys were conducted at RFP. The survey areas included the Old Landfill Area, an area east of the 903 Pad, and an area south of the landfill along the north bank of Woman Creek.

The survey along Woman Creek employed a 20 percent N-type, high purity germanium (HPGe) gamma ray detector suspended one meter above ground level (AGL). The later surveys at the Old Landfill and 903 Pad employed a similar detector, but it was suspended 7.5 meters AGL. The processed data from the Old Landfill indicated that detected radioisotopes were generally consistent with those expected from normal background emitters. However, there was clear evidence of soil disturbance, and there were areas of elevated concentrations of U-238. The processed data from the area east of the 903 Pad confirmed an earlier survey which indicated the presence of Am-241 in surface soils.

Four other RFP-wide studies have been conducted that further supplement Phase II RFI/RI activities at OU-2: the geologic characterization program, the background geochemical

characterization study, the surface water and sediment geochemical study, and the historical releases investigation.

The RFP geologic characterization program (DOE 1990b, 1991d) was undertaken to develop a comprehensive geologic framework that can be used to define the direction, rate, and volume of groundwater flow; delineate contaminant migration pathways; and characterize potential seismic risks. The study was intended to be used to formulate hydrogeologic models, design and implement groundwater monitoring programs, and plan remedial activities.

As part of the geologic characterization program, geologic mapping and shallow, high-resolution seismic reflection surveys were conducted at RFP (Rockwell International 1989; DOE 1990c, 1991e and f). A geologic map of a 60-square-mile area surrounding RFP was produced; the Upper Cretaceous Fox Hills Sandstone, Laramie Formation, and Arapahoe Formation were described and criteria were developed for their identification in the surface and subsurface; previously mapped faults were verified and further characterized; new areas of structural deformation were identified; inconsistencies in previously published geologic maps were resolved; and the stratigraphy at RFP was directly tied to the regional stratigraphy on the basis of established lithologic criteria (DOE 1992b).

Shallow, high-resolution seismic reflection surveys were conducted primarily to acquire stratigraphic information. Sandstone channels were mapped in bedrock beneath OU-2 and east of RFP along Indiana Street (Rockwell International 1989, DOE 1991e and f). Structural features were identified in the northwest part of the buffer zone, in the central part of the plant (DOE 1990c), beneath OU-2 (DOE 1991e), and near Indiana Street (DOE 1991f). A deep seismic reflection survey was conducted from Coal Creek Canyon to Jefferson County Airport and across the buffer zone north of the plant, primarily to acquire structural information (DOE 1992c).

The background geochemical characterization study summarized background data for groundwater, surface water, sediments, and geological materials, and identifies preliminary statistical boundaries of background variability (DOE 1992d). Similarly, the surface water and sediment geochemical characterization study (DOE 1992e) identified surface water and sediment characteristics and documented general geochemical trends associated with environmental contamination at RFP.

The historical releases investigation was required by the Interagency Agreement (IAG) to provide a complete listing of all spills, releases, and/or incidents involving hazardous substances that occurred since the inception of RFP operations. Information describing individual release sites was gathered by background research, file review, site visits and photography, and employee interviews. Release sites, including existing RFP IHSSs, were designated as potential areas of concern (DOE 1992a).

Plates 1.3-1 and 1.3-2 present the historical and other investigations (Pre-Phase II) borehole and monitoring well locations, respectively, that resulted from the previous investigations mentioned above.

1.3.3.2 OU-2 Phase I Investigation

The Phase I RFI/RI field program was completed at OU-2 in 1987 and a draft Phase I RFI/RI Report was submitted to the EPA and CDH in December 1987 (Rockwell International 1987c). The objectives of the Phase I RFI/RI program were to verify the existence and location of the waste disposal sites, characterize the sites, evaluate the nature and extent of contamination, and develop data needed for feasibility studies of remedial alternatives as appropriate.

The investigation consisted of the following field activities;

- Electromagnetic, resistivity, and magnetometer geophysical surveys
- Soil gas survey
- Soil sample collection from 33 boreholes
- Completion of 10 alluvial and 14 bedrock monitoring wells
- Groundwater sampling of new and previously existing wells
- Slug testing of 13 wells
- Packer testing of cored bedrock wells
- Collection of 22 surface water and seep samples
- Air monitoring for total long-lived alpha, plutonium, and volatile organics during field activities

The Phase I RFI/RI investigations lead to the general conclusions that volatile organic and radionuclide contamination exists in soils, surface water, groundwater, and sediments around several IHSSs, but the distribution and magnitude of the contamination needed to be better delineated.

Plutonium and americium were the principal radionuclide contaminants in the surface soils at OU-2 exhibiting elevated concentrations; however, conclusive evidence ruling out the presence of other radionuclides was not available because of the compositing technique used for soil samples during the Phase I investigation. The majority of the metals in the soil samples were considered below background levels. There were infrequent instances where the metals concentrations were interpreted as exceeding background by a factor of two above the tolerance intervals. Volatile organic contamination of soils appeared to be restricted to the area immediately beneath and adjacent to the 903 Pad. Volatile organic compounds were also detected at Trench T-2, the East Trenches, and the Pallet Burn Site. The Mound Area did not appear to have volatile organic soil contamination based on the Phase I data.

TCE, PCE, and CCl_4 were the principal organic contaminants in surface and groundwater. Figures 1.3-5, 1,3-6 and 1.3-7 show the distribution of these contaminants in groundwater. Lesser concentrations of other organic compounds occurred at numerous sampling sites throughout OU-2. Plutonium and americium in surface water samples were other apparent indicators of RFP-derived contamination.

Several metals and other inorganic constituents (including uranium) were also above background but the data did not permit unambiguous conclusions with regard to contamination. The uncertainty resulted in part from the absence of clear concentration gradients and from the limited knowledge of the inorganic composition of waste sources at OU-2; however, there was considerable circumstantial evidence (listed below) that formed the basis for the hypothesis that evaporative losses at groundwater discharge zones may be causing accumulation of salts (in soils) and associated local changes in water quality. The circumstantial evidence for a local evaporative concentrating process for groundwater was as follows:

- Most of the elevated elements were not known constituents of the waste sources in OU-2.

- The elevated constituents did not exhibit clear gradients away from known IHSSs, or for that matter, clear horizontal or vertical gradients.

- The variability in inorganic constituents concentrations was typically very small, and almost always within an order of magnitude.

- Some of the major ions did show very pronounced elevation above background, but the highest concentrations of inorganic constituents were in a well that was farthest from the IHSSs (29-87).

- Other parts of RFP show similar distributions of major and minor elements and locally very high concentrations of major ions that were not demonstrably derived from IHSSs (wells 5-86 and 6-86). The background characterization may not be adequate because the current data were based on one quarter of sampling, and well placement was designed without the specific goal of including evaporation-prone zones.

- The wells with the high TDS and major ions commonly also have the most elevated metals and uranium. This raises the possibility that, if the salinity is due to some concentrating process other than waste input, some or all of the minor elements may also occur in elevated concentrations. This was consistent with the observation that the uranium in groundwater at the 881 Hillside Area was of natural origin based on uranium-234/uranium-238 ratios. The RFP uses depleted uranium, which was found to be present only in some surface soils at the 881 Hillside.

No single feature of the data listed above rules out the possibility that some or all of these inorganic constituents represent contamination. However, when viewed in aggregate, the observations show that it was plausible, perhaps probable, that these elevated inorganic constituents do not reflect contamination.

Additional general conclusions from the Phase I RFI/RI investigations were as follows:

- Surficial materials in the area consisted of Rocky Flats Alluvium, colluvium, and valley fill alluvium.

- Bedrock beneath surficial materials consisted of Arapahoe Formation claystones and sandstones that dip slightly to the east (less than 2 degrees). Bedrock materials are weathered below the base of surficial materials.

- The extent of Arapahoe Formation sandstones beneath these areas was not fully characterized during the Phase I RFI/RI because of the complex depositional pattern.

- Unconfined groundwater flow within the UHSU occurred in surficial materials, subcropping sandstones, and potentially in weathered subcropping claystones. The flow system in surficial materials was not fully saturated year round. Flow in weathered claystones was not sufficiently documented, and flow directions in subcropping sandstones were poorly defined due to the complex stratigraphy.

- Confined groundwater flow occurred in deeper sandstones, LHSU. The flow system was poorly defined at the time due to the complex stratigraphy and facies changes.

- Groundwater recharge occurred as infiltration of incident precipitation and flow from ditches and surface water drainages.

- Discharge from the unconfined groundwater flow system occurred as evapotranspiration, seeps, and springs at the edge of the Rocky Flats pediment, to surface water in Woman Creek and South Walnut Creek, and to bedrock sandstones. Site contaminants had been identified in many of these seeps.

- Wastes have been removed from the 903 Drum Storage Site, the Pallet Burn Site, the Oil Drum Pit No. 2 Site, and the Mound Site. Wastes remain in place in all 11 trenches within the area. Further characterization of all potential contaminant sources was warranted.

- Boreholes were drilled adjacent to IHSSs in the Phase I RFI/RI, and soil samples were collected and analyzed for Hazardous Substances List (HSL) organics and metals, radionuclides, and inorganics. Further characterization of soils beneath IHSSs was needed.

- Surficial soils in the area were contaminated with plutonium, americium, and other radionuclides due to wind dispersal of particulates during clean up of the 903 Drum Storage Site in the late 1960s. Soil sampling results indicated that

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these compounds were most enriched near the surface, but further investigation of smaller soil intervals was necessary to assess radionuclides distribution.

- The UHSU contained volatile organic compounds. The principal volatile organic compounds present are tetrachloroethene (PCE), carbon tetrachloride (CCl_4), and trichloroethene (TCE). The extent of these contaminants in both the unconfined and confined groundwater flow systems has not been fully determined.

- Radionuclides were elevated in sediment and unfiltered surface water samples collected during the Phase I RFI/RI. Wind dispersal of radionuclides during clean-up of the 903 Drum Storage Site was the likely source of these contaminants, although confirmation of this hypothesis was needed. There were slight indications of radionuclides in a few groundwater wells (unvalidated).

- Several major and minor elements were elevated above background in soils, groundwater, surface water, and sediments, but they did not exhibit clear lateral or vertical gradients.

A site conceptual model was developed based on site physical characteristics and the nature and extent of contamination defined by the Phase I RFI/RI data. This model summarized known and suspected sources of contamination, types of contamination, affected media, contaminant migration pathways, and environmental receptors. It was used to assist in identifying sampling needs and developing the Phase II RFI/RI program.

1.3.3.3 Shallow, High Resolution Seismic Investigation

Under the Phase II Geologic Characterization Data Acquisition Program, a high-resolution seismic reflection program was undertaken to support subsurface characterization of the OU-2 area. The seismic reflection work was conducted in a phased approach beginning in 1989 and completed in early 1991. Based on the accepted geologic model at the time and results of seismic modeling efforts, it appeared that high-resolution seismic reflection could be a valuable tool for site characterization. The results of the seismic reflection program are documented in Shallow High-Resolution Reflection Profiles in OU-2 (903 Pad, Mound and East Trenches), Final Report (DOE 1991e). These results were reviewed to evaluate whether the seismic data could augment lithologic data and aid the OU-2 Phase II RFI/RI site characterization.

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In general, review of the original seismic reflection interpretation indicates that where subsurface control existed (at the time of interpretation), a good correlation between the seismic interpretation and lithology is apparent. However, the continuity of specific seismic reflection events cannot be extrapolated very far from the subsurface control. This is apparent when the original seismic interpretation is reviewed in light of the additional wells and borings completed under the Phase II RFI/RI. A comparison of the originally interpreted channel "A" sand with the presently mapped Arapahoe No. 1 Sandstone is shown in Figure 1.3-8.

The seismic data interpretation had varying success in predicting the location of the No. 1 Sandstone channel (as evidenced from the lithologic data). From the lithologic data, the No. 1 Sandstone is a mappable heterogeneous sandstone body containing siltstone and claystone layers. The acoustical contrast between the No. 1 Sandstone and surrounding lithologic units is quite variable as indicated by seismic velocity variations observed during the vertical seismic profile in B217489. The variability of the seismic velocities and velocity contrasts directly affects resolution and thus the ability to predict the location of the sand. The seismic interpretation would have been enhanced by obtaining more velocity control, as pointed out in the Shallow High-Resolution Seismic Reflection Profiling Report (DOE 1991e).

Original expectations for the seismic data to aid in locating the lower bedrock sandstones may have been too aggressive. From the lithologic data, the lower bedrock sandstones were interpreted as being deposited in a low energy deltaic environment and are characteristically silty and clayey. The existing lithologic data indicate that the lower bedrock sandstones exhibit low permeabilities and are discontinuous in nature. Geophysically, the acoustic contrast between these silty, clayey sandstones and the surrounding silty claystones is likely small. Based on correlation with recently completed deeper borings, the previously interpreted lower bedrock sandstone channel locations were not consistent with the lithologic data obtained.

As a result of the varying success of the seismic tool in locating bedrock sandstones, and due to an abundance of lithologic control, the seismic reflection data were not used in the Phase II RFI/RI site characterization.

1.3.3.4 Observations on the Occurrence of Plutonium and Americium in Ground and Surface Water

This investigation provided an observational assessment of Pu and Am contamination in ground and surface water at OU-2 (DOE 1992f). Ground and surface water radiochemistry data were

first screened to generate a reliable data set in which there was a reasonable level of confidence that the reported activity represented the true activity. Groundwater radionuclide activities were then compared with surface water radionuclide activities. This comparison revealed substantially lower groundwater Pu and Am activities than in surface water. This suggested that groundwater discharging to surface water did not account for all of the Pu and Am activity in surface water. Contrasting total Pu and Am activities to filtered water from the same stations indicated that more than one-half of the Pu and Am activity resided in material retained by a 0.45 μ filter. Comparison of total Pu and Am activity to total suspended solids concentration revealed that in some cases a correlation between suspended solids and radioactivity exists. This further suggesed that at least some of the radionuclide activity was associated with particles.

1.4 SUMMARIES OF OU-2 PHASE II RFI/RI WORK PLANS AND TECHNICAL MEMORANDA

This section presents the summaries of the Phase II RFI/RI Work Plans and Technical Memoranda (TM). As stated in the IAG, the unknown nature of many of the sites at RFP and the iterative nature of the RFI/RI process may identify additional data requirements and analyses. Therefore, technical memoranda shall be submitted that document the need for additional data and identify the Data Quality Objectives (DQOs). Upon agency approval the technical memoranda are attached as amendments to the approved Work Plans.

Nine technical memoranda were prepared as part of the OU-2 Phase II RFI/RI:

- Phase II RFI/RI Work Plan (Alluvial) (TM1) - Subsection 1.4.1
- Addendum to Final Phase II RFI/RI Work Plans (Alluvial and Bedrock) Chemical Analysis Plan (TM2) - Subsection 1.4.2
- Phase II RFI/RI Aquifer Test Work Plan (TM3) - Subsection 1.4.3
- Human Health Risk Assessment Exposure Scenarios (TM5) - Subsection 1.4.4
- Human Health Risk Assessment Model Descriptions (TM6) - Subsection 1.4.5
- Surface Soil Sampling and Analysis Plan Addendum (TM7) Subsection 1.4.6

- Revised Phase II RFI/RI Work Plan (Bedrock) (TM8) - Subsection 1.4.7

- Human Health Risk Assessment Contaminants of Concern (TM9) - Subsection 1.4.8

- Human Health Risk Assessment Toxicity Assessment (TM10) - Subsection 1.4.9

- Environmental Evaluation Work Plan (TM1) - Subsection 1.4.10

The summaries of the work plans and technical memoranda are presented as discussed in the documents at the time they were submitted and/or approved. The summaries do not present interpretations, document what has been implemented, nor present results. Some of the summaries present previous work or data used to develop the approach or plan described in the technical memoranda.

1.4.1 OU-2 Phase II RFI/RI Work Plan (Alluvial) (TM1)

TM1 presents the work plan for the Phase II RFI/RI (Alluvial) of the 903 Pad, Mound, and East Trenches Areas (OU-2) at RFP (DOE 1991a). The alluvial work plan presents results of the Phase I RFI/RI; defines DQOs and data needs based on the Phase I investigation; specifies remedial investigation/feasibility studies (RI/FS) tasks; and presents a field sampling plan (FSP). The alluvial work plan also presents site-specific plans for additional field work to characterize contaminant sources and the extent of soils, surface water, and groundwater contamination in the UHSU. Also included are plans for human health and environmental risk assessments and a RCRA Corrective Measures Study/CERCLA Feasibility Study (CMS/FS). This work plan is based on results presented in the draft Phase I RFI/RI report as well as subsequent surface water and groundwater sampling and analysis.

A final Phase II RFI/RI Work Plan (Alluvial) for OU-2 incorporating agency comments was submitted to EPA and CDH on April 12, 1991 (DOE 1991a). The Final Work Plan was modified for reasons not associated with specific agency comments. These changes were made to "update" the plan with respect to the current understanding of the site, other OU study activities that impact OU-2, and regulatory issues. Major changes were as follows:

- Revision of geological characterization based on the on-going seismic reflection study

- Addition of a concise site conceptual model
- Elaboration of DQOs
- Discussion of all RFP Treatability study programs
- Addition of five plume characterization wells between the OU and site boundary because of the recent occurrence of contamination in this location
- Elimination of surface water station sampling (except seeps) because the activity was covered by OU-5 and OU-6 as well as a site-wide surface water characterization program
- Addition of a more extensive surface soil sampling program to assess the mobility of plutonium in the soil/water environment
- Addition of a detailed environmental evaluation work plan
- Elaboration and modification to the discussion of applicable or relevant and appropriate requirements (ARARs)

The following is a summary of the information presented in TM1.

Trace elements commonly occurring above background levels in UHSU groundwater include strontium, barium, copper, and nickel, and to a lesser extent chromium, manganese, selenium, lead, zinc, and molybdenum. Also, major cations and anions and total dissolved solids were somewhat elevated above background throughout and downgradient of the 903 Pad, Mound, and East Trenches Areas. Uranium-238 was the predominant radionuclide occurring above background in the UHSU groundwater flow system, but a few samples indicate plutonium and americium downgradient of the 903 Pad and possibly north of the Mound.

An evaporative concentration conceptual model had been advanced that may explain high total dissolved solids, metals, and uranium in groundwater at OU-2. The model did not alter the borehole and well placement strategy in the Phase II plan, and its accuracy was to be tested in the background characterization study.

There was considerable interaction between surface water and groundwater. As a result, organic contamination was observed in seeps downgradient of the 903 Pad and in the upper reaches of South Walnut Creek at the Mound Area. Also, there were somewhat elevated concentrations of total dissolved solids, major ions, strontium, zinc, and uranium at many of the surface water stations.

Plutonium and americium were found to occur above background in surface soils. Other radionuclides and trace metals occur at low concentrations and infrequently above background but may also be soil contaminants at OU-2. Data suggest plutonium and americium were released to soils in the area via wind dispersion during clean up efforts at the 903 Drum Storage Site. These radionuclides occur in surface soils throughout OU-2 and other downwind areas to the southeast.

Plutonium and americium were also observed in two seeps (SW-50 and SW-53) downgradient of the 903 Pad and in the upper reaches of South Walnut Creek. This may be attributed to the water from the seeps coming in contact with surface soils exhibiting elevated concentrations of these radionuclides; the Phase II RFI/RI was designed to test this hypothesis.

The overall objectives of the Phase II RFI/RI were source characterization and determination of the magnitude and extent of groundwater and surface water contamination. Boreholes were to be drilled into waste sources to characterize any waste materials remaining in place and to assess the maximum contaminant concentrations in soils directly beneath the sites. In addition, groundwater monitoring wells were to be installed adjacent to some of the boreholes to characterize groundwater quality directly beneath the sites. This plan called for drilling and sampling 46 boreholes and installing 21 monitoring wells. Sixty-four additional alluvial monitoring wells were also to be installed to further characterize and monitor groundwater flow and quality in alluvial materials at OU-2. An unspecified number of additional bedrock monitoring wells were then to be completed in subcropping Arapahoe sandstone where it was encountered. All plume characterization wells were to be installed, developed, and sampled as the first step of the investigation. Source characterization activities were then to be subsequently completed.

In order to assess the extent of plutonium and americium in surface soils within RFP boundaries, pedologic soil samples were to be collected from 124 grids over an 800-acre area to the southeast of the 903 Pad. To delineate the vertical distribution of plutonium and americium, 26 locations were identified for soil test pit excavation for soil profile sampling.

Additional studies have been planned to assess the mobility of plutonium in the soil/water environment.

A baseline risk assessment and an environmental evaluation were intended to be prepared for OU-2 as part of the Phase II RFI/RI to evaluate the potential threat to the public health and the environment in the absence of remedial action. This risk assessment would provide the basis for determining whether or not remedial action is necessary in the area and would serve as the justification for performing remedial actions.

1.4.2 Summary of OU-2 Addendum to Final Phase II RFI/RI Work Plans (Alluvial and Bedrock) Chemical Analysis Plan (TM2)

TM2 documents the analysis and rationale for amending the analytical strategy presented in the OU-2 Phase II RFI/RI Work Plan (Alluvial and Bedrock) dated August 1991 (DOE 1991g). The Work Plans stipulated that soils, sediments, groundwater, and surface water be analyzed for all Contract Laboratory Program (CLP) Target Compound List (TCL) organic constituents. This analytical program took a conservative approach and was a comprehensive program for a Phase II RFI/RI and, therefore, was reevaluated in this document.

Comprehensive site characterization began at OU-2 in 1986, and a Phase I RFI/RI report was submitted in December 1987. Site characterization for the Phase I RFI/RI was based on analysis of soils, sediments, groundwater, and surface water for the CLP Hazardous Substance List (HSL) compounds. (Currently this list of analytes is known as the TCL; however, it should be noted that there are minor differences in the two lists.) Phase II RFI/RI Work Plans for the alluvial and bedrock hydrogeologic systems had been prepared and were designed to fill data gaps that were identified in the earlier phase of investigation.

The OU-2 work plans specified analysis of soils, sediments, groundwater, and surface water for all TCL organic compounds. Analysis for the full suite of TCL organics for groundwater and surface water beyond the first round of samples would have been dependent on the initial results. The need for continued full suite analysis was to be based on an assessment approach not unlike that presented in this document. The TCL was chosen as the basis for characterizing OU-2 because it is used by EPA in characterizing uncontrolled hazardous waste sites where historical waste disposal practices are often unknown, and because of the associated high quality assurance/quality control procedures that are widely accepted by both federal and state agencies. Although chlorinated solvents (and radionuclides) are the principal contaminants at

OU-2, based on historical waste disposal records and previously collected data, a list of all chemicals disposed at this location is not known, establishing the need for monitoring for a more comprehensive list of analytes.

With respect to soils, the full suite of TCL organics was specified because the upcoming phase of investigation was designed to provide a comprehensive characterization eliminating the need for subsequent phases of investigation. More specifically, semivolatile inorganic compounds and pesticides/polychlorinated biphenyls (PCBs) were to be analyzed because previously collected data indicated the consistent occurrence of phthalate esters and the infrequent occurrence of other semivolatile organic compounds and pesticides/PCBs. Also, several proposed waste investigation boreholes were to penetrate waste sources (IHSSs), where previously targeted soil sampling was outside the waste source boundaries. Thus, the full suite of TCL organics was specified because of the uncertainty of the types of waste that were disposed at these OU-2 IHSSs.

Groundwater and surface water were to be analyzed for the full suite of TCL organics because of the infrequent occurrence of semivolatile organic compounds and pesticides/PCBs as indicated by previously collected data, and the limited quantity of historical data for these classes of chemicals (one to two rounds). Sediments were also to be analyzed for the full suite of TCL organics largely because of their relevance to contaminant migration in surface water.

The approach taken in TM2 to define a site-specific target analyte list included the following:

- Step 1 - Summarize Existing Analytical Data by Analytical Suite
- Step 2 - Evaluate results

In Step 1, existing data were tabularized showing the total number of analyses for each chemical within an analytical suite and the total number of detections of each chemical. Three major chemical groups were identified with seven analytical suites. These groups include:

- Group A Compounds, TCL Volatiles

  I. Ketones and Aldehydes
  II. Monocyclic Aromatics
  III. Chlorinated Aliphatics

- Group B Compounds, TCL Semivolatiles

  IV. Acid Extractables
  V. Base Neutral Extractables

- Group C Compounds, Pesticides/PCBs

  VI. Pesticides
  VII. PCBs

The results of Step 1 could be one of three possible outcomes:

1. **Case 1**: Chemicals within one or more analytical suites in a specified media had not been detected above the Contract Required Quantitation Limit (CRQL).

2. **Case 2**: One or more chemicals from an analytical suite had been detected in a specified media either inconsistently or at low concentrations.

3. **Case 3**: There had been consistent detections of one or more chemicals from an analytical suite in a specified media.

In Step 2, data quality was assessed in accordance with the ER Program Quality Assurance Project Plan (QAPjP), and the General Radiochemistry and Routine Analytical Services Protocol (GRRASP) and references therein.

This evaluation also included an assessment of spatial representativeness, temporal considerations, chemical fate and transport, and human risks posed by the chemicals.

The conclusions, after summarizing existing data and evaluating it with regard to fate and transport and toxicity, are presented in Table 1.4-1. Waste characterization within IHSSs and sample analysis for source characterization monitoring wells was to include the full suite of TCL organics. If semivolatile organic compounds or pesticides/PCBs were detected in these media at significant levels, groundwater wells, surface water, and sediment stations in the proximity of these IHSSs were to be sampled and analyzed for these compounds at a later date, but prior to submittal of the Phase II RFI/RI report.

Because CLP GC/MS detection limits do not achieve "risk based" detection limits for some of the carcinogenic chlorinated solvents, EPA Method 502.2, which has detection limits as low as 0.5 μg/l, was to be used for groundwater samples that were collected from wells near the edge of the plume. This would allow achieving data quality objectives for the Phase II RFI/RI. All proposed 1991 wells (alluvial and bedrock) were to be installed to better define the plume of organic contamination, and, therefore, samples from these wells were to be analyzed for volatiles using this method. Samples from existing wells and surface water stations remote from the IHSSs were to also be analyzed for volatiles using this method.

1.4.3 Summary of OU-2 Phase II RFI/RI Aquifer Test Work Plan (TM3)

TM3 presents the aquifer test work plan as outlined in the OU-2 Phase II RFI/RI Work Plan (Alluvial), modifications to this work plan, and the basis for these modifications (DOE 1992g).

The work plan detailing the aquifer test was approved by the regulatory agencies in August of 1991. Subsequent geologic and hydrologic measurements as well as information related to previous aquifer testing necessitated changes in the original aquifer work plan.

The objective of the aquifer test was to evaluate the hydraulic properties of subsurface materials in three distinct hydrostratigraphic units at OU-2. The three principal hydrogeologic conditions within the UHSU are:

- An unsaturated Rocky Flats Alluvium underlain by a saturated uppermost Arapahoe sandstone (Site No. 1)
- A saturated Rocky Flats Alluvium underlain by a saturated uppermost Arapahoe sandstone (Site No. 2)
- A saturated Rocky Flats Alluvium underlain by a claystone of the Arapahoe formation (Site No. 3)

Aquifer tests are conducted to develop hydraulic parameters for subsurface materials. Parameters specifically sought for Sites No. 1 through No. 3 included:

- Hydraulic conductivity, dispersivity, and effective porosity for both the alluvium and the bedrock (needed for the development of movement calculations)

- The degree of hydraulic communication between the alluvium and the bedrock

Design considerations for the aquifer tests were based upon hydraulic conductivities reported in the Geologic Characterization Report (DOE 1991d). Hydraulic conductivity (K) in the uppermost Arapahoe sandstone reportedly ranged from 0.11 gpd/ft^2 to 21.2 gpd/ft^2. K values for the alluvium ranged from 0.212 gpd/ft^2 to 212 gpd/ft^2. Using an empirical equation from Bear (1979) to estimate the expected radius of influence (R) for a given K resulted in R values for the uppermost Arapahoe sandstones ranging from 2.3 feet to 33 feet and R values for the alluvium ranging from 0.83 feet to 26.34 feet. Based upon these calculations, it becomes apparent that the spacing of observations wells is critical to the success of the testing. If the spacing of the wells was greater than the radius of influence, drawdown would not be observed.

Pumping rates for the aquifer tests at each site were estimated from given R and K values (Thiem Equation). Calculated sustainable constant pumping rates for the uppermost Arapahoe sandstones ranged from 0.02 gallons per minute (gpm) to 0.3 gpm, while pumping rates for the alluvium ranged from 0.03 gpm to 1.4 gpm. Other variables taken into consideration during the design of the aquifer tests included well-bore storage, delayed yield, and boundary effects. Due to meandering paleochannels in the uppermost Arapahoe Formation sandstone beneath the RFP site, aquifer test locations for Sites No. 1 and 2 were selected such that wells would penetrate the uppermost sandstone of the Arapahoe formation.

The tests that were to be performed at each site and the data to be gathered are discussed below.

Site No. 1

A multi-well pumping test followed by a converging radial tracer test was planned for this site. An array of one production well and three observation wells was to be completed in the No. 1 Sandstone. The observation wells were to be located at distances of 5, 10, and 20 feet from the production well. A fourth observation well proposed at a location of 40 feet from the production well in TM1 was deleted from the testing program based on calculations showing that this well was outside the expected radius of influence for the proposed pumping test.

The entire pump test at this site was planned to last approximately 24 hours. After completion of the tracer test, recovery of the system was to be monitored for an additional six days.

Drawdowns in the observation and production wells would then be evaluated using methods described in Bedinger and Reed (1988) and Neuman (1972, 1973).

Site No. 2

Two multi-well pumping tests were planned to be scheduled for performance at this site. The test design of Site No. 2 as set forth in the TM1 was modified to include a single pumping well which fully penetrates the two layer aquifer. Two pairs of observations wells in the Rocky Flats Alluvium and the No. 1 Sandstone spaced 5 and 10 feet from the pumping well were to be completed as part of this test.

The pump test at this site was planned to last approximately five days. A tracer test would not be performed because of expected dilution effects from the overlying and underlying units. Drawdowns in the observation and production wells would then be derived through the development of a site-specific analytical solution derived for the two-layer aquifer present at this site.

Site No. 3

A multi-well pumping test followed by a converging radial tracer test was to be performed at this site. An array of one production well and two observation wells were scheduled for completion in the alluvium. The observation wells were to be located at distances of 5 and 10 feet from the production well. Two more observation wells proposed at locations of 30 and 75 feet, respectively, from the production well in TM1 were deleted from the testing program based on calculations showing that these wells were outside the expected radius of influence for the proposed pumping test. A single observation well would also be installed adjacent to the production well to monitor head response to a depth of approximately 5 feet into the claystone.

The entire pump test at this site was to last approximately five days. After completion of the tracer test, recovery of the system would be monitored for an additional six days. Drawdowns in the observation and production wells would then be evaluated using methods described in Bedinger and Reed (1988). The response of the observation well in the claystone was to be evaluated using methods described in Bedinger and Reed (1988), such as Lappala et al. (1987).

The construction, installation, and monitoring of all wells used as part of the aquifer tests were to follow the guidelines set forth in RFP Standard Operating Procedures (SOPs).

1.4.4 Summary of OU-2 Human Health Risk Assessment Exposure Scenarios (TM5) *(Pending Approval)*

1.4.5 Summary of OU-2 Human Health Risk Assessment Model Descriptions (TM6)

TM6 provides a description of the models selected to perform groundwater, surface water and air modeling for OU-2 in support of the Human Health Risk Assessment (risk assessment) (DOE 1993b). The technical approach used in applying selected models to the site-specific conditions at OU-2 is described in detail in Appendixes E, F and G of this Phase II RFI/RI report.

The objectives of the modeling are as follows:

1. To support the risk assessment portion of the Phase II RFI/RI Report for OU-2. This was to be accomplished by simulating the transport of chemicals of concern from OU-2 to potential exposure points for human receptors under present and anticipated future site conditions.

2. To support the evaluation of potential remedial alternatives for the CMS/FS at OU-2.

A conceptual site model (CSM) had been developed to identify and evaluate the chemical source areas, chemical release mechanisms, environmental transport media, potential human intake routes, and potential human receptors at OU-2. The purpose of the CSM was to identify human exposure pathways to be quantitatively evaluated in the risk assessment. Exposure pathways chosen for evaluation in the risk assessment that include transport media such as groundwater, surface water, and air, required fate and transport modeling to estimate chemical exposure point concentrations. TM6 described the exposure pathways to be evaluated in the risk assessment that required such modeling and identified the mathematical models to be used to estimate exposure point concentrations. The models were based on data that have been collected at the site as part of Phases I and II of the RFI/RI for OU-2. At the time this technical memorandum was prepared, only a portion of the soil and groundwater data from the Phase II RFI/RI were available. If additional data collected was found to be substantially different than those used in developing this technical memorandum revisions to the modeling approach would become necessary.

The following models were selected to meet the requirements and objectives of the modeling study:

- The U.S. Geological Survey MODFLOW numerical model for groundwater flow, and the MT3D numerical model for groundwater contaminant fate and transport in the Rocky Flats Alluvium and Arapahoe Formation No. 1 Sandstone. The ONED3 analytical model for groundwater contaminant fate and transport in the colluvium.

- The Universal Soil Loss Equation, Soil Conservation Service (SCS) Curve Number Equation, and Mass Balance Equation for surface water fate and transport.

- The Superfund Exposure Assessment Manual (SEAM) Models for soil gas fate and transport, a box model for on-site ambient air contaminant fate and transport, and Fugitive Dust Model (FDM) for off-site ambient air contaminant fate and transport of OU-2 source air emissions.

Data available for use as input for the modeling activities were evaluated based on a review of previous and ongoing investigations, and general literature. Additional data from the Phase II RFI/RI would be used in the modeling effort once those data become available.

The data that were presented in this technical memorandum were preliminary and, in some cases, not site specific. The data values or ranges of values were not intended to be fixed or final. The ranges were presented to convey what is currently known of the potential variability in the parameter values that may be used in the models.

1.4.6 Summary of OU-2 Surface Soil Sampling and Analysis Plan Addendum (TM7)

TM7 presents an addendum to the Phase II RFI/RI Work Plan (DOE 1991a). The purpose of the Addendum to the Work Plan was to modify the Surficial Soil Sampling Program to include the analysis of all contaminants that are potentially present at OU-2 for use in the human health risk assessment and the air and surface water modeling (DOE 1993c). The Surficial Soil Sampling Program contained in the Phase II RFI/RI Work Plan was designed to investigate the extent of plutonium, americium, and uranium contamination in surface soils and to study the potential vertical migration of radionuclides through the soil column. Numerous

soil studies were made at RFP before the OU-2 Phases I and II RFI/RIs, some as early as 1971. These include soil scrapes and soil borings, as well as off-site studies and aerial and surface gamma surveys. Data from these studies were useful in developing the sampling plans for OU-2 Phases I and II. However, these data were not consistently validated and, in some cases, remain unpublished.

Data from previous studies did not provide information on potential contaminants other than plutonium, americium, and uranium. In order to assess the potential human-health risks associated with exposure to OU-2 soils, an evaluation of the nature and extent of all radioactive and non-radioactive contaminants was required.

Other objectives for the surface soil sampling program were to provide additional supporting data for the environmental evaluation (EE) and allow assessment of remedial alternatives for remediation of the contaminated soils in accordance with the National Contingency Plan (NCP).

The DQO process was used in developing the Surficial Soil Sampling and Analysis Plan. To collect data representative of nonradioactive and radioactive contamination in surface soil at OU-2, a systematic sampling approach was selected. The collected samples were to be equally spaced surface soil composites taken from polygons that entirely covered the area of concern. Additionally, selected (biased) polygons that focused on known or suspected surface soil contamination were included for sampling. This approach provides for site-wide coverage and conservatively includes potential hot spots.

The size of the polygons to be sampled was selected based on the receptors that may be evaluated in the risk assessment. The human receptors to be evaluated include an industrial worker, an ecological researcher, and a resident. A future, on-site residential scenario will likely have the greatest potential exposure of the three receptors and is, therefore, the appropriately conservative approach. A sampling polygon representing an exposure area for an on-site resident was selected. The appropriate polygon size for a residential exposure area is 50 feet by 100 feet.

The OU-2 area was divided into these polygons, and the polygons were numbered sequentially. A sample population of 40 would allow an adequate number of samples to assess contaminant distribution; therefore, 40 polygons were systematically selected for sampling.

Historical information indicated that surface soil contamination would likely be identified in several IHSSs. These IHSSs include 108 (Trench T-1), 113 (Mound Site), 140 (903 Pad, Reactive Metal Destruction Site), 155 (903 Lip Site), and 216.2/216.3 (East Spray Fields). To provide for sampling and analysis of surface soil in these IHSSs, six plots corresponding to these IHSSs were specifically selected for sampling. The remaining 34 samples were evenly spaced, based on a grid, throughout the OU-2 area.

The Rock Creek Drainage vicinity was chosen as the background area due to its location and geomorphology. The background area is located generally northwest of the RFP processing area. Since the prevailing wind direction is from the northwest, it is presumed that the contaminants from operations at RFP would have had a nominal or minimal impact on the background area.

Nine randomly selected background sampling locations were identified based on the sampling plan presented for OU-1. The RFP method described in SOP GT.8, (EG&G 1992a) was selected for collection of the samples. Fifty subsamples were to be collected and composited into one sample for each polygon in both the OU-2 and background samples.

The analyte list for the surface soil sampling at OU-2 is presented in Section 2.0 of this report. The list was sufficiently comprehensive to include the expected contaminants based on the history of OU-2. However, volatile organic compounds and acid extractables were not included because of the unlikelihood that these compounds would be present in the surface soil in OU-2. In order to provide a full suite of background analyte concentrations, several analyses were added to the proposed analyte list for background samples only and are also discussed in Section 2.0. Pu-239/240; Am-241; and U-233, -234, -235, and -238 analyses were not performed in this sampling effort because substantial data were obtained from previous studies. Analyses were to be performed in accordance with methods referenced in the GRRASP.

Because chromium was a potential site-related chemical of concern in surface soil, hexavalent chromium (Cr VI) analyses was performed in 30 percent of the surface soil samples, including the two polygons to be sampled at the spray fields (IHSSs 216.2 and 216.3). Additionally, specific conductance, pH, and total organic carbon (TOC) analyses were performed on 30 percent of the OU-2 and background samples.

A subset of approximately 20 percent of the OU-2 and background samples were collected and submitted for bulk density testing. The bulk density analysis will enable the concentration units

to be converted to concentration per unit area. The 20 percent frequency was designed to provide sufficient information to characterize the soils. The polygons locations for the collection of samples for bulk density testing were randomly selected.

The quality assurance/quality control (QA/QC) for the surface soil sampling was conducted in accordance with the QAPjP and applicable SOPs for the ER Program.

1.4.7 Summary of OU-2 Revised Phase II RFI/RI Work Plan (Bedrock) (TM8)

TM8 presents the OU-2 Revised Phase II RFI/RI Work Plan (Bedrock) (DOE 1993a). This work plan, also referred to as the Revised Bedrock Work Plan (RBWP), refined and reduced the scope of work for investigation of the LHSU that was presented previously in the Phase II RFI/RI Work Plan (Bedrock) (DOE 1991b). The reduction in scope was considered appropriate based on a review of data previously collected and currently being compiled as part of the implementation of the Phase II RFI/RI Work Plan (Alluvial) (DOE 1991a). The existing OU-2 data indicated that the LHSU sandstones are discontinuous with low permeability and that substantial contamination is not present.

TM8 focused on acquiring data to verify the site conceptual model, which assumed that contamination in the LHSU is limited in extent. The field investigation program was a focused program designed to incorporate an observational approach that allowed the field results to be evaluated as each field component was completed. Therefor, additional data requirements were assessed and additional data acquired if needed, while the field program was in progress. With this approach, the investigation of the LHSU was expedited, while reducing the potential need for additional phases of field investigation. Figure 1.4-1 illustrates the decision process for using field results, as they are obtained, to evaluate the LHSU. According to that decision process, if groundwater samples could not be collected from the LHSU or analytical results indicated that contaminants are not present at detectable levels this would confirm the limited extent of contamination in the LHSU. Under such a condition, the LHSU could be considered an incomplete pathway and a quantitative assessment of the human health risks associated with a LHSU exposure pathway would not be conducted. The results of evaluation of the LHSU are presented in Sections 3.5.2, 3.6.3, and 4.7 of this Phase II RFI/RI Report. A description of the field implementation of TM8 is presented in Section 2.2.

The upper unit of the Laramie Formation, which is of concern at OU-2 because of its shallow depth and potential for communication with the UHSU at its upper boundary, is comprised of

approximately 300 to 500 feet (DOE 1992b) of deltaic claystones, siltstones, and some silty sandstones with an occasional coal layer. The LHSU sandstones are primarily distributary channel deposits and likely represent the most permeable intervals of unfractured LHSU bedrock. Prior to implementation of TM8, eight aquifer tests had been performed on various LHSU sandstones and siltstones. Seven of the eight aquifer tests indicate hydraulic conductivities in the range of 1×10^{-5} to 1×10^{-6} centimeters per second (cm/s) or less. These sandstones are approximately 15 feet thick or less, except where channels are stacked or have coalesced, which can result in a thick sandstone sequence interbedded with thinner siltstone and claystone layers. Generally, these sandstones are laterally discontinuous (refer to geologic cross-sections on Figures 1-13 through 1-23 in TM8).

The No. 1 Sandstone channel has incised into the LHSU at several known locations. At some locations, the No. 1 Sandstone is in direct contact with or in close vertical proximity to the uppermost underlying LHSU sandstone. Several LHSU sandstones are believed to subcrop beneath the colluvium along the north hillsides of the Woman Creek drainage. There is the potential for hydraulic communication between sandstones of the UHSU and LHSU; however, the quantity of water transmitted from the UHSU to LHSU is believed to be limited due to the low permeability of the silty LHSU sandstones.

Groundwater in the LHSU sandstones is believed to occur under confined conditions except where these sandstones subcrop along the drainage slopes. The flow in the LHSU sandstones is believed to be largely controlled by sandstone geometry, and is generally from west to east.

Data for the UHSU and LHSU at RFP were reviewed and used in developing TM8. Substantially more data are available for the UHSU than LHSU because most of the subsurface data collection activities conducted to date have focused on characterizing the UHSU. However, prior to implementation of TM8, data from 30 existing LHSU wells and 11 borings were available. Based on a review of those data, it appeared that potential sources of contamination to LHSU sandstones are limited to secondary groundwater plume sources within the UHSU.

Two potential scenarios for migration of groundwater contamination from the UHSU to LHSU were proposed. Scenario 1 (Figure 1.4-2) involves lateral migration of contaminants from the UHSU alluvium and/or No. 1 Sandstone to discharge points beneath the colluvium along the slope of the Woman Creek drainage. The downslope migration of the contaminated water within the colluvium results in localized recharge of the LHSU sandstones that are subcropping

beneath the colluvium. Groundwater contamination has been found in existing LHSU wells screened in the vicinity of the subcrops. It is expected that LHSU groundwater contamination resulting from this scenario will be limited to the vicinity of the subcrops because the lateral hydraulic gradient within the LHSU sandstones should be toward the drainages, thus the contamination should be discharged relatively quickly back into the colluvium. As such, groundwater contamination migration is associated with an UHSU exposure pathway through the colluvium, rather than a LHSU exposure pathway.

Scenario 2 (Figure 1.4-3) involves vertical migration of contamination from the UHSU to LHSU sandstones where LHSU sandstones are in close vertical proximity to the UHSU. Once in the LHSU sandstones, the contaminants potentially migrate laterally within the sandstones or vertically to deeper LHSU sandstone units. As such, contaminant migration for scenario 2 may be associated with a potential LHSU exposure pathway if the sandstones are hydraulically interconnected and laterally continuous.

Of the two scenarios, scenario 2 is of the most concern with regard to the LHSU because it is potentially associated with a LHSU exposure pathway. Scenario 1 is of less concern with regard to a potential LHSU exposure pathway because it is believed to be associated with an UHSU exposure pathway (i.e., migration of contaminants through the colluvium).

Data from existing OU-2 LHSU wells were evaluated to assess identified contamination in the LHSU. Where applicable, the identified contamination was evaluated relative to the LHSU contaminant source scenarios discussed above. Based on the data available prior to implementation of TM8, chlorinated hydrocarbons (CHCs) such as CCl_4, PCE, and TCE had been detected in 10 out of 26 LHSU monitoring wells for which data were available since 1990. Of those 10 wells, seven are located on the north slope of the Woman Creek drainage and are screened in LHSU sandstones near where they subcrop beneath the colluvium. These wells, which have the most consistent and highest concentration detections observed in the LHSU groundwater, are believed to be representative of the scenario 1 mechanism thought to be associated with an UHSU exposure pathway.

The other three LHSU wells with CHC detections are located in the central portion of the OU-2 plateau and may be representative of the scenario 2 mechanism. Such contaminant migration, if it occurred, may be associated with a potential LHSU exposure pathway. However, the evidence for this was limited. In general, these wells had concentrations of CHCs in the low parts per billion range, usually near the analytical method detection limits. In many cases, the

detected CHCs in these wells had also been detected in laboratory blanks indicating possible laboratory-related contamination of the samples. Based on the available data, it appeared unlikely that the contamination identified in these wells is indicative of a LHSU exposure pathway.

Prior to implementation of TM8, LHSU bedrock samples had been obtained at depths greater than six feet below the UHSU/LHSU contact from a total of 11 boreholes. Those samples indicated no substantial CHC contamination, with the exception of Boreholes BH2587 and 09991. Both boreholes reached total depth in LHSU claystones which are not expected to readily transmit groundwater. Field activities were specified in the SAP to evaluate the vertical extent of the CHC contamination in claystone at the two borehole locations where it was detected.

TM8 discussed the Conceptual Site Model for OU-2 with respect to the LHSU. Potential exposure pathways associated with the LHSU had been designated as incomplete for OU-2. Based on this designation, no quantitative assessment of human health risk through LHSU exposure pathways was anticipated for the OU-2 RFI/RI Report. Details of Human Health Risk Assessment including a discussion of the conceptual site model are presented in Section 6.0 of this Phase II RFI/RI Report.

The objective of TM8 was to gather data necessary to sufficiently verify the assumption that substantial LHSU contamination associated with potential LHSU exposure pathways does not exist, or that, if present, the permeability of the LHSU units is insufficient for them to act as a complete exposure pathway. The field program was intended to evaluate LHSU groundwater quality in areas with the highest potential for LHSU contamination and estimate the permeability of LHSU units containing contamination. This information was used to evaluate the potential for migration of contaminants within the LHSU, or the potential for the LHSU to provide sufficient water for an on-site residential water supply.

The TM8 field investigation program specified the following activities:

- Drilling and sampling of six bedrock pilot boreholes to evaluate LHSU stratigraphy and hydrogeologic conditions (Figure 1.4-4).

- Installation and development of 6 to 12 monitoring wells at six locations to allow collection of groundwater quality samples from LHSU targeted units.

- Collection of groundwater samples from each newly installed LHSU monitoring well and analysis of the samples for a selected suite of indicator parameters to evaluate whether contaminants from the UHSU have migrated to LHSU units. If contaminants are detected in the LHSU unit being monitored at a particular location, an additional monitoring well was to be installed into the next deeper permeable LHSU unit at that location to evaluate the vertical extent of contamination in the LHSU.

- Conducting hydraulic slug tests within each newly installed LHSU bedrock monitoring well to evaluate the permeability of the screened LHSU bedrock unit in that well.

- Drilling of two LHSU bedrock boreholes (SB-1 and SB-2) to collect samples of the LHSU claystone for analysis to evaluate the vertical extent of contamination previously identified in LHSU claystone at these locations.

- Examination of drill core from the borehole for existing Well 2087 to re-evaluate the lithology of the screened interval of this well.

The locations of the proposed boreholes and monitoring wells are shown on Figure 1.4-4. The rationale for each location and the activities to be performed are described below and are summarized in Table 1.4-2.

Three of the six locations for monitoring well installation (WC-1, WC-5, and WC-6) were selected to evaluate the potential for vertical migration of UHSU contamination to LHSU sandstone units (scenario 2). At these locations the investigation focused in areas where UHSU contamination has been detected at the highest levels, or where contaminants have been detected previously in the LHSU. Two locations (WC-1 and WC-6) were selected because they are within UHSU contamination "hotspots", and LHSU sandstones are in close vertical proximity to the UHSU No. 1 Sandstone. If significant contamination was not detected in these locations, it is believed unlikely that it occurs elsewhere due to vertical migration from the UHSU to LHSU since these locations are among the most likely for LHSU contamination to occur. The other location (WC-5) was selected because low levels of contamination have been identified in an existing well completed in a LHSU claystone.

The approach to investigation at these locations is diagrammatically illustrated in Figure 1.4-5 (WC-1 and WC-6) and Figure 1.4-6 (WC-5). At each location, a pilot borehole was to be drilled through the uppermost three to four LHSU sandstone units to gather stratigraphic and hydrogeologic information. Lithologic and borehole geophysical logging were to be conducted and used to identify target depths for adjacent monitoring wells (a-series). Each monitoring well was to be developed and sampled for groundwater quality. The results of expedited laboratory analysis of groundwater samples from these wells for a selected indicator parameter suite were expected to indicate the presence or absence of contamination. If contamination was detected, a second monitoring well was to be installed to the next deeper sandstone to evaluate the vertical extent of the LHSU contamination. In addition, slug tests are to be performed in each new LHSU monitoring well to evaluate the permeability of the LHSU sandstones for use in estimating the potential for contaminant migration within the LHSU.

WC-2, WC-3, and WC-4 were to be installed to evaluate the source of contaminants in LHSU sandstones near where they subcrop beneath colluvium along the Woman Creek drainage (scenario 1). The new wells were to be installed upgradient and away from the LHSU subcrop areas so as to be outside the influence of localized recharge from UHSU colluvial water to the LHSU sandstones, if it is occurring. The location WC-2 was selected to investigate the source of LHSU contamination identified in the Well 1187. The locations WC-3 and WC-4 were similarly selected to investigate the sources of LHSU contamination identified in Wells 00391 and 1487, respectively.

The approach to investigation at these locations is diagrammatically illustrated in Figure 1.4-7. At each location, a pilot borehole was to be drilled through the LHSU sandstone of interest and the next deeper two to three LHSU sandstone units to gather stratigraphic and hydrogeologic information. These data were to be used to identify target depths for adjacent monitoring wells (a-series). Each monitoring well was to be developed and sampled for groundwater quality. The results of expedited laboratory analysis of groundwater samples from these wells for a selected indicator parameter suite were expected to show the presence or absence of contamination. If contamination was not detected, it would be concluded that the contaminants detected in the existing well near the subcrop were introduced to the LHSU sandstone through an UHSU exposure pathway (scenario 1). If contaminants were detected, it would be an indication that the contamination migrated vertically to the LHSU sandstone from an UHSU secondary source area and then migrated laterally within the LHSU sandstone to the existing well near the subcrop location. Such a condition would be associated with a LHSU exposure pathway (scenario 2). In that case, a second well was to be installed into the next deeper LHSU

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sandstone to evaluate the vertical extent of the contamination in the LHSU. In addition, slug tests were to be performed in each new LHSU monitoring well to evaluate the permeability of the LHSU sandstones for use in estimating the potential for contaminant migration within the LHSU.

Boreholes SB-1 and SB-2 (Figure 1.4-4) were to be drilled adjacent to existing Boreholes 09991 and BH2587, respectively, to evaluate the vertical extent of CHC contamination identified in LHSU claystone bedrock samples previously collected in those areas. The new boreholes were to be drilled to collect samples of claystone bedrock below the depths previously collected. Details of the field methods to be implemented with regard to drilling, coring, geophysical logging, and soil/rock sampling are found in Section 2.3 of TM8.

Two sets of groundwater samples were to be collected from the newly installed LHSU monitoring wells and analyzed to evaluate groundwater quality in the LHSU. One set was to be submitted to an analytical laboratory for analysis on a quick turn-around basis for a suite of indicator parameters (Table 1.4-3) selected for their utility and reliability as indicators of site-related contamination. The second set of samples was to be submitted to another analytical laboratory for analysis for a more extensive suite of LHSU analytical parameters (Table 1.4-4). (Note: The volatile organic parameters listed in Table 2-8 of TM8 were incorrect for the specified analytical Method 524.2. Table 1.4-4 of this summary shows the correct parameters. This is discussed further in Section 2.2 of this Phase II RFI/RI Report.)

The results of the indicator parameter analyses were used to guide the scope of the remaining field investigation activities by providing preliminary information on the occurrence and vertical extent of contamination in a LHSU unit at a particular location. Specific factors considered in selecting the indicator parameters include: (1) they should have been detected in on-site waste or as existing groundwater contamination at substantial concentrations; (2) they should be mobile and relatively stable and persistent over the flow path of interest; (3) they should be measurable at low concentrations and should be unambiguous with respect to site-related contamination versus sampling/laboratory artifacts; and (4) they should be readily discernable at low levels from naturally occurring conditions.

The purpose of analyzing a second set of samples for a more extensive suite of LHSU analytical parameters was to verify the results of the indicator parameter analyses, and to fully characterize the types of contaminants, if present, in the LHSU at a particular location. The LHSU parameter analysis suite is a refinement of the full analytical parameter list used for the

Phase II RFI/RI Work Plan (Alluvial). Certain parameters or types of parameters were eliminated for TM8 LHSU parameter analysis suite because they had not been detected to date in UHSU samples at a frequency greater than five percent, are not believed to be present in on-site waste, are believed to be sampling/laboratory artifacts, or are not present at levels above background.

Bedrock claystone samples collected from Boreholes SB-1 and SB-2 were to be analyzed for the parameters listed in Table 1.4-5. This list is similar to the LHSU parameter analytical suite for groundwater (except for VOCs), and is tailored for claystone sample analysis.

The results of the field investigation were used in the evaluation of the geology, hydrogeology, contamination assessment, and risk assessment for the LHSU for the Phase II RFI/RI Report. The results and conclusions from the evaluations are presented in Sections 3.5, 3.6, 4.5 and 6.0 of this report.

1.4.8 OU-2 Human Health Risk Assessment Contaminants of Concern (TM9)

(Pending Approval)

1.4.9 OU-2 Human Health Risk Assessment Toxicity Assessment (TM10)

(Pending Approval)

1.4.10 Environmental Evaluation Work Plan

The Environmental Evaluation Work Plan was prepared as part of the Phase II RFI/RI Work Plan (Alluvial) (see Section 6.0, DOE 1991a). The objective of this work plan was to provide a framework for addressing and quantifying the ecological effects to the biotic environment (plants, animals, and microorganisms) from exposure to contaminants resulting from IHSSs within OU-2. An ecosystem approach was used as the basis to develop this work plan to be sure that ecological effects endpoints (e.g., structural diversity, biomass, phenology, nutrient cycling, trophic structure) are addressed as well as populations and individuals that are more traditionally evaluated in a risk assessment approach. Determination of the effects on biota would be performed in conjunction with the human health risk assessment. The ecosystem approach was comprehensive in that it initially addresses all ecosystem components, then progressively focused on those aspects of the system potentially affected by contamination. The approach was designed to ensure that all procedures to be performed were appropriate,

necessary and sufficient to adequately characterize the nature and extent of environmental effects to biota under the "no action" scenario.

The environmental evaluation would consist of the following ten tasks briefly described below:

- Preliminary Planning

  The preliminary planning involved defining the study area, determining the scope of the EE, identifying DQOs, and developing a plan for obtaining consensus on the selection criteria for contaminants of concern, key receptor species, reference areas, and the field sampling approach/design.

- Data Collection/Evaluation and Conceptual Model Development

  This task included a review, evaluation, and summary of available chemical and ecological data for identifying data gaps. Based on the data, contaminants of concern (COCs) were to be identified based on their documented effects on key receptor species and/or other ecological endpoints. This initial list of COCs would be refined later using data resulting from OU-2 Phase II abiotic investigations. As part of the conceptual biota model development, a food web model was to be constructed and preliminary exposure pathways identified. Results of these activities were to be used to refine the ecological and ecotoxicological field investigation sampling plans.

- Ecological Field Investigation

  Preliminary field surveys, and an ecological field inventory to characterize OU-2 biota and their trophic relationships, and to note locations of obvious zones of chemical contamination were to be conducted. Brief field surveys were intended to be performed in the spring, summer, fall, and winter to obtain information on the occurrence, distribution, variability, and general abundance of key plant and animal species. Field inventories were to be conducted in late spring and summer to obtain quantitative data on community composition in terrestrial and aquatic habitats. Samples collected as part of the activity were to be saved for tissue analyses where contaminants of concern have been identified and sampling protocol are in place. Aquatic toxicity tests using *Ceriodaphnia spp* and fathead

minnows were included. As part of these activities, all collected field data were to be reduced, evaluated, compared with, and integrated into the existing database to update knowledge of site conditions.

- Toxicity Assessment

The Toxicity Assessment was intended to be performed in conjunction with the Exposure Assessment and Pathways model task. The assessment included a summary of the types of adverse effects on biota associated with exposure to site-related chemicals, relationships between magnitude of exposure and adverse effects, and related uncertainties for contaminant toxicity, particularly with respect to wildlife.

- Exposure Assessment and Pathways Model

A site-specific pathways model based on the ecological field surveys was to be developed. This exposure-receptor pathways model was to be used to evaluate the transport of contaminants at OU-2 to biological receptors. The pathways model was based on a conceptual pathways approach and provided initial determination of the movement and distribution of contaminants, likely interactions among ecosystem components, and expected ecological effects.

- Preliminary Contamination Characterization

A characterization of the threat or risk of OU-2 contaminants to receptor populations and habitats was to be prepared. Determinations of the magnitude of the effects of contamination on OU-2 biota were to be made. The actual or potential effects of contamination on ecological endpoints (e.g., species diversity, food web structure, productivity) were to be addressed. Depending on DQOs and the quality of data collected, the contamination characterization would be expressed qualitatively, quantitatively, or a combination of the two. Information from ARARs, toxicological assessments, and the pathways model would be used to develop criteria that address biological resource protection.

- Uncertainty Analysis

  Assumptions would be identified and the evaluation of uncertainty in the environmental risk assessment analysis would be performed.

- Planning

  Additional DQOs with respect to the Ecotoxicological field investigation would be developed.

- Ecotoxicological Field Investigation

  Tissue analysis studies and any additional ecotoxicological field investigations would be performed under this task. This work would be conducted concurrently with the data collection and ecological field investigation tasks. Samples collected in the previous field studies would be used wherever possible (e.g., when contaminants of concern have been identified and sampling protocols are in place); new samples would be collected if necessary. The need for measuring additional population endpoints through reproductive success, enzyme inhibition, microbial respiration, or other ecotoxicological studies would be evaluated based on the preliminary ecological risk assessment. Selection of the target analytes, species, and tissues would be based on the determination of which contaminants are likely to be present in sufficient concentrations, quantities, and locations as to be detected in biota. Selection of these specific criteria would be developed in consultation with EPA and the State. All necessary federal and state permits would be obtained prior to any destructive sampling or collecting.

- Environmental Evaluation Report

  A final characterization of contamination in biota at OU-2 would be prepared. Results from the ecotoxicological field investigations would be used to evaluate ecosystem effects. Information on site environmental characteristics and contaminants, characterization of effects, remediation criteria, conclusions, uncertainty analysis, and limitations of the assessment would be summarized into the Environmental Evaluation Report.

TABLE 1.4-1

SITE-SPECIFIC CHEMICAL ANALYSIS ROSTER

MATRIX	ANALYTICAL SUITES			
	Volatile Organics	Acid Extractables	Base Neutral Extractables	Pesticides/ PCBs
Waste Sources	Yes[1]	Yes[2]	Yes[2]	Yes[2]
Sediments	Yes[1]	No[4]	No[4]	No[4]
Groundwater	Yes[1]	Yes[3]	Yes[3]	Yes[3]
Surface Water	Yes[1]	No[4]	No[4]	No[4]

Notes:

[1] Case III, supplemental data required.
[2] Case II, supplemental data required.
[3] Case II, supplemental data required only for source characterization alluvial monitor wells.
[4] Case II, supplemental data not required.

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TABLE 1.4-2

SUMMARY OF RATIONALE FOR BOREHOLE/MONITORING WELL LOCATIONS AND OBJECTIVES/INFORMATION TO BE GAINED
(from TM-8)

Boring/Well Location	Rationale	Objective/Information
WC-1	Located in UHSU hotspot area with potential for hydraulic communication between UHSU and LHSU.	Investigate presence or absence of contamination in uppermost LHSU sandstone unit and next deeper sandstone unit, if necessary. Evaluate permeability of LHSU sandstones.
WC-2	Located upgradient of existing LHSU well screened near sandstone subcrop beneath colluvium.	Investigate source of contamination at existing well. Investigate presence or absence of contamination in deeper LHSU sandstone, if necessary. Evaluate permeability of LHSU sandstones.
WC-3	Located upgradient of existing LHSU well screened near sandstone subcrop beneath colluvium.	Investigate source of contamination at existing well. Investigate presence or absence of contamination in deeper LHSU sandstone, if necessary. Evaluate permeability of LHSU sandstones.
WC-4	Located upgradient of existing LHSU well screened near sandstone subcrop beneath colluvium.	Investigate source of contamination at existing well. Investigate presence or absence of contamination in deeper LHSU sandstone, if necessary. Evaluate permeability of LHSU sandstones.
WC-5	Located near existing LHSU well where contamination detected in LHSU below central portion of OU-2 plateau.	Confirm presence of contamination in LHSU. Evaluate type of LHSU material in screened interval of existing well. Investigate presence or absence of contamination in deeper LHSU sandstone, if necessary. Evaluate permeability of LHSU sandstones.
WC-6	Located in UHSU hotspot area with potential for hydraulic communication between UHSU and LHSU.	Investigate presence or absence of contamination in uppermost LHSU sandstone unit and next deeper sandstone unit, if necessary. Evaluate permeability of LHSU sandstones.
SB-1	Located adjacent to previous boring where contamination detected in LHSU claystone samples.	Investigate vertical extent of contamination in LHSU claystone.
SB-2	Located adjacent to previous boring where contamination detected in LHSU claystone samples.	Investigate vertical extent of contamination in LHSU claystone.
2087*	Existing LHSU well in 903 Pad Area where contamination has been detected below central portion of OU-2 plateau.	Re-evaluate lithology of screened interval as either a LHSU claystone or sandstone.

* Well 2087 is an existing well.

TABLE 1.4-3

SUMMARY OF GROUNDWATER INDICATOR PARAMETERS FOR REVISED BEDROCK WORK PLAN
(from TM-8)

HALOGENATED VOLATILE ORGANICS
Vinyl Chloride
1,1-Dichloroethene
total 1,2-Dichloroethene
1,1,1-Trichloroethane
Carbon tetrachloride
Trichloroethene
Tetrachloroethene

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TABLE 1.4-4

SUMMARY OF LHSU PARAMETER ANALYTICAL SUITE FOR GROUNDWATER SAMPLES FOR REVISED BEDROCK WORK PLAN

(From TM-8 except for VOCs, which have been revised to reflect Method 524.2)

METALS (Dissolved)
Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc
Lithium
Tin

OTHER METALS
Molybdenum
Cesium
Strontium
Lithium
Tin

OTHER PARAMETERS
pH
Specific Conductance
Temperature
Total Dissolved Solids
Cations/Anions
Cyanide
Total Organic Carbon

DISSOLVED RADIONUCLIDES
Gross Alpha
Gross Beta
Uranium 233+234, 235 and 238 (Dissolved)
Americium 241 (Dissolved)
Plutonium 239+240 (Dissolved)
Tritium

ORGANICS: VOLATILES
1,1,1,2-Tetrachloroethane
1,1,1-Trichloroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane
1,1-Dichloroethane
1,1-Dichloroethene
1,1-Dichloropropene
1,2,3-Trichlorobenzene
1,2,3-Trichloropropane
1,2,4-Trichlorobenzene
1,2-Dibromoethane
1,2-Dichloropropane
1,2-Dichlorobenzene
1,2-Dichloroethane
1,3-Dichlorobenzene
1,3-Dichloropropane
1,4-Dichlorobenzene
Benzene
Benzene, 1,2,4-Trimethyl
Benzene, 1,3,5-Trimethyl
Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
Cumene
Dibromochloromethane
Dibromethane

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TABLE 1.4-4
(Concluded)

ORGANICS: VOLATILES
(continued)
Dichlorodifluoromethane
Ethylbenzene
Hexacylorobutadiene
Methylene chloride
Naphthalene
Propane, 1,2-Dibromo-3-chloro
Styrene
Tetrachloroethene
Toluene
Trichloroethene
Trichlorofluoromethane
Vinyl chloride
cis-1,2-Dichloroethene
cis-1,3-Dichloropropene
m, p-xylene
n-Butylbenzene
n-Propylbenzene
o-Chlorotoluene
o-Xylene
p-Chlorotoluene
p-Cymene
sec-Butylbenzene
sec-Dichloropropane
tart-Butylbenzene
trans-1,2-Dichloroethene
trans-1,3-Dichloropropene

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TABLE 1.4-5

LHSU ANALYTICAL PARAMETERS FOR BOREHOLE SAMPLES
(from TM-8)

METALS
Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc

OTHER METALS
Molybdenum
Cesium
Strontium
Lithium
Tin

GENERAL PARAMETERS
pH
Cyanide
Moisture Content

RADIONUCLIDES
Gross Alpha
Gross Beta
Uranium 233+234, 235 and 238
Americium 241
Plutonium 239+240
Tritium

ORGANICS: VOLATILES
Chloromethane
Bromomethane
Vinyl Chloride
Chloroethane
Methylene Chloride
Acetone
Carbon Disulfide
1,1-Dichloroethene
1,1-Dichloroethane
total 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
Ethyl Benzene
Styrene
Total Xylenes
Tetrachloroethene
Toluene
Chlorobenzene

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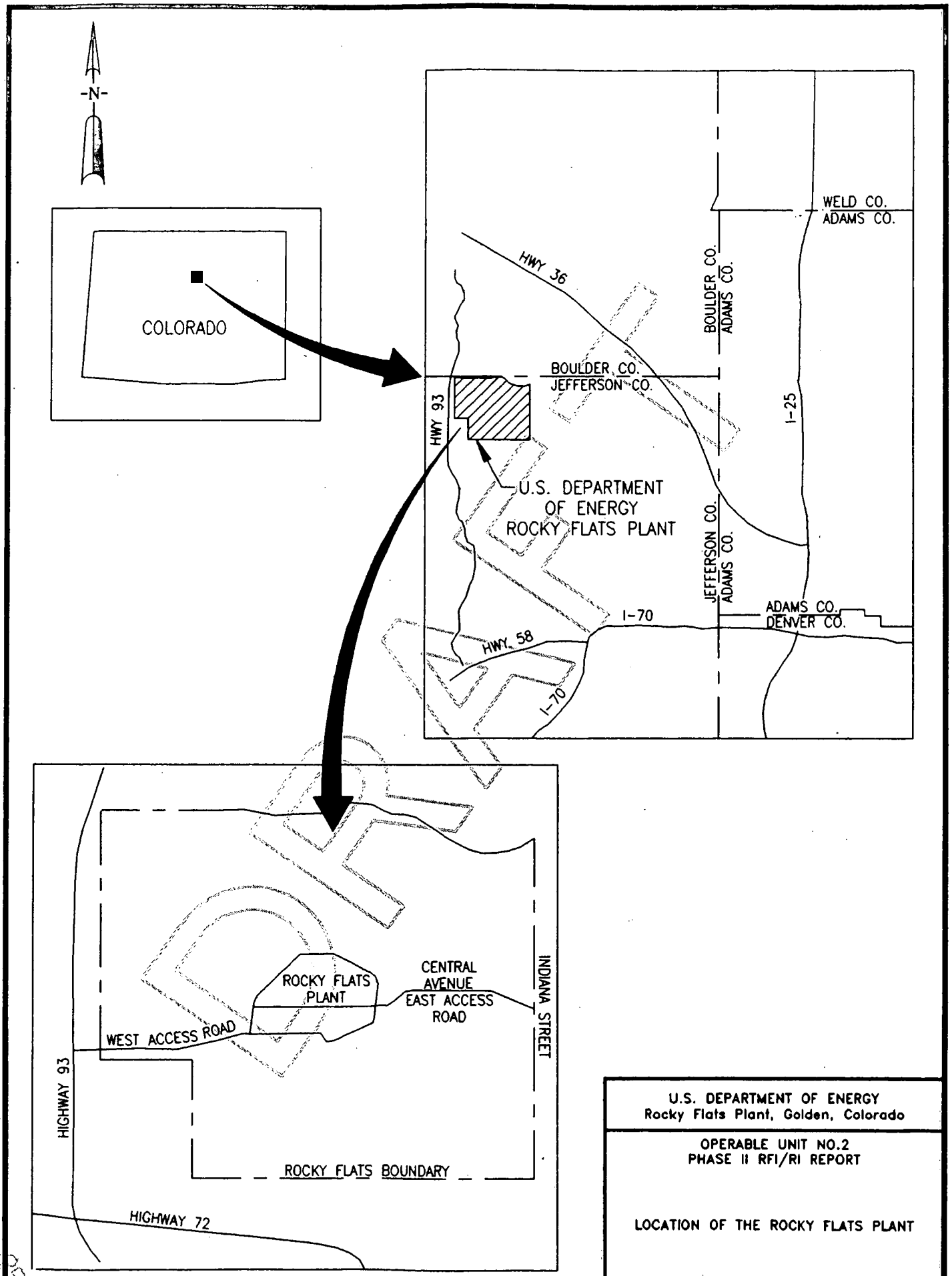

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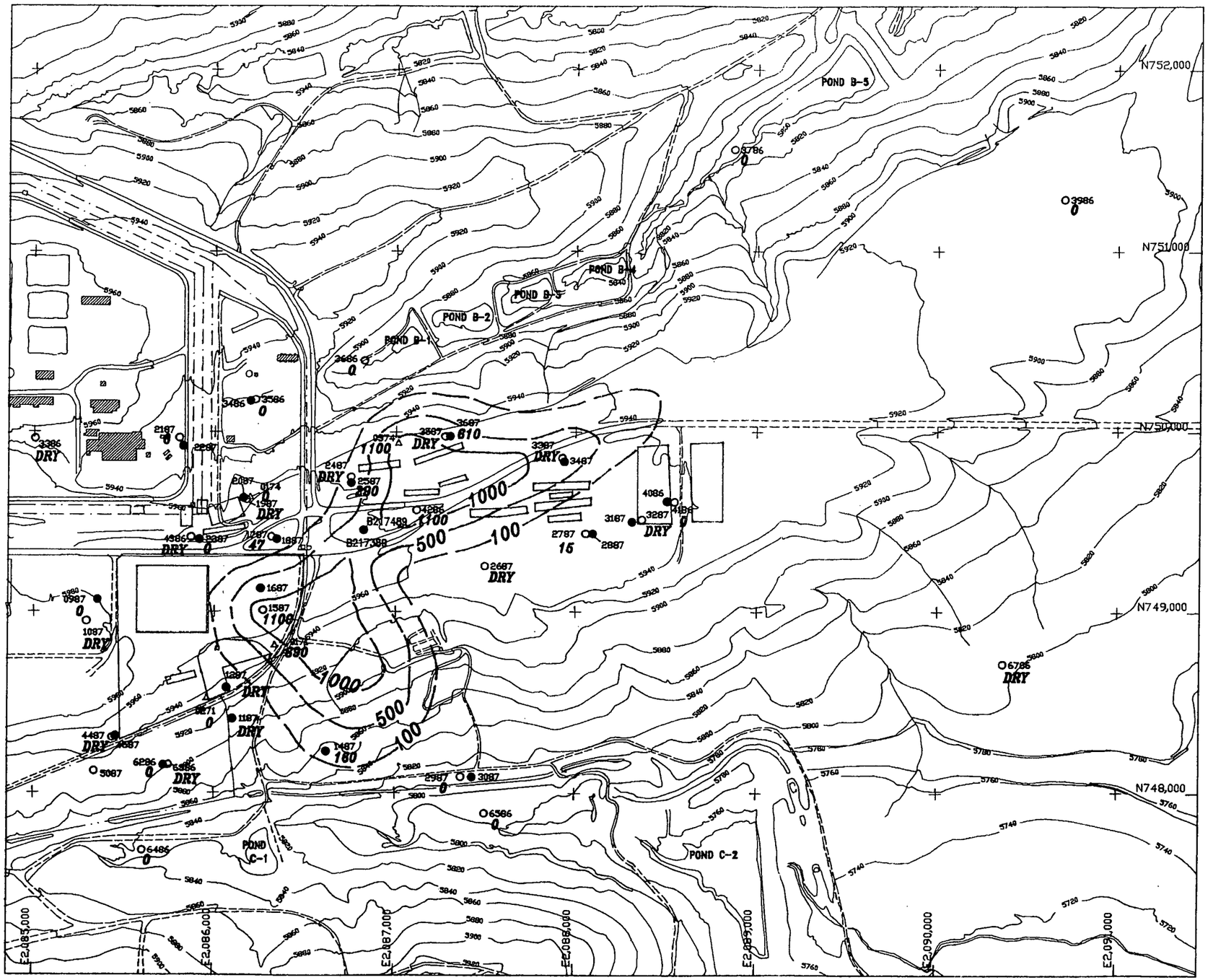
LOCATION OF THE ROCKY FLATS PLANT

FIGURE 1.3-1 OCTOBER 1993

OU2R1275 1-1



EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS)

500 — LINE OF EQUAL CCl_4 CONCENTRATION (µg/l) DASHED WHERE APPROXIMATELY LOCATED

290 — CCl_4 CONCENTRATION (µg/l)

2587 ● BEDROCK MONITOR WELL

3587 ○ ALLUVIAL MONITOR WELL

0174 △ PRE-1986 MONITOR WELL

N

Scale: 1" = 600'

0' 300' 600'

CONTOUR INTERVAL = 20'

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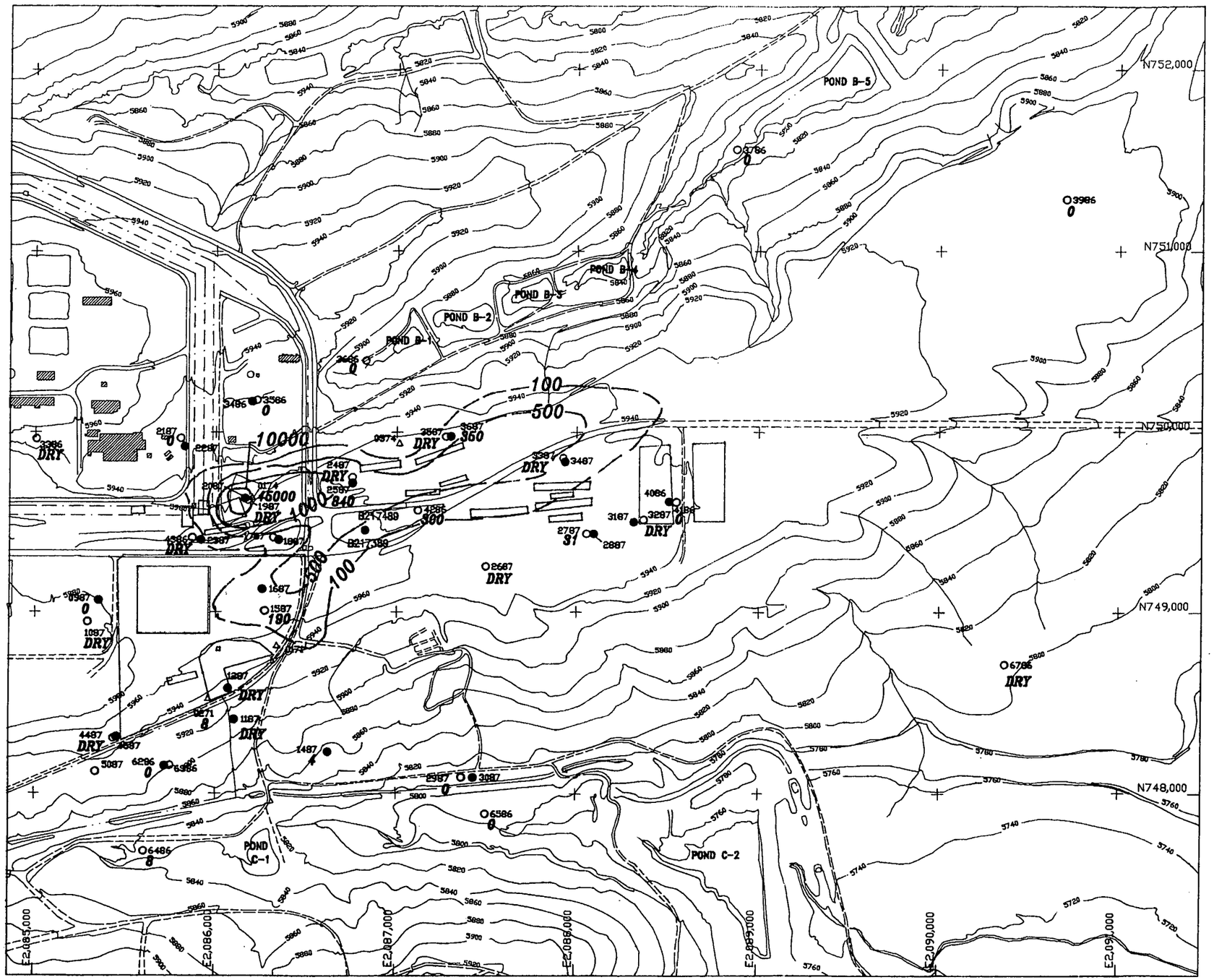
CARBON TETRACHLORIDE ISOPLETHS FOR THE UPPER HYDROSTRATIGRAPHIC GROUNDWATER FLOW SYSTEM
2nd QUARTER 1989
(PRIOR TO PHASE II REMEDIAL INVESTIGATION)

FIGURE 1.3-5

OCTOBER 1993

R33M030.MBJ—080791/600



EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS)

500 — LINE OF EQUAL PCE CONCENTRATION (µg/l) DASHED WHERE APPROXIMATELY LOCATED

160 — PCE CONCENTRATION (µg/l)

2587 ● BEDROCK MONITOR WELL

3587 ○ ALLUVIAL MONITOR WELL

0174 △ PRE-1988 MONITOR WELL

N

Scale: 1" = 600'

0' 300' 600'

CONTOUR INTERVAL = 20'

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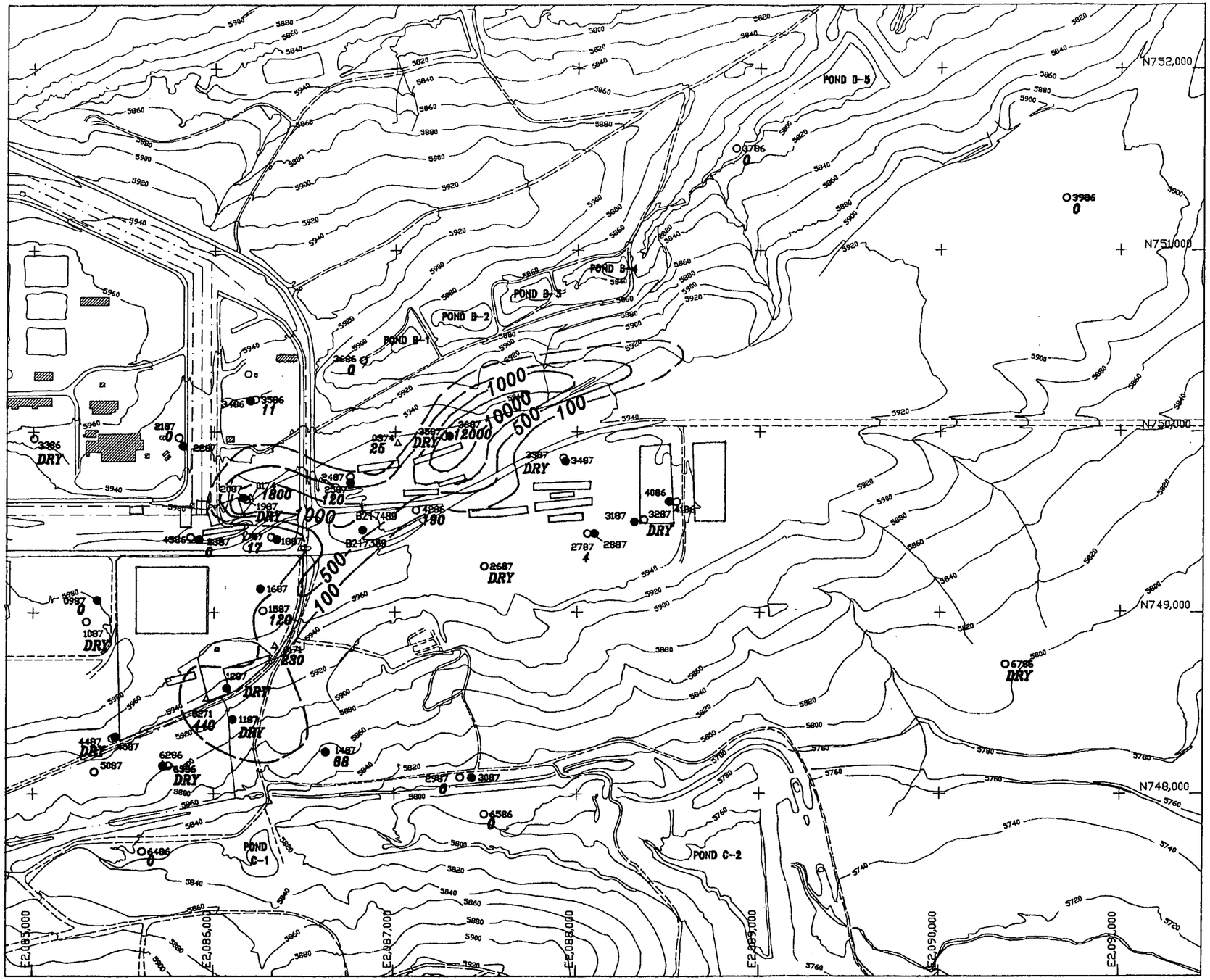
PHASE II RFI/RI REPORT

TETRACHLOROETHENE ISOPLETHS FOR THE UPPER HYDROSTRATIGRAPHIC GROUNDWATER FLOW SYSTEM
2nd QUARTER 1989
(PRIOR TO PHASE II REMEDIAL INVESTIGATION)

FIGURE 1.3-6

OCTOBER 1993

R33M031.MBp/-080791/600



EXPLANATION

INDIVIDUAL HAZARDOUS SUBSTANCE SITE (IHSS)

500 — LINE OF EQUAL TCE CONCENTRATION (µg/l) DASHED WHERE APPROXIMATELY LOCATED

120 — TCE CONCENTRATION (µg/l)

2587 ● BEDROCK MONITOR WELL

3587 ○ ALLUVIAL MONITOR WELL

0174 △ PRE-1986 MONITOR WELL

N

Scale: 1" = 600'

0' 300' 600'

CONTOUR INTERVAL = 20'

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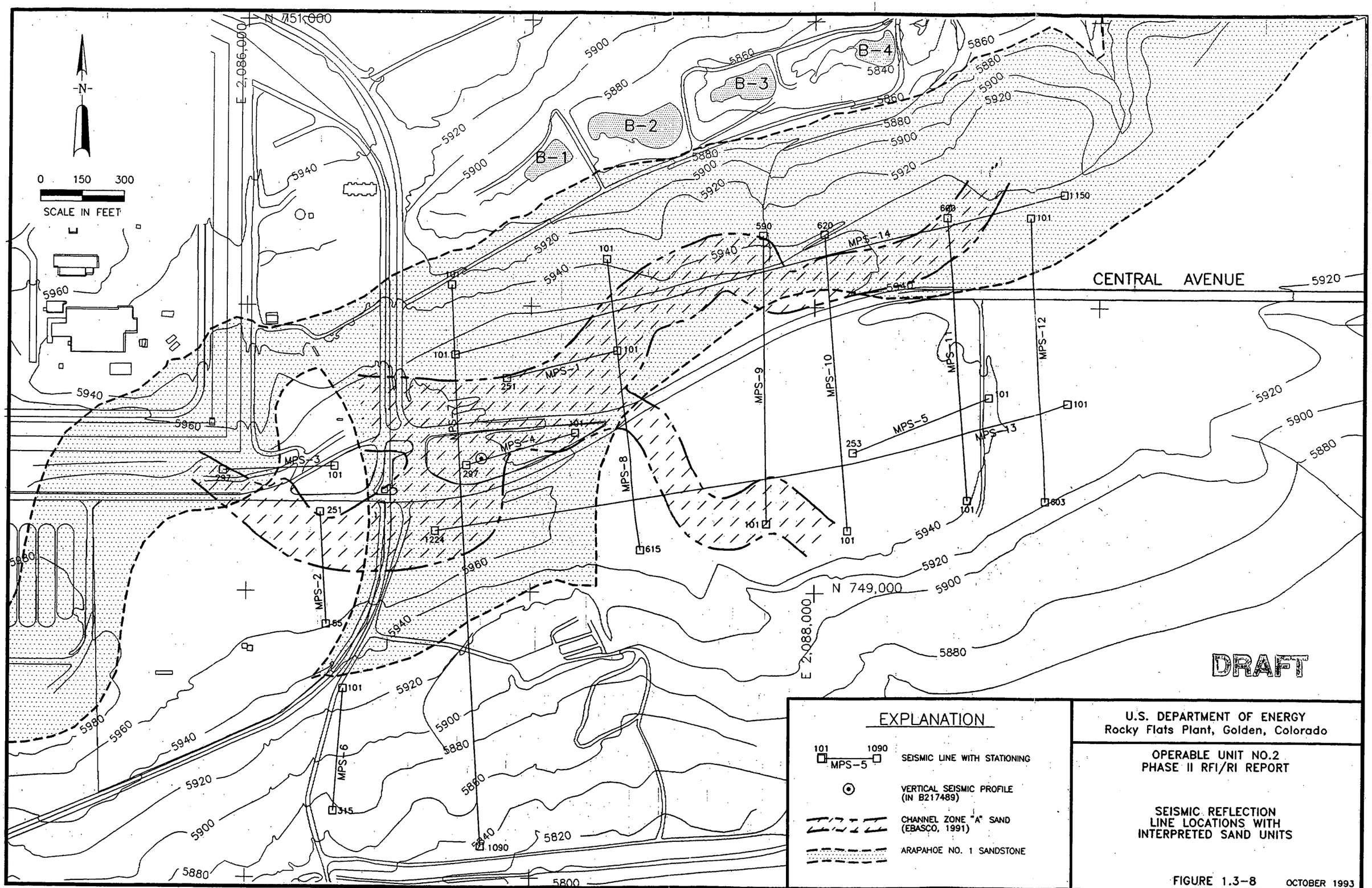
TRICHLOROETHENE ISOPLETHS FOR THE UPPER HYDROSTRATIGRAPHIC GROUNDWATER FLOW SYSTEM
2nd QUARTER 1989
(PRIOR TO PHASE II REMEDIAL INVESTIGATION)

FIGURE 1.3-7 OCTOBER 1993

R33M032.MBp/-080791/600



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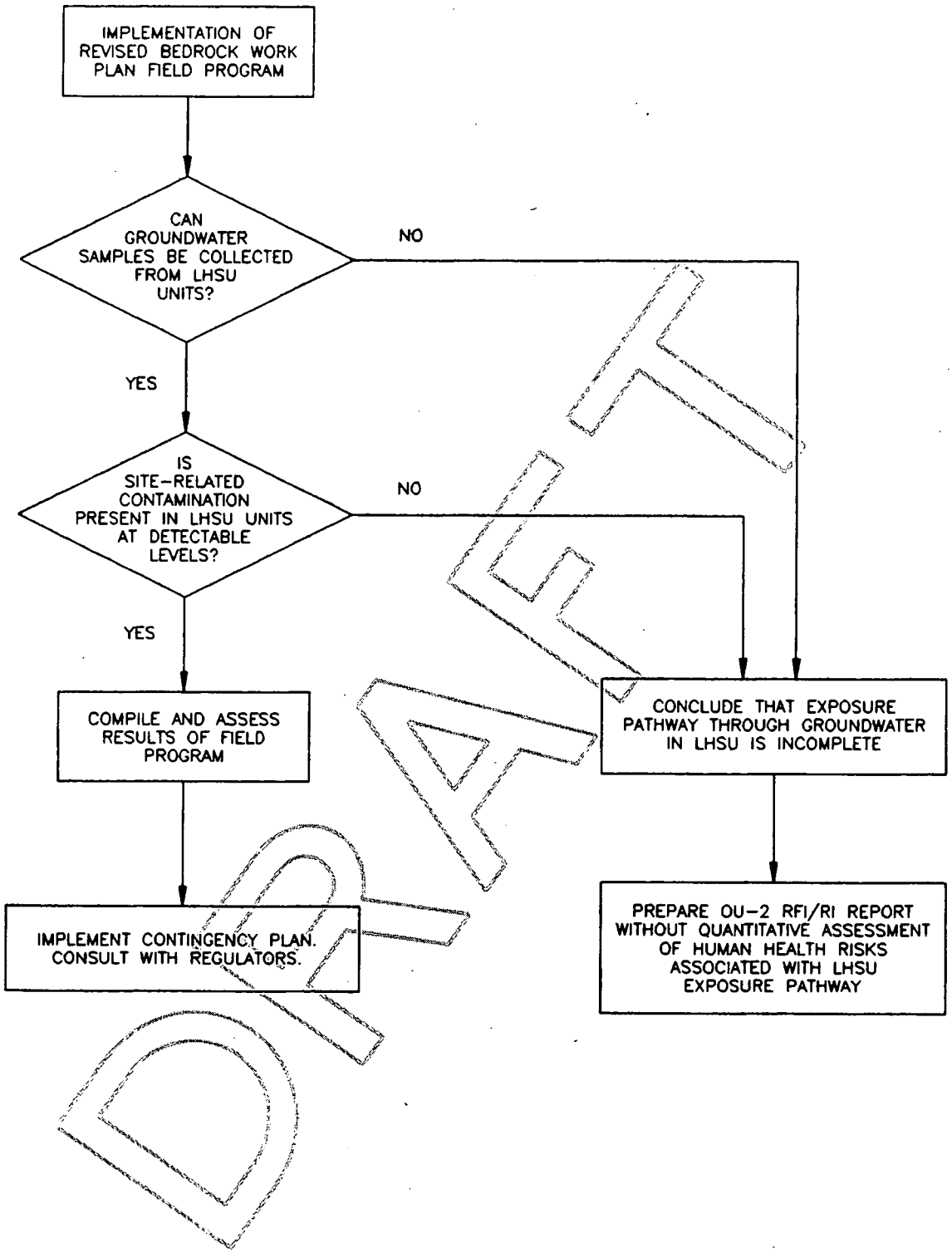
SEISMIC REFLECTION
LINE LOCATIONS WITH
INTERPRETED SAND UNITS

FIGURE 1.3-8 OCTOBER 1993

0U2RI182 1=300



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* ADDITIONAL INVESTIGATION OF THE LHSU, IF NECESSARY, BEYOND THAT DESCRIBED IN THE SAP (SECTION 2) WILL BE ADDRESSED IN THE CONTINGENCY PLAN

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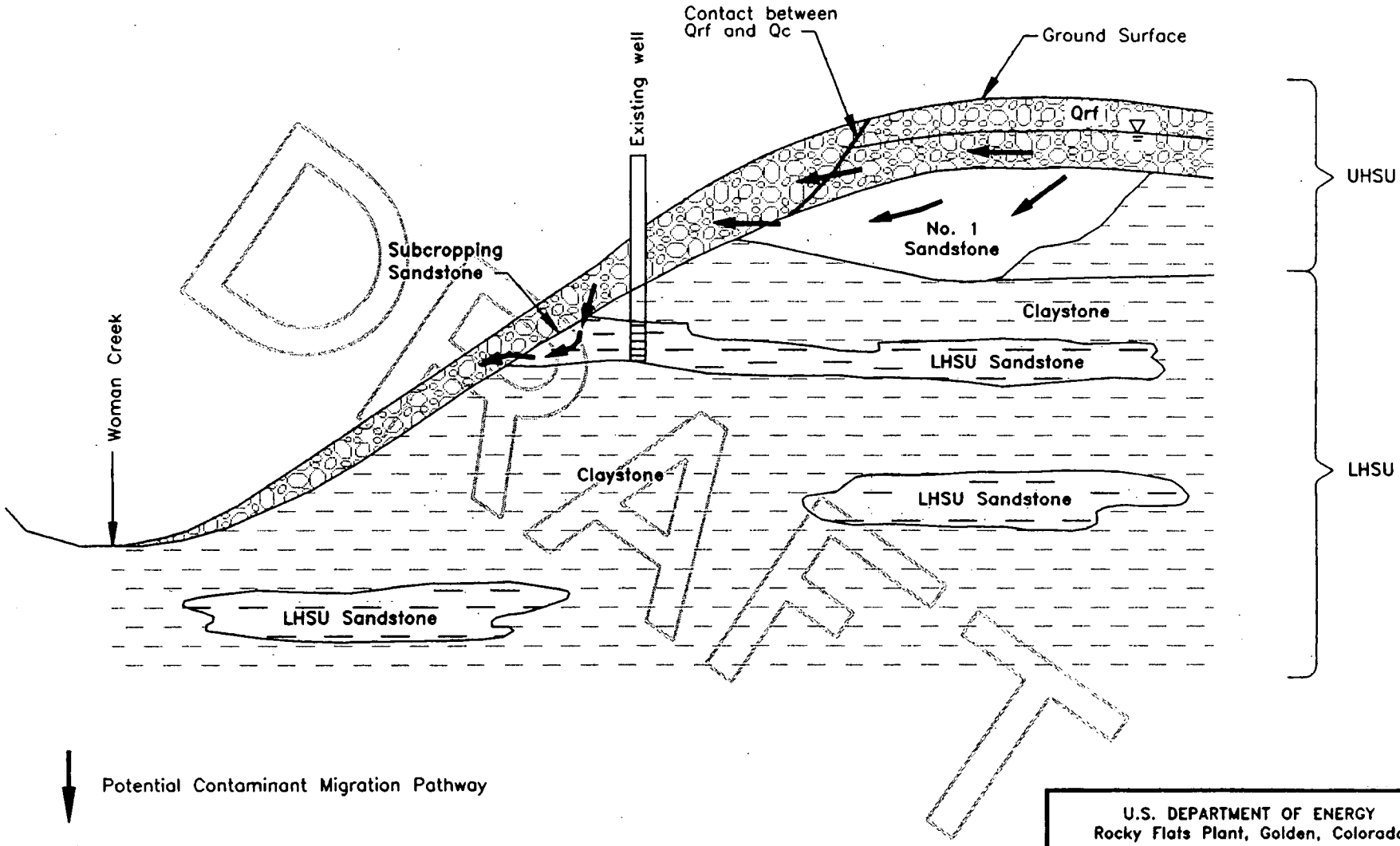
APPROACH FOR REVISED BEDROCK WORK PLAN (FROM TM-8)

FIGURE 1.4-1 OCTOBER 1993

OU2RI169 1-1



Potential Contaminant Migration Pathway

Monitoring Well

Pilot Borehole

Water Table

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DIAGRAM OF POTENTIAL
SOURCE OF CONTAMINATION
TO SUBCROPPING LHSU
SANDSTONES
(SCENARIO 1)
(FROM TM-8)

FIGURE 1.4-2 OCTOBER 1993

OU28172 1-1

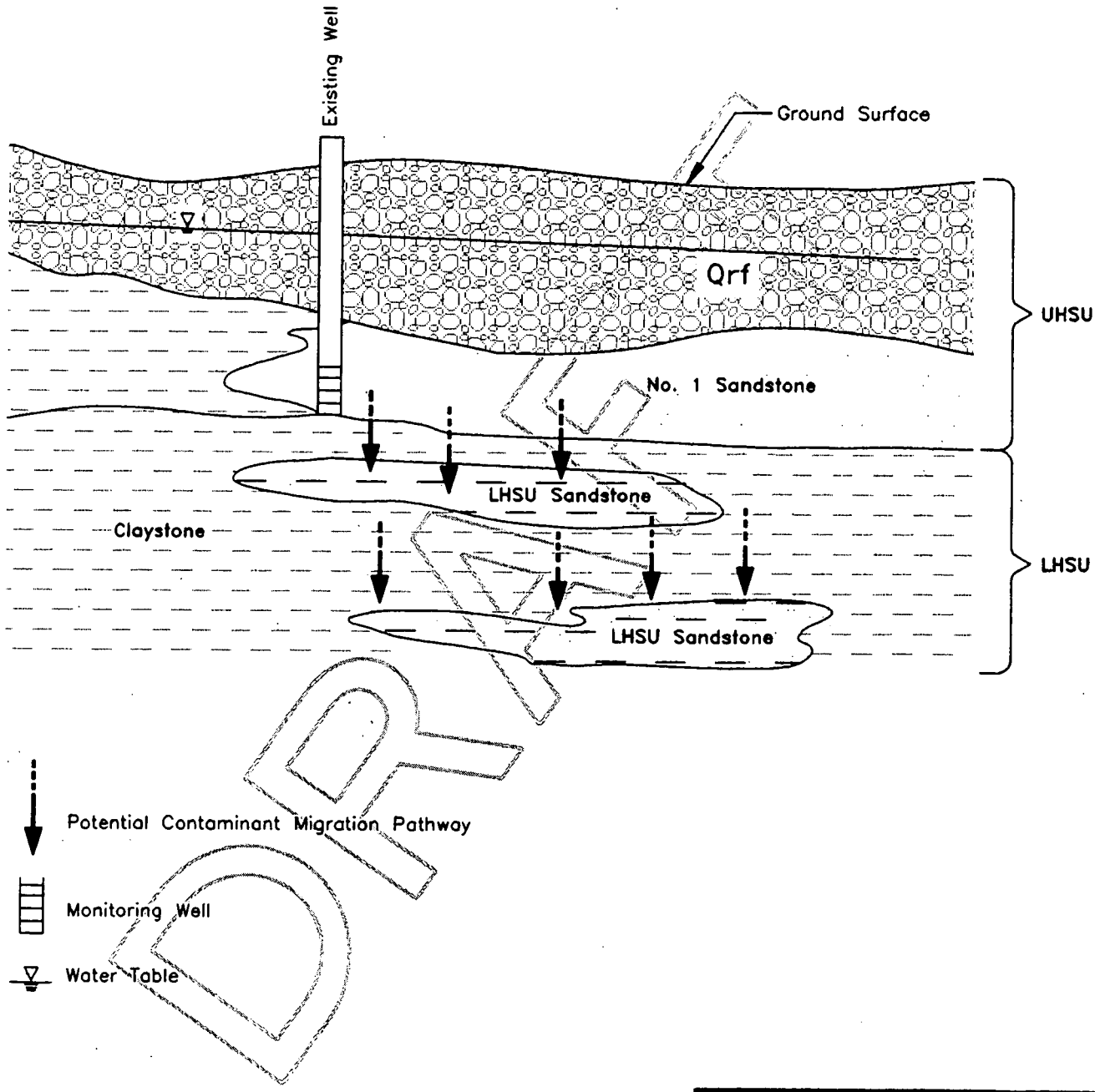

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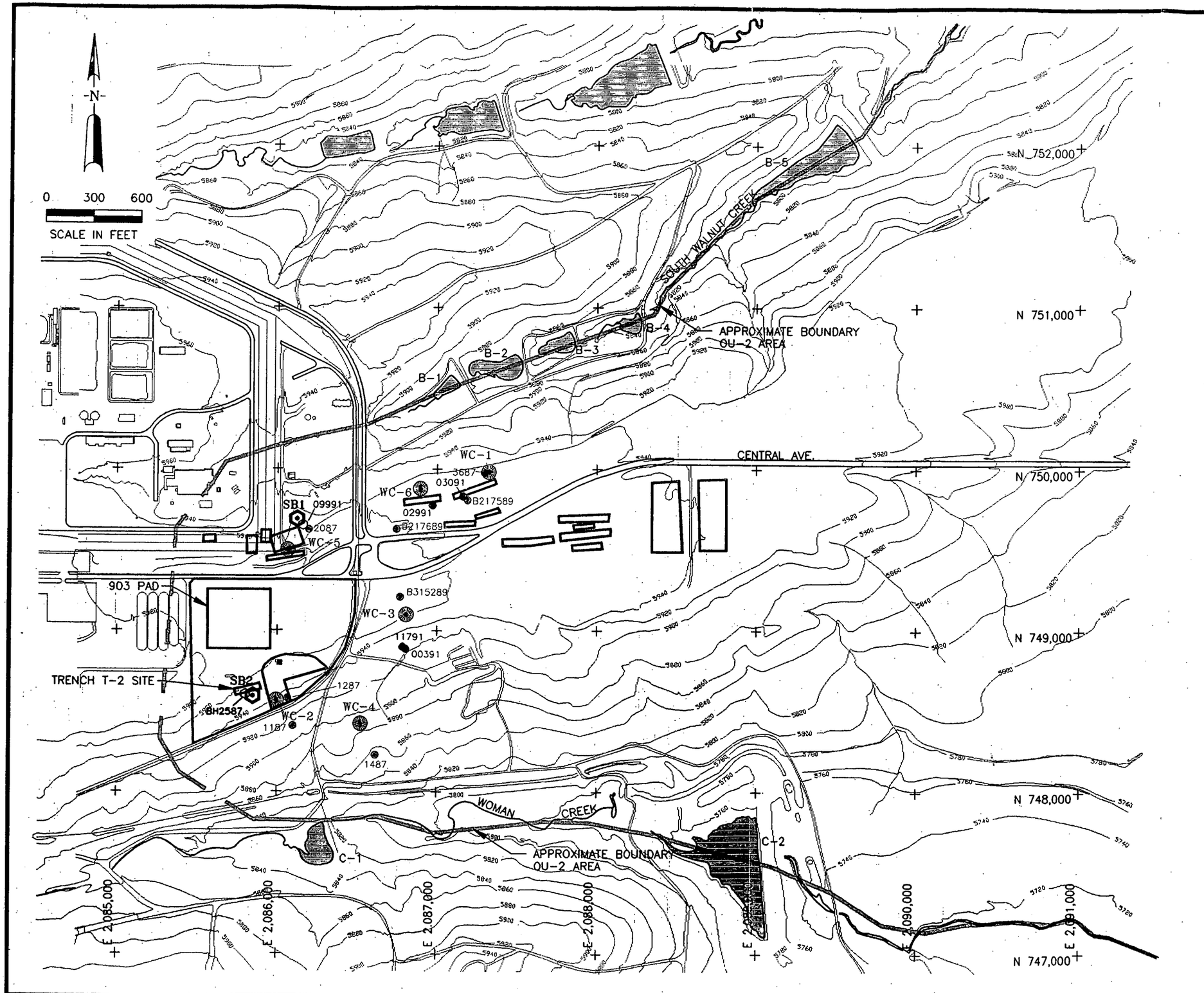
DIAGRAM OF POTENTIAL
VERTICAL MIGRATION OF
CONTAMINANTS FROM UHSU TO LHSU
(SCENARIO 2)
(FROM TM-8)

FIGURE 1.4-3 OCTOBER 1993

OU2R173 1-1



EXPLANATION

- 1991–1992 BEDROCK MONITORING WELL
- BOREHOLE
- HISTORICAL BEDROCK MONITORING WELL
- INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
- APPROXIMATE BOUNDARY OF OU-2 AREA

PROPOSED LOCATIONS

- WC-1 PROPOSED LHSU BEDROCK WELL CLUSTER
- SB1 SOURCE BOREHOLE

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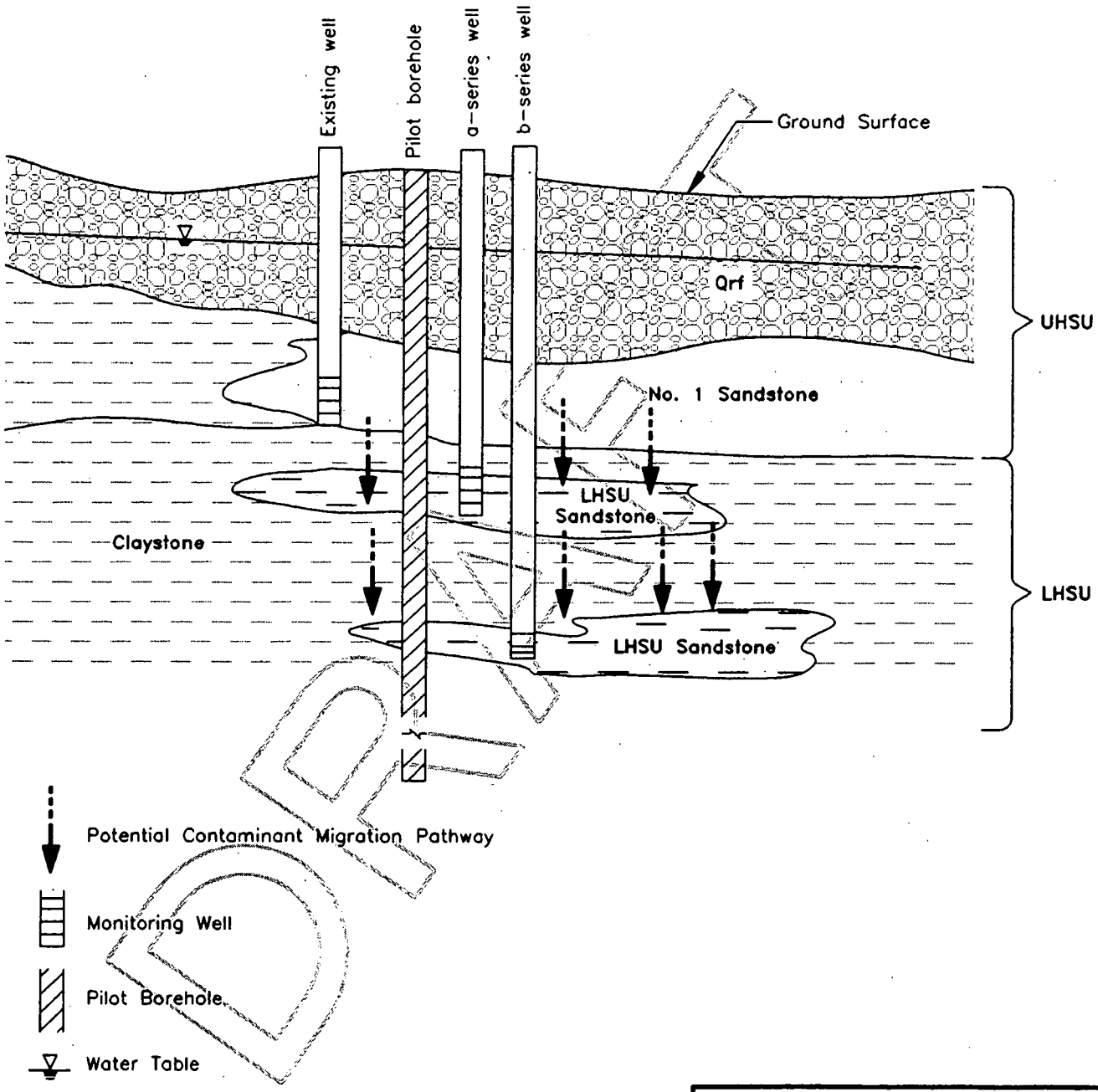
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

PROPOSED INVESTIGATION LOCATIONS
(FROM TM-8)

FIGURE 1.4-4 OCTOBER 1993

OU2RI174 1=600



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U.S. DEPARTMENT OF ENERGY
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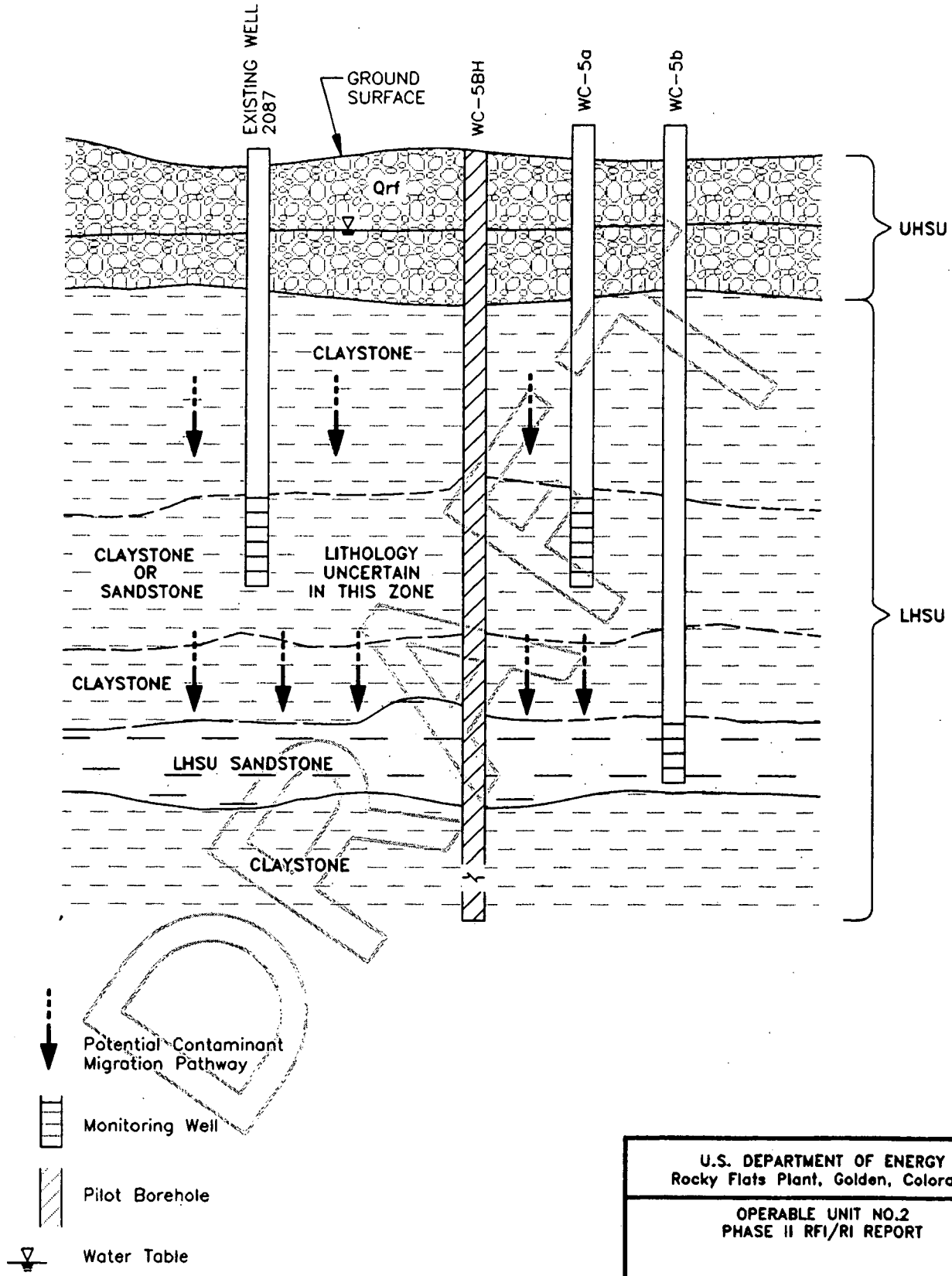
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

TYPICAL LHSU WELL CLUSTER
TO EVALUATE VERTICAL MIGRATION
OF CONTAMINANTS FROM
UHSU TO LHSU
(SCENARIO 2)
(FROM TM-8)

FIGURE 1.4-5 OCTOBER 1993

OU2R1175 1-1



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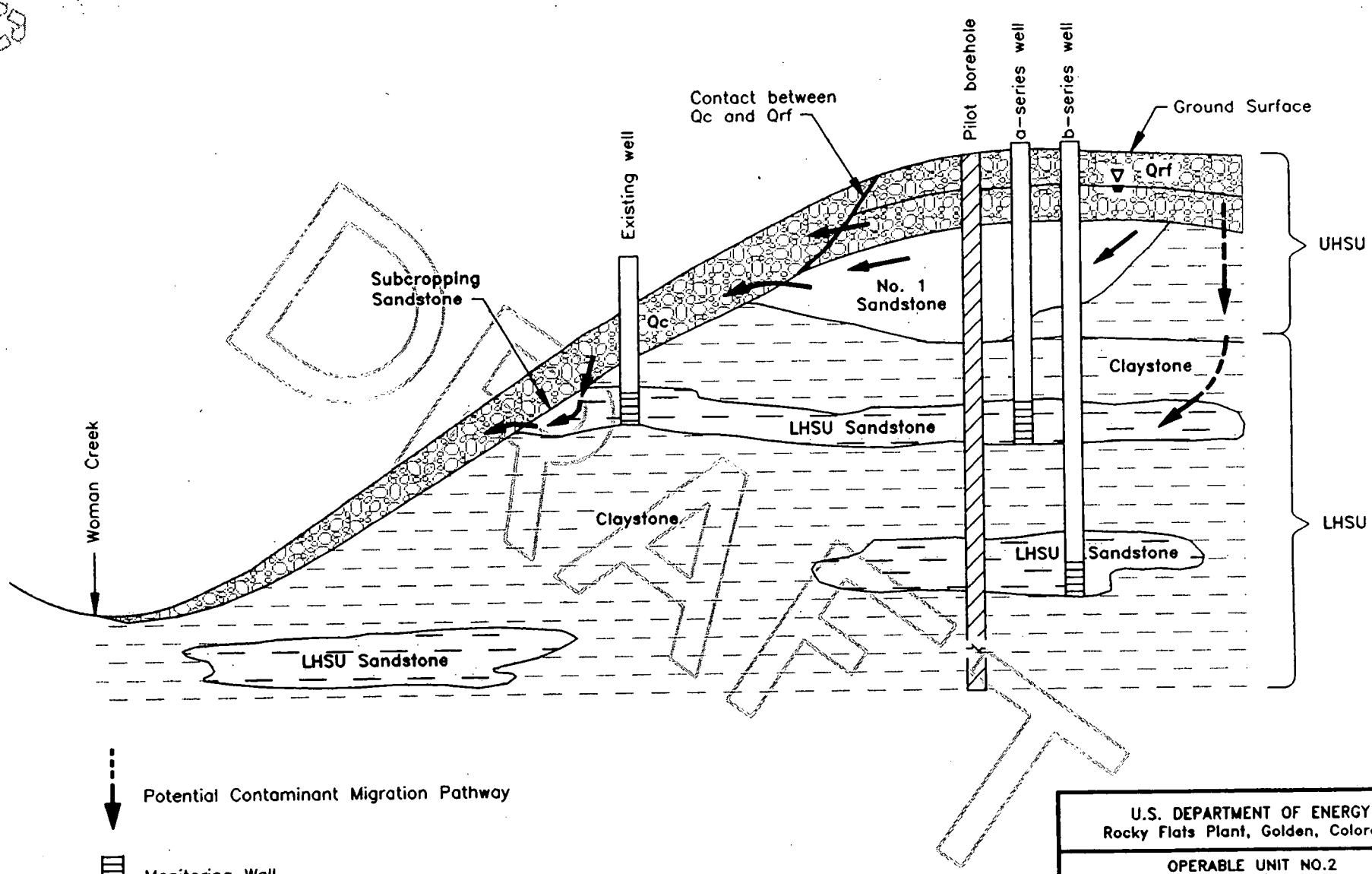
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

DIAGRAM OF WELL CLUSTER WC-5 (FROM TM-8)

FIGURE 1.4-6 OCTOBER 1993

OU2RI176 1-1



Potential Contaminant Migration Pathway

Monitoring Well

Pilot Borehole

Water Table

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

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

TYPICAL WELL CLUSTER TO
EVALUATE SOURCE OF CONTAMINANTS
IDENTIFIED IN SUBCROPPING LHSU
SANDSTONES
(SCENARIO 1)
(FROM TM-8)

FIGURE 1.4-7 OCTOBER 1993

OU2R177 1-1

This section provides a description of the OU-2 Phase II alluvial and bedrock field investigations. The alluvial investigation, conducted in 1991 and 1992, gathered data to characterize the UHSU, which consists of the Rocky Flats Alluvium and the Arapahoe Formation No. 1 Sandstone. The bedrock field investigation, conducted in 1993, gathered data to characterize conditions in the LHSU of the Laramie Formation bedrock. This section discusses the objectives of the field investigations; drilling and sampling of boreholes; installation, development and sampling of monitoring wells; and deviations from the work plans.

2.1 PHASE II ALLUVIAL INVESTIGATION

One of the overall objectives of the OU-2 Phase II RFI/RI is to characterize the nature and extent of soil and groundwater contamination within the UHSU as outlined in the OU-2 Final Phase II RFI/RI Work Plan (Alluvial) (DOE 1991a), hereafter referred to as the Alluvial Work Plan. A summary of the Alluvial Work Plan is presented in Section 1.3.1. A FSP was developed as part of the Alluvial Work Plan to define field activities to be performed to meet this objective.

A four step approach was used for the FSP, as follows:

1. Review existing data
2. Conduct preliminary field and screening study activities
3. Conduct a detailed field sampling program
4. Conduct field and analytical laboratory testing programs

Step 1 consisted of collecting, reviewing, and analyzing the OU-2 Phase I RFI/RI report, previous drafts of the Alluvial Work Plan, regulatory agency comments on the draft work plans, responses to these comments, and other relevant documents (e.g., data, plans, and reports from other Operable Unit investigations).

Step 2 consisted of preliminary field and screening study activities conducted in advance of implementing the detailed field sampling plan (Step 3). Step 2 activities included surveying boreholes and IHSS locations; Field Instrument for Detection of Low Energy Radiation

(FIDLER) monitoring surveys; air monitoring; surface soil and environmental evaluation reconnaissance; mobilization of the drilling and sampling program; setting up temporary waste handling facilities and temporary sample storage facilities; and, establishing health and safety procedures.

Step 3 was the implementation of detailed field studies that consisted of:

- Well installation and sampling for plume characterization
- Borehole sampling and well installation/sampling for source characterization
- Surficial soil sampling
- Environmental evaluation study

Table 2.1-1 outlines the work proposed in the Alluvial Work Plan (DOE 1991a) and the work completed during the alluvial field investigation.

Step 4 consisted of testing activities, including field screening tests for volatile organics and radioactivity, hydraulic pumping and tracer tests, and analytical testing of soil and water samples. Data obtained from these activities were compiled in the EG&G Rocky Flats Environmental Database System (RFEDS).

Details of the Alluvial Work Plan field program are provided below.

2.1.1 Subsurface Soils Investigation

In general, field operations for the alluvial investigation were conducted in accordance with existing RFP SOPs, as contained in EG&G Rocky Flats Environmental Management Department (EMD) SOPs, Volume I, Field Operations, Volume II, Groundwater, and Volume III, Geotechnical (EG&G 1992a). In some cases, however, modifications to the ER SOPs were necessary to perform the field activities specified. Where procedures differ from those stated in the ER SOPs, they were documented in a document change notice (DCN). Table 2.1-2 summarizes the ER SOPs utilized for the alluvial field investigation.

The drilling of boreholes and installation of monitoring wells for the alluvial investigation were conducted from August 26, 1991 to April 15, 1992. A total of 57 borings were drilled (Figures 2.1-1 and 2.1-2). Of these, 40 source characterization boreholes were drilled and sampled. The remaining 17 boreholes were abandoned attempts at monitoring well installation.

Twenty of the 40 source characterization boreholes were completed as monitoring wells. In addition, 88 monitoring wells, 2 pumping wells, and 8 observation wells were drilled and installed. Tables 2.1-3 and 2.1-4 summarize the location and purpose of each borehole and monitoring well, respectively. Table A3 (Appendix A) provides borehole details and Table B2 (Appendix B) provides monitoring well installation details.

Prior to the start of drilling activities, drilling and sampling equipment was decontaminated at the RFP main decontamination facility in accordance with ER SOPs (EG&G 1992a). In addition, the equipment was decontaminated at the conclusion of the drilling program prior to leaving the site. Downhole and sampling equipment (e.g., hollow-stem augers, flightless augers, core barrels) were decontaminated between individual sites during the drilling program. Drill rigs were decontaminated before moving to an area with a different historical characterization (Figures 2.1-1 and 2.1-2 show the four different areas) and at the conclusion of the drilling program. Equipment was screened with a Ludlum 12-1A radiation detector with an air proportional or zinc sulfide probe and alpha small-area smears prior to decontamination and before being released off site.

Drilling activities were conducted in accordance with the Site Health and Safety Plan (EG&G 1991a). As specified in the health and safety plan, radiation and volatile organic compound (VOC) monitoring was performed during drilling and monitoring well installation to characterize personnel exposure and set personal protection levels. In addition, the VOC measurements were used as an indicator of possible VOC contamination of the cuttings and core to identify intervals for sampling. Radiation and VOC real time monitoring was conducted in accordance with ER SOPs (EG&G 1992a).

Prior to drilling, the boreholes and monitoring wells were approximately located in the field by pacing. Following drilling and well installation, coordinate locations and elevations were surveyed for the boreholes and monitoring wells. Boreholes and monitoring wells were located to a minimum relative accuracy of 0.1 feet horizontally and 0.01 feet vertically and were reported in State Plane Coordinates. For horizontal control, the surveyed point was either the center of the monitoring well casing cap or, in the case of an abandoned borehole, at the center of the aluminum borehole marker. Three elevation measurements were taken for monitoring wells: the top of the concrete apron adjacent to the well casing, the top of the well casing, and the top of the protective casing. For consistency, measurements were made on the north side of each monitoring well/borehole. Appendix A1 contains the survey data for the boreholes and monitoring wells completed during the Alluvial Work Plan field investigation.

Drilling locations, specified in the Alluvial Work Plan as monitoring wells, were numbered 1-91 through 64-91. Drilling locations specified as boreholes were given a "BH" designation and were numbered BH0191 through BH4691. Some locations were a combination borehole and monitoring well and were given a dual number (e.g., 65-91/BH0191).

To reduce confusion related to the dual designations/numbers, the boreholes and monitoring wells were renumbered 00191 through 13591 and 20091 through 21191. The original Alluvial Work Plan site designations/numbers are shown as "Work Plan Site Numbers" in Tables 2.1-3 through 2.1-5. The corresponding new (field) site designations/numbers are also shown, and are used throughout this report. Figure 2.1-1 shows the locations of the boreholes and Figure 2.1-2 shows the locations of the monitoring wells installed for the Alluvial Work Plan field investigation. In addition, Table 2.1-5 summarizes the status of sites (boreholes and monitoring wells) that were abandoned, moved, added to the program, or not drilled.

2.1.2 Individual Hazardous Substance Site Characterization

Source characterization boreholes were drilled into OU-2 IHSSs, where access was feasible, in order to characterize waste materials remaining in place, and to assess the maximum contaminant concentrations in the alluvium and bedrock materials directly beneath the sites. In addition, groundwater monitoring wells were installed in selected boreholes to characterize groundwater quality directly beneath the sites.

The source characterization boreholes were advanced using 3-1/4-inch inside diameter (ID) hollow-stem augers according to ER SOP GT.2 (EG&G 1992a). Samples were obtained by using a 3-inch ID, split-spoon sampler with stainless steel VOC liner. The split-spoon sampler was advanced using continuous-coring techniques. Soil samples were classified in the field as they were obtained by the rig geologist using the Unified Soil Classification System (USCS) in accordance with ER SOP GT.1 (EG&G 1992a). The depth at which water was first encountered and the water level at the completion of drilling were also recorded on the borehole log. After reaching total depth, boreholes (except for those completed as monitoring wells) were abandoned in accordance with ER SOP GT.5 (EG&G 1992a). Logs of the OU-2 Phase II boreholes are provided in Appendix A4.

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2.1.2.1 Source Characterization Borehole Sampling

Boreholes drilled into IHSSs extended from the ground surface to approximately 6 feet below the base of alluvial material, if no sandstone was encountered. Continuous borehole samples were collected for lithologic descriptions for the entire borehole depth according to ER SOP GT.2 (EG&G 1992a). Figure 2.1-3 illustrates the typical sampling scheme for source characterization boreholes. Discrete 3-inch samples were collected and submitted for laboratory VOC analyses beginning 2 feet below the ground surface and continuing at a frequency of one sample per 4-foot interval until water or bedrock was encountered (Figure 2.1-3). A sample for VOC analysis was also collected from the bottom of the first drive sample below water. In addition, a discrete VOC sample was collected for analysis if elevated OVM readings, staining, discoloration, odor, or other anomaly was observed during drilling. A final VOC sample was collected for chemical analysis from the base of the first drive within bedrock immediately below the alluvial material. In addition to the VOC samples, composite samples consisting of approximately 6-foot intervals were also collected and submitted to the laboratory for chemical analysis. If a sandstone was encountered beneath the alluvium, the composite borehole sampling continued until claystone bedrock was encountered. Composite samples were collected to approximately 6 feet into claystone bedrock. In addition, samples for VOC analysis were collected from the top of the sandstone and the top of the claystone units. Sampling of the source characterization borehole continued to the total depth of the borehole. The analytical parameters are listed in Table 2.1-6.

After the split-spoon sampler was removed from the borehole, it was opened and radiation and VOC field screening measurements were taken. The VOC stainless steel liner was then removed, capped with Teflon™ tape and plastic caps, sealed with black electrical tape, labeled, sealed in Ziplock™-type bags, and placed in a cooler with ice.

For source characterization boreholes, the split-spoon sampler was then closed and placed in a location out of the sun. After three consecutive 2-foot drilling runs had been completed, a composite sample was collected. Composite material consisted of scrapings of the core from three consecutive 2-foot drilling intervals after it had been peeled in accordance with ER SOP GT.2 (EG&G 1992a). The composite material was collected and mixed in such a manner that the sample was representative of the entire 6-foot interval. The composite interval was approximately 6 feet, but the interval was sometimes slightly more or less than 6 feet depending on drilling conditions and recovery. Sample compositing was conducted by combining the material in a stainless steel bowl or pan. The material was thoroughly mixed using a stainless

steel scoop. The sample was then quartered and each quarter was mixed individually. The entire sample was then mixed together again until as homogeneous a mixture as possible was obtained. The composite sample was then placed in the appropriate sample containers, and the containers were placed in bags in a cooler with ice. Split-spoon samplers were decontaminated between individual coring runs.

For each sample, a corresponding radiological screen (RAD screen) sample was collected. RAD screen samples were collected to analyze radiological levels ensuring that analytical samples were handled and shipped correctly as outlined in ER SOP FO.18 (EG&G 1992a). The RAD screen samples were shipped off site and analyzed before the corresponding analytical samples were shipped off site.

Discrete VOC and composite samples were shipped off site for analysis of the parameters listed in Table 2.1-6. Analytical results are presented and interpreted in Section 4.0. Samples for geological characterization were placed in core boxes and retained for detailed analysis and logging by the project stratigrapher as described in Section 2.1.4.

Following drilling and sampling of the source characterization boreholes, the boreholes were plugged and abandoned in accordance with ER SOP GT.5 (EG&G 1992a).

2.1.2.2 Source Characterization Borehole Analytical Parameters

Source characterization borehole samples were analyzed for the parameters listed in Table 2.1-6. Table 2.1-7 lists the analytical methods, sample containers, sample preservation, and sample holding times for all OU-2 sampling. These parameters are essentially the same as those analyzed during the Phase I RI except that oil and grease and RCRA characteristics were eliminated. Oil and grease have not proven useful in determining extent of soil contamination, and RCRA hazardous waste characteristics from Phase I samples have been within acceptable limits. The TCL for organics and the target analyte list (TAL) list for inorganics are nearly the same as the previously used HSL list for organics and inorganics.

Quality Control (QC) procedures were followed in the field for sampling according to the Rocky Flats ER SOPs, the RFP Site-Wide Quality Assurance Project Plan (EG&G 1992b), and the project-specific Quality Assurance Addendum (EG&G 1992c). QC samples collected include equipment rinsates and duplicates. Rinsate samples were collected at a frequency of one per

drilling rig per day if sampling was conducted. Duplicate samples were collected at a frequency of one per twenty investigative samples.

2.1.2.3 Data Management

Field and laboratory data collected during the Phase II field investigations were incorporated into the RFEDS. The RFEDS is used to track, store, and retrieve project data. Data were input to the RFEDS via diskettes subsequent to data validation as outlined in the Environmental Restoration Program QAPjP (EG&G 1990b). Hardcopy reports were then generated from the system for data interpretation and evaluation.

2.1.3 Groundwater Investigation

The purpose of the Phase II RFI/RI alluvial groundwater investigation was to delineate the horizontal and vertical extent of volatile organic, semivolatile organic, inorganic, and radiological contaminants in groundwater within the UHSU. Monitoring wells were installed to allow groundwater samples to be collected from the alluvial and bedrock (weathered claystone and subcropping No. 1 sandstone) systems of the UHSU. Bedrock groundwater investigations for the LHSU at OU-2 are presented in Section 2.2.

Certain monitoring well sites were designated as driver or contingency well sites as detailed in the Alluvial Work Plan and summarized in Table 2.1-4. The driver wells were drilled and completed prior to the drilling and installation of contingency wells. The groundwater sample data obtained from the driver wells were reviewed and evaluated to determine the necessity for further plume characterization. If additional plume characterization was needed, the contingency wells were subsequently installed. Table 2.1-5 describes the status of contingency sites. Contingency well sites 04791, 05491, 05591, 05791, and 05891 were not drilled because additional plume identification was not necessary.

The number of monitoring wells per location and the screened interval of each monitoring well depended on the saturated thickness encountered during drilling. If the saturated thickness was 10 feet or less, a single monitoring well was installed and the screened interval extended from 5 feet above the water table to the base of the water-bearing zone. A cluster of two monitoring wells was installed if the saturated thickness was greater than 10 feet and less than 30 feet. One monitoring well was completed at the water table as described above, and the second monitoring well was completed across the lower part of the water-bearing unit. If a saturated thickness

greater than 30 feet was encountered, a third monitoring well was added to the cluster and was completed at the base of the water-bearing unit. In addition, a bedrock monitoring well was installed if a subcropping sandstone was encountered.

The well borings were advanced using 3-1/4-inch ID hollow-stem augers according to ER SOP GT.2 (EG&G 1992a). Samples were logged by using a 2.5-inch ID, split-spoon sampler with a stainless steel VOA liner installed at the drive shoe. The split-spoon sampler was advanced using continuous-coring techniques. Soil samples were logged in the field as they were obtained by the rig geologist using the USCS, in accordance with ER SOP GT.1 (EG&G 1992a). Preliminary groundwater information was recorded during drilling. The depth at which water was first encountered and the water level at the completion of drilling were recorded on the borehole log. Summary logs of the monitoring wells are provided in Appendix A4. Interpretation of the water level data is provided in Section 3.6.

The soil sampling program for boreholes to be completed as monitoring wells in alluvium consisted of collecting continuous hollow-stem auger 2-foot core runs for lithologic logging, and the collection of two discrete samples per boring for VOC analyses: one at the water table and one at the alluvium/bedrock contact. After opening the split-spoon sampler, the stainless steel liner for VOC analyses was removed and capped with Teflon™ tape and plastic caps, sealed with black electrical tape, labeled, sealed in Ziploc™-type bags, and placed in a cooler with ice. For each VOC sample, a corresponding RAD screen sample was also collected. The RAD screen samples were shipped off site and analyzed before the corresponding VOC samples were shipped off site. Samples for geological characterization were retained in core boxes for detailed analysis and logging by the project stratigrapher.

2.1.3.1 Monitoring Well Installation

Monitoring wells were installed according to ER SOP GT.6 (EG&G 1992a). The general construction of the monitoring wells is shown in Figure 2.1-4. Prior to well installation, the borings were reamed using 6-1/4-inch ID hollow-stem augers. Monitoring wells were then completed inside of the 6-1/4-inch ID augers prior to removal of the augers. Screened intervals were constructed of 2-inch ID Schedule 40 polyvinyl chloride (PVC) pipe with 0.01-inch machined slots. Nonslotted (blank) Schedule 40 PVC riser pipe was used above the screened interval and for a sediment sump below the screened interval. Filter pack consisting of 16-40 silica sand was placed around the monitoring well casing from the total depth of the boring to a minimum of 6 inches above the screened interval (Figure 2.1-4). Construction details are

summarized in Table B2 (Appendix B) and shown in Appendix A4 for each monitoring well completed.

The above-ground completion details of the monitoring wells are depicted in Figure 2.1-5. Vented caps and vented, lockable steel casings were installed for each monitoring well. In areas of heavy vegetation or traffic, 3-inch ID steel guard posts were installed around the monitoring wells at a distance of approximately four feet radially from the surface casing. Protective steel casings and guard posts, when installed, were covered with primer and enamel paint suitable for outdoor exposure.

2.1.3.2 Monitoring Well Development and Groundwater Sampling

Following installation, groundwater monitoring wells were developed and sampled by the RFP site-wide groundwater program. Monitoring well development was conducted in accordance with ER SOP GW.2 (EG&G 1992a) and groundwater sampling was conducted in accordance with ER SOP GW.6 (EG&G 1992a). Analytical parameters for the Alluvial groundwater sampling program are provided in Table 2.1-8. Analytical methods, sample containers, sampler preservation, and sample holding times are listed in Table 2.1-7. Results from this sampling program are presented in Section 4.0.

2.1.3.3 Hydraulic Testing Program

Three multi-well pumping tests were performed to evaluate the hydraulic properties of the subsurface materials at OU-2. The goals of the evaluation (DOE 1991a) were to:

- Develop estimates of parameter values for rate of movement calculations (hydraulic conductivity, dispersivity, and effective porosity) for both the bedrock and alluvial materials.
- Evaluate the degree of hydraulic communication between alluvium and bedrock (both sandstone and claystone).
- Develop parameter values for estimation of production rates from remedial groundwater collection systems.

The design of the testing program was based on the hydrogeologic conceptual model of the subsurface. Three distinct hydrogeologic situations are present in the UHSU:

- The Rocky Flats Alluvium is unsaturated and is directly underlain by the Arapahoe Formation No. 1 Sandstone (saturated).
- The Rocky Flats Alluvium is directly underlain by the No. 1 Sandstone and both are saturated.
- The Rocky Flats Alluvium is saturated and is underlain by claystone bedrock of the Arapahoe Formation.

Hydraulic pumping tests were designed to evaluate hydraulic conductivity, storage properties, and the effective porosity for each of these situations. The rationale for the hydraulic testing program and testing procedures is contained in the Phase II RFI/RI Work Plan (Alluvial) (DOE 1991a) and Aquifer Test Work Plan TM3 (DOE 1992g). Details of well installation and aquifer test results are presented in the Phase II RFI/RI Aquifer Test Report (DOE 1992h). Figure 2.1-2 shows the locations of the pumping and observation wells. The sites were numbered 20091 through 21191. Three pumping wells were installed (numbers 20691, 21191 and 20891), and 7 observation wells were installed (20191, 20291, 20491, 20591, 20791, 20991 and 21091). Results of the hydraulic testing are summarized in Section 3.6.

2.1.4 Geological Investigation

Geological investigations for the alluvial program were designed to (1) refine the knowledge of the UHSU, and (2) select target intervals for monitoring well installation. More detailed descriptions of the geology of the OU-2 area are provided in Section 3.5.

Drill cuttings and cores obtained from the boreholes and monitoring wells were examined by the rig geologist for gross lithologic units and general features. A preliminary borehole log was completed by the rig geologist in accordance with ER SOP GT.1. The geologist recorded the depths of each coring run, intervals of no recovery, general lithologies encountered, depths of samples collected, and notes regarding unusual drilling conditions. The drill cuttings and cores were packed in core boxes and delivered to the project stratigrapher for detailed logging.

Detailed logging was also performed in accordance with ER SOP GT.1, by the project stratigrapher. Detailed logging consisted of sieving soil samples to determine grain size distribution for soil type classification and degree of grading. Grain roundness and composition were evaluated using microscope techniques. Visual inspection of the core samples was made to describe color (using color charts), internal structures, bedding, fractures, and other features of interest. In addition, a test for plasticity was performed on the clay size fraction. The alluvial, colluvial and soil intervals were classified using the USCS. Each core box was labeled and photographed as part of this logging. Summary logs of the Phase II boreholes are provided in Appendix A4.

In addition to subsurface investigations, the Phase II RFI/RI included surface geological mapping within the OU-2 area during the summers of 1992 and 1993. Field mapping was done on 1:3,600 and 1:1,200 scale base maps. Plotting of geological contacts onto base maps was accomplished by standard field methods described in Compton (1962).

Methods include:

1. Plotting directly by visual inspection when the configuration of features makes it possible to identify them positively on the base map.

2. Plotting by taking bearings from a known surface feature using a hand-held Brunton transit. Distances along the bearing are measured by pacing.

3. Plotting by measuring elevation changes from a known surface feature or previously plotted contact by leveling with a hand-held Brunton transit.

Previously published interpretations of surface geology were used to assist in mapping where possible. Aerial photographs were also used to identify geologic contacts, geomorphic features, historical changes in landscape, and the presence of past man-made features and activities.

Surface field investigations were carried out during the spring and summer of 1992 and summer of 1993 to identify groundwater discharge (seep) points within the OU-2 area. Mapping was done on 1:1,200 and 1:3,600 scale base maps. The extent and shape of vegetated areas associated with groundwater seepage were placed on base maps using methods discussed previously. Vegetated areas were observed during high and low groundwater periods to determine qualitative and relative discharge rates for seepage areas. One seepage flow was

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quantitatively measured during April and May 1993 using a 2000 ml graduated cylinder and stop watch.

The physical properties of on-site geologic materials were characterized to provide data to support future evaluation of remedial action alternatives. Bulk samples of the drill cuttings from borings were collected in bags to characterize each of the materials found within the 903 Pad, Mound and East Trenches Areas (Rocky Flats Alluvium, colluvium, valley fill alluvium, and weathered bedrock). Specifically, 10 samples of each geologic material type were submitted for moisture content, dry density, grain size analyses (sieve and hydrometer analyses), Atterberg limits testing, and recompacted permeability testing to evaluate the variability of these parameters across the site. The geotechnical testing specifications are listed in Table 2.1-9. The results of the geotechnical testing are provided in Section 3.5.

2.1.5 Work Plan Deviations

The purpose of this section is to summarize and explain deviations from the Alluvial Work Plan that occurred during field work. In general, work performed during the Alluvial Work Plan field investigation was in accordance with the Alluvial Work Plan (DOE 1991a). However, because many of the specified activities in the work plan were based on anticipated conditions, modifications and adjustments to the field activities were necessary when actual conditions differed from those anticipated.

Deviations which occurred during the field work included modifications to numbers and locations of boreholes drilled and monitoring wells installed, changes in drilling and sampling procedures, and changes in sampling locations. The following paragraphs discuss specific deviations.

2.1.5.1 Site Status Summary

Table 2.1-5 summarizes the status of sites (boreholes and monitoring wells) that were abandoned, moved, added to the program, or not drilled. Four sites (01591, 01691, 07791, and 10091) were not drilled because they are located in the PA or were within the PA security fences (Figures 2.1-1 and 2.1-2). The PA is a high security area at RFP.

Five monitoring well sites (04791, 05491, 05591, 05791, and 05891) were not drilled because they were specified as contingency monitoring well sites in the Alluvial Work Plan. Based on the

results from the driver wells, it was determined that these contingency wells were not necessary. Site 03291 was not drilled because there were numerous underground power lines at the site, which prevented access by the drill rig. Site 04391 was an original pump test site location and was not drilled because the pump test sites were moved as amended by TM-3.

Nine monitoring well sites (00591, 01091, 01191, 03491, 07491, 07591, 07691, 11091, and 11991) were abandoned because the bedrock surface was too close to the ground surface to install an alluvial well. Site 07091 was abandoned because auger refusal occurred; this site was replaced by site 13091. Two sites (08191 and 11591) were abandoned because augers were lost down the borehole. Site 08191 was replaced by 12891, and 11591 was replaced by 11691. Site 11191 was abandoned because the augers used were not properly decontaminated, and it was replaced by 4991. Monitoring well site 11391 was abandoned because of water and flowing sands in the hole and was replaced by 05691. Monitoring well site 12591 was an offset hole drilled in an attempt to encounter sandstone, and it was abandoned because sandstone was not present. Pumping well site 20091 was abandoned because the well casing collapsed while an adjacent observation well was being drilled. It was replaced by 21191. Observation well site 20391 was abandoned because of flowing sands and caving of the borehole.

Three additional bedrock monitoring wells were drilled and installed to characterize the nature and extent of contamination in the No. 1 Sandstone (12391, 12491, and 12691). Table 2.1-5 lists the additional sites and the site number(s) that they are paired with. Nine additional monitoring wells were drilled and installed because the saturated thickness at these sites was greater than 10 feet. Table 2.1-5 also lists these sites with their paired site number.

2.1.5.2 Drilling Procedures

Three different geologic situations are present at OU-2. The cases and the different drilling procedures for each case are:

- Case 1: Subcropping Arapahoe No. 1 Sandstone is in contact with the overlying alluvium. Drilling continued through the sandstone until approximately 6 feet of claystone was encountered. The claystone portion of the borehole was backfilled, and an alluvial or bedrock monitoring well was installed. Surface casing was not necessary because the alluvium was in contact with the subcropping No. 1 sandstone.

- Case 2: Approximately 3 to 5 feet of claystone separate the alluvium from Arapahoe No. 1 Sandstone. Under this condition, drilling stopped at 6 feet into bedrock, and the borehole was completed as an alluvial monitoring well. If the sandstone was saturated, a bedrock monitoring well was also installed within 20 feet of the alluvial well. If the claystone separating the alluvium from the sandstone was less than 3 feet thick, the bedrock well was completed without surface casing as in Case 1.

- Case 3: If water was not encountered within the borehole after approximately six feet of bedrock had been penetrated, and no subcropping sandstone had been encountered, only an alluvial monitoring well was installed. If the alluvium was too thin to allow the installation of an alluvial well, an upper bedrock well was installed in some locations.

Surface casing was not installed for any sites during the Alluvial field program. The bedrock penetration was not always six feet. In some cases, auger refusal occurred before six feet of bedrock was drilled.

2.1.5.3 Sampling Deviations

Composite samples for source characterization boreholes were collected from intervals approximately six feet in length. In some cases, composite sample intervals were slightly less or more than six feet based on recovery and drilling conditions. Also, the last composite interval coincided with the bottom of the hole, which was drilled approximately 6 feet into bedrock. As a result, the last composite interval was usually not 6 feet in length (Figure 2.1-3). In addition, VOC samples were not always collected at 4-foot intervals, generally due to intervals of no recovery. When there was no recovery in an interval where a VOC sample was planned, the VOC sample was taken on the next 2-foot run where there was recovery.

At sites that required offset boreholes for monitoring well installation, continuous coring was not conducted on the offset borehole because it was within 10 to 20 feet of the original borehole, and logging of the original hole adequately characterized the materials present. In the offset boreholes, drill cutting samples were collected in 250-ml glass jars every 2 feet for logging analysis. Drive samples or continuous core samples were then taken when drilling approached intervals of interest (e.g., monitoring well screened interval) to confirm the depths and nature of these contacts.

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2.2 PHASE II REVISED BEDROCK WORK PLAN INVESTIGATION

The general objective of the Phase II Revised Bedrock Work Plan (TM8) field program was to gather data necessary to sufficiently verify the assumption that contamination in the LHSU has limited nature and extent and, thus, the LHSU human health exposure pathway is incomplete. A summary of TM8 is presented in Section 1.4.7. To accomplish the objectives, it was necessary to:

- Evaluate the presence or absence of contamination in LHSU units, and if present, the source, nature, and vertical extent of contaminants in the LHSU. For Scenario 1 (see Section 1.4.7), the potential lateral extent of contamination was also evaluated.

- Establish and evaluate the permeability of LHSU units containing contamination to evaluate whether viable migration pathways to human receptors exists, or if the LHSU units have sufficient well production capability to supply a hypothetical on-site resident.

The TM8 Sampling and Analysis Plan (SAP) specified field activities to acquire data for the following purposes:

- Evaluate LHSU groundwater quality in areas with the highest potential for LHSU contamination (i.e., beneath areas where high levels of contamination are present in the UHSU and where the potential for hydraulic communication between the UHSU and LHSU is great).

- Investigate source and vertical extent of contamination in LHSU where contamination has been detected previously (e.g., in LHSU sandstone units which subcrop beneath the colluvium).

- Estimate permeability of LHSU units containing contamination to evaluate potential for migration of contaminants within LHSU, or potential for contaminated LHSU units to supply sufficient water for an on-site residential water supply.

To accomplish these objectives, the following general activities were performed or attempted:

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- Drilling of pilot boreholes at six well cluster locations (identified in TM8 SAP as WC-1BH through WC-6BH) to evaluate LHSU bedrock stratigraphy and hydrogeologic conditions.

- Installation, development and sampling of two monitoring wells (identified in the TM8 SAP as WC-1a and WC-6a) to allow collection of groundwater quality samples from the uppermost LHSU sandstone/siltstone unit beneath areas where contamination has been identified in the UHSU, and where the potential for hydraulic communication between the UHSU and LHSU is expected to be high.

- Installation, development, and sampling of one monitoring well (identified in the TM8 SAP as WC-5a) to allow collection of groundwater quality samples from the LHSU in an area where contamination has been detected previously in the LHSU.

- Installation, development, and sampling of three monitoring wells (identified in the TM8 SAP as WC-2a, WC-3a, and WC-4a) to allow collection of groundwater quality samples from LHSU sandstone units that subcrop beneath the colluvium in the Woman Creek drainage and where contaminants have been previously detected.

- Analysis of groundwater samples from the a-series monitoring wells (identified in the TM8 SAP as WC-1a through WC-6a) for a selected suite of indicator parameters to evaluate whether contaminants from the UHSU have migrated to LHSU bedrock units. For each particular location, if contaminants were detected in the LHSU unit being monitored, an additional monitoring well (e.g, WC-1b) was installed into the next deeper permeable LHSU bedrock unit at that location. Groundwater samples were then collected from the b-series wells to evaluate the vertical extent of contamination in the LHSU.

- Conduct hydraulic slug tests within each newly-installed LHSU bedrock monitoring well to evaluate the permeability of LHSU bedrock units in which the monitoring wells were installed.

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- Drilling of two LHSU bedrock source characterization boreholes (identified in the TM8 SAP as SB-1 and SB-2) to collect samples of LHSU claystone for laboratory analysis to evaluate the vertical extent of contamination previously identified in the LHSU claystone at these locations.

- Examination of drill core from the borehole for existing Well 2087 to re-evaluate the lithology of the screened interval of this well.

2.2.1 Subsurface Soils Investigation

In general, field operations during the bedrock program were conducted in accordance with existing RFP ER SOPs, as contained in EG&G Rocky Flats EMD ER SOPs, Volume I, Field Operations, Volume II, Groundwater, and Volume III, Geotechnical (EG&G 1992a). In some cases, however, modifications to the ER SOPs were necessary to perform the field activities specified. Where procedures differed from those stated in the ER SOPs, they were documented in a DCN. Table 2.2-1 is a summary of ER SOPs used during the OU-2 bedrock field investigation.

The drilling of boreholes and installation of monitoring wells for the bedrock investigation was conducted from April 12, 1993 to July 16, 1993. A total of 17 borings were drilled (Figure 2.2-1). Of these, six were pilot boreholes, two were source characterization boreholes, and two were abandoned boreholes. The remainder were completed as six a-series monitoring wells and one b-series monitoring well.

Figure 2.2-1 shows the locations of the pilot boreholes, source characterization boreholes, and monitoring wells installed for this program. The rationale for each location and the activities performed at each are summarized in Table 2.2-2. A summary of the boreholes and monitoring wells installed can be found in Section 3.5. Table 2.2-3 compares the estimated borehole and well depth information from TM8 with actual depth information. Borehole drilling details are provided in Table A3 (Appendix A) and a summary of monitoring well installation details is provided in Table B2 (Appendix B).

Prior to the start of drilling activities, drilling and sampling equipment was decontaminated at the RFP main decontamination facility in accordance with ER SOPs FO.3 and FO.4 (EG&G 1992a). Downhole and sampling equipment (e.g., hollow-stem augers, drill rods, and core barrels) were decontaminated between individual sites during the drilling program. Drill rigs

were decontaminated before moving to an area with a different historical characterization (Figure 2.2-1 shows the four different areas) and at the conclusion of the drilling program. Equipment was screened with a Ludlum 12-1A radiation detector with an air proportional or zinc sulfide probe and alpha small-area smears prior to decontamination and before being released off site.

Drilling activities were conducted in accordance with the Site Health and Safety Plan (EG&G 1993b). As specified in the health and safety plan, radiation and VOC monitoring was performed during drilling and monitoring well installation to monitor personnel exposure and set personal protection levels. In addition, the VOC measurements were used as an indicator of possible VOC contamination of the cuttings or core to identify intervals for sampling. Radiation and VOC monitoring were conducted in accordance with ER SOPs FO.15 and FO.16 (EG&G 1992a).

Prior to drilling, the boreholes and monitoring wells were approximately located in the field by pacing. Following drilling and monitoring well installation, coordinate locations and elevations were surveyed for the boreholes and monitoring wells. Boreholes and monitoring wells were located to a minimum relative accuracy of 0.1 feet horizontally and 0.01 feet vertically and were reported in State Plane Coordinates. For horizontal control, the surveyed point was either the center of the monitoring well casing cap or in the case of an abandoned borehole, at the center of the aluminum borehole marker. Three elevation measurements were taken for monitoring wells: the top of the concrete apron adjacent to the well casing, the top of the well casing, and the top of the protective casing. For consistency, measurements were made on the north side of each monitoring well/borehole. Appendix A1 contains the survey data for the boreholes and monitoring wells completed during the OU-2 Phase II Bedrock Investigation.

Drilling locations in TM8 (DOE 1993a) were numbered WC-1 through WC-6 and SB-1 and SB-2. Drilling locations specified as pilot boreholes were given a "BH" designation (e.g., WC-1BH) and were numbered WC-1BH through WC-6BH. Drilling locations specified as monitoring wells were give an "a" or "b" designation, denoting that they were a- or b-series monitoring wells (e.g., WC-1a or WC-1b). Source characterization boreholes were given an "SB" designation (e.g., SB-1).

At the time of the field activities, the boreholes and monitoring wells were renumbered 21193 through 22593 and 23193 through 23293 by EG&G to be consistent with the RFP well and borehole numbering system. The original TM8 site designations/numbers are shown as "Work

Plan Site Numbers" in Tables 2.2-2 and 2.2-3. The corresponding EG&G assigned (field) site designations/numbers are also shown, and are used throughout this report. Figure 2.2-1 shows the locations of the boreholes and monitoring wells installed for the OU-2 bedrock field investigation.

Boreholes and monitoring wells were completed using four truck-mounted drill rigs, including two CME Model 75 drill rigs, one CME Model 95 drill rig, and one Simco Model 431 coring drill rig.

Six pilot boreholes were installed at sites 21193, 21293, 21393, 21493, 21593, and 21693 (identified as WC-1BH, WC-2BH, WC-3BH, WC-4BH, WC-5BH, and WC-6BH, respectively in TM8) to evaluate stratigraphic and hydrogeologic conditions at each site and to identify target depths for the installation of monitoring wells.

Pilot boreholes at 21193 and 21693 were drilled to investigate areas with the highest potential for downward migration of contaminants from the UHSU to the LHSU. These locations were selected because they are within UHSU volatile organic contamination groundwater plumes, and the uppermost LHSU sandstone/siltstone is in close vertical proximity to the overlying Arapahoe Formation No. 1 Sandstone (Figure 2.2-1).

Pilot borehole 21593 was drilled in the Mound Area where contamination has been previously detected in an existing well (2087) completed in LHSU claystone (Figure 2.2-1).

Pilot boreholes at 21293, 21393, and 21493 were drilled in an apparent upgradient location from areas where contaminants have been detected in LHSU sandstone units where they subcrop beneath the colluvium along the north slope of the Woman Creek drainage (Figure 2.2-1).

Two source characterization boreholes were drilled at locations 21793 and 21893 (identified as SB-1 and SB-2, respectively, in TM8). These boreholes were drilled adjacent to existing boreholes 09991 and BH2587, respectively, to evaluate the vertical extent of contamination identified in LHSU claystone bedrock samples previously collected at those locations.

Six a-series monitoring wells (23193, 22093, 22193, 22293, 22393, and 23293) were installed to allow collection of groundwater samples from LHSU sandstone/siltstone units. These monitoring wells (identified as WC-1a, WC-2a, WC-3a, WC-4a, WC-5a, and WC-6a, respectively, in the TM8) were screened across the uppermost substantial LHSU sandstone/siltstone unit

identified from the pilot borehole field lithologic logs and geophysical logs (23193 and 23293), or in the target interval for the site (22093, 22193, 22293, and 22393).

Two boreholes (21993 and 22493), planned as a-series monitoring wells, were abandoned due to difficulties encountered during the installation of isolation casing. Monitoring wells, 23193 and 23293, respectively, were installed to replace the abandoned monitoring well attempts.

Because low-level contamination (9 ppb TCE) was detected based on indicator parameter screening in the groundwater sample from Well 23193, a b-series monitoring well (22593, identified as WC-1b in TM8) was installed into the next deeper LHSU sandstone/siltstone unit to evaluate whether the contaminant had migrated vertically to that unit. No contamination was detected in the b-series monitoring well, 22593, based on results from the indicator parameter screening of the groundwater sample taken from this well. Because contamination was not detected based on indicator parameter screening in samples from the other a-series wells (22093, 22193, and 22293), or the a-series wells did not produce sufficient water for development or sampling (22393 and 23293), no other b-series wells were installed.

The following subsections discuss details of the field activities.

2.2.2 Individual Hazardous Substance Site Investigation

Two source characterization boreholes (21793 and 21893) were drilled into IHSS Nos. 113 and 109, respectively, as shown on Figure 2.2-1 and described previously. These boreholes were drilled to evaluate the vertical extent of contamination identified previously in LHSU claystones in those areas. Two previously drilled boreholes (09991 and BH2587) were drilled to depths of 20 and 22.5 feet, respectively. Samples of claystone bedrock collected from the bottom of those boreholes contained volatile organic compounds.

Source characterization borehole 21793 was drilled approximately 8 feet east of borehole 09991 (within IHSS No. 113), which was drilled previously to a depth of 20 feet. Analysis of the deepest claystone bedrock sample collected from borehole 09991 indicated that PCE was present at a concentration of 180 ppb. Borehole 21793 was drilled to a depth of about 50 feet to allow collection of claystone bedrock samples from the 20 to 50 foot depth interval to aid in evaluating the vertical extent of contaminants in the LHSU claystone in this area.

Borehole 21893 was drilled in the approximate vicinity of borehole BH2587 (within IHSS No. 109), which was previously drilled to a depth of 22.5 feet. Since the actual borehole could not be sited in the field and the survey for BH2587 is believed to be in error, the borehole 21893 was located midway between 9291 and 9491. Analysis of claystone bedrock samples collected from borehole BH2587 indicated that TCE and PCE were present at concentrations of 13,000 ppb and 2,100 ppb, respectively, in the deepest sample from this borehole. Borehole 21893 was drilled to a depth of about 50 feet to allow collection of claystone bedrock samples from the 22.5 to 50 foot depth interval to aid in evaluating the vertical extent of contaminants in the LHSU claystone in this area

Drilling of the source boreholes was performed using hollow-stem drilling methods. Hollow-stem drilling and sampling was performed in accordance with ER SOP GT.2 (EG&G 1992a). The initial drilling conducted at each location consisted of installing an isolation casing across the UHSU using hollow-stem auger drilling methods prior to drilling into the underlying LHSU bedrock as shown in Figure 2.2-2. This casing isolated the bedrock borehole from the UHSU to limit the potential for cross contamination. Drilling proceeded through the UHSU with 3-1/4-inch inside diameter (ID) hollow-stem augers. As drilling progressed through the UHSU, continuous core samples were collected using a 3-inch ID split-spoon sampler with stainless steel liners. Following completion of drilling with the 3-1/4-inch ID augers, the borehole was reamed to a diameter of approximately 12 inches or greater using hollow-stem augers.

Following drilling and reaming, an 8-inch ID schedule 40 PVC isolation casing with water tight threaded couplings was installed to isolate the borehole from the UHSU. Following installation, the isolation casing was sealed in place by placing a bentonite seal at the bottom of the casing annulus, and then grouting the remainder of the annulus with a tremie pipe. Installation and sealing of isolation casing was performed in accordance with the procedures specified in TM8 and ER SOP GT.3, as modified by DCN (EG&G 1992a). The grout used to seal the isolation casing was allowed to cure for a minimum of 24 hours prior to initiating drilling of the source characterization borehole into LHSU bedrock.

Following curing of the isolation casing grout seal, hollow-stem auger drilling was performed within the isolation casing to extend the borehole into the LHSU bedrock underlying the UHSU. The source characterization boreholes were advanced using 3-1/4-inch ID hollow-stem augers. Samples were obtained using a 3-inch ID split-spoon sampler with stainless steel VOC liners. The split-spoon sampler was advanced using continuous-coring techniques.

All core collected during drilling of the source boreholes was lithologically logged in accordance with ER SOP GT.1, Logging Alluvial and Bedrock Materials (EG&G 1992a). Lithologic logs for the source boreholes are included in Appendix A4.

2.2.2.1 Source Characterization Borehole Sampling

Source characterization boreholes extended from the ground surface to approximately 50 feet in depth. Figure 2.2-3 illustrates the typical sampling scheme for source characterization boreholes. Continuous borehole samples were collected over 2-foot intervals for lithologic descriptions for the entire borehole depth. Discrete samples were collected and submitted for laboratory volatile organic compound (VOC) analyses beginning 2 feet below the isolation casing and continuing at a frequency of one sample per 4-foot interval until total borehole depth. Additional discrete VOC samples were collected for analysis if elevated OVM readings, staining, discoloration, odor, or other anomalies were observed during drilling. In addition to the VOC samples, composite samples collected over approximately 6-foot intervals were also submitted to the laboratory for chemical analysis for non-VOC parameters.

After the split-spoon sampler was removed from the borehole, it was opened and radiation and VOC field screening measurements were taken. The VOC stainless steel liner was then removed, capped with Teflon™ tape and plastic caps, sealed with black electrical tape, labeled, sealed in Ziplock™-type bags, and placed in a cooler with ice.

For each sample, a corresponding RAD screen sample was collected. RAD screen samples were collected to analyze radiological levels to ensure that analytical samples were handled and shipped correctly. The RAD screen samples were shipped to an off-site laboratory and analyzed before the corresponding analytical samples were shipped off site.

After removal of the VOC and RAD samples, the split-spoon sampler was closed and placed in a location out of the sun. After three consecutive 2-foot drilling runs had been completed, a composite sample was prepared from the split-spoon material. Composite sample material consisted of scrapings of the core from three consecutive 2-foot drilling intervals after it had been peeled in accordance with ER SOP GT.2 (EG&G 1992a). The composite material was collected and mixed in such a manner that the sample was representative of the entire 6-foot interval. The composite interval was approximately 6 feet, but the interval was sometimes slightly more or less than 6 feet depending on drilling conditions and recovery. Sample compositing was conducted by combining the material in a stainless steel bowl or pan. The

material was thoroughly mixed using a stainless steel scoop. The sample was then quartered and each quarter was mixed individually. The entire sample was then mixed together again until as homogeneous a mixture as possible was obtained. The composite sample was then placed in the appropriate sample containers, and the containers were placed in bags in a cooler with ice. Split-spoon samplers were decontaminated between individual coring runs.

Samples collected for geological characterization were placed in core boxes and retained for detailed analysis and logging by the project stratigrapher as described in Section 2.2.4. Samples collected for chemical analysis were analyzed for the parameters listed in Table 2.2-4. Analytical methods, sample containers, sample preservation, and sample holding times used are provided in Table 2.2-5. Analytical results are presented and interpreted in Section 4.0.

Following drilling and sampling of the source characterization boreholes, the boreholes were plugged and abandoned in accordance with ER SOP GT.5, Plugging and Abandonment of Boreholes (EG&G 1992a).

2.2.3 Groundwater Investigation

As discussed previously, LHSU groundwater was investigated for potential contamination based on two scenarios (see Section 1.3.7). For each site a pilot borehole was drilled and continuously sampled to collect stratigraphic and hydrogeologic data and identify target intervals for the placement of isolation casings and screened intervals for the a-series and b-series monitoring wells. Six pilot boreholes were drilled (21193, 21293, 21393, 21493, 21593, and 21693) at RBWP sites WC-1 through WC-6 (Figure 2.2-1).

Six a-series monitoring wells (22093, 22193, 22293, 22393, 23193, and 23293) and one b-series monitoring well (22593) were installed into the LHSU (Figure 2.2-1). The a-series monitoring wells were located approximately 15 feet away from pilot borehole at each location, and the b-series well (22593) is approximately 10 feet from a-series well 23193. Wells 23193, 22393, 23293, and 22593 were installed for the purpose of investigating the potential for downward migration of contaminants from the UHSU to the LHSU as depicted in Figure 2.2-4. Monitoring wells 22093, 22193, and 22293 were installed to investigate the source of contaminants previously detected in LHSU sandstone units where they subcrop beneath the colluvium along the north slope of the Woman Creek drainage, as shown in Figure 2.2-5. Details of the rationale and objectives of the monitoring wells are provided in Section 2.0 of TM8 (DOE 1993a).

Following installation and development, groundwater samples were collected from each monitoring well (where sufficient water was present) to evaluate LHSU groundwater quality. Well development and sampling analysis activities are discussed in Section 2.2.3.3.

2.2.3.1 Pilot Boreholes

Six pilot boreholes were drilled at sites 21193, 21293, 21393, 21493, 21593, and 21693, as discussed previously. These boreholes were drilled to collect stratigraphic and hydrogeologic information and to provide data for selection of target intervals for monitoring wells. General construction details of the pilot boreholes are shown in Figure 2.2-6.

Similar to the source characterization boreholes, the initial drilling at each pilot borehole consisted of installing an isolation casing across the UHSU prior to drilling into the underlying bedrock. This casing isolated the LHSU from the UHSU. Drilling proceeded to the base of the UHSU with 3-1/4-inch ID hollow-stem augers. In general, the base of the UHSU was identified by the presence of unweathered claystone. As drilling progressed through the UHSU for each pilot borehole, continuous core samples were collected using a 3-inch ID split-spoon sampler with stainless steel liners. The borehole was then reamed to a diameter of approximately 12 inches using 8-1/4-inch ID hollow-stem augers. Hollow-stem drilling and sampling was performed in accordance with ER SOP GT.2 (EG&G 1992a).

Following drilling and reaming, a 6-inch ID Schedule 40 PVC flush-jointed isolation casing was installed to isolate the borehole from the UHSU. The isolation casings were sealed in place by one of two different methods depending on borehole conditions. At locations 21293, 21393, 21493, and 21593, the casings were installed as specified in TM8. At these locations, a bentonite seal was placed at the bottom of the annulus surrounding the isolation casing, and the remainder of the annulus was grouted using a tremie pipe. At locations where substantial groundwater flow into the borehole occurred (i.e., 21193 and 21693), this approach was not feasible. At these locations, the isolation casings were installed using pressure grouting techniques as prescribed in ER SOP GT.3 (EG&G 1992a).

Following placement of the casings, the grout was allowed to cure for a minimum of 24 hours prior to initiating drilling into the underlying bedrock. Following curing of the isolation casing grout seal, continuous core drilling (HX size) was performed within the isolation casing to extend the borehole into the LHSU bedrock underlying the UHSU.

LHSU drilling was conducted using mud rotary methods with a water/variflo mud mixture as the drilling fluid. Drilling mud was used to create a higher hydraulic head within the borehole than in the surrounding bedrock, thereby inducing a hydraulic gradient away from the borehole to the surrounding bedrock and preventing or limiting inflow of groundwater as the borehole passed through LHSU permeable zones. In this way, the potential for cross-contamination between permeable zones in the LHSU bedrock through the borehole was minimized. As drilling progressed, continuous core samples were collected with a core barrel. Coring was performed in accordance with ER SOP GT.4, Rotary Drilling and Rock Coring (EG&G 1992a).

All drill core collected from the pilot boreholes was lithologically logged in accordance with ER SOP GT.1, Logging Alluvial and Bedrock Material (EG&G 1992a). Lithologic logs for the pilot boreholes are included in Appendix A4.

Core samples of LHSU bedrock material removed from the borings were immediately screened in the field for VOCs using an OVM 580B (or equivalent) photoionization detector. In addition to the VOC screening, radiation field screening measurements were taken using a Ludlum 12-1A radiation detector with an air proportional or zinc sulfide probe. If VOCs were detected during field screening, a VOC sample was submitted for laboratory analysis. Core samples submitted for laboratory analysis were handled in accordance with ER SOP FO.13, Containerization, Preserving, Handling, and Shipping of Soil and Water Samples (EG&G 1992a). Elevated radiation levels were not detected in the field in LHSU materials at any of the pilot borehole locations.

2.2.3.2 Monitoring Well Installation

General construction details for the a-series and b-series monitoring wells are shown in Figure 2.2-6.

Similar to the pilot boreholes, the initial drilling of each monitoring well borehole consisted of installing an isolation casing across the UHSU prior to drilling into the underlying bedrock. This casing isolated the bedrock borehole from the UHSU.

Drilling proceeded through the UHSU with hollow-stem augers. For well borings 21993 and 22493, continuous core samples were collected as drilling progressed through the UHSU. For the remaining boreholes, it was decided that continuous coring of the UHSU was not necessary because continuous UHSU coring had been performed in the adjacent pilot boreholes. In

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general, hollow-stem drilling and sampling of the UHSU was performed in accordance with ER SOP GT.2 (EG&G 1992a).

Following drilling of the UHSU for the a-series wells, an 8-inch ID isolation casing was installed in the borehole. For wells 22193, 22393, 23193, and 23293, the isolation casing consisted of flush threaded steel casing with water-tight threads. For wells 22093 and 22293, Schedule 80 PVC isolation casing with water-tight threads was used to minimize costs. For b-series well 22593, 10-inch ID steel isolation casing with water-tight threads was installed in the borehole. A larger UHSU isolation casing was required for the b-series well to accommodate a second LHSU isolation casing to isolate the borehole from the LHSU interval screened by the paired a-series well (23193).

With the exception of well 22093, the isolation casings were sealed in place by pressure grouting method. For well 22093, the casing was sealed in place with a bentonite seal and tremie grout method, as specified in TM8. In either case, installation and sealing of the isolation casing was performed in accordance with ER SOP GT.3, as modified by DCN (EG&G 1992a). The grout was allowed to cure for a minimum of 24 hours prior to initiating drilling into the underlying bedrock.

Following curing of the UHSU isolation casing grout, the borehole was advanced into the LHSU. For the a-series well boreholes, the borehole was advanced to the target depth for the monitoring well. For the b-series well, the borehole was advanced to a depth below the LHSU unit screened by the a-series well, but above the target interval for the b-series well to allow installation of a second LHSU isolation casing.

For the a-series monitoring wells, the borehole was advanced in the LHSU using air rotary coring methods. Air drilling methods were used to avoid problems associated with drilling mud which can sometimes impact the permeability of the borehole walls and the quality of water samples, and to reduce the amount of waste generated from drilling fluids. The well borehole was advanced to a depth of about 5 feet below the bottom of the interval to be screened. Continuous core samples were collected across the screened interval to verify the lithology of the screened interval.

For the b-series monitoring well (22593), drilling in the LHSU initially proceeded using air drilling methods, as specified in TM8. However, following drilling of the concrete plug in the bottom of the UHSU isolation casing, hydraulic communication was established in the LHSU

between borehole 22593 and the adjacent a-series well 23193, which result in discharge of water from the top of the casing of 23193. The actual pathway of the communication between 22593 and 23193 is unknown, but it is believed that air was forced into the LHSU unit screened by the a-series well, and the resulting pressure change within that unit caused water to be discharged from the top of 23193.

At that point, drilling in 22593 was discontinued pending reevaluation of the drilling method. Upon reevaluation, it was decided to modify the drilling method for installation of the second LHSU isolation casing from air drilling to mud-rotary drilling. The borehole was then advanced to the target depth for the isolation casing using mud-rotary methods.

Following drilling, a 6-inch ID Schedule 80 PVC isolation casing with water-tight threads was installed in the borehole and was sealed by pressure grouting methods. Installation and sealing of the isolation casing was performed in accordance with ER SOP GT.3, Isolating Bedrock from the Alluvium with Grouted Surface Casing (EG&G 1992a), except as modified as necessary for this application. The grout was allowed to cure for a minimum of 24 hours prior to continuing drilling in the LHSU for well installation.

To minimize the potential for inflow of drilling mud and grout into 23193 during drilling of 22593, RFP potable water was introduced into the casing of 23193 to maintain a pressure head away from 23193. Records of the amount of water introduced into 23193 were maintained to support redevelopment of 23193 following installation of 22593.

Following curing of the isolation casing grout in 22593, the borehole was advanced using air coring methods to the target depth of the b-series well. Continuous core samples were collected across the screened interval of the well to verify the lithology of the screened interval.

All drill core collected from the monitoring well boreholes was lithologically logged in accordance with ER SOP GT.1 (EG&G 1992a). Detailed logging of core collected from the abandoned monitoring wells, 21993 and 22493, was determined to be unnecessary because of the close proximity to the logged replacement monitoring wells, 23193 and 23293, respectively. Lithologic logs for the monitoring well boreholes are included in Appendix A4.

LHSU core samples collected from the well boreholes for the a-series and b-series wells were field screened for VOCs and radiation. If VOCs or elevated radiation levels were detected

during field screening, samples of LHSU core in which the constituents were detected were submitted for laboratory analysis. There were no radiological levels detected above background.

Following drilling of each a-series and b-series well borehole, a monitoring well was installed within the borehole to allow collection of groundwater samples from the LHSU unit of interest. The monitoring wells were installed with screen lengths ranging from 7 to 15 feet depending on the geologic conditions encountered, and were screened to monitor the most permeable portion of the LHSU unit of interest.

Monitoring wells were installed according to ER SOP GT.6, Monitoring Wells and Piezometer Installation (EG&G 1992a). The general construction of the monitoring wells is shown in Figure 2.2-6. Monitoring wells were constructed of 2-inch ID Schedule 80 PVC pipe and well screen with 0.01-inch machined slots. Nonslotted (blank) Schedule 80 PVC riser pipe was used above the screened interval and for a sediment sump below the screened interval. Filter pack consisting of 16-40 silica sand was placed around the well casing from the total depth of the boring to a minimum of 6 inches above the screened interval (Figure 2.2-6). Construction details are summarized in Table B2 (Appendix B) and shown in Appendix A4 for each monitoring well completed.

The above-ground completion details of the monitoring wells are depicted in Figure 2.1-5. Vented caps and vented, lockable steel casings were installed for each monitoring well. In areas of heavy vegetation or traffic, 3-inch ID steel guard posts were installed around the monitoring wells at a distance of approximately four feet radially from the surface casing. Protective steel casings and guard posts, when installed, were painted with primer and enamel paint suitable for outdoor exposure.

2.2.3.3 Monitoring Well Development and Groundwater Sampling

Following installation, groundwater monitoring wells were developed to remove fluids or materials potentially introduced during well installation activities, and to allow collection of groundwater samples representative of LHSU groundwater quality. Four of the a-series monitoring wells (22093, 22193, 22293 and 23193) were developed and sampled. The remaining two a-series wells (22393 and 23293) produced insufficient water to allow for well development and were not sampled. The one b-series monitoring well installed (22593) was developed and sampled.

Well development was performed in accordance with ER SOP GW.2, Well Development (EG&G 1992a). Under normal RFP well development procedures, wells which do not produce sufficient water to be developed are transferred to a monthly monitoring schedule for a year or until they produce sufficient water for development. If they still do not meet development specifications after a year, they are transferred to a quarterly monitoring schedule. For the purposes of this bedrock program, extra development efforts were implemented to allow continued monitoring and/or development of wells that did not produce sufficient water to be developed in a timely manner. This was necessary because the LHSU wells, in general, have low water production rates. For this program, wells were monitored and/or purged of water every few days or at least once a week for a period of up to five weeks in an attempt to meet development specifications. Three wells (22393, 22593, and 23293) did not meet development specifications, even after five weeks. In accordance with TM8, these wells were not sampled, but were transferred to the RFP site-wide monitoring program for ongoing monitoring. While under the RFP site-wide monitoring program, well 22593 was able to be sampled in mid-September 1993. The remaining wells (22093, 22193, 22293, and 23193) met development specifications within a period of four to five weeks and were sampled in accordance with TM8.

Groundwater samples were collected from the four a-series wells (22093, 22193, 22293, and 23193) and one b-series well (22593) that were developed. Groundwater sampling was conducted by the RFP site-wide groundwater program in accordance with ER SOP GW.6 (EG&G 1992a).

Two sets of groundwater samples were shipped to off-site laboratories for chemical analysis. One set of samples was submitted for analysis on a quick turn-around basis (24 hours) for the suite of indicator parameters listed in Table 2.2-6. These parameters were selected for their utility and reliability as indicators of site-related contamination. The results from these analyses were used as specified in TM8 to guide the scope of the field investigation activities by providing preliminary information on the occurrence and vertical extent of contamination in the LHSU as field work progressed. The second set of samples were submitted for analysis for a more extensive suite of LHSU analytical parameters (hereafter referred to as the LHSU analyte suite) to confirm the results of the indicator parameter analyses, and to fully characterize the types of contaminants present in the LHSU (Table 2.2-6). Following a review of the contaminants detected in the UHSU during the alluvial investigation, the following parameters analyzed for during the alluvial investigation were eliminated from the LHSU analyte suite:

- Semivolatile compounds

- Pesticides
- PCBs
- Chloride, nitrate, and nitrite
- Cesium 137, strontium 89 and 90, and radium 226 and 228

Table 2.2-5 lists the analytical methods, sample containers, sample preservation, and sample holding times used for the analysis of borehole and groundwater samples for the bedrock field investigation. Analytical results and interpretation for the indicator parameters and full LHSU analyte suite for the bedrock field investigation are presented in Section 4.5.

2.2.3.4 Slug Testing

Field hydraulic testing (slug testing) was conducted on four a-series monitoring wells (22093, 22193, 22293, and 23193). Three wells (22393, 22593, and 23293) were not tested because they produced insufficient water to meet well development specifications. Field hydraulic testing was performed to estimate the in-situ hydraulic conductivity of LHSU materials screened by the monitoring wells. Slug testing was conducted in accordance with ER SOP GW.4, Slug Tests (EG&G 1992a), except that rising head tests were conducted in addition to the falling head tests specified in the ER SOP. Results of the hydraulic testing are presented in Section 3.6.

2.2.4 Geological Investigation

Geological investigations for the bedrock field program consisted of detailed lithological logging of core from boreholes and monitoring wells, borehole geophysical logging in pilot boreholes, and geotechnical laboratory testing of core samples from pilot boreholes.

Lithologic logging of the boreholes and monitoring wells was performed by both the rig geologist and the project stratigrapher. Drill cuttings and cores were examined first by the rig geologist for lithology and general features. A preliminary borehole log was completed by the rig geologist in accordance with ER SOP GT.1, Logging Alluvial and Bedrock Material (EG&G 1992a). The geologist recorded the depths of each coring run, intervals of no recovery, general lithologies encountered, depths of samples collected, and notes regarding moisture conditions and unusual drilling conditions. The drill cuttings and cores were packed in core boxes and delivered to the project stratigrapher for detailed logging.

Detailed logging was also performed in accordance with ER SOP GT.1 by the project stratigrapher. Detailed logging consists of sieving soil/rock samples to determine grain size distribution for soil/rock type classification and degree of grading/sorting. Grain roundness, composition, estimated porosity and cementation were evaluated using microscope techniques. Visual inspection of the core samples was made to describe color (using color charts), friability, internal structures, bedding, fractures, and other features of interest. The alluvial, colluvial and soil intervals were classified using the USCS, whereas bedrock was classified according to Compton (1962) as described in ER SOP GT.1. Each core box was labeled and photographed as part of this logging. Summary logs of the OU-2 Phase II boreholes are provided in Appendix A4.

Following completion of drilling and coring, downhole geophysical logging was performed in the pilot boreholes to provide information on geologic and hydrogeologic conditions within the LHSU bedrock surrounding the boreholes. Except as noted below, the following geophysical logs were run within each pilot borehole:

- Temperature
- Fluid resistivity
- Spontaneous potential
- Resistivity, 16-inch and 64-inch
- Guard
- Induction
- Gamma density
- Neutron
- Natural gamma
- Sonic (full wave form)
- Caliper
- Acoustic televiewer

In pilot borehole 21393, temperature, fluid resistivity, and induction logs were not run due to swelling within the borehole which prevented lowering of the probe past a depth of 51 feet. All other logs were run in this borehole.

The geophysical logging was conducted while the borehole contained drilling mud. Geophysical logging was performed in accordance with ER SOP GT.15, Geophysical Borehole Logging

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(EG&G 1992a). Following geophysical logging, the pilot borehole was plugged and abandoned in accordance with ER SOP GT.5, Plugging and Abandonment of Boreholes (EG&G 1992a).

Discussion of the geophysical logging suite and composites showing selected log curves and generalized core lithologies for each pilot borehole are presented in Section 3.5.

Cores collected from the pilot boreholes were used to guide the installation of monitoring wells. The depth to the UHSU/LHSU boundary and the depths of permeable units within the LHSU were determined from visual observation of the cores and review of geophysical logs. These depths were used to target the placement of isolation casing and screened interval in each well installed for the OU-2 bedrock field program.

Selected portions of pilot borehole core samples were submitted to an off-site geotechnical laboratory for testing to evaluate the permeability and physical properties of the LHSU bedrock materials. Geotechnical sample intervals were determined by the project stratigrapher and were collected at representative distinct lithologic units (i.e., sandstone, siltstone, claystone) encountered within the borehole. Samples were tested in a geotechnical laboratory for vertical and horizontal (radial) permeability, porosity, moisture content, dry density, void ratio, saturation, grain size distribution, and specific gravity. Geotechnical testing results are presented in Section 3.5.

2.2.5 Work Plan Deviations

This section summarizes deviations from TM8 that occurred during performance of the field work.

Changes to ER SOPs were made where appropriate to facilitate the installation of boreholes and monitoring wells with the approval of the EG&G Project Manager. These changes are documented by DCNs.

A comparison between the total depths, isolation casing depths, and depths of screened intervals proposed for boreholes and monitoring wells in TM8 and the actual completion depths is provided in Table 2.2-3.

Deviations from the work plan are listed below:

- The temperature, fluid resistivity, and induction geophysical borehole logs could not be run in pilot borehole 21393 due to swelling in the borehole at about 51 feet. This reduction in hole size prevented lowering these downhole tools past that interval. All other logs were run in this borehole.

- The Guard resistivity log was added to the geophysical logging program after the initial pilot borehole 21193 was logged.

- In monitoring well 22093, the LHSU Parameter sample for groundwater analysis was not collected at the same time as the Indicator Parameter sample due to insufficient water. The LHSU Parameter sample was collected on August 17, 1993.

- In monitoring well 22293, the groundwater sample was analyzed by the EPA-CLP method instead of Method 524.2 for the LHSU Parameter VOC suite. The well was resampled on August 17, 1993 and analyzed for VOCs by the 524.2 method.

- Slug tests could not be performed in monitoring wells 22393, 23293, and 22593 due to insufficient water production.

- The drilling method for installation of the second isolation casing at 22593 was changed from air rotary to mud rotary when the air method caused hydraulic communication with adjacent well 23193.

- The proximity of Borehole SB-2 to borehole BH2587 is uncertain because the location of BH2587 could not be established in the field. Location of BH2587 using survey coordinates was not possible because survey data for BH2587 is believed to be erroneous. The location of SB-2 was selected to be approximately half way between boreholes 9291 and 9491.

- In addition to the falling head slug test analysis required by ER SOP GW.04, slug test analyses were also performed for rising head data.

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- VOC samples collected as part of the LHSU Parameter suite were analyzed by Method 524.2, as specified in TM8. However, the VOC analytes from the 524.2 analyses do not agree with the VOC analytes listed in Table 2-8 of TM8. The correct VOC analyte list for Method 524.2 is presented in Table 2.2-6.

- pH and specific conductance were measured in the field only to be consistent with site-wide groundwater monitoring practices. Table 2-9 of TM8 incorrectly specifies a laboratory method for measurement of pH and specific conductance.

- Cis- and trans- 1,2-DCE were analyzed as separate isomers rather than total 1,2-DCE as listed in Tables 2-4 and 2-8 of TM8.

- Schedule 40 PVC was installed for the isolation casings in all pilot boreholes and source boreholes, rather than Schedule 80 PVC, as specified in TM8. These boreholes and isolation casings were grouted and abandoned following drilling, as specified in TM8.

2.3 AIR QUALITY AND METEOROLOGICAL INVESTIGATION

This section provides a general discussion of the air quality programs and meteorological data collected at RFP. Air quality and meteorological data pertinent to the description of site conditions at OU-2 will be addressed in detail.

2.3.1 Air Quality

Air quality monitoring programs have been conducted at RFP since the early 1950's. The plant currently incorporates air quality programs that protect the plant employees, the general public, and the environment through appropriate engineering, administrative controls, and subsequent monitoring and assessment of the impact to the air from both radiological and nonradiological sources. As part of this effort, an annual RFP site environmental report is published that includes all air monitoring data and associated impact analyses. The latest issue of this annual report is dated 1991 and covers the period from January through December 1991 (EG&G 1992d). The program currently includes monitoring for radionuclides and nonradioactive ambient air monitoring which includes total suspended particulates and respirable particulates less than or equal to 10 micrometers (PM_{10}).

2.3.1.1 Radionuclides Ambient Monitoring

Currently monitored air quality data includes data collected as part of the Radiological Ambient Air Monitoring Program (RAAMP). The RAAMP ambient air samplers monitor airborne dispersion of radioactive materials from RFP into the surrounding environment. Samplers are designated in three categories by their proximity to the main facilities area. Twenty-three on-site samplers are located within RFP, concentrated near the main facilities area. Fourteen perimeter samplers border RFP along major highways on the north (Highway 128), east (Indiana Street), south (Highway 72), and west (Highway 93). Sampler locations are shown in Figure 2.3-1. Ambient samplers operate continuously at a volumetric flow rate of approximately 25 cubic feet per minute (cfm) using a RFP designed sampler which incorporates a brushless induction blower assembly. The samplers collect particulate matter on a fiberglass filter medium. Manufacturer's test specifications rate this filter media to be 99.97 percent efficient for relevant particle sizes under conditions typically encountered in routine ambient air sampling. Sampler flow rates are checked weekly, and filters are collected biweekly. Filters taken from the sampling network are analyzed for plutonium and americium. Onsite and perimeter sites within OU-2 for 1991 are given in Table 2.3-1 and locations are shown on Figure 2.3-1.

2.3.1.2 Nonradionuclides Ambient Monitoring

Nonradioactive ambient air monitoring was conducted in 1991 for total suspended particulate (TSP) and respirable particulates less than or equal to 10 micrometers in diameter (PM_{10}). Ambient particulates are regulated by EPA and CDH under the Clean Air Act Amendments of 1977 (US Congress 1977), as defined by the National Ambient Air Quality Standards (NAAQS) and Colorado Air Quality Control Commission Ambient Air Standards. The NAAQS was originally based on TSP, a measure of total particulate recovery and not based on particulate size. The present EPA standard is based on the PM_{10}. However, the CDH TSP standard also remains in effect.

Ambient air monitoring at RFP provides baseline information on particulate levels. TSP and PM_{10} samplers are located near the east entrance to RFP, unobscured by structures, and generally downwind from plant buildings. The reference method hi-volume TSP sampler and Wedding PM_{10} sampler are operated on the EPA sampling schedule of 1 day per every 6th day.

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2.3.2 Meteorology

Meteorological data collected for this report are based on the primary meteorological station at RFP, the 61-meter tower located in the west buffer zone. The tower is instrumented at 10, 25, and 60 meters to measure horizontal wind speed, vertical wind speed, wind direction and temperature. Dew point measurements are made at the 10m level. Solar radiation measurements are taken by a radiometer mounted on an unobstructed platform at 1.5 meters above ground level. Ground level precipitation and pressure are also measured. The climate data is taken from data collected in 1991 as summarized in the annual environmental report (EG&G 1992d). The meteorological data included in this report represent 98 percent data recovery. The data set used in the air dispersion modeling analysis is from the more complete data set (greater than 99 percent data recovery) collected in 1992. Mixing height data was calculated from twice daily radio sounds from Stapleton International Airport during 1992.

2.4 SURFACE WATER AND SEDIMENT INVESTIGATION

This section provides a brief discussion of the surface water investigation which is part of the site-wide Surface Water Data Collection Program. Only seep and sediment locations pertinent to OU-2 will be discussed in more detail.

2.4.1 Sample Locations, Collection, and Frequency

Under the Environmental Restoration Program, the RFP Surface Water Data Collection Program is conducted at a network of fixed sites, involving surface water, seep, sediment and detention pond sample collection. Routine surface water and sediment sites are sampled quarterly, with the exception of several "seasonal" sites that are sampled on a monthly basis from March to June. Sampling locations are divided into nine program areas:

1. Rock Creek
2. Landfill
3. Protected Area (PA)
4. 881 Hillside
5. Woman Creek
6. South Interceptor Ditch
7. North Walnut Creek
8. South Walnut Creek
9. Mound Area

Seeps represent the only source (excluding stormwater runoff) of surface flow originating in OU-2. The seeps are sampled under the site-wide surface monitoring program, but due to

seasonal variations, which often result in very low to non-existent flow rates, it is frequently impossible to obtain samples from the seeps. Annual fluctuations in the water table produce periods during which no flow occurs from seeps in OU-2. Surface water sampling stations which include seep locations are designated as SW. Sediment sampling locations are designated as SED.

The seep sampling locations, with associated sediment sampling locations in OU-2 (see Figure 2.4-1) are as follows:

Mound Area	903 Pad Area		East Trenches Area
SW059	SW050	--	SW103
SW056	SW057	Sed 051	
	SW052	Sed 038	
	SW058	--	
	SW053	--	
	SW064	Sed 031	
	SW063		

Rocky Flats Plant ER SOPs are used during surface water, sediment, and pond sampling activities. Surface water samples are collected as grab or as composite samples in a priority order. Samples are collected in accordance with ER SOP SW.3, Surface Water Sampling. Equipment for surface water sampling is also described in ER SOP SW.3.

Sediment samples are collected using core samplers or a stainless steel scoop. Core samplers are used for the collection of volatile organic compounds and composite samples of bed materials that are saturated. Stainless steel scoops are used for composite sample collection of dry bed materials. Large particles and debris are removed from composite samples.

Sediment samples are collected in accordance with ER SOP SW.6, Sediment Sampling. ER SOP SW.6 also includes a description of sampling equipment. The effectiveness of the equipment cleaning procedures is monitored by submitting rinse water for analysis to laboratories.

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Measurement of field parameters at surface water sites is conducted in accordance with ER SOP SW.2, Field Measurement of Surface Water Field Parameters. Residual chlorine can act as an oxidizer for VOCs, cyanide, and BNA. If the concentration of total residual chlorine (TRC) is ≥ 0.2 mg/l, the samples are preserved.

Parameters measured at surface water sites are air temperature, water temperature, dissolved oxygen (DO), pH, TRC, alkalinity, and specific conductance. Air temperature, water temperature, and DO are measured in situ. TRC, alkalinity, and specific conductance are measured in a grab sample taken in accordance with ER SOP SW.3. Equipment for the surface water field parameter measurements is described in ER SOP SW.2.

2.4.2 Seep and Sediment Analytical Parameters

Analytical parameters for the seeps are identical to the list of parameters for site-wide surface water samples, but change periodically depending on the site-wide data needs. Analytical parameters for sediments also are revised periodically under the site-wide monitoring program.

2.5 SURFACE SOIL INVESTIGATION

The OU-2 Phase II RFI/RI surface soil sampling program was the most comprehensive investigation of the nature and extent of contamination in surface soils conducted at RFP to date. The OU-2 Phase I study, conducted in 1987, examined soils collected from depths of 0 to 2 feet. For risk assessment purposes, surface of the soil in this report is defined as the interval from 0 to 5 centimeters (cm) depth. Therefore, the results of the Phase I study are not representative of the nature and extent of contamination in surface soils. Prior to the Phase I study, surface soil sampling programs conducted at RFP were limited to the investigation of radionuclide contamination and, therefore, of limited use. Additionally, these data were not consistently validated, and in some cases, remain unpublished. Data from these studies were useful in developing the sampling plans for the OU-2 Phase I and II investigations, but are not included here.

The OU-2 Phase II RFI/RI surface soil sampling program was conducted in two stages. The first stage was conducted to investigate the spatial extent as well as the fate and transport of actinides (plutonium and americium). The second stage was conducted in support of the OU-2 Human Health Risk Assessment. The work plan for the first stage was presented in

Attachment 1, Surficial Soil Sampling Plan of the OU-2 Alluvial Work Plan (DOE 1991a). The objectives of the Alluvial Work Plan surface soils sampling program were to:

- Determine the spatial and vertical extent of plutonium and americium in surface (0 to 5 cm) and near-surface (0 to 96 cm) soils in the remedial investigation areas, and in the buffer zone.

- Study the physiochemical characteristics of the soil that govern fate and transport of actinides in an area east of the 903 Pad and above a perched aquifer (SW-53).

- Study the movement of water and actinides in colloidal and dissolved phases through the soil system.

- Evaluate the hydrogeochemical relationships between the vadose zone and the water table.

To meet these objectives, the first stage of the Phase II surface soil sampling program, conducted in the summers of 1991, 1992, and 1993, consisted of both surface and near surface (soil profiles) sampling.

The second stage of the Phase II surface soil sampling program was conducted in March 1993. The objectives were to analyze for all contaminants that are potentially present in surface soils at OU-2 (i.e., SVOCs, metals, radionuclides) for use in the OU-2 Human Health Risk Assessment; provide additional supporting data for the EE; and allow assessment of remedial alternatives for remediation of the contaminated soils in accordance with the NCP. The work plan for the second stage of sampling is presented in TM7, Addendum to Final Phase II RFI/RI Work Plan, Surface Soil Sampling and Analysis Plan (DOE 1993c).

The following sections outline both stages of the Phase II RFI/RI surface soil sampling program.

2.5.1 Surface Soil Sampling for Evaluating the Spatial Extent of Actinides

In order to assess the spatial extent of plutonium and americium in surface soils within the OU-2 boundaries, surface soil samples were collected across an area of approximately 800 acres

as shown in Figure 2.5-1. Plots were selected for sampling based on a review of previous investigation results, analysis of data from unpublished material, and radiological surveys (DOE 1991a).

The surface soil sampling plots were 2.5 and 10 acres in size. Because of the large variations in Pu distribution near the source area, 2.5-acre plots were sampled immediately east of the 903 Pad and around the East Trenches Areas, and 10-acre plots were sampled for the remainder of the study area (Figure 2.5-1). This sampling design served two purposes: (1) to increase the confidence in soil plutonium estimates around the 903 Pad and East Trenches Areas; and (2) to expand the number of soil data for spatial estimating procedures.

The first stage of the OU-2 Phase II surface soil sampling program was conducted using the CDH Method. The CDH method was preferred for evaluating the spatial extent of contamination. In addition to the surface soil sampling performed using the CDH method, each grid was resampled in 1991 and 1992 using the RFP method. It has been hypothesized that the level of Pu-239/240 in surface soils is method dependent. Hence, a study is currently being conducted to compare the spatial distribution of actinides as a function of the method used. The RFP method samples an interval from 0 to 5 cm deep. All surface soil sampling was conducted in accordance with ER SOP GT.8 (EG&G 1992a). The CDH and RFP sampling methods are discussed in the following subsections.

2.5.1.1 CDH Method Sampling

2.5.1.1.1 Methodology. Initially, the CDH method was used for surface soil sampling during the summer of 1991 so that the soil radionuclide concentrations could be evaluated according to State of Colorado guidelines, which require special construction techniques on lands with plutonium concentrations greater than 0.9 pCi/g of dry soil.

The four corners of each 2.5 and 10-acre surface soil plot were surveyed and identified with an appropriately-marked steel post. Plots were oriented on the cardinal compass directions. The individual subsample locations for each plot were located with a hand-held compass and pacing using one of the corners as the starting point.

Under the CDH method, surface soil samples were collected by driving a stainless steel sampling template (Figure 2.5-2) into undisturbed soil. The sample within the template cavity was collected using the CDH spade (Figure 2.5-2) and placed in a stainless steel sample

container. Twenty-five equally spaced and uniformly distributed subsamples were composited within each 2.5-acre or 10-acre plot (Figure 2.5-3). After all subsamples were collected, the sample material was placed in a stainless steel container and composited. Compositing was conducted by thoroughly mixing the material using a stainless steel scoop. The sample was then quartered and each quarter was mixed individually. The entire sample was then mixed together again until as homogeneous as possible a mixture was obtained. The composite sample was then placed in the appropriate sample containers, and the containers were placed in plastic bags in a cooler. RAD screen samples were collected at each plot to analyze radiological levels to ensure that analytical samples are handled and shipped correctly (ER SOP FO.18, Environmental Sample Radioactivity Content Screening) (EG&G 1992a). The RAD screen samples were analyzed before the composite samples were shipped off site. The composite samples were analyzed for Pu-230, Pu-240, Am-241, and U-233,234, U-235, and U-238. Analytical results are presented and interpreted in Appendix D and summarized in Section 4.2.

2.5.1.1.2 **<u>Work Plan Deviations</u>**. A total of 124 plots were proposed for CDH sampling in the Alluvial Work Plan. A total of 118 plots were sampled using the CDH method during 1991. One plot (Plot 0) was added during the field investigation to provide additional spatial information (Figure 2.5-1). Plot numbers 2, 8, and 9 were not sampled because they are covered with structures and/or pavement. Plot numbers 7, 14, 17, and 18 were not sampled because the plots are inside the PA fences where the surface is highly disturbed, and therefore, a meaningful sample could not be obtained. Figure 2.5-1 shows the plots that were sampled, and also shows the plots that were not sampled. Though the Surficial Soil Sampling Plan in the Phase II RFI/RI Work Plan Alluvial did not include the analysis of U-233,234, U-235, and U-238, this analysis was performed at the request of the Agencies.

Several of the plots had obstructions (e.g., roads, ditches, ponds, etc.) that required modification of the sampling scheme shown in Figure 2.5-3. In this case, the sample spacing was condensed or the sampling scheme was changed so that as many of the 25 subsamples as possible were collected. All deviations were documented on a Field Activities Report Surficial Soil Sampling (Form GT.8B) (see ER SOP GT.8 [EG&G 1992a]). All original field forms are kept in EG&G's RFP library.

In addition to the samples collected for chemical analyses, surface soil samples were collected and submitted to a laboratory for particle size analysis.

2.5.1.2 RFP Method Sampling

2.5.1.2.1 Methodology. Under the RFP method, surface soil samples were collected by driving a stainless steel cutting tool (Figure 2.5-2) 5 cm into undisturbed soil. The sample within the tool cavity was collected using a stainless steel scoop and placed in a stainless steel sample container. Ten subsamples were collected from the corners and the center of two 1-meter squares, spaced 1 meter apart at the center of each 2.5 acre or 10-acre plot (Figure 2.5-3). Each set of 10 subsamples was composited using the method described in Section 2.5.1.1. Sampling equipment was decontaminated between composite locations (plots).

After compositing was complete, the sample was then placed in the appropriate sample container, and the containers were placed in plastic bags in a cooler. A RAD screen sample was collected for each plot. The RAD screen sample was analyzed before the composite sample was shipped off site. The composite analytical samples were analyzed for Pu-239/240 and Am-241. Analytical results are presented and interpreted in Appendix D and summarized in Section 4.2.

2.5.1.2.2 Work Plan Deviations. Only the plots that were previously sampled using the CDH method were sampled during the RFP sampling event conducted in 1991 and 1992. Therefore, a total of 118 plots were sampled at OU-2 using the RFP method. Figure 2.5-1 shows the plots that were sampled, and also shows the plots that were not sampled under the CDH program. The Surficial Soil Sampling Plan in the Phase II RFI/RI Work Plan Alluvial did not include the resampling event using the RFP method. The resampling was conducted so that a comparison of the results could be made.

2.5.2 Soil Profile Investigation

Transport of plutonium in soil is highly affected by soil series, moisture content, texture, structure, and particle characteristics such as shape, density, and cohesiveness (Burley 1990). As a result, soil profiles (pits) were excavated in all soil series east of the 903 Pad to assess the vertical distribution of plutonium and americium in soil.

2.5.2.1 Vertical Distribution Study of Actinides in Soils

2.5.2.1.1 Methodology. Twenty-six soil profiles (pits) were excavated, described, and sampled in 1991 and 1992 to assess the vertical distribution of plutonium and americium in soils east and south of the RFP industrial area. The locations of these pits are shown on Figure 2.5-4. Eleven soil pits were excavated in the immediate vicinity of the 903 Pad, East Trenches, and Seep SW-53, and an additional 12 soil pits were excavated according to soil series, direction, and distance from the 903 Pad. All major soil series east of the 903 Pad were sampled. Three additional pits were located in the Operable Unit No. 1 study area. The soil pits were excavated in undisturbed or the least disturbed sites, which are characterized by natural short grass, prairie, pasture, and valley side vegetation (Clark et al. 1980). The exact location of the soil pits was determined in the field using aerial photographs, soil and topographic maps, radiological surveys, and professional judgement. Soil samples from the 26 soil pits were collected using a modified trench method (Harley 1972) (ER SOP GT.7, Logging and Sampling of Test Pits, Trenches and Construction Excavation [EG&G 1992a]).

The samples were then placed in the appropriate sample containers, and the containers were placed in plastic bags in a cooler. A RAD screen sample was collected for each analytical sample. The RAD screen samples were analyzed before the analytical samples were shipped off site. The composite samples were analyzed for Pu-239/240 and Am-241. Analytical results are presented and interpreted in Appendix D and summarized in Section 4.2.

In addition to the actinide determination, the following physical, chemical, and mineralogical analyses were conducted on all samples from the soil pits:

- Particle size distribution
- Bulk density
- Specific surface area
- Clay mineralogy and morphology
- Total organic carbon
- pH
- Calcium carbonate content
- Specific conductance
- Cation exchange capacity
- Major exchangeables (Ca, Mg, K, and Na)
- Sesquioxide content

Additional samples were collected for sequential extraction experiments. Results from these are being documented as the experiments are still ongoing.

2.5.2.2 Fate and Transport of Actinides in Soils

The fate and transport of actinides in soil as well as the soil physiochemical properties that govern the behavior of these actinides were studied by developing a Soil Water Monitoring System (SWMS). The SWMS was installed to collect real time data of freely flowing soil interstitial waters, moisture content, matric potential, soil temperature, and site precipitation. The SWMS also collected soil solutions at different matric potentials for actinide analyses. The SWMS was installed in five pits in an area characterized by lateral discontinuities.

The SWMS consists of six major modules: (a) an automated zero-tension sampler that collects freely flowing water (Ψ = 0 to 5 kPa) mainly through macropores; (b) a cluster of time domain reflectometry (TDR) probes and tension samplers that measures in-situ water content and collects soil interstitial waters at higher matric potentials (Ψ = 5 to 40 kPa) for radiochemistry analyses; (c) a semi-automated tensiometer network that measures the soil matric potential; (d) five piezometers that monitor groundwater level; (e) automated temperature probes network; (f) a tipping bucket rain gauge; and (g) telemetry communication network coupled with a graphic user interface that remotely controlled data acquisition, processing, and archiving (Figure 2.5-5).

The movement of actinides in the soil environment was evaluated by using the SWMS in conjunction with natural and simulated rainfall episodes which ranged widely in intensity, frequency, and duration. The results are presented in Appendix D and summarized in Section 4.2.

2.5.2.2.2 Work Plan Deviations. Recent work has shown that random sampling within the vadose zone in areas characterized by preferential flow is likely to underestimate contaminant transport (Kung and Donohue 1991). Hence, the location of the five instrumented pits was determined by Ground-Penetrating Radar (GPR) survey. These pits are approximately 250 meters east of the former storage site and above a perched aquifer. The survey was performed on an area approximately 1,670 m^2.

2.5.3 Surface Soil Sampling for Human Health Risk Assessment

2.5.3.1 Methodology

In order to assess the potential human health risks associated with exposure to OU-2 surface soils, an evaluation of the nature and extent of non-radioactive contamination (SVOCs and metals) as well as other radioactive contamination in surface soil (in addition to plutonium, americium, and uranium) was required. Therefore, the second stage of the OU-2 Phase II sampling was conducted to more fully characterize surface contamination.

The size of the polygons (plots) to be sampled (50 feet by 100 feet) was selected based on a representative exposure area for a future on-site resident. To determine the sampling locations, the OU-2 area was divided into 9,126 contiguous 50 feet by 100 feet plots. Forty plots were systematically selected for sampling. Six of the 40 plots were biased plot locations specifically selected for sampling because they were located within IHSSs potentially containing contaminated surface soils (based on a review of the activities conducted in OU-2). The remaining 34 plots were evenly spaced throughout the OU-2 area. If a sample plot was determined to be located within a disturbed area (road, french drain, etc.), the sample location was eliminated and replaced by an adjacent, undisturbed plot. Plate 2.5-1 shows the plots selected for sampling. The four corners and center of each plot were surveyed and identified with a wooden lath. The rationale for the sampling is outlined in TM 7, Addendum to the Phase II RFI/RI Work Plan, Surface Soil Sampling and Analysis Plan (DOE 1993c).

One composite soil sample was taken from each of the plots using the RFP method, which is described in Section 2.5.1.2. Ten subsamples were collected from the corners and center of two 1-meter squares, placed 1 meter apart. The 1-meter squares were sampled in the corners and center of each plot for a total of 50 subsamples per plot (Figure 2.5-6). Each set of 50 subsamples was composited using the method described in Section 2.5.1.1. Sampling equipment was decontaminated between composite locations (plots).

After compositing was complete, the sample was placed in the appropriate container and the containers were placed in plastic bags in a cooler. A RAD screen sample was collected for each plot. The RAD screen sample was analyzed before the composite sample was shipped off site. The composite samples were analyzed for semivolatiles, metals, and radionuclides. Analytical results are presented and interpreted in Section 4.2. In addition, ten samples were collected and submitted for bulk density testing.

2.5.3.2 Work Plan Deviations

To reduce confusion related to sample numbering, the surface soil plots were renumbered SS200093 through SS203993 (referred to as reference point numbers in the work plan). Plate 2.5-1 shows the original work plan numbers and the new plot numbers. The new numbers are used throughout this report.

Four plots were moved to avoid obstructions. Plot SS200093 was moved to avoid asphalt pavement and a parking lot. Plot SS200693 was moved to avoid a fence and gravel road. Plot SS200993 was moved to obtain a surface soil sample at IHSS 216.2, which was relocated based on a review of historical information (see the Final Historical Release Report [DOE 1992a]). Plot SS201493 was moved to avoid a pond. Plate 2.5-1 shows the location of the plots.

2.5.4 Background Surface Soil Sampling

2.5.4.1 Methodology

In order to evaluate the surface soil and analytical data for OU-2, it was necessary to evaluate background concentrations for the analytes of interest in areas that have not been impacted by facility operations.

The objectives and rationale for the background sampling is outlined in TM 7, Surface Soil Sampling and Analysis Plan (DOE 1993c). Background samples were collected from the Rock Creek Drainage area at RFP under the Operable Unit No. 1 sampling plan. However, not all the OU-2 analytes of potential concern were analyzed (e.g., Cs-137, lithium). Therefore, additional randomly selected background plots were sampled from the Rock Creek Drainage and analyzed during the second stage of the OU-2 Phase II surface soil sampling program. Several analyses, not contained in the OU-2 analyte list, were added to the background analyte list, in order to get a complete suite of background analyte concentrations. The RFP sampling method was used for collecting the background samples. Figure 2.5-7 shows the plots sampled during the OU-1 investigation and the sites for the OU-2 investigation. The results from the OU-2 background sampling event are discussed in Section 4.2.

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2.5.4.2 Work Plan Deviations

To reduce confusion related to the numbers, the background surface soil plots were renumbered SS204093 through SS204893 (referred to as B-1 through B-9 in the work plan). Figure 2.5-7 shows the original work plan numbers and the new background plot numbers. The new numbers are used throughout this report.

2.5.5 Data Management

Field and laboratory data collected during OU-2 surface soil sampling program were incorporated into the RFEDS. The RFEDS is used to track, store, and retrieve project data. Data were input to the RFEDS via diskettes subsequent to data validation as outlined in the Environmental Restoration Program QAPjP (EG&G 1990b). Hardcopy reports were then generated from the system for data interpretation and evaluation. See Section 4.1 for details pertaining to the data management and manipulation process required for data interpretation and evaluation.

2.6 ECOLOGICAL INVESTIGATION

The ecological investigation was conducted to describe biotic conditions within OU-2 as they relate to potential contamination arising from OU-specific sources. The field investigation was based on the OU-2 Phase II RFI/RI Environmental Evaluation Workplan (DOE 1991a). The assessment of ecological community composition was based on: (1) species occurrence and abundance as a general indicator of environmental health, (2) presence and concentration of contaminants in tissues of selected plant and animal species, and (3) measured or estimated exposure of ecological receptors to OU-2 contaminants. The result is an evaluation of the nature and extent of contamination in biota, its relationship to abiotic sources, and the extent and type of adverse effects at the ecosystem, community, population, and individual levels of biological organization. A summary of the field investigation is presented in this section. A more complete description of the field methods and discussion of results is presented in Appendix I.

The objectives of the EE are to: (1) use existing data and site conceptual models to identify receptors of concern and pathways by which these receptors may be exposed to contaminants of concern, (2) collect data to assess existing impacts to ecological receptors and exposure of ecological receptors to site contaminants, and (3) ascertain whether OU-2 contamination has

resulted in impacts to biota at RFP, and to assess whether contaminants represent a future risk to ecological receptors.

The scope of the EE included a review of data collected prior to the Phase II RFI/RI field activities. These data were used to identify potential contaminants of concern and target analytes for the ecological investigation. Analysis of potential exposure pathways include direct exposure to contaminants in environmental media and indirect exposure via ingestion of contaminated food items. The field sampling program was designed to quantify contaminant loads in tissues and to assess ecosystem community, and population impacts on the area biota.

Details of the ecological investigation and deviations from the work plan are discussed in the Environment Evaluation Report found in Appendix I.

2.6.1 Contaminants of Concern

Contaminants of Concern (COC) are chemicals associated with activities at OU-2, are suspected to occur in environmental media, and are potentially toxic to ecological receptors or ecosystems. In this context, COCs include organic compounds, inorganic compounds, and elements. The list of potential COCs was used to select target analytes for testing biota and/or environmental media for contamination. Identification of potential COCs was based on criteria developed by the EPA in conjunction with EG&G and includes occurrence of the chemical in the environmental media, the ecotoxicity of the chemical, and the extent of the contamination.

Potential COCs were identified from data presented in the OU-2 Phase I RFI/RI Report and the Phase II RFI/RI Work Plan. To be considered a candidate for listing, metals and radionuclides must have been detected above the natural background levels listed in the Background Geochemical Characterization Report 1989 (DOE 1992d), and organics must have been detected in greater than five percent of samples. Target analytes were chosen from potential COCs based on the potential for bioaccumulation. The target analytes for OU-2 include: arsenic, cadmium, chromium, copper, lead, mercury, and selenium, Am-241, Pu-239,240, total uranium, NO_2 and NO_3.

The final COCs are identified using results of Phase II investigations. Contaminants are identified on the basis of "nature and extent" of contamination and COCs identified by evaluating the potential toxicity of the contaminants. Risk characterization are conducted for each COC using data collected during the Phase II investigation.

2.6.2 Sampling Locations

Study sites were selected in areas of potential impact from disturbance or contamination. These sites are within and adjacent to source areas within IHSSs, and areas upgradient and downgradient from suspected contaminant sources. Sampling sites were stratified by habitat type to facilitate the analysis and interpretation of data. Habitat types were defined in accordance with EMAD.OPs 5.11 (EG&G 1992a). The location of sample sites within each habitat was obtained following specific procedures outlined in the appropriate taxon-specific ER SOPs (ER SOPs 5.1-5.10 EG&G 1991). All recognized habitat types are represented among the study sites and they include xeric grassland, mesic upland grassland, and mesic bottomland grassland. Flora, fauna and surface soil sample locations were co-located, to the greatest extent possible.

Reference sites were sampled and the data used as one basis of evaluating community, population, and habitat impacts and tissue contaminant loads potentially associated with OU-2 contamination. Two reference areas were selected and sampled in 1991 so that a wider range of natural habitats at RFP could be included in the analysis. The first was in the Rock Creek and North Walnut Creek drainages north of RFP. Rock Creek is considered outside the zone of impact of RFP activities and was used as a reference area for both ecological comparisons and tissue contaminant loads. The second ecological reference area is located in the Smart Ditch Creek south of RFP. The Smart Ditch Creek drainage is also remote from RFP and appeared to be more ecologically similar to OU-2 but was potentially downwind of RFP. Therefore, Smart Ditch Creek was used only for comparison of ecological (not tissue) parameters.

2.6.3 Key Receptors

Key receptors were selected for representation endpoints to assess contaminant effects to biota, and measure contaminant tissue loads. Key receptors were selected on the basis of their sensitivity to the potential COCs and their function within the ecosystem. They were selected from different trophic levels to enable an evaluation of potential exposure through both direct accumulation from the abiotic environment, and indirectly through bioaccumulation through the food chain. Key receptors were identified as assessment endpoints, measurement endpoints or both. For taxa selected as measurement endpoints, additional criteria to distinguish those sampled by destructive techniques (e.g., those analyzed for contaminant concentrations or histopathological effects) from those sampled solely by nondestructive techniques (e.g., population surveys).

2.6.4 Ecological Investigations

Ecological investigations were conducted from May to November 1991. Additional vegetation sampling was performed during the Fall of 1992. Methods and study design were developed in accordance with the EE workplan and standard operating procedures for ecological data collection (EMAD.OPs) (EG&G 1992a). Investigation endpoints included species richness, community composition, vegetation cover, shrub density, production, and tissue collection. The study areas under consideration included xeric hilltop grassland and mesic upland grassland, mesic bottom land grassland, reclaimed and disturbed communities.

2.6.4.1 Vegetation

Vegetation measurement endpoints included foliar cover, species richness, woody plant and cacti density, productivity and tissue collection. Foliar cover was estimated using the point-intercept method at a minimum of ten 50-m transects in each of the habitats types. Fewer transects were used when the areal extent did not permit ten transects. Production in each habitat was assessed by clipping the above-ground biomass within five 0.5-m^2 plots along each of at least five transects within each habitat. Tissue sampling entailed the collection of target species within the belt transects centered over the cover transects. Tissue samples were collected from at least five transects within each habitat.

2.6.4.2 Small Mammals

Small mammals were included in qualitative and quantitative studies because they live in contact with the soil and may ingest contaminants through their plant or invertebrate food. Mice and voles occupy home ranges small enough to be restricted to OU-2 and they are a major component of the prey base for many predators.

Trapping was performed at four grids per habitat type in the study and reference areas (Figure 2.6-1). At each sampling location, trapping was performed over a period of four nights using the method specified in EMAD.OPs 5.6 (EG&G 1992a). Measurement endpoints for small mammals included species richness (number of species per trapping grid) and relative abundance (number of individuals by species per 100 trap-nights). Data on mean weight, weight-length (head and body) ratio, sex and age classes, and reproductive status were recorded for each individual.

Tissue samples were taken from all small mammal-sampling locations in the study. At least three, but not more than six, 25-g samples of each species were collected, and analyzed for target analytes.

2.6.4.3 Birds

Songbird and raptor surveys were conducted within OU-2 habitat and in reference areas. Songbird surveys were conducted during May 1991 to characterize site use by breeding populations. Use of the site by sensitive species is a good general indicator of habitat quality. Density (number per hectare) and species richness were evaluated at three to eight 100-m by 100-m (1 hectare) plots in each habitat type (EMAD OPs 5.7) (EG&G 1992a). Counts were made at each plot on four consecutive mornings. Qualitative studies were conducted during non-breeding months to assess general site use.

Red-tailed hawks and other common raptors are top predators in the Rocky Flats food web. Therefore, information on site use by these species was evaluated to assess potential food web interactions. Qualitative rapture surveys were conducted throughout the study.

2.6.4.4 Terrestrial Arthropods

Terrestrial arthropods consisting primarily of insects and arachnids (spiders) are similar to small mammals as indicators of ecological health because of their intimate contact with the soil, consumption of plant material (or other invertebrates), and importance as prey to some predators. Terrestrial arthropods were sampled with sweep nets along 50-m transects co-located with the vegetation cover transects, in accordance with ER SOP 5.9 (EG&G 1992a).

Measurement endpoints include richness and biomass (g/m^2 of selected taxa collected from each transect). Orthopterans (mostly grasshoppers) were chosen for tissue analysis because they are ground-dwelling, and relatively abundant. These factors make them good candidates for analysis of biological fate of soil contaminants.

Tissue samples collected from the major taxonomic groups were preserved and shipped according to standard operating procedures for ecology, and standard protocols for shipping samples to off-site laboratories.

Data collected on ecological community structure is used to identify impacts potentially due to contamination on OU-2. These data are also used to evaluate potential food-web interactions important to contaminant fate and transport. Exposure of key receptors to COCs is evaluated using data on nature and extent of contamination at OU-2, and tissue data collected during field investigations.

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TABLE 2.1-1
COMPARISON OF OU-2 ALLUVIAL PROPOSED AND COMPLETED WORK

Task/Objective	Proposed Work	Completed Work
1. IHSS Characterization		
1a. 903 Pad Area	Drill 23 Source Characterization Boreholes	Drilled 24 Source Characterization Boreholes Drilled 3 Abandoned Monitoring Wells
1b. Mound Area	Drill 4 Source Characterization Boreholes	Drilled 2 Source Characterization Boreholes[1]
1c. Northeast Trenches Area	Drill 5 Source Characterization Boreholes	Drilled 5 Source Characterization Boreholes Drilled 8 Abandoned Monitoring Wells, Observation Wells, or Pumping Wells
1d. Southeast Trenches Area	Drill 13 Source Characterization Boreholes	Drilled 12 Source Characterization Boreholes[1] Drilled 1 Abandoned Monitoring Well
2. Groundwater and Plume Characterization		
2a. 903 Pad Area	Install 14 alluvial wells	Installed 19 alluvial wells Installed 8 bedrock wells(2) (4 No. 1 Sandstone, 4 Laramie Sandstone)
2b. Mound Area	Install 20 alluvial wells	Installed 2 alluvial wells[1] Installed 9 bedrock wells(2) (All No. 1 Sandstone)
2c. Northeast Trenches Area	Install 15 alluvial wells	Installed 18 alluvial wells Installed 15 bedrock wells(1) (All No. 1 Sandstone)

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TABLE 2.1-1
COMPARISON OF OU-2 ALLUVIAL PROPOSED AND COMPLETED WORK

Task/Objective	Proposed Work	Completed Work
2d. Southeast Trenches Area	Install 16 alluvial wells	Installed 16 alluvial wells Installed 2 bedrock wells(2) (1 No. 1 Sandstone, 1 Claystone
3. Surface Soil Sampling		
3a. 1991 CDH Method Sampling	Sample 124 Total Plots	Sampled 118 Total Plots
	- Sample 40 2.5-acre Plots	- Sampled 34 2.5-acre Plots(3)
	- Sample 84 10-acre Plots	- Sampled 84 10-acre Plots
3b. 1991 RFP Method Sampling	Sample 0 Plots	Sampled 118 Plots(4)
3c. 1993 RFP Method Sampling	Sample 49 Total Plots	Sampled 49 Total Plots
	- Sample 40 Regular Plots	- Sampled 40 Regular Plots
	- Sample 9 Background Plots	- Sampled 9 Background Plots

43 Background

Notes : CDH - Colorado Department of Health
RFP - Rocky Flats Plant

1. See Table 2.1-5 (Site Status Summary) for further information. Table 2.1-5 outlines sites that were not drilled, abandoned, moved, or added.
2. Installation based on conditions encountered in the field during alluvial well drilling. Bedrock wells installed if saturated subcropping sandstone was greater than 10 feet in thickness.
3. Samples were not taken if the designated plot was covered with concrete/pavement or inside the PA.
4. RFP sampling method was added in the first stage of the OU-2 Phase II surficial soil sampling program.

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TABLE 2.1-2
SUMMARY OF STANDARD OPERATING PROCEDURES USED IN THE OU-2 ALLUVIAL WORK PLAN FIELD INVESTIGATION

SOP NUMBER	TITLE
FO.1	Air Monitoring and Dust Control
FO.2	Field Document Control
FO.3	General Equipment Decontamination
FO.4	Heavy Equipment Decontamination
FO.8	Handling of Drilling Fluids and Cuttings
FO.10	Receiving, Labeling, and Handling Environmental Material Containers
FO.13	Containerization, Preserving, Handling, and Shipping of Soil and Water Samples
FO.14	Field Data Management
FO.15	Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)
FO.16	Field Radiological Measurement
GT.1	Logging Alluvial and Bedrock Material
GT.2	Drilling and Sampling Using Hollow-Stem Auger Techniques
GT.5	Plugging and Abandonment of Boreholes
GT.6	Monitoring Wells and Piezometers Installation
GT.10	Borehole Clearing
GT.11	Plugging and Abandonment of Wells
GW.02	Well Development
GW.04	Slug Testing
GW.06	Well Sampling

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TABLE 2.1-3
BOREHOLE SUMMARY

Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)
06591	65-91/BH0191	Characterization upgradient (west) of 903 Pad.	52.2	15.4
06691	66-91/BH0391	Groundwater quality beneath 903 Pad. Source characterization 903 Pad.	28.0	22.0
06791	67-91/BH0591	Groundwater quality downgradient (south) of 903 Pad. Soil characterization adjacent to 903 Pad.	28.0	21.2
06891	68-91/BH0691	Groundwater quality downgradient (north) of 903 Pad.	20.0	14.0
06991	69-91/BH1191	Groundwater quality downgradient (east) of 903 Pad. Soil characterization adjacent to 903 Pad.	35.0	28.6
07091	70-91/BH1291	Groundwater quality downgradient (east) of 903 Pad. Soil Characterization adjacent to 903 Pad..	15.0	NE
07191	71-91/BH1391	Groundwater quality downgradient (south) of 903 Pad. Soil characterization adjacent to 903 Pad.	26.0	20.0
07291	72-91/BH1691	Groundwater quality downgradient (south) of 903 Pad and upgradient of Trench T-2 (north) to differentiate between sources.	26.0	20.0
07391	73-91/BH1991	Groundwater quality downgradient (south) of Trench T-2. Extent of soil contamination. Driver well for contingency well 7-91 and 55-91.	16.0	8.1
07491	74-91/BH2091	Source characterization Reactive Metal Destruction Site.	12.0	6.3
07591	75-91/BH2191	Groundwater quality downgradient (south) of Reactive Metal Destruction Site.	14.0	8.1
07691	76-91/BH2391	Groundwater quality downgradient of Reactive Metal Destruction Site. Extent of soil contamination.	8.0	1.4
07791	77-91/BH2591	Groundwater quality beneath Mound Site. Source characterization.	Not Drilled	NA
07891	78-91/BH3291	Groundwater quality beneath Trench T-11. Source characterization.	31.0	27.5
07991	79-91/BH3491	Groundwater quality beneath Trench T-9. Source characterization.	36.5	26.0
08091	80-91/BH3591	Groundwater quality beneath Trench T-5. Source characterization.	22.0	16.1
08191	81-91/BH3691	Groundwater quality beneath Trench T-5. source characterization.	44.0	37.5
08291	82-91/BH3891	Groundwater quality beneath Trench T-7. Source characterization.	20.0	14.0
08391	83-91/BH3991	Groundwater quality beneath Trench T-7. Source characterization.	44.0	37.2
08491	84-91/BH4091	Groundwater quality beneath Trench T-8. Source Characterization.	22.0	16.0
08591	85-91/BH4191	Groundwater quality beneath Trench T-8. Source Characterization.	48.0	40.7
08691	BH0291	Source characterization 903 Pad.	22.0	16.0
08791	BH0491	Source characterization 903 Pad.	28.0	20.9
08891	BH0791	Source characterization 903 Pad.	30.0	23.0

TABLE 2.1-3
BOREHOLE SUMMARY

Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)
08991	BH0891	Source characterization 903 Pad.	34.0	28.3
09091	BH0991	Source characterization 903 Pad.	30.0	24.0
09191	BH1091	Source characterization 903 Pad.	30.0	24.0
09291	BH1491	Source characterization Trench T-2.	56.0	1.6
09391	BH1591	Source characterization Trench T-2. Extent of soil contamination.	10.0	2.3
09491	BH1791	Source characterization Trench T-2. Extent of soil contaminant	10.0	3.4
09591	BH1891	Source characterization Trench T-2. Extent of soil contamination.	14.0	NE
09691	BH2291	Source characterization Reactive Metal Destruction	20.0	3.1
09791	BH2491	Extent of soil contamination.	22.4	13.2
09891	BH2691	Source characterization.	20.0	13.2
09991	BH2791	Extent of soil contamination Mound Site.	20.0	13.1
10091	BH2891	Investigation possible Pallet Burn Site location.	Not Drilled	NA
10191	BH2991	Source characterization.	54.0	14.5
10291	BH3091	Source characterization.	60.0	18.0
10391	BH3191	Source characterization.	62.0	19.5
10491	BH3391	Source characterization.	49.0	30.0
10591	BH3791	Source characterization.	18.0	12.0
10691	BH4291	Source characterization.	48.0	40.2
10791	BH4391	Groundwater quality beneath the East Spray Field. Source characterization.	50.0	46.0
10891	BH4491	Source characterization.	50.0	44.5
10991	BH4591	Source characterization.	56.0	45.2
12791	BH4691	Source characterization.	10.0	4.0

Notes :
1. NA - Not Applicable
2. For those sites listed as Not Drilled, see Table 2.1-5 for explanation.
3. If two site numbers are listed, the first is a plume characterization well and the second is a borehole.

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TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
00191	1-91	Volatile organic plume definition downgradient (east) of 903 Pad and Mound Areas.	34.0	24.2	15.0-25.0
00291	2-91	Volatile organic plume definition downgradient (east) of 903 Pad and Mound Areas.	58.0	16.0	44.0-54.0
00391	3-91	Volatile organic plume definition downgradient (southeast) of 903 Pad and Mound Areas. Extent of saturated colluvium.	26.9	16.9	16.8-21.8
00491	4-91	Volatile organic plume definition downgradient (southeast) of 903 Pad . Extent of saturated colluvium.	23.3	10.9	7.5-17.5
00591	5-91	Volatile organic plume definition downgradient (southeast) of 903 Pad. Extent of saturated colluvium. Driver well for contingency well 6-91.	12.9	4.6	NA
00691	6-91	Volatile organic plume definition downgradient (southeast) of 903 Pad. Extent of saturated colluvium. Contingency well based on driver wells 5-91 and 59-81.	18.5	NE	5.3-12.3
00791	7-91	Volatile organic plume definition downgradient (southeast) of 903 Pad. Extent of saturated colluvium. Contingency well based on driver wells 59-91 and 73-91.	24.5	17.6	8.5-18.5
00891	8-91	Volatile organic plume definition downgradient (south) of 903 Pad. Extent of saturated colluvium.	23.9	18.2	7.9-17.9
00991	9-91	Volatile organic plume definition downgradient (south) of 903 Pad Area. Groundwater/surface water interaction at South Interceptor Ditch (SID).	14.3	2.9	5.0-10.0
01091	10-91	Volatile organic plume definition downgradient (southeast) of the 903 Pad Area. Groundwater/surface water interaction at SID.	14.0	2.1	NA
01191	11-91	Volatile organic plume definition downgradient (southeast) of the 903 Pad Area.	13.4	9.2	NA
01291	12-91	Volatile organic plume definition downgradient (southeast) of the 903 Pad Area.	18.9	12.9	5.3-13.3
01391	13-91	Groundwater quality upgradient (west) of OU-2.	22.0	14.5	6.0-14.0
01491	14-91	Groundwater quality and extent of saturation adjacent (south) to possible Pallet Burn Site.	30.0	1.6	14.0-24.0

TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
01591	15-91	Groundwater water quality downgradient (north) of Pallet Burn Site.	Not Drilled	NA	NA
01691	16-91	Groundwater quality downgradient (south) of Oil Burn Pit Site.	Not Drilled	NA	NA
01791	17-91	Groundwater quality downgradient (south) of Mound Site.	24.0	8.0	10.0-18.0
01891	18-91	Groundwater quality upgradient of Trench T-1 and downgradient of the 903 Pad to differentiate between sources.	35.9	12.4	20.0-30.0
01991	19-91	Volatile organic plume definition downgradient (east) of 903 Pad and Mound Areas.	44.8	29.4	28.8-38.8
02091	20-91	Volatile organic plume definition downgradient (east) of Mound Area.	36.2	16.1	15.6-30.6
02191	21-91	Volatile organic plume definition downgradient (north) of Mound Area.	20.8	13.5	8.0-13.0
02291	22-91	Volatile organic plume definition downgradient (north) of Mound Area. Driver well for contingency well 25-91.	19.5	8.8	11.5-16.5
02391	23-91	Volatile organic plume definition downgradient (northeast) of Mound Area.	12.9	6.9	3.0-6.0
02491	24-91	Volatile organic plume definition downgradient (northeast) of Mound Area.	24.2	8.5	11.8-16.8
02591	25-91	Volatile organic plume definition downgradient (northeast) of Mound Area. Contingency well based on driver well 22-91.	51.1	39.8	42.1-49.1
02691	26-91	Volatile organic plume definition downgradient (northeast) of Mound Area.	18.3	1.1	6.0-16.0
02791	27-91	Volatile organic plume definition downgradient (north) of Trench T-3. Replacement for well 3-74.	15.9	8.0	6.5-9.5
02891	28-91	Groundwater quality downgradient (east) of Trench T-3 and upgradient (west) of Trench T-4 to differentiate between sources.	14.9	9.1	6.0-9.0
02991	29-91	Volatile organic plume definition downgradient (south) of Trench T-3	57.9	15.8	42.0-52.0
03091	30-91	Groundwater quality downgradient (south) of Trench T-4 and upgradient (north) of Trench T-11 to differentiate between sources.	56.7	17.3	35.0-50.0
03191	31-91	Groundwater quality downgradient (south of Trench T-4) and upgradient (north) of Trench T-10 to differentiate between sources.	27.4	21.1	11.2-21.2
03291	32-91	Volatile organic plume definition downgradient (east) of Trench T-10.	Not Drilled	NA	NA

TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
03391	33-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area. Driver well for contingency well 36-91.	46.0	10.8	29.9-39.9
03491	34-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area.	12.9	4.9	NA
03591	35-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area.	37.7	30.1	20.1-30.1
03691	36-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area. Contingency well based on driver wells 33-91 and 37-91.	46.0	7.5	30.0-40.0
03791	37-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area. Driver well for contingency well 36-91.	54.1	4.9	38.0-48.0
03891	38-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area.	9.0	7.4	4.0-7.0
03991	39-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area. Contingency well based on driver well 56-91.	43.0	37.0	27.4-37.4
04091	40-91	Volatile organic plume definition and extent of saturation downgradient (northeast) of East Trenches Area. Contingency well based on driver well 56-91.	42.0	36.0	28.0-36.0
04191	41-91	Groundwater quality upgradient (west) of southern East Trenches.	25.0	17.1	7.1-17.1
04291	42-91	Groundwater quality downgradient (south) of Trench T-9.	30.5	17.0	18.1-23.1
04391	43-91	Groundwater quality downgradient (east) of Trenches T-5, T-6, and T-7. Evaluate influence of East Spray Field Sites on groundwater flow and quality.	Not Drilled	NA	NA
04491	44-91	Volatile organic plume definition downgradient (southeast) of East Trenches Area.	33.0	27.0	17.0-27.0
04591	45-91	Volatile organic plume definition downgradient (southeast) of East Trenches Area. Driver well for contingency well 54-91.	50.9	44.2	34.1-44.1

TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
04691	46-91	Volatile organic plume definition downgradient (southeast) of East Trenches Area. Driver well for contingency wells 47-91 and 54-91.	50.1	43.9	33.9-43.9
04791	47-91	Volatile organic plume definition downgradient (southeast) of East Trenches Area. Contingency well based on driver well 46-91.	Not Drilled	NA	NA
04891	48-91	Evaluate influence of East Spray Field Sites on groundwater flow and quality. Driver well for contingency wells 54-91 and 57-91.	45.8	39.7	29.7-39.7
04991	49-91	Evaluate influence of East Spray Field Sites on groundwater flow and quality. Driver well for contingency well 57-91.	46.1	40.2	30.3-40.3
05091	50-91	Evaluate influence of East Spray Field Sites on groundwater flow and quality. Driver well for contingency well 58-91.	49.5	43.5	34.0-44.0
05191	51-91	Evaluate influence of East Spray Field Sites on groundwater flow and quality.	50.7	44.8	36.0-46.0
05291	52-91	Evaluate influence of East Spray Field Sites on groundwater flow and quality.	41.0	34.7	25.1-35.1
05391	53-91	Volatile organic plume definition and extent of saturation downgradient (north) of East Trenches Area.	48.0	34.7	25.1-35.1
05491	54-91	Groundwater quality southeast of East Trenches Area. Contingency well based on driver wells 45-91, 46-91, and 48-91.	Not Drilled	NA	NA
05591	55-91	Volatile organic plume definition downgradient (south) of 903 Pad Area. Contingency well based on driver well 73-91.	Not Drilled	NA	NA
05691	56-91	Groundwater quality downgradient (northeast) of Trench T-4. Driver well for contingency well 39-91.	42.6	35.2	25.1-35.1
05791	57-91	Groundwater quality downgradient (east) of East Trenches. Contingency well based on driver wells 48-91 and 49-91	Not Drilled	NA	NA
05891	58-91	Groundwater quality downgradient (eat) of East Trenches. Contingency well based on driver well 50-91.	Not Drilled	NA	NA
05991	59-91	Groundwater quality downgradient (southeast) of 903 Pad and Reactive Metal Destruction Site. Driver well for contingency wells 6-91 and 7-91.	31.0	22.1	12.1-22.1
06091	60-91	Groundwater quality downgradient (northeast) of East Trenches Area.	44.5	39.1	30.7-40.7

TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
06191	61-91	Groundwater quality downgradient (northeast) of East Trenches Area.	38.2	32.0	22.1-32.1
06291	62-91	Volatile organic plume definition and extent of saturation downgradient (northeast) of East Trenches Area.	34.9	23.3	27.9-32.9
06391	63-91	Volatile organic plume definition and extent of saturation downgradient (northeast) of East Trenches Area.	28.6	21.2	17.6-22.6
06491	64-91	Volatile organic plume definition and extent of saturation downgradient (northeast) of East Trenches Area.	19.1	2.2	10.9-15.9
06591	65-91/BH0191	Characterization upgradient (west) of 903 Pad.	52.2	15.4	33.0 - 48.0
06691	66-91/BH0391	Groundwater quality beneath 903 Pad. Source characterization 903 Pad.	28.0	22.0	13.1 - 23.1
06791	67-91/BH0591	Groundwater quality downgradient (south) of 903 Pad. Soil characterization adjacent to 903 Pad.	28.0	21.2	11.2 - 21.2
06891	68-91/BH0691	Groundwater quality downgradient (north) of 903 Pad.	20.0	14.0	6.0 - 14.0
06991	69-91/BH1191	Groundwater quality downgradient (east) of 903 Pad. Soil characterization adjacent to 903 Pad.	35.0	28.6	14.0 - 29.0
07191	71-91/BH1391	Groundwater quality downgradient (south) of 903 Pad. Soil characterization adjacent to 903 Pad.	26.0	20.0	11.1 - 21.1
07291	72-91/BH1691	Groundwater quality downgradient (south) of 903 Pad and upgradient of Trench T-2 (north) to differentiate between sources.	26.0	20.0	10.6 - 20.6
07391	73-91/BH1991	Groundwater quality downgradient (south) of Trench T-2. Extent of soil contamination. Driver well for contingency well 7-91 and 55-91.	16.0	8.1	5.4 - 11.4
07891	78-91/BH3291	Groundwater quality beneath Trench T-11. Source characterization.	31.0	27.5	18.0 - 28.0
07991	79-91/BH3491	Groundwater quality beneath Trench T-9. Source characterization.	36.5	26.0	16.1 - 26.1
08091	80-91/BH3591	Groundwater quality beneath Trench T-5. Source characterization.	22.0	16.1	11.3 - 16.3
08291	82-91/BH3891	Groundwater quality beneath Trench T-7. Source characterization.	20.0	14.0	6.0 - 14.0
08391	83-91/BH3991	Groundwater quality beneath Trench T-7. Source characterization.	44.0	37.2	28.0 - 38.0
08491	84-91/BH4091	Groundwater quality beneath Trench T-8. Source Characterization.	22.0	16.0	6.0 - 16.0
08591	85-91/BH4191	Groundwater quality beneath Trench T-8. Source Characterization.	48.0	40.7	32.0 - 42.0

TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
08891	BH0791	Source characterization 903 Pad.	30.0	23.0	15.3 - 25.3
09091	BH0991	Source characterization 903 Pad.	30.0	24.0	14.7 - 24.7
09691	BH2291	Source characterization Reactive Metal Destruction Site.	20.0	3.1	6.0 - 14.0
10991	BH4591	Source characterization.	56.0	45.2	46.0 - 51.0
11291	NA	Alluvial offset to well 06091, due to saturated thickness greater than 10 feet at time of drilling in well 06091.	33.0	NE	21.0 - 31.0
11491	NA	Alluvial offset to well 05691, due to saturated thickness greater than 10 feet at time of drilling in well 05691.	27.3	NE	10.3 - 25.3
11691	NA	Bedrock offset to well 03791, due to saturated thickness greater than 10 feet at time of drilling well 03791.	35.5	9.5	18.5 - 33.5
11791	NA	Bedrock offset to well 00391, due to saturated thickness greater than 10 feet at time of drilling in well 00391.	15.7	6.9	8.7 - 13.7
11891	NA	Bedrock offset well to well 03391, due to saturated thickness greater than 10 feet at time of drilling well 03391.	30.0	12.0	13.0 - 28.0
12091	NA	Bedrock offset well to well 01891, due to saturated thickness greater than 10 feet at time of drilling in well 01891.	26.0	13.2	14.0 - 24.0
12191	NA	Bedrock offset well to well 02191, due to saturated thickness greater than 10 feet at time of drilling in well 02191.	35.0	15.7	18.0 - 33.0
12291	NA	Bedrock offset well to well 01491, due to saturated thickness greater than 10 feet at the time of drilling in well 01491.	16.1	2.0	7.1 - 14.1
12391	NA	Bedrock offset well to well 05391 to characterize the No. 1 Sandstone.	70.4	36.5	58.4 - 68.4
12491	NA	Bedrock offset well to well 05691 to characterize the No. 1 Sandstone.	62.0	30.0	45.0 - 60.0
12691	NA	To characterize No. 1 Sandstone.	65.1	20.0	48.1 - 63.1
12891	NA	Replacement well for abandon location 08191.	37.5	37.0	25.5 - 35.5
12991	NA	Bedrock offset well to well 00291, due to saturated thickness greater than 10 feet at the time of drilling in well 00291.	36.5	16.1	19.5 - 34.5
13091	NA	Replacement well for abandon location 07091.	23.3	19.5	11.3 - 21.3
13191	NA	Bedrock offset well to well 06591, due to saturated thickness greater than 20 feet in well 06591 at the time of drilling.	27.7	NA	15.7 - 25.7
13291	NA	Alluvial offset well to well 06591, due to saturated thickness greater than 20 feet in well 06591 at the time of drilling.	17.7	NA	5.7 - 15.7

TABLE 2.1-4
MONITORING WELL SUMMARY

New Site Number	Work Plan Site Number	Purpose	Total Depth (ft BGS)	Depth to Bedrock (ft BGS)	Screened Interval (ft BGS)
13391	NA	Alluvial offset well to well 02591, due to saturated thickness greater than 10 feet in well 02591 at the time of drilling.	41.0	38.6	29.0 - 39.0
13491	NA	Alluvial offset well to well 01991, due to saturated thickness greater than 10 feet in well 01991 at the time of drilling.	31.0	29.4	19.0 - 29.0
13591	NA	Alluvial offset well to well 00291, due to saturated thickness was greater than 10 feet in well 00291 at the time of drilling.	18.0	16.0	6.0 - 16.0
20191	NA	Pump test observation well	76.0	NA	37 - 57
20291	NA	Pump test observation well	35.6	33.1	18 - 53
20491	NA	Pump test observation well	32.6	NA	16.6 - 31.6
20591	NA	Pump test observation well	24.6	NA	4.1 - 24.1
20691	NA	Pump test observation well	25.8	NA	4.5 - 24.5
20791	NA	Pump test observation well	37.9	24.5	29.5 - 34.5
20891	NA	Pump test observation well	64.0	NA	21.7 - 63.7
20991	NA	Pump test observation well	70.0	19.4	21 - 63
21091	NA	Pump test observation well	68.0	15.0	19 - 63
21191	NA	Pump test observation well	58.0	NA	35.8 - 57.8

Notes : NA - Not Applicable
NE - Not Encountered
BGS - Below Ground Surface

1. For those sites listed as Not Drilled, see Table 2.1-5 for explanation.

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TABLE 2.1-5
SITE STATUS SUMMARY

New Site Number	Work Plan Site Number	Site Type	OU-2 Area	Site Status/Comments
SITES NOT DRILLED				
01591	15-91	MW	Mound	Not drilled because site was in Protected Area (PA)
01691	16-91	MW	Mound	Not drilled because site was in PA
03291	32-91	MW	NE Trenche	Not drilled due to underground power lines
04391	43-91	MW	SE Trenches	Test well site that was not drilled
04791	47-91	MW	SE Trenches	Contingency well
05491	54-91	MW	SE Trenches	Contingency well
05591	55-91	MW	903 Pad	Contingency well
05791	57-91	MW	SE Trenches	Contingency well
05891	58-91	MW	SE Trenches	Contingency well
07791	7-91/BH259	BH/MW	Mound	Not drilled because site was inside PA fence
10091	BH2891	BH	Mound	Not drilled because site was inside PA fence
SITES ABANDONED				
00591	5-91	MW	903 Pad	Abandoned due to thin alluvial section*
01091	10-91	MW	903 Pad	Abandoned due to thin alluvial section*
01191	11-91	MW	903 Pad	Abandoned due to thin alluvial section*
03491	34-91	MW	NE Trenche	Abandoned due to thin alluvial section*
07091	0-91/BH129	BH/MW	903 Pad	Abandoned due to refusal
07491	4-91/BH209	BH/MW	903 Pad	Abandoned due to thin alluvial section*
07591	5-91/BH219	BH/MW	903 Pad	Abandoned due to thin alluvial section*
07691	6-91/BH239	BH/MW	903 Pad	Abandoned due to thin alluvial section*
08191	1-91/BH369	BH/MW	SE Trenches	Abandoned because augers were lost downhole
11091	NA	MW	NE Trenche	Abandoned due to thin alluvial section*
11191	NA	MW	SE Trenches	Abandoned due to contaminated augers
11391	NA	MW	NE Trenche	Abandoned because of water influx
11591	NA	MW	NE Trenche	Abandoned because augers were lost downhole
12591	NA	MW	NE Trenche	Abandoned because sandstone was not encountered
11991	NA	MW	NE Trenche	Abandoned due to thin alluvial section
20091	NA	PW	NE Trenche	Abandoned due to collapsed well casing
20391	NA	OB	NE Trenche	Abandoned due to flowing sands and water influx
SITES MOVED				
02591	25-91	MW	NE Trenche	Contingency well and was moved to avoid underground utilities
03691	36-91	MW	NE Trenche	Contingency well was moved to avoid underground activities
03991	39-91	MW	NE Trenche	Moved to optimize chance of encountering sandstone
04091	40-91	MW	NE Trenche	Moved to optimize chance of encountering sandstone

TABLE 2.1-5
SITE STATUS SUMMARY

New Site Number	Work Plan Site Number	Site Type	OU-2 Area	Site Status/Comments
ADDITIONAL SITES				
11091	NA	BH	NE Trenche	Pair to Bedrock Well 06491 - Abandoned
11191	NA	BH	NE Trenche	Pair to Alluvial Well 04991 - Abandoned
11291	NA	MW	NE Trenche	Pair to Alluvial Well 06091 - Alluvial Well required because of saturated thickness
11391	NA	BH	NE Trenche	Pair to Alluvial Well 05391 - Abandoned
11491	NA	MW	NE Trenche	Pair to Alluvial Well 05691and Bedrock Well 12491 - Alluvial Well required because of saturated thickness
11591	NA	BH	NE Trenche	Pair to Bedrock Well 03791 - Abandoned
11691	NA	MW	NE Trenche	Pair to Bedrock Well 03791 - Bedrock Well replacement for 11591.
11791	NA	MW	903 Pad	Pair to Bedrock Well 00391 - Bedrock Well
11891	NA	MW	NE Trenche	Pair to Bedrock Well 03391 - Bedrock Well required because of saturated thickness
11991	NA	BH	NE Trenche	Pair to Alluvial Well 03891 - Abandoned
12091	NA	MW	Mound	Pair to Bedrock Well 01891 - Bedrock Well required because of saturated thickness
12191	NA	MW	NE Trenche	Pair to Bedrock Well 02991 - Bedrock Well required because of saturated thickness
12291	NA	MW	Mound	Pair to Bedrock Well 01491 - Bedrock Well required because of saturated thickness
12391	NA	MW	NE Trenche	Pair to Alluvial Well 05391 - Bedrock Well
12491	NA	MW	NE Trenche	Pair to Alluvial Wells 05691 and 11491 - Bedrock Well
12591	NA	BH	NE Trenches	Sandstone offset; abandoned because sandstone was not encountered in the offset hole
12691	NA	MW	NE Trenche	Pair to Alluvial Well 03191 - Bedrock Well
12791	BH4691	BH	903 Pad	Site BH4691 in original work plan
12891	NA	MW	SE Trenches	Replacement for 08191
12991	NA	MW	903 Pad	Pair to Bedrock Well 00291 and Alluvial Well 13591 - Bedrock Well required because of saturated thickness
13091	NA	MW	903 Pad	Replacement for 07091
13191	NA	MW	903 Pad	Pair to Bedrock Well 06591 and Alluvial Well 13291 - Bedrock Well required because of saturated thickness
13291	NA	MW	903 Pad	Pair to Bedrock Wells 06591 and 13191 - Alluvial Well required because 06591 and 13191 were installed as bedrock wells
13391	NA	MW	NE Trenche	Pair to Bedrock Well 02591 - Alluvial Well required because 02591 was installed as a bedrock well
13491	NA	MW	NE Trenche	Pair to Bedrock Well 01991 - Alluvial Well required because 01991 was installed as a bedrock well

TABLE 2.1-5
SITE STATUS SUMMARY

New Site Number	Work Plan Site Number	Site Type	OU-2 Area	Site Status/Comments
13591	NA	MW	903 Pad	Pair to Bedrock Wells 00291 and 12991 - Alluvial Well required because 00291 and 12991 were installed as bedrock wells

Notes : BH - Borehole
MW - Monitoring Well
OB - Observation Well
PW - Pump Test Well
NA - Not Applicable
OU-2 - Operable Unit No. 2
PA - Protected Area

1. Sites that do not have a Work Plan site number are additional sites that were added to the OU-2 Program in the field.

* Alluvium/colluvium thickness was less than 5 feet.

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TABLE 2.1-6
OU-2 ALLUVIAL SOURCE CHARACTERIZATION
BOREHOLE ANALYTICAL PARAMETERS

TOTAL METALS
Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc

OTHER
pH
Sulfide
Nitrate-Nitrite (as N)
Percent Solids
Cyanide
Moisture Content
Orthophosphate
Bromide
Ammonium
Silica (as Si and SiO2)
Total Petroleum Hydrocarbons

OTHER METALS
Molybdenum
Strontium
Cesium
Lithium
Tin

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

VOLATILE ORGANIC COMPOUNDS
Chloromethane
Bromomethane
Vinyl Chloride
Chloroethane
Methylbenzene Chloride
Acetone
Carbon Disulfide
1,1-Dichloroethene
1,1-Dichloroethane
Total 1,2-Dichloroethene
Chloroform
1,2-Dichloroethane
2-Butanone
1,1,1-Trichloroethane
Carbon Tetrachloride
Vinyl Acetate
Bromodichloromethane
1,1,2,2-Tetrachhlorethane
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

PESTICIDES/PCBs
alpha-BHC
beta-BHC
delta-BHC
gamma-BHC (Lindane)
Heptachlor
Aldrin
Heptchlor 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

INDICATORS
Dissolved Organic Carbon
Total Organic Carbon

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TABLE 2.1-6
OU-2 ALLUVIAL SOURCE CHARACTERIZATION
BOREHOLE ANALYTICAL PARAMETERS

SEMI-VOLATILES		
Phenol	Acenaphthene	
bis(2-Chloroethyl)ether	2,4-Dinitrophenol	
2-Chlorophenol	4-Nitrophenol	
1,3-Dichlorobenzene	Dibenzofuran	
1,4-Dichlorobenzene	2,4-Dinitrotoluene	
Benzyl Alcohol	2,6-Dinitrotoluene	
1,2-Dichlorobenzene	Diethylphthalate	
2-Methylphenol	4-Chlorophenyl Phenyl Ether	
bis(2-Chloroisopropyl)ether	Fluorene	
4-Methylphenol	4-Nitroaniline	
N-Nitroso-Dipropylamine	4.6-Dinitro-2-methylphenol	
Hexachloroethane	N-nitrosodiphenylamine	
Nitrobenzene	4-Bromophenyl Phenyl Ether	
Isophorone	Hexachlorobenzene	
2-Nitrophenol	Pentachlorophenol	
2,4-Dimethylphenol	Phenanthrene	
Benzoic Acid	Anthracene	
bis(2-Chloroethoxy)methane	Di-n-butylphthalate	
2,4-Dichlorophenol	Fluoranthene	
1,2,4-Trichlorobenzene	Pyrene	
Napthalene	Butyl Benzylphthalate	
4-Chloroaniline	3,3'-Dichlorobenzidine	
Hexachlorobutadiene	Benzo(a)anthracene	
4-Chloro-3-methylphenol (para-chloro-meta-cresol)	bis(2-ethylhexyl)phthalate	
2-Methylnapthalene	Chrysene	
Hexachlorocylopentadiene	Di-n-octyl Phthalate	
2,4,6-Trichlorophenol	Benzo(b)fluoranthene	
2,4,5-Trichlorophenol	Benzo(k)fluoranthene	
2-Chloronaphthalene	Benzo(a)pyrene	
Dimethylphthalate	Indeno(1,2,3-cd)pyrene	
Acenaphthlene	Dibenz(a,h)anthracene	
3-Nitroaniline	Benzo(g,h,i)perylene	

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TABLE 2.1-7
OU-2 ANALYTICAL METHODS, SAMPLE CONTAINERS, SAMPLE PRESERVATION, AND SAMPLE HOLDING TIMES

Parameter	EPA Analytical Method	Container	Preservative	Holding Time
Bedrock Samples				
Organic Compounds:				
Volatile Organics	EPA-CLP(1)	1 x 4 oz wide mouth Teflon-lined glass vials	Cool, 4 deg C	14 days
Inorganic Analytes:				
Target Analyte List				
Metals and Other Metals	EPA-CLP(2)	1 x 8-oz wide-mouth glass jar	Cool, 4 deg C	180 days(c)
Cyanide	335.2 or 335.3(3)	1 x 8-oz wide-mouth glass jar	Cool, 4 deg C	14 days
pH	9045(4)	1 x 8-oz wide-mouth glass jar	Cool, 4 deg C	14 days
Moisture Content	A001(5)	1 x 8-oz wide-mouth glass jar	Cool, 4 deg C	14 days
Radionuclides	GRRASP(6)	1 x 8-oz wide-mouth glass jar	Cool, 4 deg C	45 days
Water Samples				
Organic Compounds:				
Volatile Organics	524.2(7)	2 x 40-mL VOA vials with Teflon-lined septum caps	Cool, 4 deg C(a) with HCl to pH <2	7 days 14 days
Inorganic Analytes:				
Target Analyte List				
Metals and Other Metals	EPA-CLP(2)	1 x 1-L polyethylene bottle	Nitric acid pH <2; Cool, 4 deg C	180 days(c)
Cyanide	335.2 or 335.3(3)	1 x 1-L polyethylene bottle	Sodium hydroxide(d) pH >12; Cool, 4 deg C	14 days
Anions		1 x 1-L polyethylene bottle	Cool, 4 deg C	14 days
Chloride	325.2(3)			
Sulfate	375.4(3)			
Carbonate	310.1(3)			
Bicarbonate	310.1(3)			

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TABLE 2.1-7
OU-2 ANALYTICAL METHODS, SAMPLE CONTAINERS, SAMPLE PRESERVATION, AND SAMPLE HOLDING TIMES

Parameter	EPA Analytical Method	Container	Preservative	Holding Time
pH	150.1(3)	1 x 1-L polyethylene bottle	Cool, 4 deg C	28 days
Specific Conductance	120.1(3)	1 x 1-L polyethylene bottle	Cool, 4 deg C	28 days
Total Dissolved Solids (TDS)	160.1(3)	1 x 1-L polyethylene bottle	Cool, 4 deg C	48 hours
Total Organic Carbon (TOC)	415.1(3)	1 x 125-ml amber glass bottle	Cool, 4 deg C	28 days
Radionuclides	GRRASP(6)	12 x 1-L polyethylene bottle	Nitric acid pH <2	180 days

NOTES:

(a) Add 0.008 percent sodium thiosulfate (NA(2),S(2),O(3) in the presence of residual chlorine.

(b) Container requirement is for any or all of the parameters given.

(c) Holding time for mercury is 28 days.

(d) Use ascorbic acid only if the sample contains residual chlorine. Test a drop of sample with potassium iodine-starch test paper, a blue color indicates need for treatment. Add ascorbic acid, a few crystals at a time until a drop of sample produces no color on the indicator paper. Then add an additional 0.6g of ascorbic acid for each liter of sample volume.

REFERENCES:

(1) EPA-CLP for Organics U.S. EPA Contract Laboratory Program Statement of Work for Organic Analysis, Multi-Media, Multi-Concentration, 2/88 or latest version.

(2) EPA-CLP for Inorganics - U.S. EPA Contract Laboratory Program Statement of Work for Inorganic Analysis, Multi-Media, Multi-Concentration, 7/88 or latest version.

(3) Methods for Chemical Analysis of Water and Wastes EPA-600/4-79-020, Revised March 1983.

(4) Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (SW-846, Third Edition).

(5) Sampling and Analysis Methods for Hazardous Waste Combustion. EPA-600/8-84-002, August, 1984.

(6) GRRASP - General Radiochemistry and Routine Analytical Services Protocol. ER Program, Rocky Flats Plant, Golden CO - August, 1990.

(7) Methods for the Determination of Organic Compounds in Drinking Water. EPA/600/4-88/039. December 1988.

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TABLE 2.1-8
OU-2 ALLUVIAL MONITORING WELLS
GROUNDWATER ANALYTICAL PARAMETERS

DISSOLVED METALS	OTHER METALS	FIELD PARAMETERS
Aluminium	Molybdenum	pH
Antimony	Strontium	Specific Conductance
Arsenic	Cesium	Temperature
Barium	Lithium	Dissolved Oxygen
Beryllium	Tin	
Cadmium		**PESTICIDES/PCBs**
Calcium	**INDICATORS**	alpha-BHC
Chromium	Total Dissolved Solids	beta-BHC
Cobalt	Total Organic Carbon	delta-BHC
Copper	Dissolved Organic Carbon	gamma-BHC (Lindane)
Iron	pH	Heptachlor
Lead		Aldrin
Magnesium	**OTHER PARAMETERS**	Heptachlor Epoxide
Manganese	Total Petroleum Hydrocarbons	Endosulfan I
Mercury		Dieldrin
Nickel	**DISSOLVED RADIONUCLIDES**	4,4'-DDE
Potassium	Gross Alpha	Endrin
Selenium	Gross Beta	Endosulfan II
Silver	Uranium-233 & 234, 235, and 238	4,4'-DDD
Sodium	Tritium	Endosulfan Sulfate
Thallium	Strontium-89, 90	4,4'-DDT
Vanadium	Cesium 137	Endrin Ketone
Zinc	Rdium 226, 228	Methoxychlor
	Tritium	alpha-Chlordane
ANIONS		gamma-Chlordane
Carbonate	**TOTAL RADIONUCLIDES**	Toxaphene
Bicarbonate	Plutonium-239 & 240	AROCLOR-1016
Chloride	Americium-241	AROCLOR-1221
Sulfate	Tritium	AROCLOR-1232
Nitrate as N		AROCLOR-1242
Cyanide		AROCLOR-1248
Fluoride		AROCLOR-1254
Bromide		AROCLOR-1260
Silica (as Si and SiO2)		
Ammonium		
Orthophosphate		

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TABLE 2.1-8
OU-2 ALLUVIAL MONITORING WELLS
GROUNDWATER ANALYTICAL PARAMETERS

VOLATILE ORGANIC COMPOUNDS	SEMI-VOLATILES	
Chloromethane	Phenol	Acenaphthene
Bromomethane	bis(2-Chloroethyl)ether	2,4-Dinitrophenol
Vinyl Chloride	2-Chlorophenol	4-Nitrophenol
Chloroethane	1,3-Dichlorobenzene	Dibenzofuran
Methylbenzene Chloride	1,4-Dichlorobenzene	2,4-Dinitrotoluene
Acetone	Benzyl Alcohol	2,6-Dinitrotoluene
Carbon Disulfide	1,2-Dichlorobenzene	Diethylphthalate
1,1-Dichloroethene	2-Methylphenol	4-Chlorophenyl Phenyl Ether
1,1-Dichloroethane	bis(2-Chloroisopropyl)ether	Fluorene
Total 1,2-Dichloroethene	4-Methylphenol	4-Nitroaniline
Chloroform	N-Nitroso-Dipropylamine	4,6-Dinitro-2-methylphenol
1,2-Dichloroethane	Hexachloroethane	N-nitrosodiphenylamine
2-Butanone	Nitrobenzene	4-Bromophenyl Phenyl Ether
1,1,1-Trichloroethane	Isophorone	Hexachlorobenzene
Carbon Tetrachloride	2-Nitrophenol	Pentachlorophenol
Vinyl Acetate	2,4-Dimethylphenol	Phenanthrene
Bromodichloromethane	Benzoic Acid	Anthracene
1,1,2,2-Tetrachhlorethane	bis(2-Chloroethoxy)methane	Di-n-butylphthalate
1,2-Dichloropropane	2,4-Dichlorophenol	Fluoranthene
Trans-1,3-Dichloropropene	1,2,4-Trichlorobenzene	Pyrene
Trichloroethene	Napthalene	Butyl Benzylphthalate
Dibromochloromethane	4-Chloroaniline	3,3'-Dichlorobenzidine
1,1,2-Trichloroethane	Hexachlorobutadiene	Benzo(a)anthracene
Benzene	4-Chloro-3-methylphenol	bis(2-ethylhexyl)phthalate
cis-1,3-Dichloropropene	2-Methylnapthalene	Chrysene
Bromoform	Hexachlorocylopentadiene	Di-n-octyl Phthalate
2-Hexanone	2,4,6-Trichlorophenol	Benzo(b)fluoranthene
4-Methyl-2-pentanone	2,4,5-Trichlorophenol	Benzo(k)fluoranthene
Tetrachloroethene	2-Chloronaphthalene	Benzo(a)pyrene
Toluene	Dimethylphthalate	Indeno(1,2,3-cd)pyrene
Chlorobenzene	Acenaphthlene	Dibenz(a,h)anthracene
Ethyl Benzene	3-Nitroaniline	Benzo(g,h,i)perylene
Styrene		
Total Xylenes		

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TABLE 2.1-9
OU-2 ALLUVIAL GEOTECHICAL TESTING SPECIFICATIONS

Test	Specification
Moisture content	ASTM D-2937
Dry density	ASTM D-2937
Gradation	ASTM D-422-63
Permeability	ASTM D-5084-90
Liquid limit	ASTM-D-4318
Plastic limit	ASTM-D-4318
Plastic index	ASTM-D-4318

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TABLE 2.2-1
SUMMARY OF STANDARD OPERATING PROCEDURES USED IN THE OU-2 REVISED BEDROCK WORK PLAN FIELD INVESTIGATION PROGRAM

SOP NUMBER	TITLE
FO.1	Air Monitoring and Dust Control
FO.2	Field Document Control
F0.3	General Equipment Decontamination
F0.4	Heavy Equipment Decontamination
F0.8	Handling of Drilling Fluids and Cuttings
F0.10	Receiving, Labeling, and Handling Environmental Material Containers
F0.13	Containerization, Preserving, Handling, and Shipping of Soil and Water Sampled
F0.14	Field Data Management
F0.15	Photoionization Detectors (PIDs) and Flame Ionization Detectors (FIDs)
F0.16	Field Radiological Measurement
FO.18	Environmental Sample Radioactivity Content Screening
GT.1	Logging Alluvial and Bedrock Material
GT.2	Drilling and Sampling Using Hollow-Stem Auger Techniques*
GT.3	Isolating Bedrock from Alluvium with Grouted Surface Casing*
GT.4	Rotary Drilling and Rock Coring
GT.5	Plugging and Abandonment of Boreholes
GT.6	Monitoring Wells and Piezometers Installation*
GT.10	Borehole Clearing
GT.11	Plugging and Abandonment of Wells
GT.15	Geophysical Borehole Logging
GW.02	Well Development
GW.04	Slug Testing
GW.06	Well Sampling

* Modified for Revised Bedrock Work Plan field activities. Modifications were documented with a DCN.

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TABLE 2.2-2
OU-2 REVISED BEDROCK WORK PLAN
OBJECTIVES AND COMPLETED WORK

New Site Number	Work Plan Site Number	OU-2 Area	Rationale	Objective/Information
21193 21993 23193 22593	WC-1BH WC-1(1) WC-1a WC-1b	NE Trenches	Located in UHSU hotspot area with potential for hydraulic communication between UHSU and LHSU.	Investigate presence or absence of contamination in uppermost substantial LHSU sandstone unit and next deeper sandstone unit. Evaluate permeability of LHSU sandstones.
21293 22093	WC-2BH WC-2a	903 Pad	Located at apparent upgradient location from existing LHSU well (1187) screened near sandstone subcrop beneath colluvium.	Investigate source of contamination at existing well. Evaluate permeability of LHSU sandstones.
21393 22193	WC-3BH WC-3a	903 Pad	Located at apparent upgradient location from existing LHSU (00391) well screened near sandstone subcrop beneath colluvium	Investigate source of contamination at existing well. Evaluate permeability of LHSU sandstones.
21493 22293	WC-4BH WC-4a	903 Pad	Located at apparent upgradient location from existing LHSU well (1487) screened near sandstone subcrop beneath colluvium.	Investigate source of contamination at existing well. Evaluate permeability of LHSU sandstones.
21593 22393	WC-5BH WC-5a	903 Pad	Located near existing LHSU well (2087) where contamination detected in LHSU below central portion of OU-2 plateau.	Confirm presence of contamination in LHSU. Evaluate type of LHSU material in screened interval of existing well. Evaluate permeability of LHSU sandstones.
21693 22493 23292	WC-6BH WC-6(1) WC-6a	NE Trenches	Located in UHSU hotspot area with potential for hydraulic communication between UHSU and LHSU.	Investigate presence or absence of contamination in uppermost substantial LHSU sandstone unit. Evaluate permeability of LHSU sandstones.
21793	SB-1	Mound	Located adjacent to previous boring (09991) where contamination detected in LHSU claystone samples.	Investigate vertical extent of contamination in LHSU claystone.
21893	SB-2	903 Pad	Located adjacent to previous boring (BH2587) where contamination detected in LHSU claystone samples.	Investigate vertical extent of contamination in LHSU claystone.

1. 21993 and 22493 were started as a-series monitoring well boreholes, but were abandoned due to problems encountered during drilling. 23193 replaced 21993, and 23293 replaced 22493.

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TABLE 2.2-3
COMPARISON OF PROPOSED AND ACTUAL DEPTHS FOR BORINGS AND MONITORING WELLS

Work Plan Site Number	New Site Number	Total Depth		Isolation Casing Depth		Screened Interval	
		Proposed	Actual	Proposed	Actual	Proposed	Actual
WC-1BH	21193	160	160.2	65	67.6	NA	NA
WC-1a	23193	77	77	65	65	66-72	66.8-73.8
WC-1b	22593	115	99.5	65,75	65,80	100-110	85-95
WC-2BH	21293	140	148.8	17	26.4	NA	NA
WC-2a	22093	52	64.3	17	24.1	37-47	48-63
WC-2b	NI	115	----	17,50	----	100-110	----
WC-3BH	21393	200	209.8	50	45	NA	NA
WC-3a	22193	70	59.7	50	44	55-65	49.6-56.4
WC-3b	NI	115	----	50,68	----	85-95	----
WC-4BH	21493	130	130.4	18	43	NA	NA
WC-4a	22293	70	84.5	18	51	55-65	67-82
WC-4b	NI	100	----	18,68	----	75-85	----
WC-5BH	21593	175	175	18	24.3	NA	NA
WC-5a	22393	130	121	18	58.2	110-120	108.2-118
WC-5b	NI	145	----	18,130	----	130-140	----
WC-6BH	21693	150	163	53	47	NA	NA
WC-6a	23293	70	89.5	53	45	55-65	77.8-87.7
WC-6b	NI	117	----	53,68	----	102-112	----
SB-1	21793	50	50.1	16	16	NA	NA
SB-2	21893	50	50	18	18.6	NA	NA

NA = Not Applicable
NI = Not installed

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TABLE 2.2-4
LHSU SOURCE CHARACTERIZATION
BOREHOLE ANALYTICAL PARAMETERS

TARGET ANALYTE LIST

METALS

Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc

OTHER METALS

Cesium
Lithium
Molybdenum
Strontium
Tin

GENERAL PARAMETERS

Cyanide
Moisture Content
pH

RADIONUCLIDES

Americium 241
Gross Alpha
Gross Beta
Plutonium 239+240
Tritium
Uranium 233+234, 235 and 238

VOLATILE ORGANIC COMPOUNDS

1,1,1-Trichloroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane
1,1-Dichloroethane
1,1-Dichloroethene
1,2-Dichloroethane
1.,2-Dichloropropane
2-Butanone
2-Hexanone
4-Methyl-2-pentanone
Acetone
Benzene
Bromodichloromethane
Bromoform
Bromomethane
Carbon Disulfide
Carbon tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
cis-1,3-Dichloropropene
Dibromochloromethane
Ethyl Benzene
Methylene Chloride
Styrene
Tetrachloroethene
Toluene
total 1,2-Dichloroethene
Total Xylenes
trans-1,3-Dichloropropene
Trichloroethene
Vinyl Acetate
Vinyl Chloride

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TABLE 2.2-5
ANALYSIS METHODS, SAMPLE CONTAINERS, SAMPLE PRESERVATION, AND SAMPLE HOLDING TIMES FOR LHSU ANALYTICAL PARAMETERS FOR THE REVISED BEDROCK WORK PLAN

Parameter	EPA Analytical Method	Container	Preservative	Holding Time
Bedrock Samples				
Organic Compounds:				
Volatile Organics	EPA-CLP	1 x 4 oz wide mouth Teflon-lined glass vials	Cool, 4°C	14 days
Inorganic Analytes:				
Metals and Other Metals	EPA-CLP	1 x 8-oz wide-mouth glass jar	Cool, 4°C	180 days(c)
Cyanide	335.2 or 335.3	1 x 8-oz wide-mouth glass jar	Cool, 4°C	14 days
pH	9045	1 x 8-oz wide-mouth glass jar	Cool, 4°C	14 days
Moisture Content	A001	1 x 8-oz wide-mouth glass jar	Cool, 4°C	14 days
Radionuclides	GRRASP	1 x 8-oz wide-mouth glass jar	Cool, 4°C	45 days
Water Samples				
Organic Compounds:				
Volatile Organics	524.2	2 x 40-mL VOA vials with Teflon-lined septum caps	Cool, 4°C(a) with HCl to pH <2	7 days 14 days
Inorganic Analytes:				
Metals and Other Metals	EPA-CLP	1 x 1-L polyethylene bottle	Nitric acid pH <2; Cool, 4°C	180 days(c)
Cyanide	335.2 or 335.3	1 x 1-L polyethylene bottle	Sodium hydroxide(d) pH >12; Cool, 4°C	14 days
Anions		1 x 1-L polyethylene bottle	Cool, 4°C	14 days
Chloride	325.2			
Sulfate	375.4			
Carbonate	310.1			
Bicarbonate	310.1			
Cations	EPA-CLP	1 x 1-L polyethylene bottle	Cool, 4°C	180 days

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TABLE 2.2-5
ANALYSIS METHODS, SAMPLE CONTAINERS, SAMPLE PRESERVATION, AND SAMPLE HOLDING TIMES FOR LHSU ANALYTICAL PARAMETERS FOR THE REVISED BEDROCK WORK PLAN

Parameter	EPA Analytical Method	Container	Preservative	Holding Time
pH	150.1	1 x 1-L polyethylene bottle	Cool, 4°C	28 days
Specific Conductance	120.1	1 x 1-L polyethylene bottle	Cool, 4°C	28 days
Total Dissolved Solids (TDS)	160.1	1 x 1-L polyethylene bottle	Cool, 4°C	48 hours
Total Organic Carbon (TOC)	415.1	1 x 125-ml amber glass bottle	Cool, 4°C	28 days
Radionuclides	GRRASP	12 x 1-L polyethylene bottle	Nitric acid pH <2	180 days

NOTES:

(a) Add 0.008 percent sodium thiosulfate (NA(2),S(2),O(3) in the presence of residual chlorine.

(b) Container requirement is for any or all of the parameters given.

(c) Holding time for mercury is 28 days.

(d) Use ascorbic acid only if the sample contains residual chlorine. Test a drop of sample with potassium iodine-starch test paper, a blue color indicates need for treatment. Add ascorbic acid, a few crystals at a time until a drop o sample produces no color on the indicator paper. Then add an additional 0.6g of ascorbic acid for each liter of sample volume.

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TABLE 2.2-6
LHSU GROUNDWATER ANALYTICAL PARAMETERS

INDICATOR PARAMETERS

Vinyl Chloride
1,1-Dichloroethene
total 1,2-Dichloroethene
1,1,1-Trichloroethane
Carbon Tetrachloride
Trichloroethene
Tetrachloroethene

LHSU ANALYTE SUITE

TARGET ANALYTE LIST

METALS (Total and Dissolved)

Aluminum
Antimony
Arsenic
Barium
Beryllium
Cadmium
Calcium
Chromium
Cobalt
Copper
Iron
Lead
Magnesium
Manganese
Mercury
Nickel
Potassium
Selenium
Silver
Sodium
Thallium
Vanadium
Zinc

OTHER METALS (Total and Dissolved)

Cesium
Lithium
Molybdenum
Strontium
Tin

VOLATILE ORGANIC COMPOUNDS

1,1,1,2-Tetrachloroethane
1,1,1-Trichloroethane
1,1,2,2-Tetrachloroethane
1,1,2-Trichloroethane
1,1-Dichlorethane
1,1-Dichloroethene
1,1-Dichloropropene
1,2,3-Trichlorobenzene
1,2,3-Trichloropropane
1,2,4-Trichlorobenzene
1,2-Dibromoethane
1,2-Dichloropropane
1,2-Dichlorobenzene
1,2-Dichloroethane
1,3-Dichlorobenzene
1,3-Dichloropropane
1,4-Dichlorobenzene
Benzene
Benzene, 1,2,4-Trimethyl
Benzene, 1,3,5-Trimethyl-Bromobenzene
Bromochloromethane
Bromodichloromethane
Bromoform
Bromomethane
Carbon Tetrachloride
Chlorobenzene
Chloroethane
Chloroform
Chloromethane
Cumene
Dibromochloromethane
Dibromethane
Dichlorodifluoromethane
Ethylbenzene
Hexacylorobutadiene
Methylene Chloride
Naphtalene
Propane, 1,2-dirbomo-3-chloro
Styrene
Tetrachloroethene
Toluene
Trichloroethene
Trichlorofluoromethane
Vinyl Chloride
cis-1,2-Dichloroethene
cis-1,3-Dichloropropene
m, p-xylene
n-Butylbenzne
n-Propylbenezene
o-Chlorotoluene
o-Xylene
p-Chlortoluene
p-Cymene
sec-Butylbenzene
sec-Dichloropropane
tert-Butylbenzene
trans-1,2-Dichloroethene
trans-1,3-Dichloropropene

OTHER PARAMETERS

Bicarbonate
Carbonate
Chloride
Cyanide (total)
Fluoride
pH
Specific Conductance
Sulfate
Temperature
Total Dissolved Solids
Total Organic Carbon
Total Suspended Solids

RADIONUCLIDES (Total and Dissolved)

Gross Alpha
Gross Beta
Uranium 233/234, 235 and 238
Americium 241
Plutonium 239+240
Tritium (total only)

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TABLE 2.3-1
SUMMARY OF RADIOLOGICAL AMBIENT AIR MONITORING PROGRAM SAMPLERS WITHIN OU-2

Station	Number of Samples
ONSITE IN OU-2	
S6	12
S7	12
S8	10
S9	11
S19	11
PERIMETER SITES ON OU-2	
S36	12
S37	11
S38	11
S39	11
ALL RFP ONSITE SAMPLERS (S-1 THRU S-25)	
Overall	248
ALL PERIMETER RFP SITES (S-31 THRU S-44)	
Overall	157
ALL COMMUNITY SITES (S-51 THRU S-73)	
Overall	141

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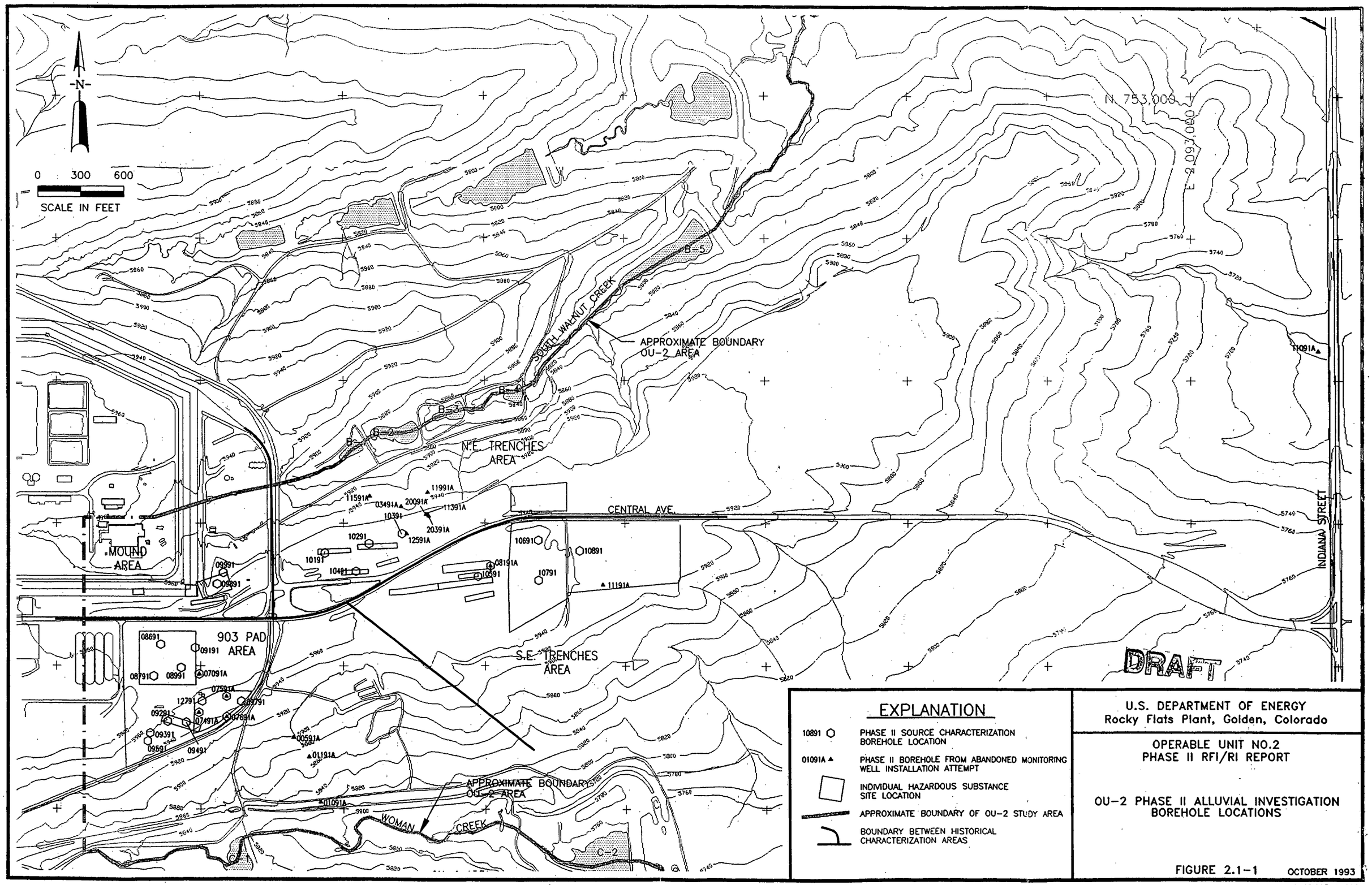
-N-
0 300 600
SCALE IN FEET
N 753,000
E 2,093,000
SOUTH WALNUT CREEK
APPROXIMATE BOUNDARY
OU-2 AREA
B-5
B-4
B-3
B-2
B-1
N.E. TRENCHES
AREA
CENTRAL AVE.
MOUND
AREA
903 PAD
AREA
S.E. TRENCHES
AREA
INDIANA STREET
WOMAN CREEK
C-1
C-2
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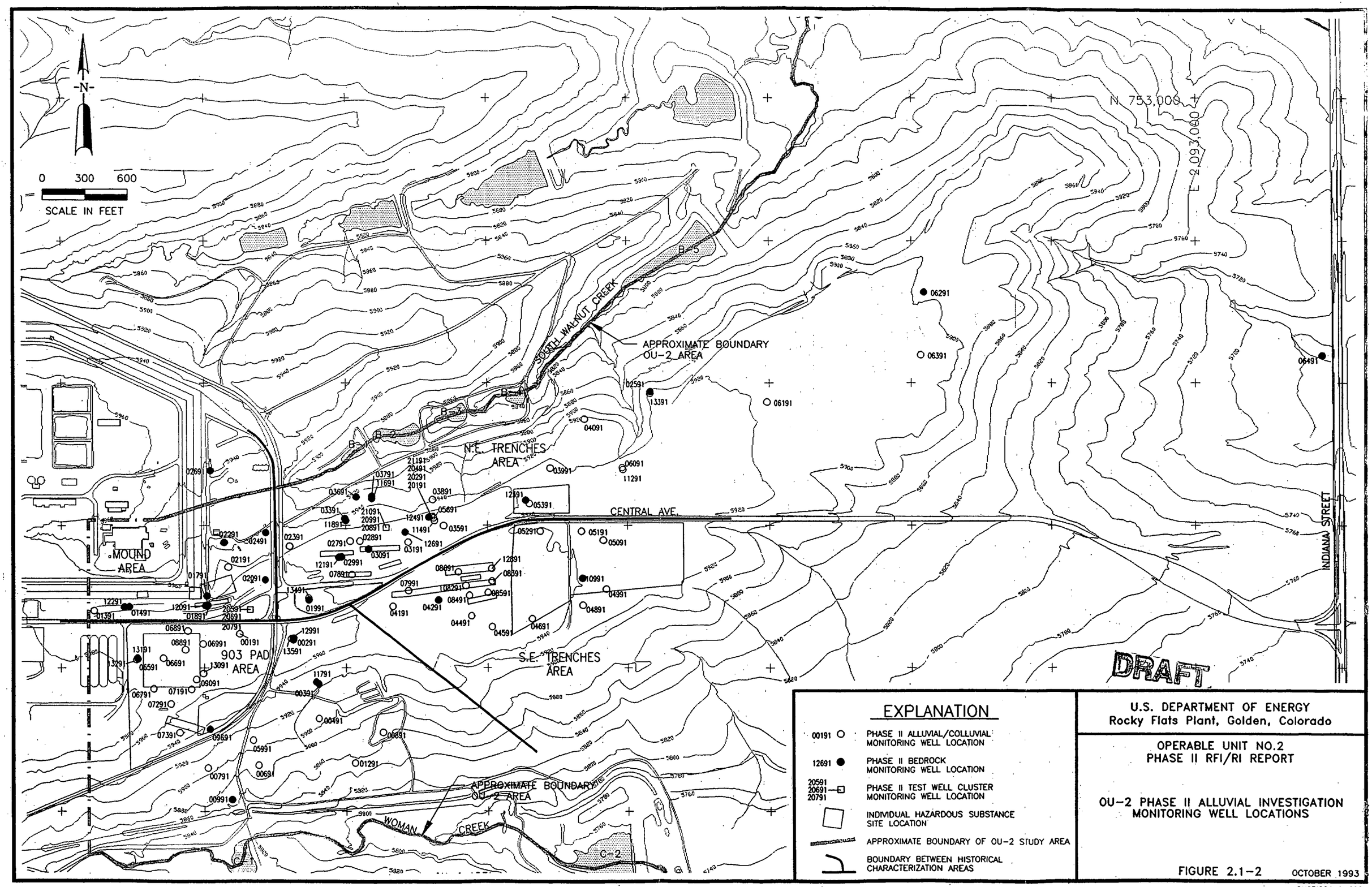
EXPLANATION
10891 PHASE II SOURCE CHARACTERIZATION BOREHOLE LOCATION
01091A PHASE II BOREHOLE FROM ABANDONED MONITORING WELL INSTALLATION ATTEMPT
INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
APPROXIMATE BOUNDARY OF OU-2 STUDY AREA
BOUNDARY BETWEEN HISTORICAL CHARACTERIZATION AREAS
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT
OU-2 PHASE II ALLUVIAL INVESTIGATION
BOREHOLE LOCATIONS
FIGURE 2.1-1
OCTOBER 1993
0U2RI003 1=600


-N-
0 300 600
SCALE IN FEET
N 753,000
E 2,093,000
SOUTH WALNUT CREEK
APPROXIMATE BOUNDARY
OU-2 AREA
B-5
B-4
B-3
B-2
B-1
N.E. TRENCHES
AREA
CENTRAL AVE.
INDIANA STREET
MOUND
AREA
903 PAD
AREA
S.E. TRENCHES
AREA
APPROXIMATE BOUNDARY
OU-2 AREA
WOMAN CREEK
C-2
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EXPLANATION
00191 PHASE II ALLUVIAL/COLLUVIAL MONITORING WELL LOCATION
12691 PHASE II BEDROCK MONITORING WELL LOCATION
20591 20691 20791 PHASE II TEST WELL CLUSTER MONITORING WELL LOCATION
INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
APPROXIMATE BOUNDARY OF OU-2 STUDY AREA
BOUNDARY BETWEEN HISTORICAL CHARACTERIZATION AREAS
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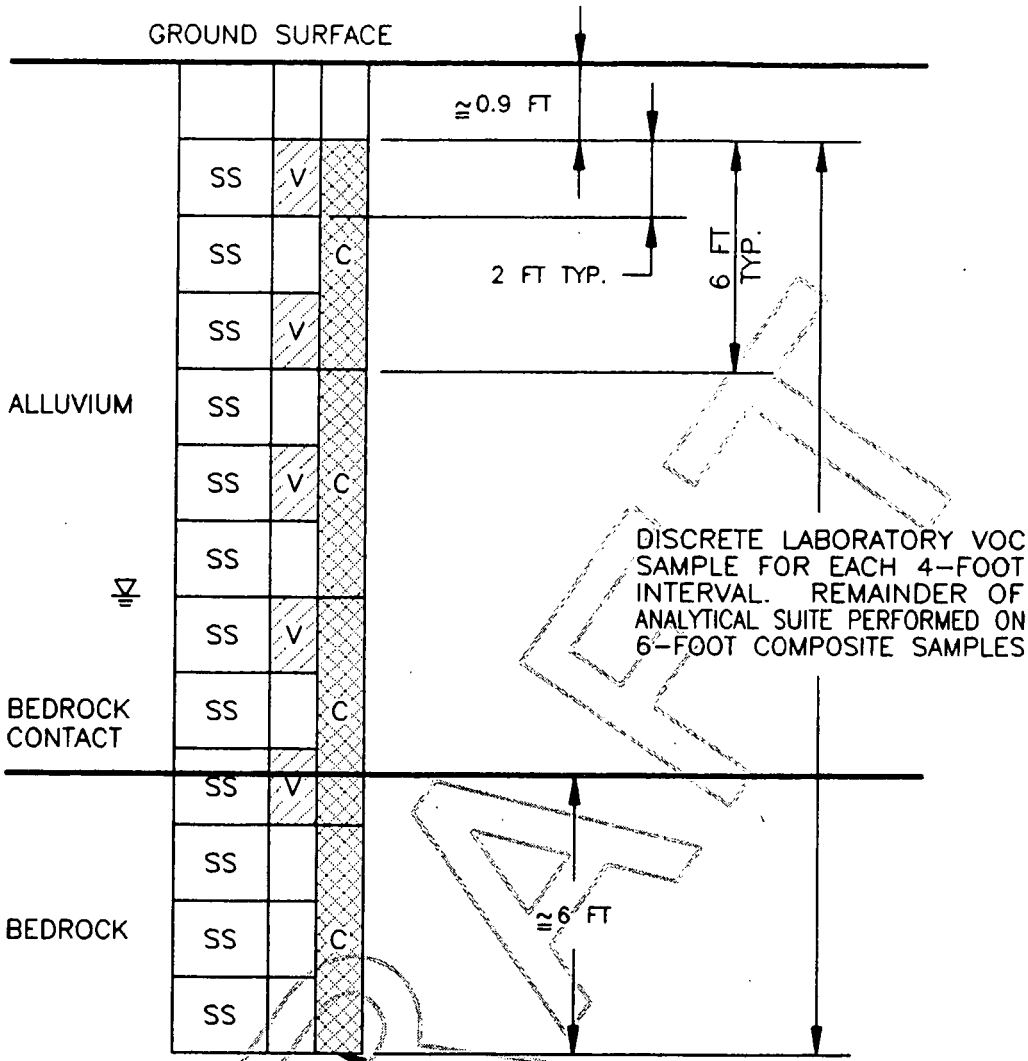
PHASE II RFI/RI REPORT
OU-2 PHASE II ALLUVIAL INVESTIGATION
MONITORING WELL LOCATIONS
FIGURE 2.1-2
OCTOBER 1993
OU2RI004 1=600



NOTE:
COMPOSITE INTERVALS ARE APPROXIMATE AND MAY NOT BE EXACTLY 6 FEET IN LENGTH

NOT TO SCALE

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EXPLANATION

- SS — 2-FOOT HOLLOW-STEM AUGER CONTINUOUS CORE RUN WITH SPLIT SPOON (SS)
- V — DISCRETE SAMPLE FOR VOC ANALYSIS TAKEN IN THIS 2-FOOT INTERVAL
- C — COMPOSITED APPROXIMATELY 6-FOOT INTERVALS FOR ANALYSIS OF REMAINDER OF ANALYTICAL SUITE
- ▽ — WATER TABLE

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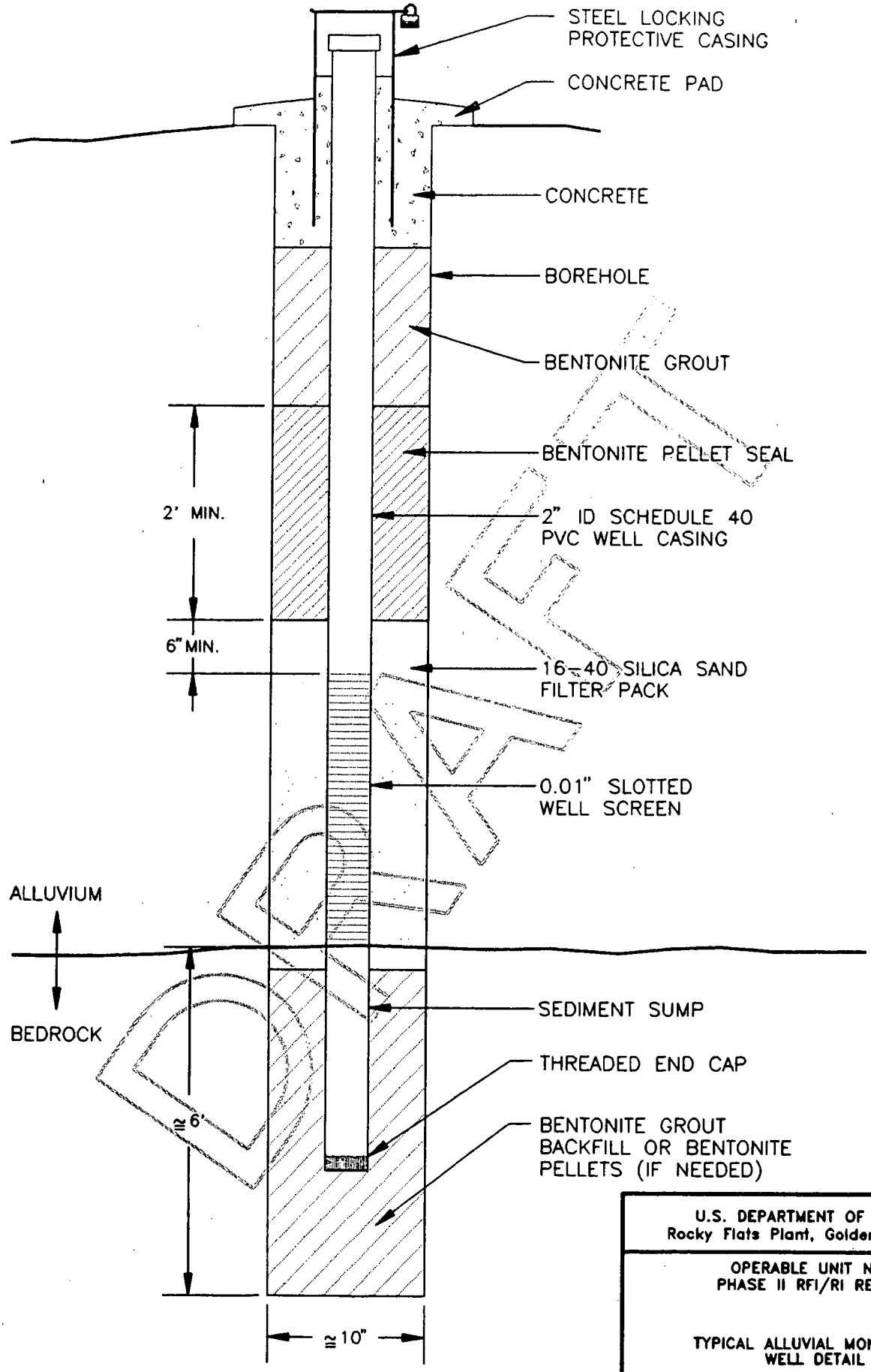
TYPICAL LITHOLOGIC AND CHEMICAL SAMPLING FOR SOURCE CHARACTERIZATION BOREHOLES

FIGURE 2.1-3 OCTOBER 1993

OU2R0022 1=1



NOT TO SCALE

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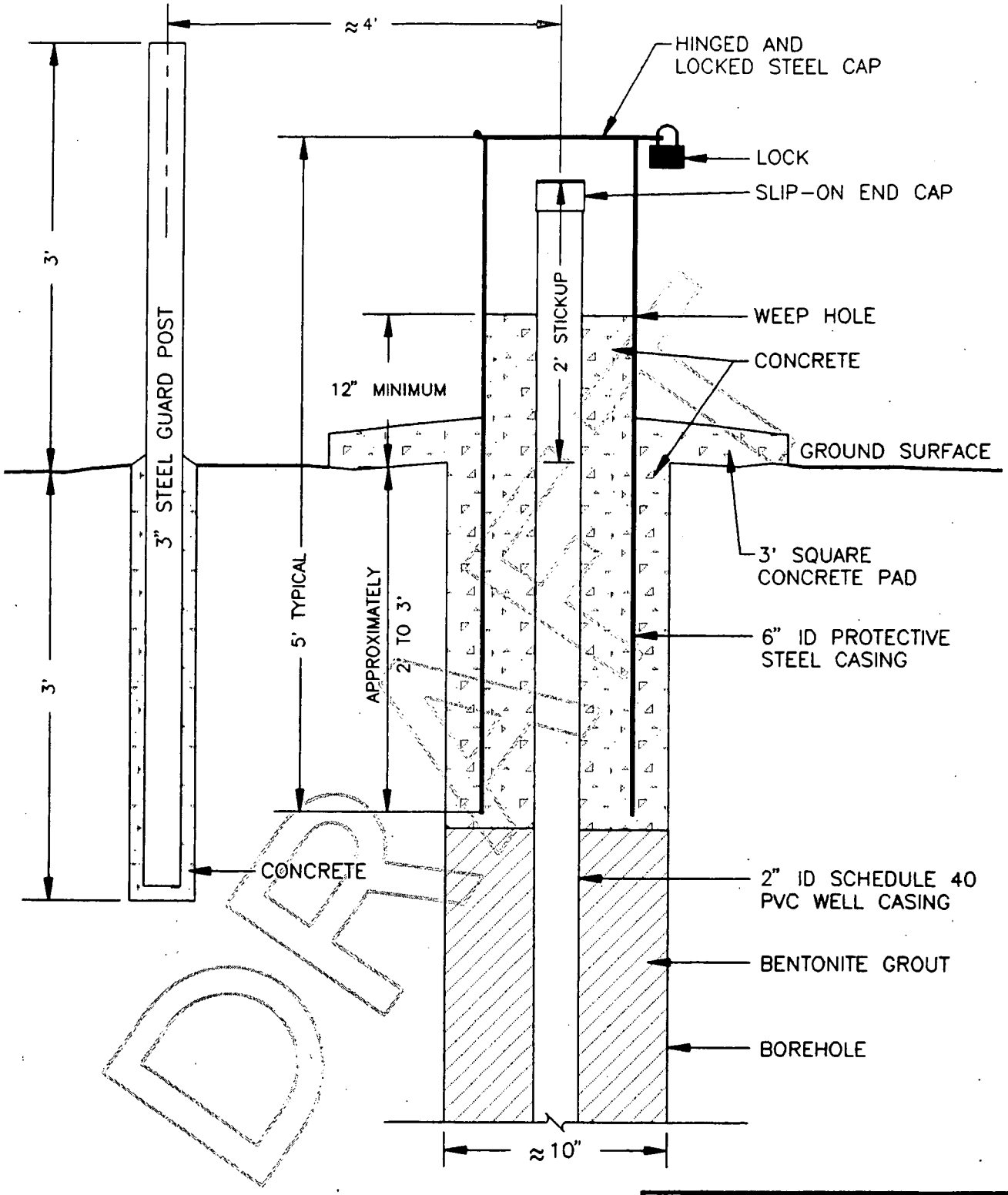
PHASE II RFI/RI REPORT

TYPICAL ALLUVIAL MONITORING WELL DETAIL

FIGURE 2.1-4 OCTOBER 1993

OU2R0025 1-1



NOT TO SCALE

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TYPICAL MONITORING WELL FEATURES
AT GROUND SURFACE

FIGURE 2.1-5 OCTOBER 1993

OU2R0026 1=1

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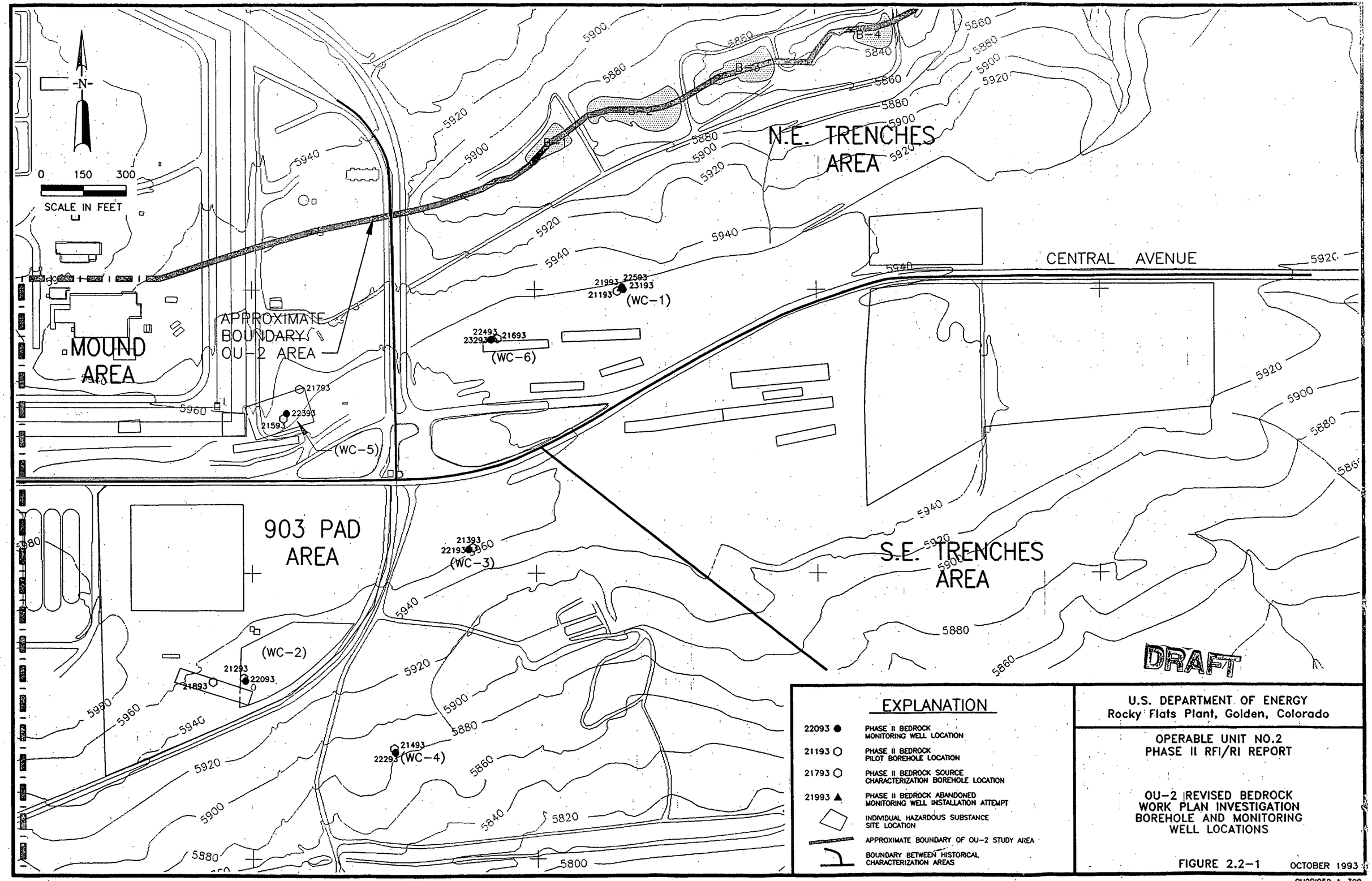
100


-N-
0 150 300
SCALE IN FEET
MOUND AREA
APPROXIMATE BOUNDARY OU-2 AREA
903 PAD AREA
N.E. TRENCHES AREA
S.E. TRENCHES AREA
CENTRAL AVENUE
B-1
B-2
B-3
B-4
(WC-1)
(WC-2)
(WC-3)
(WC-4)
(WC-5)
(WC-6)
21993
22593
23193
21193
22493
23293
21693
21793
22393
21593
21393
22193
21293
22093
21893
21493
22293
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EXPLANATION
22093 ● PHASE II BEDROCK MONITORING WELL LOCATION
21193 ○ PHASE II BEDROCK PILOT BOREHOLE LOCATION
21793 ○ PHASE II BEDROCK SOURCE CHARACTERIZATION BOREHOLE LOCATION
21993 ▲ PHASE II BEDROCK ABANDONED MONITORING WELL INSTALLATION ATTEMPT
INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
APPROXIMATE BOUNDARY OF OU-2 STUDY AREA
BOUNDARY BETWEEN HISTORICAL CHARACTERIZATION AREAS
U.S. DEPARTMENT OF ENERGY
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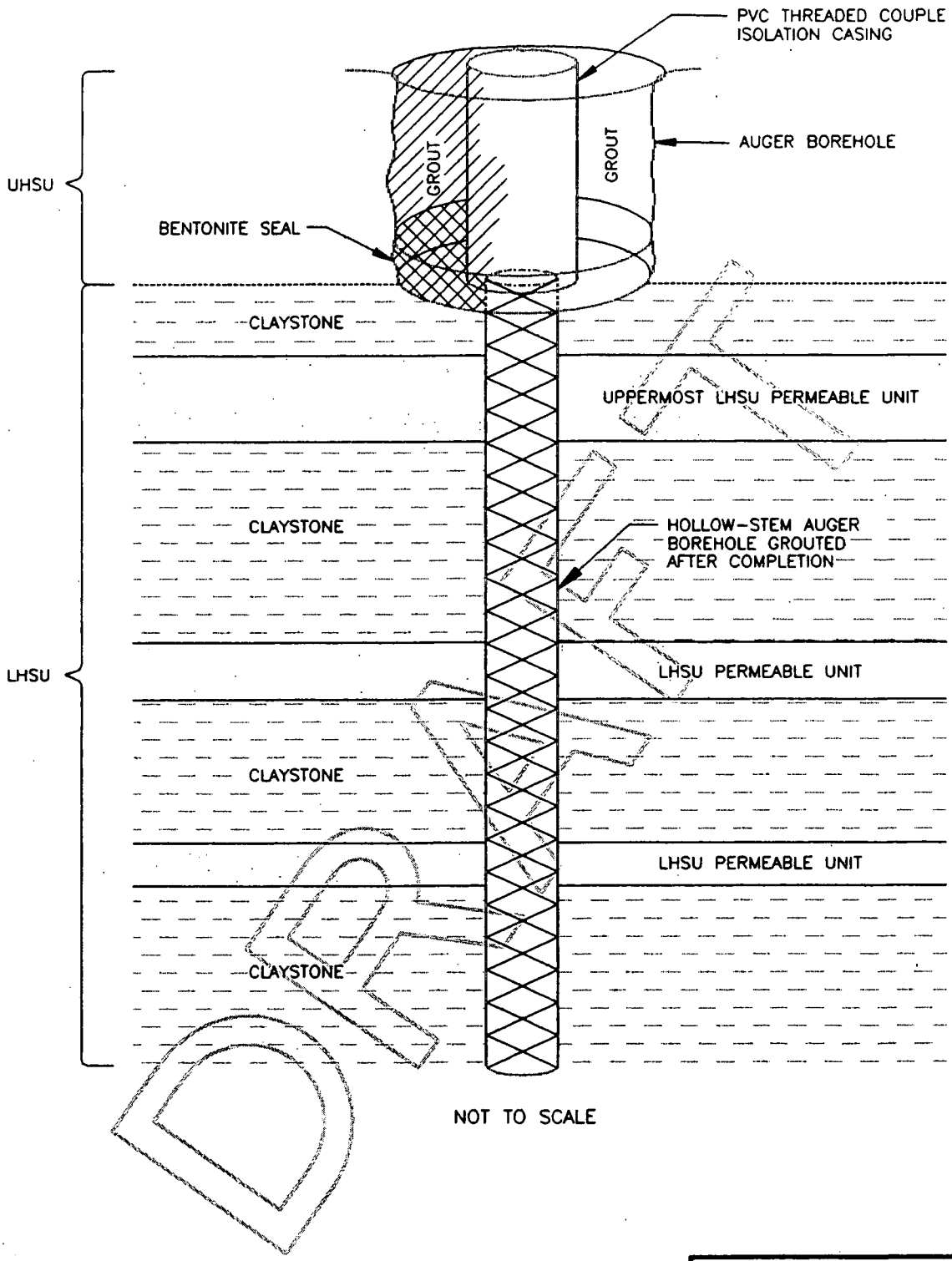
PHASE II RFI/RI REPORT
OU-2 REVISED BEDROCK WORK PLAN INVESTIGATION BOREHOLE AND MONITORING WELL LOCATIONS
FIGURE 2.2-1
OCTOBER 1993
OU2RI052 1=300



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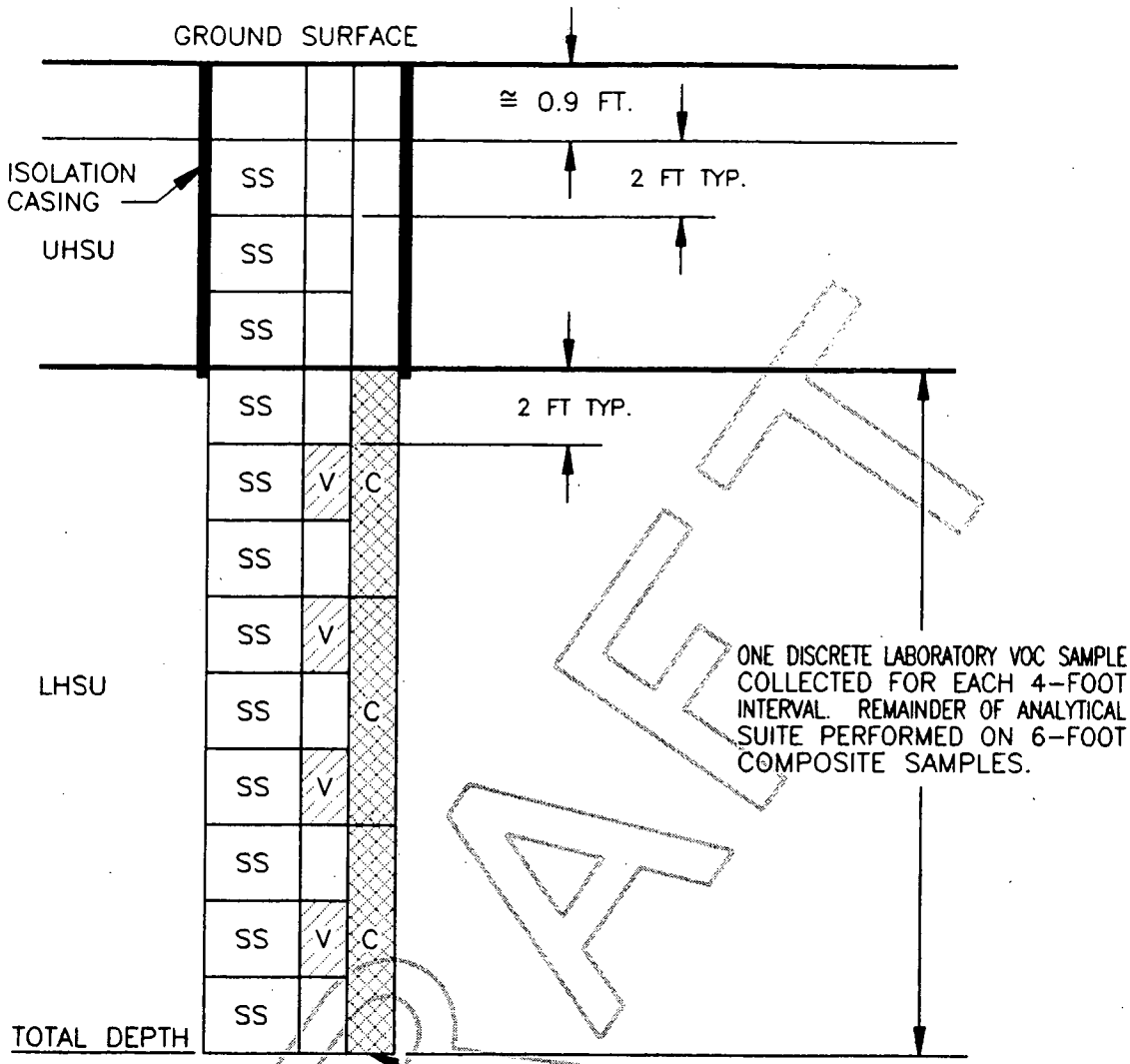
PHASE II RFI/RI REPORT

DIAGRAM OF DETAILS OF
TYPICAL SOURCE CHARACTERIZATION
BOREHOLE

FIGURE 2.2-2 OCTOBER 1993

OU2R178 1-1



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EXPLANATION

SS	2-FOOT CONTINUOUS HOLLOW-STEM AUGER CONTINUOUS CORE RUN WITH SPLIT SPOON (SS)
V	DISCRETE SAMPLE FOR VOC ANALYSIS TAKEN IN THIS 2-FOOT INTERVAL
C	COMPOSITED APPROXIMATELY 6-FOOT INTERVALS FOR ANALYSIS OF REMAINDER OF ANALYTICAL SUITE
UHSU	UPPER HYDROSTRATIGRAPHIC UNIT
LHSU	LOWER HYDROSTRATIGRAPHIC UNIT

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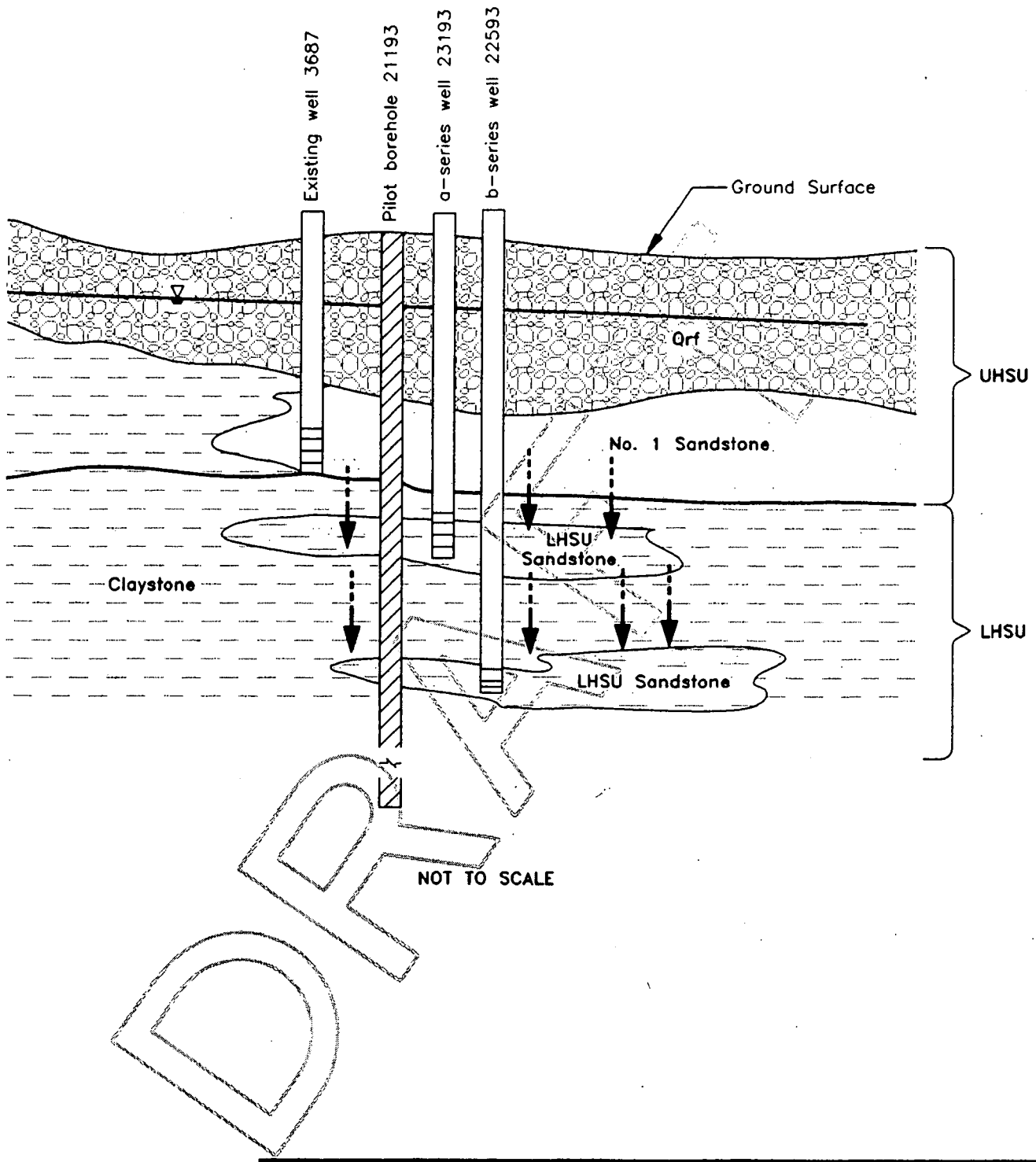
PHASE II RFI/RI REPORT

OU-2 BEDROCK
TYPICAL LITHOLOGIC AND CHEMICAL SAMPLING FOR SOURCE CHARACTERIZATION BOREHOLES

FIGURE 2.2-3 OCTOBER 1993

OU2RI020 1-1



DRAFT

EXPLANATION

UHSU	Upper Hydrostratigraphic Unit
LHSU	Lower Hydrostratigraphic Unit
Qrf	Rocky Flats Alluvium
	Potential Contaminant Migration Pathway
	Monitoring Well Screened Interval
	Pilot Borehole
	Water Level

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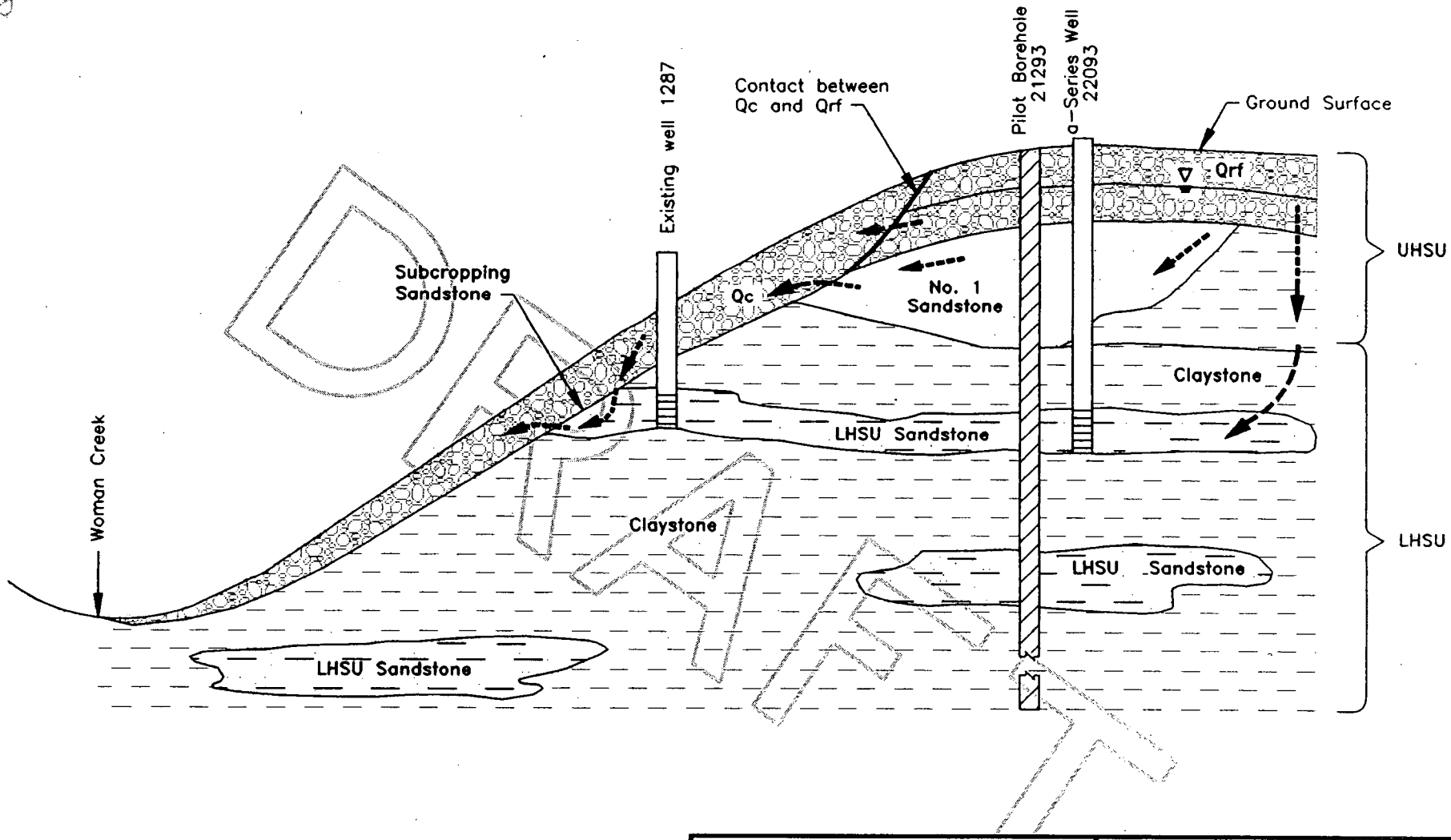
SCHEMATIC DIAGRAM OF TYPICAL
LHSU WELL CLUSTER
(SCENARIO 2)

FIGURE 2.2-4 OCTOBER 1993

OU2R028 1=1



EXPLANATION

UHSU	UPPER HYDROSTRATIGRAPHIC UNIT
LHSU	LOWER HYDROSTRATIGRAPHIC UNIT
Qrf	ROCKY FLATS ALLUVIUM
Qc	COLLUVIUM
No.1	ARAPAHOE FORMATION SANDSTONE
	POTENTIAL CONTAMINANT MIGRATION PATHWAY
	MONITORING WELL
	PILOT BOREHOLE
	WATER TABLE

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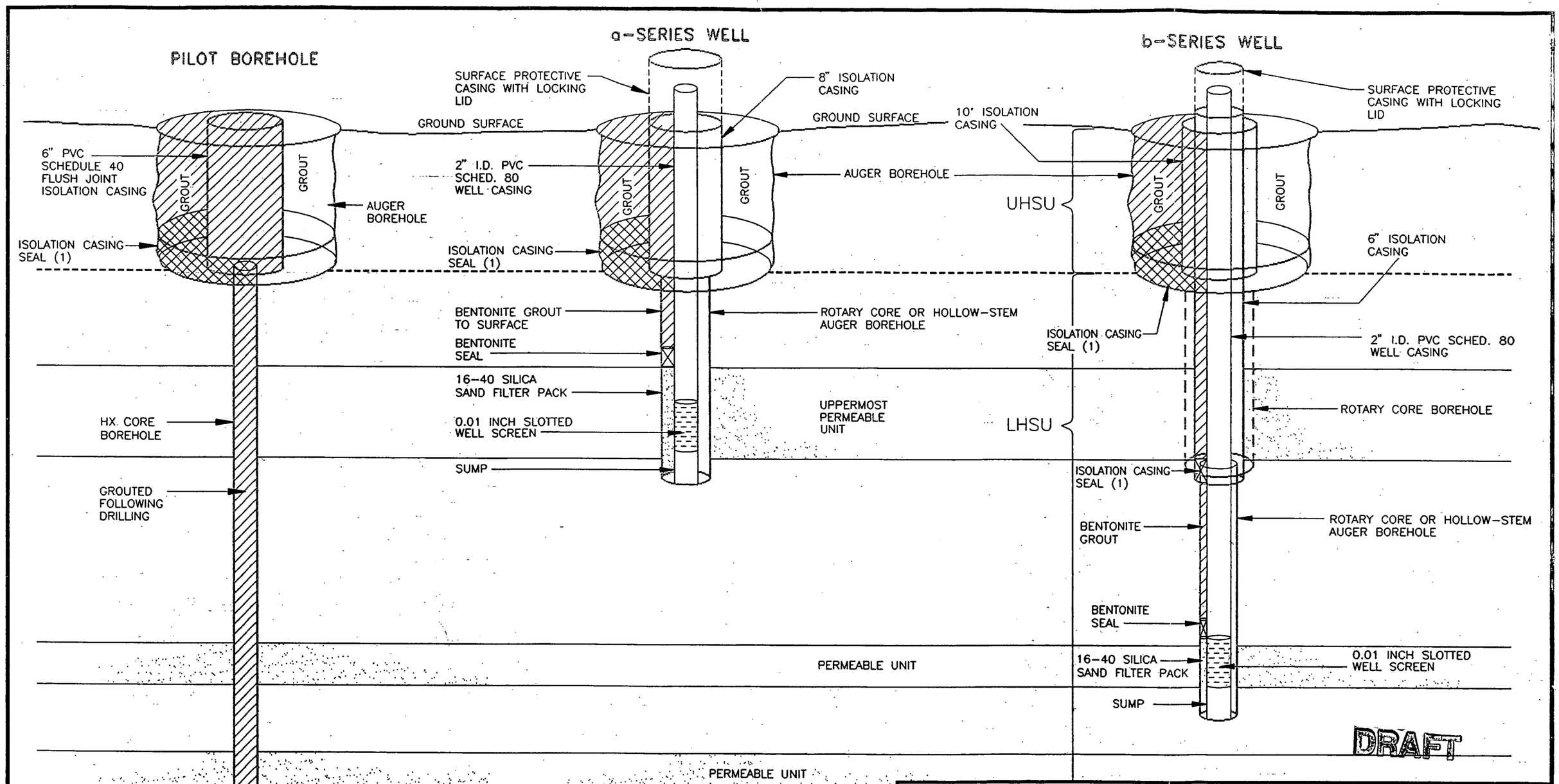
SCHEMATIC DIAGRAM OF TYPICAL WELL CLUSTER TO EVALUATE SOURCE OF CONTAMINANTS IDENTIFIED IN SUBCROPPING LHSU SANDSTONES (SCENARIO 1)

FIGURE 2.2-5 OCTOBER 1993

OU2R0087 1-1



EXPLANATION

UHSU UPPER HYDROSTRATIGRAPHIC UNIT

LHSU LOWER HYDROSTRATIGRAPHIC UNIT

NOTE:

1. ISOLATION CASING INSTALLED USING EITHER BENTONITE PELLET SEAL OR PRESSURE GROUTING

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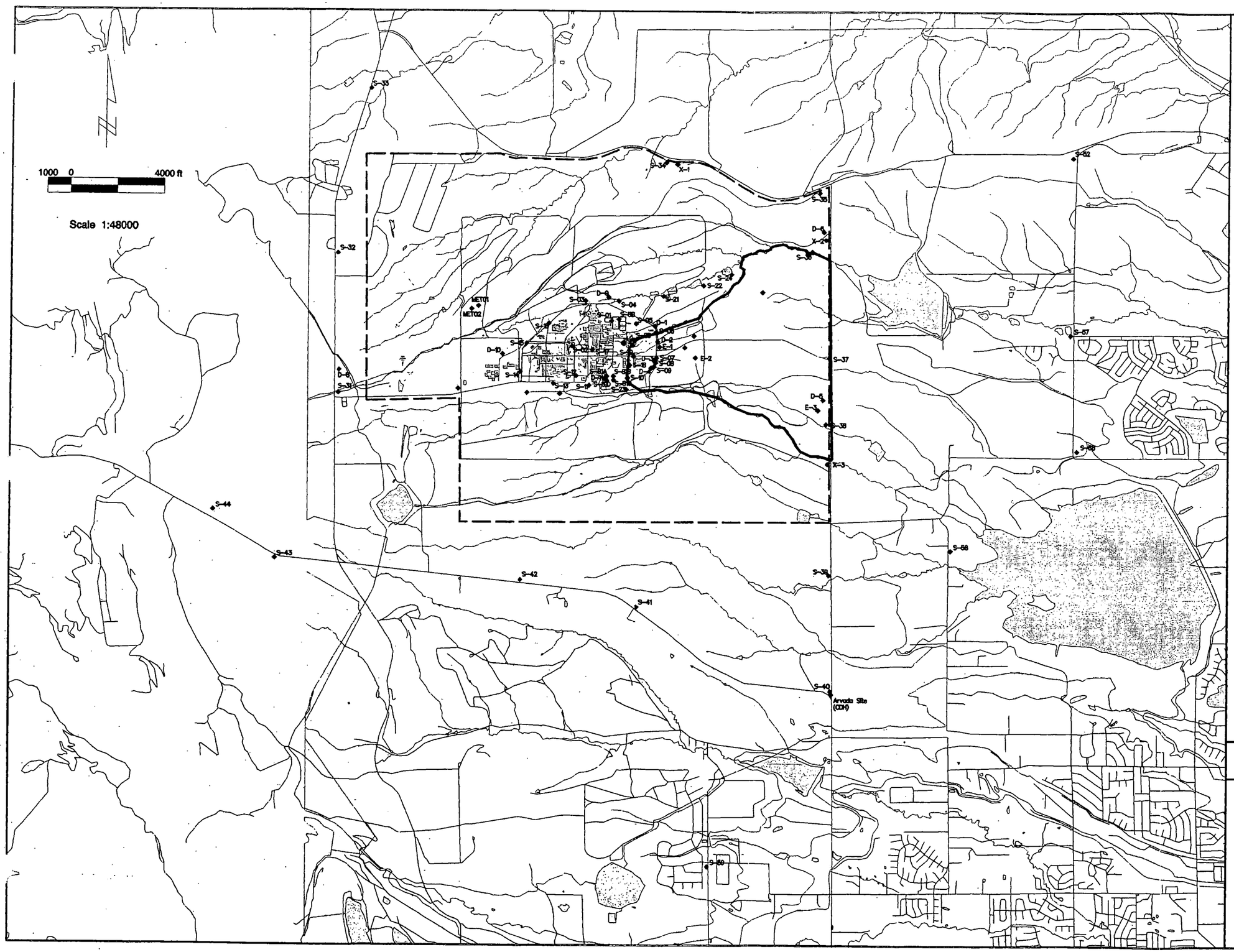
OU-2 BEDROCK
PILOT BOREHOLE AND MONITORING WELL
CONSTRUCTION DETAILS

FIGURE 2.2-6 OCTOBER 1993

OU2RI029 1=1



EXPLANATION

- OU2 Boundary
- Roads
- Ponds/Lakes
- Buildings or other structures
- Air Sampler

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OPERABLE UNIT NO. 2
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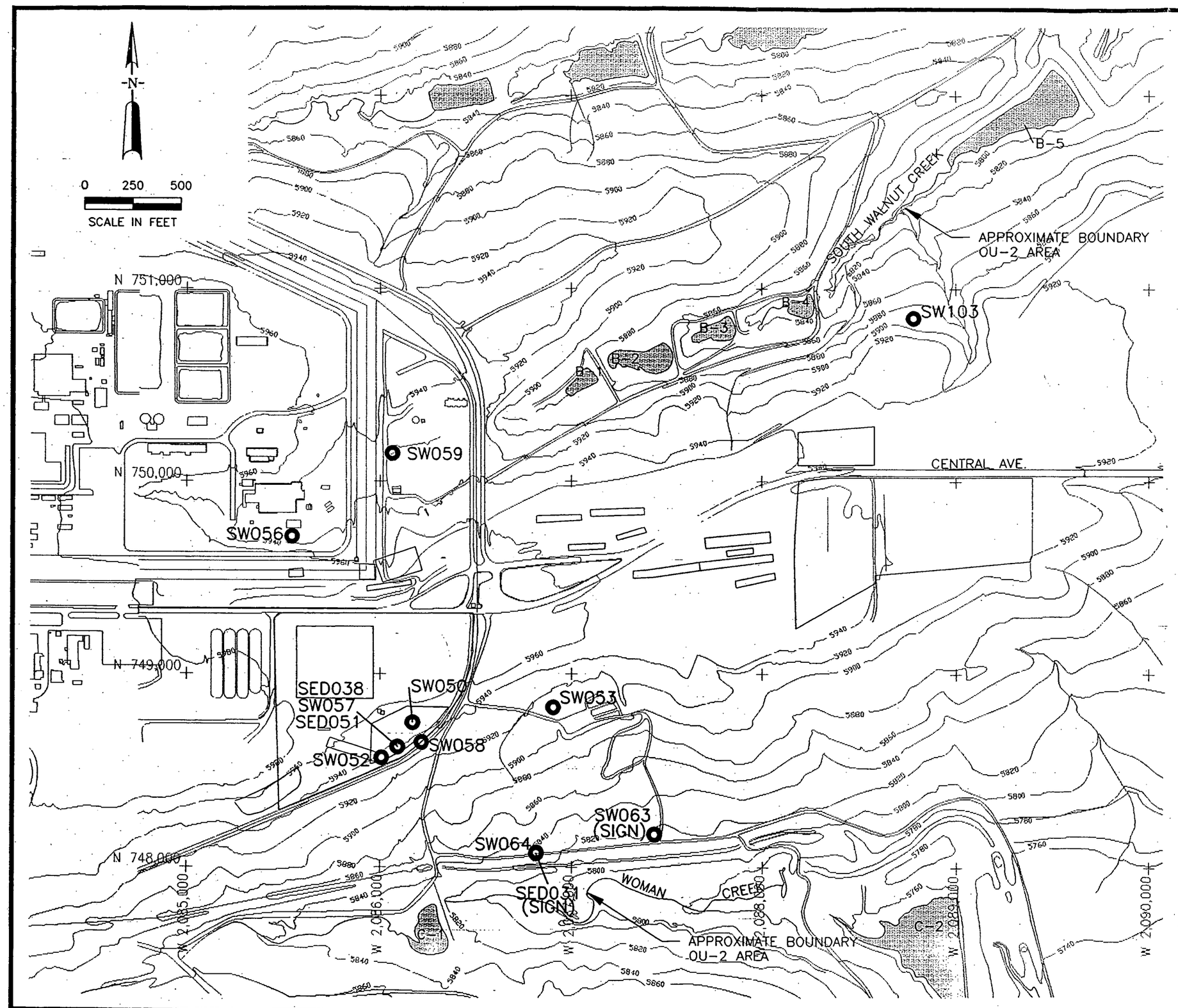
ONSITE AND PERIMETER AMBIENT AIR SAMPLERS

FIGURE 2.3-1

OCTOBER, 1993



EXPLANATION

SURVEYED SAMPLE STATION

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OPERABLE UNIT 2
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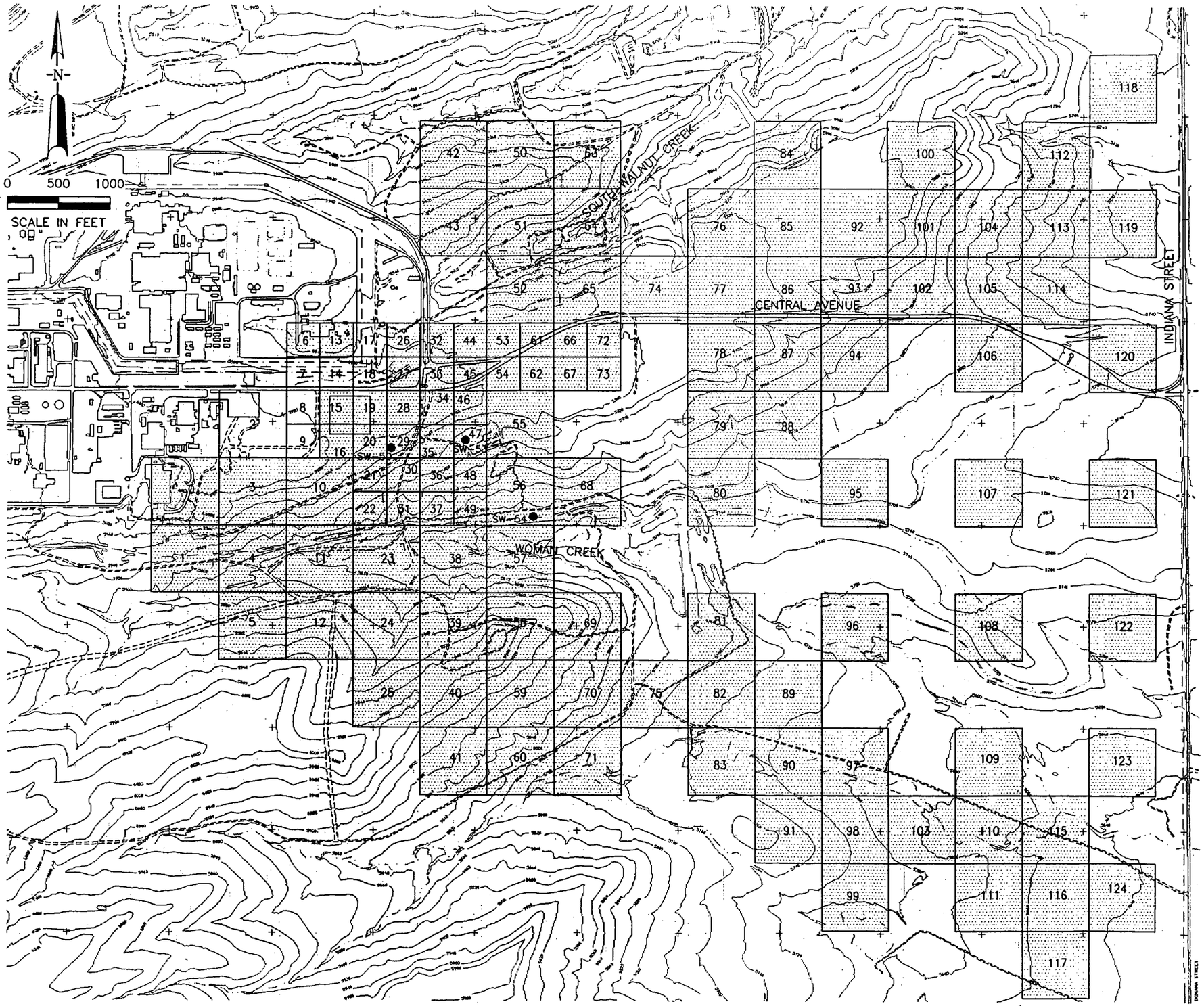
OU2 SEEP AND ASSOCIATED SEDIMENT SAMPLING LOCATIONS

FIGURE 2.4-1

OCTOBER 1993

OU2RI258 1=500



EXPLANATION

1	10-ACRE SAMPLING PLOT LOCATION
6	2.5-ACRE SAMPLING PLOT LOCATION
2	10-ACRE PLOT NOT SAMPLED
7	2.5-ACRE PLOT NOT SAMPLED
SW-50 ●	SURFACE WATER SAMPLING LOCATION

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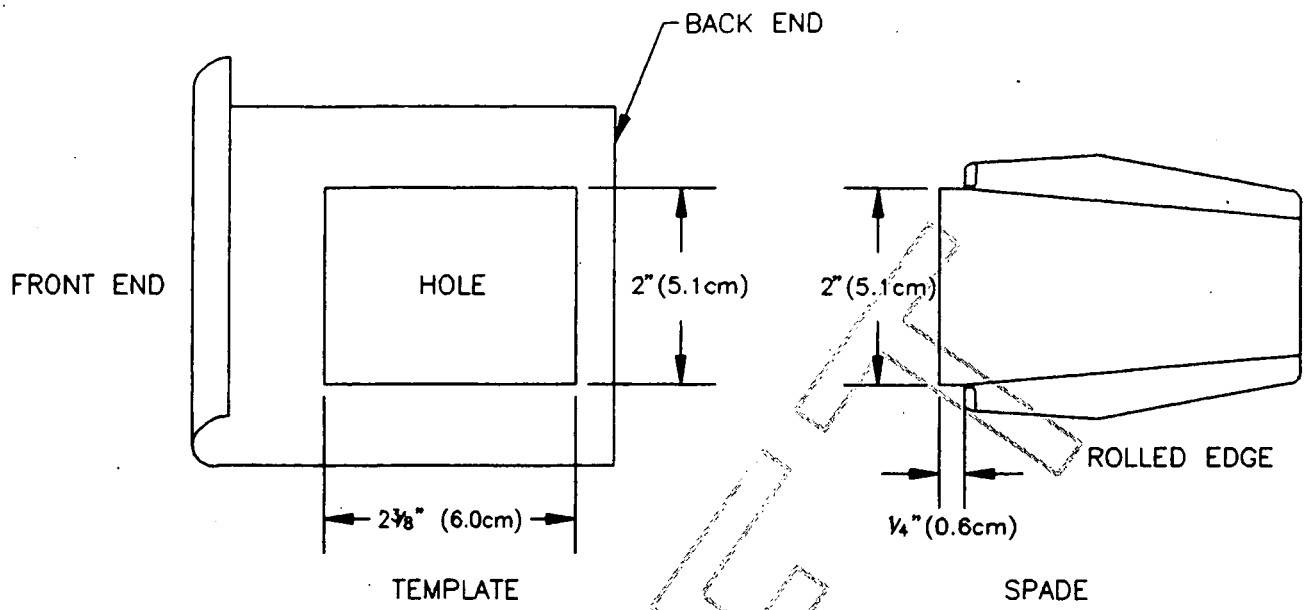
1991 RADIONUCLIDE SURFACE
SOIL SAMPLING PLOT LOCATIONS

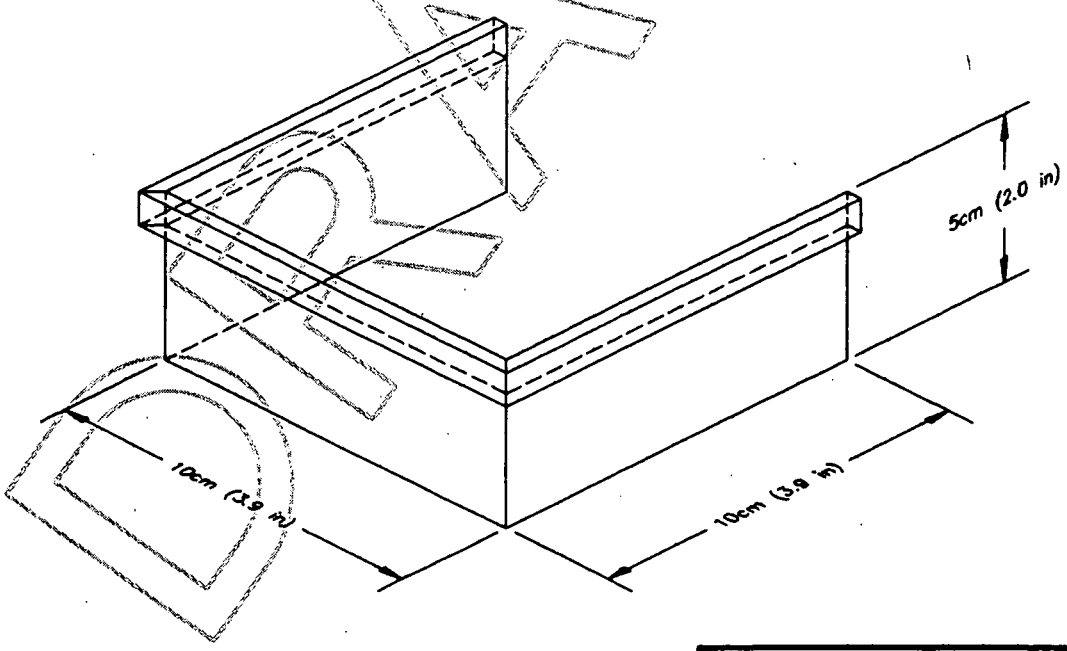
FIGURE 2.5-1 OCTOBER 1993

OU2RI012 1=1000

CDH SAMPLING JIG



RFP SAMPLING JIG



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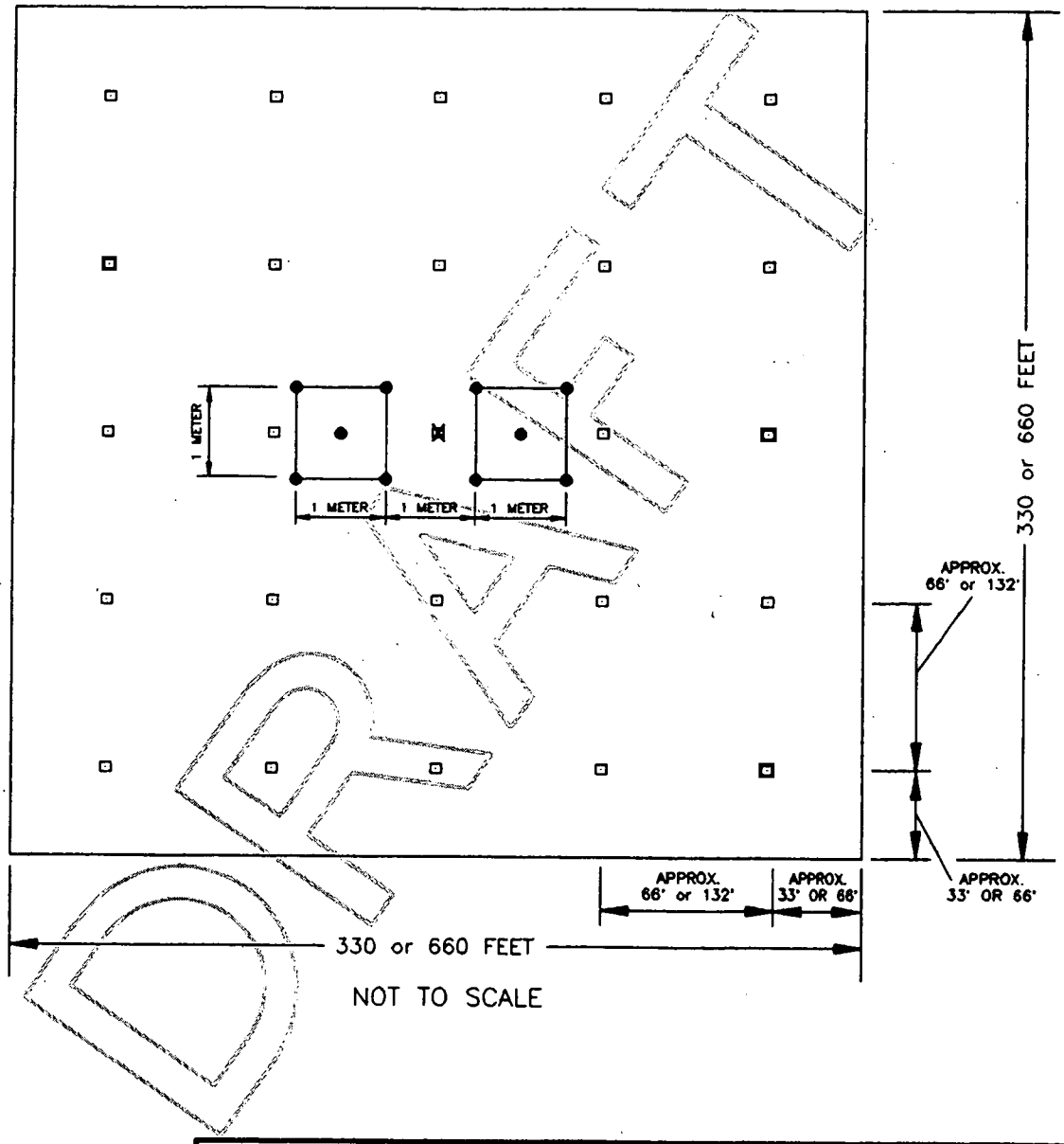
CDH AND RFP SURFACE
SOIL SAMPLING JIGS

FIGURE 2.5-2 OCTOBER 1993

OU2R027 1-1

110

2.5 ACRE OR 10-ACRE SAMPLING PLOT



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EXPLANATION

X CENTER OF PLOT

● RFP METHOD SUBSAMPLE LOCATION (10 TOTAL)

▣ CDH METHOD SUBSAMPLE LOCATION (25 TOTAL)

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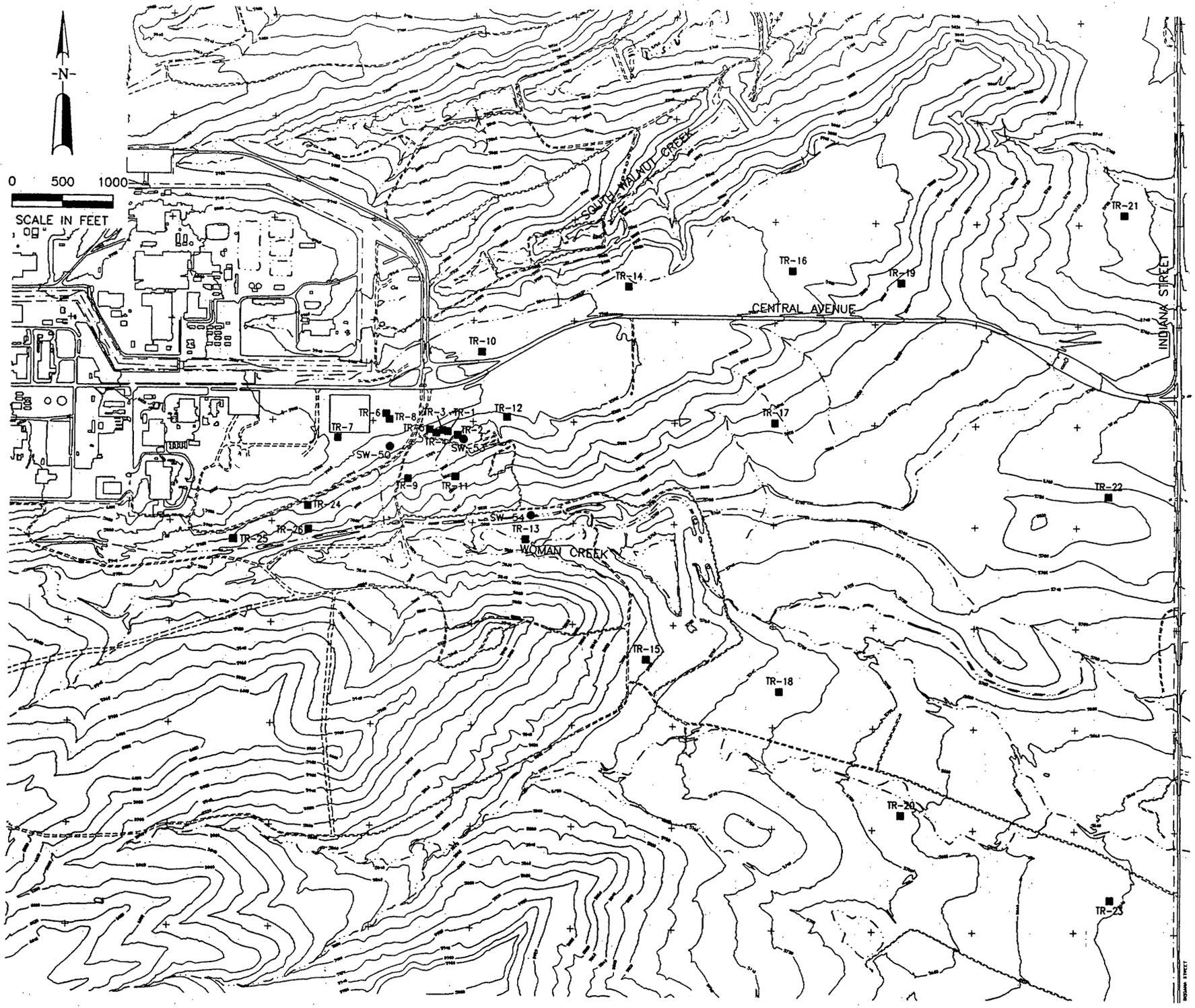
1991 TYPICAL CDH AND RFP SAMPLING SCHEMES

FIGURE 2.5-3 OCTOBER 1993

OU2R1024 1-1



EXPLANATION

TR-1 ■ PIT LOCATION

SW-50 ● SURFACE WATER SAMPLING LOCATION

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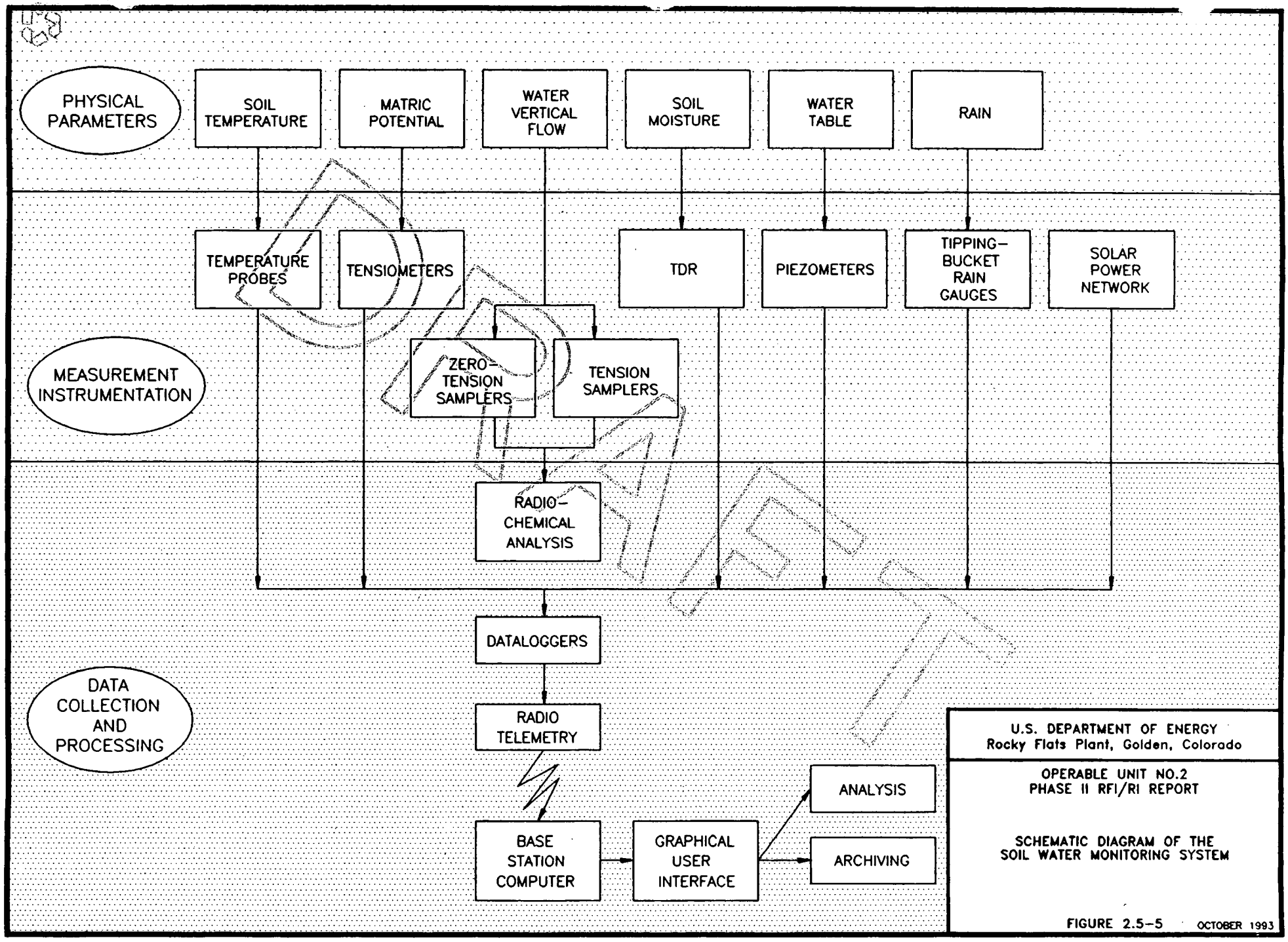
OU-2
PIT LOCATIONS

FIGURE 2.5-4 OCTOBER 1993

OU2RI050 1=1000



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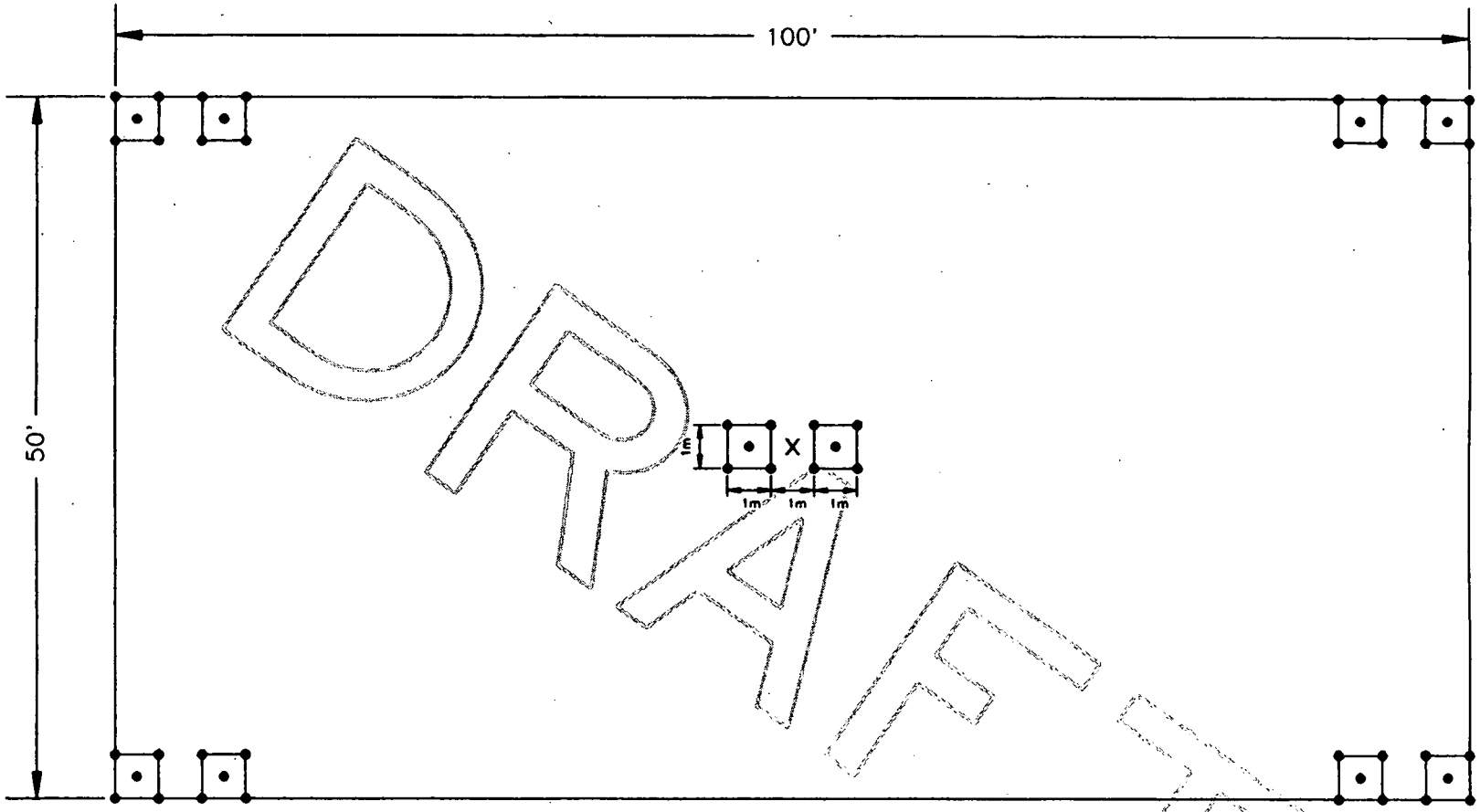
SCHEMATIC DIAGRAM OF THE
SOIL WATER MONITORING SYSTEM

FIGURE 2.5-5 OCTOBER 1993

OU2RI329 1-1



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NOT TO SCALE

EXPLANATION

X CENTER OF PLOT

● RFP METHOD SUBSAMPLE LOCATION (50 TOTAL)

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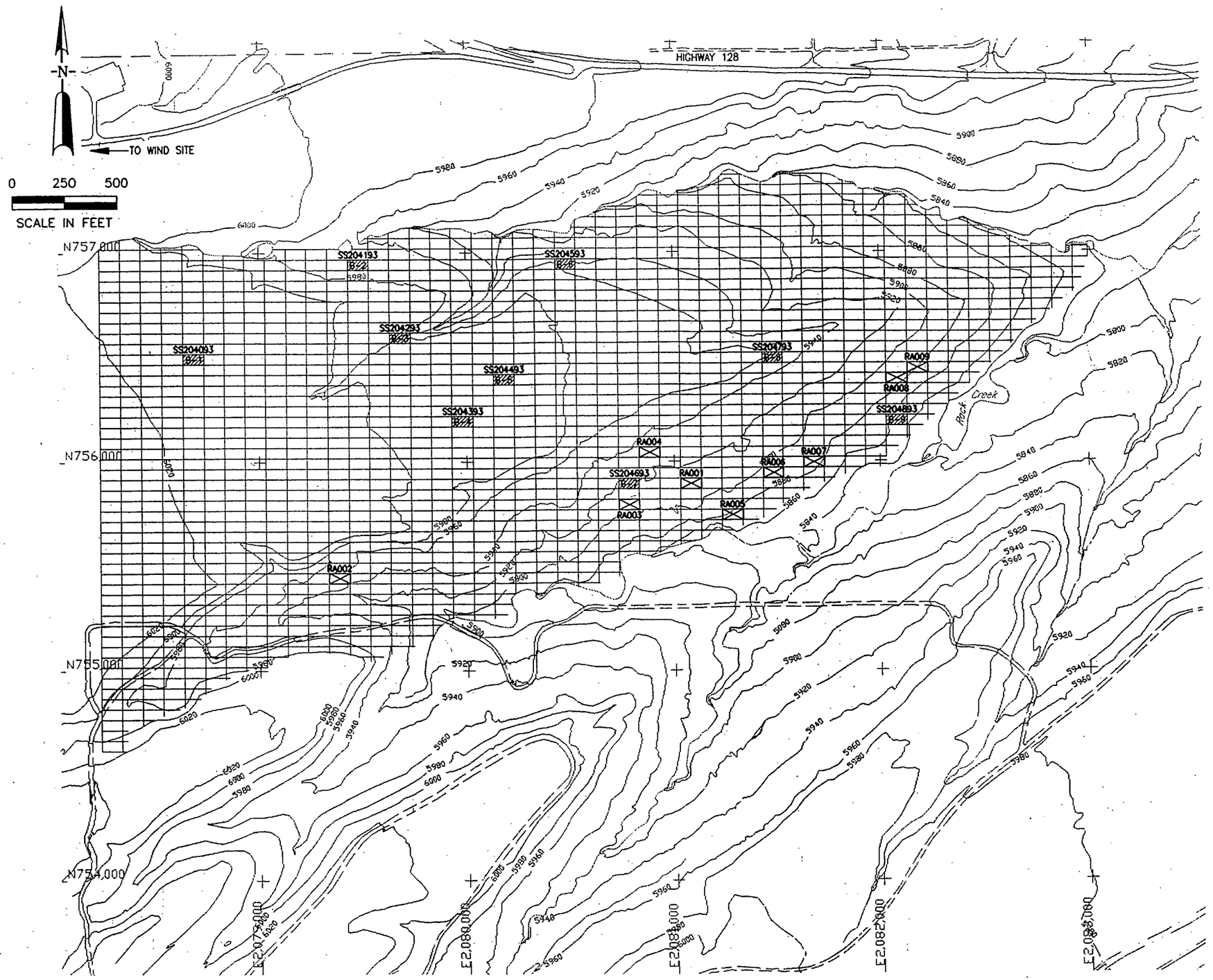
1993 MODIFIED RFP
SAMPLING SCHEME

FIGURE 2.5-6

OCTOBER 1993

OU2R0023 1-1



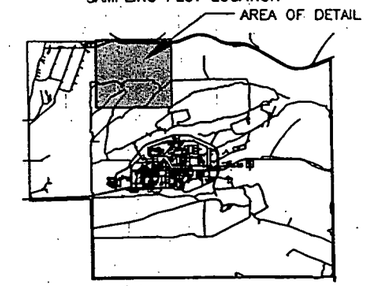
EXPLANATION

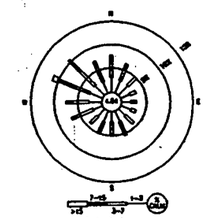
SURFACE SOIL POLYGON (100' X 50')

SS204093 — OU-2 BACKGROUND SURFACE SOIL SAMPLING PLOT LOCATION

RA002 — OU-1 BACKGROUND SURFACE SOIL SAMPLING PLOT LOCATION

AREA OF DETAIL





RFP 1990 WIND ROSE
SOURCE: EG&G, 1990d

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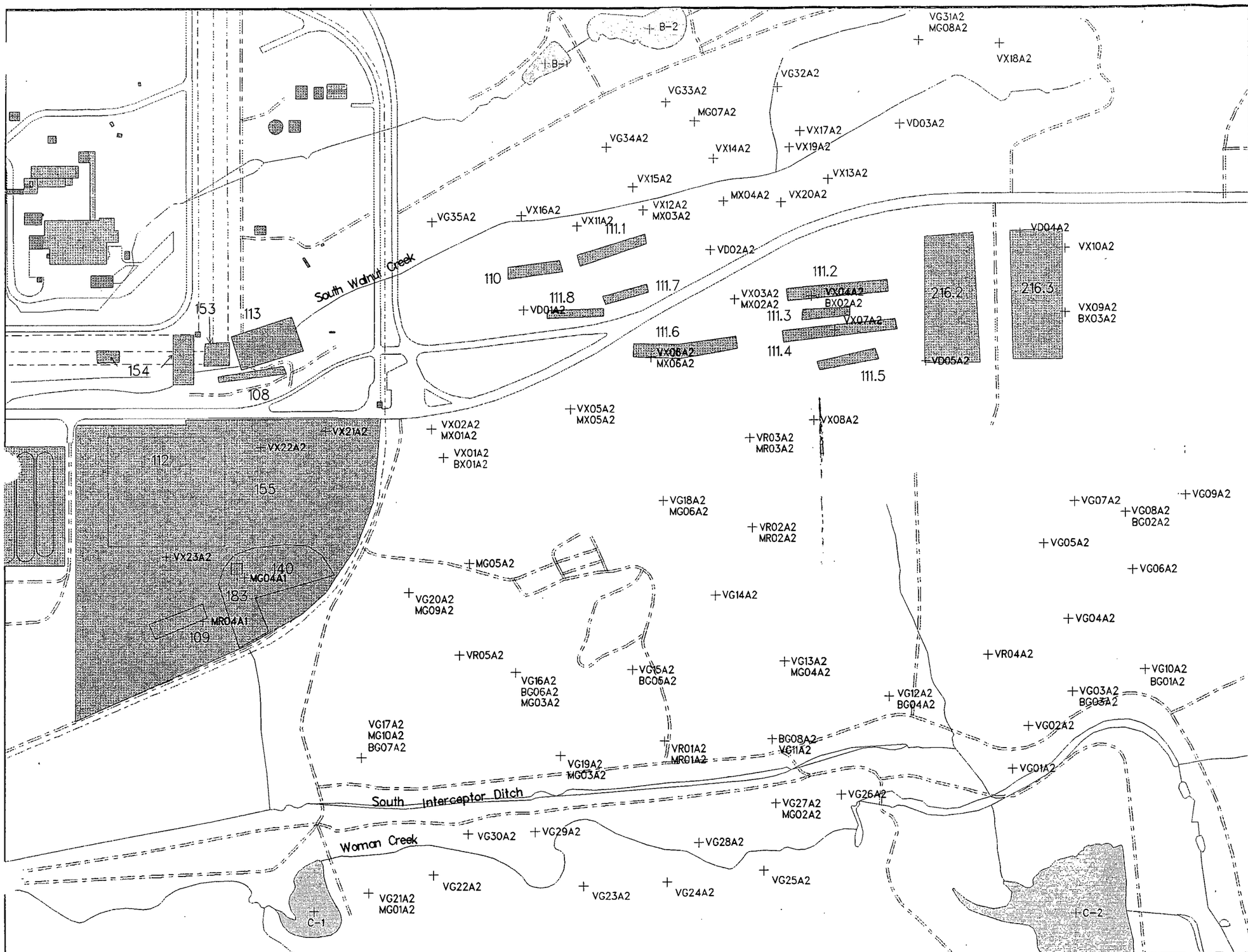
OU-1 AND OU-2 BACKGROUND SURFACE SOIL SAMPLING PLOT LOCATIONS

FIGURE 2.5-7 OCTOBER 1993

OU2RI010 1=500



Map Legend

- Individual Hazardous Substance Sites
- Buildings
- Surface Water Impoundments
- Streams, Dithes, and Other Drainages
- RFP Boundary
- Paved Roads
- Dirt Roads

+ VG01A2
-Vegetation Sampling Site

+ BG01A2
-Bird Sampling Site

+ MG01A2
-Small Mammal Sampling Site

DRAFT

N

0 feet 325 650
0 meters 100 200

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Biota Sampling Sites

Figure 2.6-1 November 1993

11/09/93 /home/data/au/au2als.map

This section describes the physical characteristics of RFP and OU-2. Included are subsections on physiographic features of RFP and OU-2; demography and land use; meteorology and climatology; soils, and geology and hydrogeology of the OU-2 area. Geology and hydrogeology sections address the UHSU and LHSU.

3.1 PHYSIOGRAPHIC FEATURES

3.1.1 Regional

RFP is located at an elevation of approximately 6,000 feet above mean sea level on the western margin of the Colorado Piedmont section of the Great Plains Physiographic Province (Fenneman 1931). The Colorado Piedmont ranges in elevation from 4,000 feet on the east to 7,000 feet on the west. The piedmont merges to the east with the High Plains section of the Great Plains Province and is terminated abruptly on the west by the Front Range section of the Southern Rocky Mountain Province.

The Colorado Piedmont is an area of dissected topography and denudation representing an old erosional surface along the eastern margin of the Rocky Mountains. The piedmont surface is broadly rolling and slopes gently to the east with a topographic relief of only several hundred feet. This relief is due both to resistant bedrock units that locally rise above the surrounding landscape and to the presence of incised stream valleys. Major stream valleys which transect the piedmont from west to east have their origin in the Front Range. Small local valleys have developed as tributaries to these major streams within the piedmont.

The eastern margin of the Front Range, a few miles west of RFP, is characterized by a narrow zone of hogback ridges and flatirons formed by steeply east-dipping Mesozoic strata (such as the Dakota Sandstone and the Fountain Formation). Less resistant sedimentary units were removed by erosion. The Front Range reaches elevations of 12,000 to 14,000 feet above mean sea level 15 miles farther west. The range itself is broad and underlain by resistant gneiss, schist, and granitic rocks of Precambrian age. The resistant nature of these rocks has restricted stream erosion so that deep, narrow canyons have developed in the Front Range.

Several pediments have been eroded across both hard and soft bedrock in the area of RFP during Quaternary time (Scott 1963). The Rocky Flats pediment is the most extensive of these, forming a broad flat surface south of Coal Creek. The broad pediments and more narrow terraces are covered by thin alluvial deposits of ancient streams draining eastward into the Great Plains. The sequence of pediments reflects repetitive physical processes associated with cyclic changes in climate. Each erosional surface and stratigraphic sequence deposited on it probably represents a single glacial cycle. The oldest and highest pediment, the Subsummit Surface (Scott 1960), truncates the hogback ridges of the Front Range. Three successively younger pediments, veneered by alluvial gravels (including the Rocky Flats Alluvium), extend eastward from the mountain front. Erosion of valleys into the pediments followed each depositional cycle so that, near the mountain fronts, stratigraphically younger geologic units occur at topographically lower elevations as narrow terrace deposits along the streams. These alluvial deposits in the OU-2 area are described in Section 3.5.1.

The PA of RFP is located on a relatively flat surface of Rocky Flats Alluvium. The pediment surface and overlying alluvium (generally 10 to 50 feet thick, although the alluvium is as much as 100 feet thick west of the RFP) have been eroded by Walnut Creek on the north and Woman Creek on the south so that terraces along these streams range in height from 50 to 150 feet. The grade of the gently eastward-sloping, dissected Rocky Flats Alluvium varies from 0.7 percent at the industrial area of RFP approximately 2 percent just east of the industrial area.

3.1.2 Operable Unit 2

OU-2 is located adjacent to the eastern and southeastern edge of the PA of RFP (Figure 3.1-1). The IHSSs of OU-2 are located on a relatively flat ridge between Woman Creek on the south and South Walnut Creek to the north. OU-2 elevations range from 5,920 feet above mean sea level on the southeast side of the 903 Pad Area to 5,980 feet along the top of the ridge on the west side of the site. Drainage from OU-2 is both to the south to the South Interceptor Ditch and Woman Creek and to the north to South Walnut Creek.

3.2 DEMOGRAPHICS AND LAND USE

3.2.1 Demographics

Demographic information described below is primarily from "1989 Population, Economic, and Land Use Data for Rocky Flats Plant" (DOE 1990d), developed by the Denver Regional

Council of Governments (DRCOG). This DRCOG study encompassed an 81-kilometer (50-mile) radius area from the center of RFP and included all or part of 14 counties and 72 incorporated cities with a 1989 combined population of 2,206,550.

RFP is located in a rural area of unincorporated Jefferson County, approximately 16 miles northwest of Denver and approximately 10 miles south of Boulder. RFP is situated on a 6,550-acre parcel of federally owned land. The PA is located in the approximate center of the parcel and is surrounded by a buffer zone of approximately 6,150 acres. The area to the west of RFP is mountainous and sparsely populated. The area east of RFP is generally a high arid plain and densely populated. The majority of the population included in the DRCOG study is located within 30 miles of RFP, to the east and southeast in the Denver metropolitan area. The majority of the development of the plains to the east of RFP has occurred since the plant was built.

Within a 10.3-kilometer (6.4-mile) radius of the center of RFP, there is little residential or commercial development. Between 6.4 and 16 kilometers (4 and 10 miles), development increases, with approximately 316,000 residents within a 16-kilometer (10-mile) radius. The most significant development exists to the southeast, in the cities of Westminster, Arvada, and Wheat Ridge. The cities of Boulder, to the northwest; Broomfield, Lafayette, and Louisville, to the northeast; and Golden, to the south, also contain significant developments within this 16-kilometer (10-mile) radius (DOE 1990d).

Recent population estimates registered by DRCOG for the eight-county Denver metropolitan area display distinct growth patterns. Between 1980 and 1985, the population of the metropolitan area increased by 197,890, a 2.4 percent annual growth rate. Between 1985 and 1989, a population gain of 71,575 was recorded, representing a 1.0 percent annual increase (the national average). The 1989 population showed an increase of 2,225 (or 0.1 percent) from the same date in 1988 (DRCOG 1989).

The DRCOG study also projected populations through the year 2010. Figure 3.2-1 (DOE 1990d) illustrates the 1989 residential population found within an 8-kilometer (5-mile) radius of RFP. The 2010 projected residential population is illustrated in Figure 3.2-2 (DOE 1990d). Sectors 1 and 2 represent land within the RFP boundary. Sectors 3, 4, and 5 represent property outside the RFP boundary. Radial Segments E and F are the general area of OU-2. Radial Segments D through I represent the predominant downwind and downstream directions from the OU-2 area. Table 3.2-1 summarizes the 1989 and projected 2010 population data shown in

Figures 3.2-1 and 3.2-2 as well as the 1989 and projected 2010 population for the region within the 8- to 16-kilometer (5- to 10-mile) radius of RFP. The information presented in Table 3.2-1 indicates that zero population growth is projected during the next 20 years for the areas immediately adjacent to the RFP boundary (Sector 3).

Eight public schools are within six miles of RFP. The nearest school is Witt Elementary School, which is approximately 4.4 kilometers (2.7 miles) east of the RFP buffer zone (DOE 1991a). There are 93 schools, 8 nursing homes, and 4 hospitals within a 16-kilometer (10-mile) radius of RFP (DOE 1990d).

The nearest drinking water supply is Great Western Reservoir, located approximately 3.7 kilometers (2.3 miles) to the east of the center of RFP. The City of Broomfield operates a water treatment facility immediately downstream from Great Western Reservoir. This facility supplies drinking water to approximately 28,000 persons. Standley Lake, a drinking water supply for the cities of Thornton, Northglenn, Westminster, and Federal Heights, is located 3.5 miles to the southeast of RFP.

3.2.2 Off-Site Land Use

3.2.2.1 Current Land Use

Current land use in the area surrounding RFP within a radius of 16 kilometers (10 miles) is described in "1989 Population, Economic, and Land Use Data for Rocky Flats Plant" (DOE 1990d). In general, current land use surrounding RFP includes open space (recreational), agricultural, residential, and commercial/industrial. Open space (recreational) land includes an open space parcel to the northwest owned by the City of Boulder, Golden Gate State Park to the west, White Ranch Park to the south, Standley Lake Park to the southeast, and other open space lands to the southeast associated with Westminster and Arvada. The majority of the agricultural land is located to the northeast of the Plant. Some agricultural land is also located east of the Plant, while parcels of range land are located to the southwest. The majority of residential land use is 6 to 16 kilometers (4 to 10 miles) to the southeast. The primary commercial/industrial area within 8 kilometers (5 miles) of the Plant is the Jefferson County Airport area. Additional commercial/industrial areas within 16 kilometers (10 miles) of the Plant include areas in Westminster and Arvada to the east and south, Broomfield to the east, Lafayette and Louisville to the northeast, Boulder to the northwest, and Golden to the south.

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The northeastern Jefferson County and RFP area is currently one of the most concentrated areas of industrial development in the Denver metropolitan area.

Current land use in the area immediately southeast of OU-2 includes all of the uses mentioned above, with the predominant uses appearing to be open space, single-family detached dwellings, and agricultural (livestock) operations. Industrial facilities within 8 kilometers (5 miles) of RFP include the TOSCO laboratory (a 40-acre site located two miles south), the Great Western Inorganics Plant (two miles south), the Western Aggregates, Inc. Plant (2.4 miles northwest), and the Jefferson County Airport and Industrial Park (a 990-acre site located 4.8 miles northeast).

3.2.2.2 Future Land Use

Future land use is generally expected to follow existing land use patterns. The North Plains Community Plan (Jefferson County 1990) was prepared to serve as a guide to the county and cities to achieve compatible land use and development decisions, regardless of the jurisdiction. Jefferson County expects that industrial land uses will continue to dominate the northeastern portion of the county. The plan identifies the RFP and the Jefferson County Airport as constraints to future residential developments in the area, and recommends office and light industrial development. The plan further identifies the acquisition of lands for open-space uses as a high priority for the area, recommending that large amounts of undeveloped land be provided for this purpose (Jefferson County 1990).

Maps presented in the North Plains Community Development Plan (Jefferson County 1990) and the Jefferson Center Comprehensive Development Plan show that the predominant future land uses to the south and southeast of RFP will consist of commercial, industrial, and office space. Directly to the east, the zoning and uses are expected to remain open-space and agricultural/vacant. The areas closest to RFP are planned for industrial, commercial, or office space, with the areas further from RFP designated for residential development. This planning is consistent with the projected zero residential growth rate in the next 20 years for areas immediately adjacent to RFP (DOE 1990d).

The cities of Broomfield and Superior have participated in the Jefferson County cooperative planning process and are planning business, industrial, and mixed land uses for the area north of RFP (Jefferson County 1990, City of Broomfield 1990, Boulder County 1991).

3.2.3 On-Site Land Use

3.2.3.1 Current Land Use

RFP production and maintenance activities do not occur in the OU-2 area. The 903 Pad portion of OU-2 is capped with asphalt paving. A large portion of OU-2 is located within the buffer zone, outside the security fence and PA. Current activities in OU-2 consist of environmental investigations and routine security surveillance.

3.2.3.2 Future Land Use

Occupation by private industry is being considered by DOE for the future use of the on-site RFP production area. Areas of OU-2 immediately adjacent to the industrial portion of the Plant could be considered as part of future industrial development. With the present open space located nearby, it is plausible that the buffer zone and OU-2 area will be preserved as open space. Ecological surveys of the buffer zone, performed in compliance with the Threatened and Endangered Species Act, may indicate the presence of several listed species at RFP. Because the buffer zone has not been impacted by commercial development for many years, thus allowing progressive re-establishment of quality native habitats, the future use of this area as an ecological preserve is reasonable. This type of site use is also consistent with the Jefferson County Planning Department's recommendations for the provisions of large amounts of undeveloped land in the area (Jefferson County 1990)

3.3 METEOROLOGY AND CLIMATOLOGY

The RFP area has a semiarid climate that is characteristic of much of the central Rocky Mountain region. The average annual precipitation at RFP is estimated at 15.16 inches (DOE 1991h). Approximately 35 percent of the 16-inch annual precipitation falls during the spring season, much of it as snow. Thunderstorms (June to August) account for an additional 45 percent of the annual precipitation. Autumn and winter are drier seasons, accounting for 19 percent and 11 percent of the annual precipitation, respectively. Snowfall averages 85 inches per year, falling from October through May (DOE 1980). During 1990, RFP recorded 12.8 inches of precipitation. The maximum precipitation for a 15-minute period was 0.53 inches, occurring on August 6, 1991. The most precipitation recorded on a single day was 1.32 inches between June 1 and 2, 1991.

Temperatures are moderate with extremely warm or cold weather rare and for very short durations. On the average, daily summer temperatures range from 55 to 85 degrees Fahrenheit, and winter temperatures range from 20 to 45 degrees Fahrenheit. The low average relative humidity (46 percent) is due to the blocking effect of the Rocky Mountains. Table 3.3-1 presents the annual climatic summary compiled for 1991.

The wind flow around RFP is strongly influenced by the close proximity of the Rocky Mountains and High Plains which produce a diurnal cycle of the wind patterns (upslope and downslope) when there are no strong storm systems or synoptic patterns within the region. The east-west running canyons to the west of RFP can further channel the local wind conditions. The wind generally flows downslope from the mountains to the plains at night while daytime wind directions may flow upslope. The South Platte River Valley is the area for the confluence and divergence of the airflow patterns for the region between the Front Range and the Denver Metropolitan area. Chinook windstorms may occur during the spring as winds moving from west to east over the Continental Divide plunge down the east side of the mountain slopes.

Table 3.3-2 is an annual joint frequency distribution of the wind direction categorized by wind speed class at RFP, based on the pre-processed meteorological data for 1992 used in the dispersion modeling analysis. These data are presented as a wind rose in Figure 3.3-1. Compass point designations indicate the true bearing when facing the wind (direction from which the wind flows). Northwest winds are predominant at RFP.

Pasquill-Gifford stability classes were used in atmospheric dispersion estimates. Stability classes at RFP were calculated using the Sigma Theta method, which categorizes the class of stability as a function of the standard deviation of horizontal wind direction by horizontal wind speed and time of day. The classes range from A to F, extremely unstable to moderately stable, respectively. The D class represents neutral stability characteristics. The data show that unstable characteristics (A through C) occur about 11 percent of the time. Stable cases (E and F) occur about 43 percent of the time. Thus, neutral conditions (D) occur about 46 percent of the time.

3.4 SOILS

The surface soils at OU-2 are predominantly deep, well-drained loams, clay loams, and very cobbly sandy loams with slow permeability. The soils along the flood plain and low terraces of Woman and South Walnut Creeks consist of stratified loamy alluvium from the Haverson series and the Nunn clay loam (Figure 3.4-1). The soils at the top of the OU-2 mesa, where gravel

and cobbles of the Rocky Flats Alluvium are common, consist of gravelly and sandy loam from the Flatirons series. Along the slope of the mesa, soils consist of cobbly to sandy loamy alluvium with moderate permeability from the Nederland series and clay loams from the Denver, Denver-Kutch-Midway, and Midway series. The clay loams of the Denver-Kutch series and Englewood series are found along the eastern edge of OU-2. Small areas of the Leyden-Primen-Standley series, a cobbly clay loam, and the Standley-Nunn series, a gravelly clay loam, occur north of Central Avenue near Indiana Street. Runoff is generally rapid, and erosion hazard is severe on the steep portions of the hillside. Runoff is slow to moderate and erosion hazard is slight to moderate on flatter slopes near Woman Creek, near Indiana Street, and on top of the mesa. Shrink-swell potential is low in the Haverson series, low to moderate in cobbly and gravelly units, and high in all other units.

Most of the soil series are classified within the Argiustoll great group (Table 3.4-1). Argiustolls are generally characterized as well-drained soils with molic (dark) epipedons, argillic "B" horizons, and calcic "C" horizons. They exist in aridic and ustic (limited moisture) regimes, which are adequate for plant growth during the growing season. The two predominant subgroups are Torretic and Aridic. Torretic Argiustolls have a higher shrink-swell potential than Aridic Argiustolls (Department of Agriculture 1980).

3.5 GEOLOGY

This section, which presents descriptions, interpretations, and discussions of the geology of the OU-2 area, is divided into two subsections: Surficial Geology and Bedrock Geology. Geologic information presented in these sections uses data gathered during historical, Phase I, Phase II (alluvial and bedrock), and other ongoing investigations. The regional geologic setting surrounding the plant site is discussed in each section to assist in understanding the local geology. For more detailed discussions on the regional geology of the Front Range and High Plains surrounding the RFP site, the reader is referred to the Final Geologic Characterization Report (DOE 1991d).

Geologic interpretations in this section use both subsurface and surface data. Subsurface stratigraphic control was obtained from lithologic logs of core and/or cuttings collected during the drilling of boreholes and monitoring wells, lithologic mapping along trench walls, and borehole geophysical logs. Pre-1991 core and/or cuttings were logged according to a visual geologic protocol (DOE 1991d, Appendix G). Post-1991 core and/or cuttings were logged systematically and uniformly according to ER SOP GT.1 (EG&G 1992a). Table 3.5-1 lists the

investigations that have placed boreholes, monitoring wells and trenches in the OU-2 area along with the number of each category. Logs from 182 monitoring wells, 111 boreholes, and 3 trenches were used in this study. Appendix A4 contains the lithologic logs for monitoring wells and boreholes used in this study. Specific stratigraphic information obtained from these lithologic logs and used in construction of subsurface maps is summarized in Appendix A3. The locations of historical and Phase II boreholes and wells are shown in Plates 1.3-1 and 1.3-2 and Figures 2.1-1 and 2.1-2, respectively.

Surface geologic data were obtained from field geologic mapping of surficial deposits, bedrock outcrops, and air photo interpretation. Specific field activities involved in mapping are listed in Section 2.1.4. Field geologic mapping was conducted over the entire OU-2 study area, which extends from approximately 1,000-feet west of the 903 Pad eastward to Indiana Avenue, and from South Walnut Creek southward to Woman Creek.

The geology of the USHU (surficial deposits and Arapahoe No. 1 Sandstone) was evaluated based on available data from the historical, Phase I, and Phase II (alluvial and bedrock) field investigations. In some cases, data used in the evaluations are not shown on UHSU maps and cross-sections presented in this Phase II RFI/RI Report because the data were not available prior to preparation of the figures, or because of space limitations on the figures, as described below. However, all UHSU stratigraphic data used in the evaluations are included in this Phase II RFI/RI Report (Appendix A4).

Alluvial and No. 1 Sandstone stratigraphic data from 17 LHSU boreholes drilled during the 1993 Revised Bedrock Work Plan field program were not included on UHSU maps and cross-sections presented in this Phase II RFI/RI Report because those figures were completed prior to completion of the bedrock field program in the fall of 1993. However, the data from those 17 boreholes were reviewed against the completed UHSU maps and cross-sections and were judged not to conflict with or significantly alter the UHSU interpretations already presented on the figures. Therefore, revision of the UHSU maps and cross-sections to incorporate those 17 boreholes was judged to be unnecessary and was not performed. However, the UHSU stratigraphic data obtained from the 17 LHSU boreholes are included in this Phase II RFI/RI Report on lithologic logs presented in Appendix A4.

In addition, in some cases, certain alluvial and No. 1 Sandstone stratigraphic data are not shown on UHSU figures because of space constraints. Most alluvial and bedrock maps depicting geologic interpretations are illustrated at a horizontal scale of 1 inch = 300 feet. At this scale,

data from all closely spaced boreholes (particularly for multiple closely spaced boreholes drilled for well clusters) cannot be shown clearly, and therefore, some data not shown. However, the data from all boreholes were considered in the evaluations, and the data that are shown are representative of conditions in those areas. Furthermore, all USHU data are used in the interpretations are included in this Phase II RFI/RI Report on lithologic logs presented in Appendix A4.

Phase I and II subsurface remedial investigations within OU-2 have emphasized IHSS characterization and near-source and downgradient groundwater plume characterization. Closely spaced borehole and monitoring well control is, therefore, concentrated in an area extending from approximately 400 feet west of the 903 Pad to the eastern end of the East Spray Fields (Plates 1.3-1 and 1.3-2 and Figures 2.1-1 and 2.1-2). Phase II subsurface investigations reveal that a high degree of geologic variability occurs within the OU-2 area. A low degree of confidence and reliability exists if geologic features and trends are extrapolated from areas of closely spaced subsurface control into areas of sparse control. Due to this fact, subsurface mapping is restricted to the area of closely spaced subsurface control outlined above. Subsurface control outside this area is discussed when it adds to the geologic understanding of the OU-2 area.

Previous and present field programs within the OU-2 area have concentrated their investigations on the near surface (less than 300 feet depth) geologic units within the area. These units are of primary concern in terms of nature and extent of contamination due to past waste disposal practices at RFP. The main geologic units of concern are the Rocky Flats Alluvium, Arapahoe Formation, and the upper portion of the Laramie Formation (Figure 3.5-1).

3.5.1 Surficial Geology

Surficial geologic units within the OU-2 area consist of alluvial, hillslope, and man-made deposits. Alluvial deposits include the Pleistocene age Rocky Flats Alluvium, high terrace alluviums, and various Pleistocene to Holocene age valley-fill alluviums. Hillslope deposits consist of Holocene age colluvium, debris fans and slumps. Man-made deposits are artificial fill, soil and debris dumps, and areas of disturbed surficial soil. These deposits, their relative positions, and their ages shown in Figure 3.5-2.

The distribution of surficial units within the OU-2 area is shown in the Surficial Geology Map for the area (Plate 3.5-2). Stratigraphic relationships between the various alluvial deposits are

diagrammatically illustrated in Figure 3.5-3. Each surficial deposit is discussed in detail in the following sections.

3.5.1.1 Rocky Flats Alluvium

The Rocky Flats Alluvium is the topographically highest and the oldest alluvial deposit beneath RFP (Figure 3.5-3). According to Scott (1960), the Alluvium is believed to be Pleistocene (Nebraskan to Aftonian) in age (Figure 3.5-2). Rocky Flats Alluvium was deposited as large laterally coalescing alluvial fans along the base of the adjacent mountain front (Hurr 1976). These alluvial fans spread eastward over an extensive unconformity or erosional pediment surface that extended eastward from the mountain front. Regionally, the pediment surface slopes gently eastward toward the plains, yet locally it can be quite irregular with relief of as much as 50 feet (Malde 1955; Hurr 1976). This local relief is attributed to a well developed network of west- to east-trending paleostream drainages incised into the pediment surface beneath the alluvium (DOE 1991d).

Rocky Flats Alluvium beneath and in the vicinity of RFP was deposited in an alluvial fan that has its head in the mouth of Coal Creek Canyon west of the plant (Malde 1955). Fan deposits can be traced eastward from the mouth of the canyon for approximately seven miles. This deposit and underlying pediment surface have been subsequently dissected by down-cutting along the present drainage systems, leaving remnants of the deposit now capping the ridges or mesas between the drainages.

The Rocky Flats Alluvium within the OU-2 area caps the relatively flat divide or mesa between South Walnut and Woman Creeks and is completely truncated to the north, east, and south by those drainages. Rocky Flats Alluvium does not extend from the OU-2 mesa across the eastern OU-2/RFP boundary (i.e., Indiana Street) (Plate 3.5-2). The surface expression of the contact between the alluvium and underlying bedrock can be observed visually where the alluvium reaches a thickness of approximately 10 feet or greater. Under this condition, the alluvium forms steep resistant ledges, capping the hillsides of the adjoining drainages. A noticeable decrease in surface slope occurs at the base of the alluvium due to the less resistant nature of the underlying bedrock claystones and sandstones. The many groundwater seeps issuing from the alluvial/bedrock contact are indicative of the position of the base of the deposit. Vegetation change from the rocky/sandy soil of the Rocky Flats Alluvium to the clayey soil of bedrock is also a general indicator of the base of the alluvium.

3.5.1.1.1 **Top of Bedrock Features Controlling the Thickness and Geometry of the Rocky Flats Alluvium.** Relief on the top of the Rocky Flats Alluvium is relatively flat within the OU-2 area (1.3 degrees east dip). The unconformable contact between the Rocky Flats Alluvium and the underlying bedrock units, however, is highly irregular due to the shape of the underlying erosional top of bedrock surface. Therefore, the thickness and geometry of the Rocky Flats Alluvium is controlled by certain top of bedrock features. These features are discussed in the surficial geology section rather than the bedrock geology section (Section 3.5.2), because of their relevance to the geology of the Rocky Flats Alluvium.

As mentioned above, the erosional pediment surface beneath the Rocky Flats Alluvium locally has relief due to channeling by paleostreams. These streams represent a drainage system, either predating Rocky Flats Alluvium deposition or representing the incipient drainage system that brought Rocky Flats Alluvium deposition into the area.

Historical investigations in the OU-2 area defined several erosional features on the top of bedrock beneath the Rocky Flats Alluvium. The Phase I RFI/RI investigation of OU-2 (Rockwell International 1987c) defined four such features, namely two paleoridges and two paleovalleys. Figure 3.5-4 shows the major top of bedrock features interpreted in the historical reports for OU-2. One paleovalley was interpreted to be located north of the 903 Pad. The feature extends eastward roughly following Central Avenue. In the Southeast Trenches Area, the paleovalley joins another paleovalley, which trends northeast. This second paleovalley is projected to the northeast beyond subsurface control.

A paleoridge was interpreted to be located directly south of the 903 Pad. The ridge extends east/northeast and terminates approximately beneath the Southeast Trenches Area. A second paleoridge is shown located beneath the Mound Area and extends north of the Northeast Trenches Area (Figure 3.5-4). The ridge is projected further to the east beyond subsurface control.

A later sitewide investigation (DOE 1991d) summarized and reinterpreted these and other data. The report defines, "a prominent step in the bedrock surface" occurring beneath the east end of the SE Trenches Area (Figure 3.5-4). The bedrock step trends north-northeast. A 30-foot drop in elevation of the top of bedrock surface across the feature (west to east) is reported. The earlier Phase I RFI/RI report illustrated this "step" on its top of bedrock elevation map and presumably considered the feature to be a steep flank of the southern paleoridge and not a separate feature. DOE (1991d) suggests that this bedrock "step" may delineate the eastern limit

of a north-south oriented meander segment of the underlying Arapahoe No. 1 Sandstone. The sandstone, being more resistant to erosion than the surrounding claystones, would presumably hold up the higher portion of the step and adjoining paleoridge. Based on Phase II field investigations, this DOE (1991d) interpretation, although plausible, is considered to be unlikely (Section 3.5.2).

Phase II field investigations have confirmed the existence of the two paleoridges, two paleovalleys, and a bedrock step feature mentioned above. Figure 3.5-5 shows the contoured surface of the top of bedrock using historical, Phase II, and other subsurface control; and Figure 3.5-6 shows the revised locations of the ridge crests and trough lines based on that control. Figure 3.5-7 is a "shaded" relief view of the top of bedrock surface, and Plate 3.5-1 is a "three-dimensional" perspective view showing the relationship of OU-2 topographical features to the underlying top of bedrock surface. Profiles of the top of bedrock illustrating the main erosional features are shown in Figure 3.5-8. The geometry and extent of the features are changed in certain areas from earlier interpretations based on subsurface control obtained from the Phase II and other drilling programs. Changes are significant beneath and around the 903 Pad Area and in an area east of the Northeast Trenches Area and north of the Southeast Trenches Area (compare Figures 3.5-4 and 3.5-6). Little to no subsurface data were available for these areas during Phase I and earlier investigations.

For purposes of further discussion, the previously mentioned top of bedrock features are referred to as the following:

- North paleoridge
- South paleoridge
- Medial paleoscour (western paleovalley of Rockwell International 1987c)
- Eastern low (eastern paleovalley of Rockwell International 1987c)
- Bedrock step

North Paleoridge: The presence and geometry of the north paleoridge is clearly indicated by borehole control from the Mound Area to several hundred feet northeast of the Northeast Trenches Area (Figure 3.5-5). West of the Mound Area, the presence of the ridge is less certain. The contoured north flank of the paleoridge in this area (Figure 3.5-5), may be an artifact of PA construction (i.e., top of bedrock may have been artificially lowered by grading and leveling during PA construction). Northeast of the Northeast Trenches Area, the top of bedrock surface was intersected for a distance of approximately 140 feet by two overlapping

trenches (Dames and Moore 1981). The top of bedrock surface exposed in those trenches was observed to rapidly lose elevation by about 13 feet over this distance. East of these trenches, the location and geometry of the north paleoridge is speculative since subsurface control is limited.

South Paleoridge: The presence and geometry of the south paleoridge is clearly indicated by subsurface control from an area southwest of the 903 Pad to the Southeast Trenches Area (Figure 3.5-5). In the Southeast Trenches Area, the ridge trends to the north and then trends eastward again. North of the East Spray Fields, the ridge location and geometry are more speculative due to limited subsurface control. Along the western portion of the south paleoridge, the crest elevation is from about 4 to 14 feet lower than the adjoining north paleoridge (Figure 3.5-8, sections A-A' and B-B'). To the east, the adjoining paleoridge crests are at similar elevations (Figure 3.5-8, sections C-C' and D-D'). These crest elevation relationships are important factors in controlling groundwater flow and alluvial seep locations along the South Walnut and Woman Creek drainages. These relationships will be discussed later in Section 3.6 (Hydrogeology).

Medial Paleoscour: In this report, the medial paleoscour refers to the western paleovalley feature defined by Rockwell International (1987c). From the 903 Pad Area to an area approximately 400 feet east of the Northeast Trenches Area, subsurface control clearly indicates the presence and geometry of the medial paleoscour (Figure 3.5-5). To the west, the trough line of the paleoscour is located beneath the southeast corner of the 903 Pad. It extends east-northeastward directly beneath the inner east gate entrance. Near the Southeast Trenches Area, the Paleoscour bends to the north, then resumes an east-northeast trend. Further to the east, the feature is interpreted to take a northward bend and is truncated along the South Walnut Creek hillside. Where this paleoscour intersects the hillside, a well-developed surface drainage gully has developed (Figure 3.5-6). Groundwater is observed to seep from the Rocky Flats Alluvium along the head of this drainage gully during portions of the year. This groundwater discharge in turn feeds surface water flow in this drainage. This intersection of the medial paleoscour along the South Walnut Creek hillside is discussed further in Section 3.6 (Hydrogeology).

The relief between the trough line of the paleoscour and the adjoining ridge crests is shown in Figure 3.5-8. Maximum relief, located east of the Northeast Trenches Area, is approximately 30 feet (Figure 3.5-8, cross-section C-C'). West and east of cross-section C-C', along the scour, relief ranges from about 10 to 26 feet (cross-sections A-A',B-B',D-D').

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Bedrock Step: This is a north-northeast trending feature located beneath the eastern end of the Southeast Trenches Area (Figures 3.5-5 and 3.5-7, and Plate 3.5-1) characterized by an abrupt west to east drop (approximately 30 ft) in the elevation of the top of bedrock (Figure 3.5-8, Section F-F'). It is uncertain whether the feature extends north or south of the Southeast Trenches Area, because of the lack of subsurface data in those areas.

For the purposes of this discussion and to be consistent with previous reports (DOE 1991d), the term "bedrock step" is used to refer to the physiographic nature of this feature (i.e., the drop in top of bedrock elevation). As discussed below, the origin of this feature is uncertain and the term "bedrock step" does not infer a mechanism for the origin of this feature.

In 1976, Hurr discussed the possibility that the Eggleston Fault (north of RFP) may extend onto RFP. The geologic map in that report, showed the fault projected into the OU-2 area at the approximate location of the bedrock step. He inferred a vertical separation across the fault of approximately 20 feet. Dames and Moore (1981) investigated this possible extension of the Eggleston fault by excavating three trenches to bedrock along Hurr's projected fault within the OU-2 area. Numerous small-scale faults offsetting bedrock units were observed. Associated with these faults were zones of very steeply dipping bedding, contorted and disrupted bedding, and abruptly truncated beds. The faults were also characterized by the absence of fault gouge, lack of brecciated rock, and a high degree of induration. These characteristics led Dames and Moore to conclude that these features are not tectonic structures but rather syndepositional features (i.e., gravity slumps or growth faults) occurring during deposition of the bedrock material (refer to Dames and Moore 1981 for details on this investigation).

During the Phase II field program, the possibility of intersection of the bedrock step with the hillsides of South Walnut and Woman Creeks was investigated. The base of the Rocky Flats Alluvium (i.e., top of bedrock), where the bedrock step might intersect the hillsides, was closely observed and mapped. No conclusive evidence to project the bedrock step from the Southeast Trenches Area into either hillside was identified. Therefore the interpreted location of the feature is confined to directly beneath the Southeast Trenches Area. Also, the presently available subsurface control does not show any offset of bedrock lithic units across the feature. To date, a tectonic origin for the feature cannot be conclusively established or refuted based on the available geologic data. The location of the feature suggests it may be a steep erosional portion of the flank of the south paleoridge. The flanks of the medial scour, northwest of the step, exhibit similar steep flanks which are believed to be erosional in origin.

For the purposes of the Phase II RFI/RI investigation, the exact nature of the bedrock step feature does not appear to be of substantial importance because hydrogeologic data do not indicate that this feature substantially influences groundwater flow or contaminant migration (Sections 3.6 and 5.0). Therefore, resolution of the question of whether the origin of this feature is tectonic or erosional does not appear to be necessary at this time.

Eastern Low: A broad northeast trending bedrock low formerly referred to as a paleovalley (Rockwell International 1987c) is located beneath the East Spray Fields and directly east of the bedrock step (Figures 3.5-5 and 3.5-7, and Plate 3.5-1). East of the East Spray Fields, the geometry of the low is unknown because subsurface data are absent. The relief between the low and the adjacent paleoridge is approximately 12 feet (Figure 3.5-8, cross-section D-D').

3.5.1.1.2 Alluvial Thickness. A contour map of the thickness of the Rocky Flats Alluvium is shown in Figure 3.5-9. As discussed above, alluvial thicknesses is controlled primarily by the underlying top of bedrock features. Thickest alluvial sections correspond with the medial paleoscour and eastern low. Thinner sections occur along the crests of the adjacent paleoridges. Alluvium is thinnest along the north paleoridge where it ranges from about 5 feet (borehole 03491) to 17 feet (well 4386). The south paleoridge is capped with alluvium ranging in thickness from about 12 feet (boreholes 10591 and BH5087) to 22 feet (well 1587). Alluvium in the medial paleoscour ranges in thickness from about 20 feet (borehole 42792) to 38 feet (borehole 11391). The thickest section of alluvium occurs in the head area of the eastern low (beneath the East Spray Fields). Here, the thickness reaches about 46 feet (well 3287 and borehole 10791). Figure 3.5-10 illustrates representative cross-sections of alluvial thickness along the same lines as the top of bedrock profiles in Figure 3.5-8.

3.5.1.1.3 Alluvial Lithofacies.

Alluvial Fan Deposition: As mentioned earlier (Section 3.5.1.1), the Rocky Flats Alluvium is a pediment gravel deposited in an alluvial fan environment along the base of the adjacent mountain front (Malde 1955). Alluvial fans typically develop where streams and/or debris flows emerge from the confines of a valley or canyon into an adjoining basin. As sediment-laden streams exit the mouths of canyons, the lack of confinement allows the stream to flow over a wider, less restricted area. As stream flow widens, flow velocity decreases and some or most of the sediment load is deposited.

Two main depositional processes have been identified on modern fans (Spearing 1971). These are mass-flow (debris flow) and water-flow, including stream channel and sheetflow. Debris flows usually occur during periods of intense rainfall when geologic material containing fine debris, especially clay, loses its sheer strength and moves down slope as a dense viscous mass. The high viscosity of the flows inhibit sorting and therefore deposits characteristically display a chaotic orientation of cobbles and boulders in a matrix of fine material (Spearing 1971). Debris flow deposits usually occur in rather narrow lobes along the fan surface and seldom produce extensive sheet deposits (Reading 1986).

Water-flow across the fan surface occurs either as channelized flow within main braided stream channels or as sheet flow across the surface during flood events. Water-lain deposits can form more laterally extensive deposits than debris flows, and the abundance of water allows the finer material to be winnowed out. The resulting deposits typically contain only minor amounts of clay matrix (Spearing 1971). Alluvial fans that are dominated by stream deposition produce thick sequences of stacked channel deposits (Reading 1986).

Classification System: The Rocky Flats Alluvium within the OU-2 area consists predominantly of beds and lenses of poorly to moderately sorted gravels and sands. A few lenses of clay and silt also occur. Alluvial materials obtained during the drilling of boreholes and monitoring wells were classified according to the Unified Soil Classification System (USCS; U.S. Army Engineer Waterways Experiment Station 1960). The USCS is a textural classification system based upon the percentage of gravel, sand, silt and clay, the observed plasticity of the fines and the organic content of the material. At RFP prior to 1991, alluvial materials were classified into the USCS by visual estimations of these textural parameters. Alluvial materials obtained during and after 1991 were classified into the USCS by grain-size sieve analysis and plasticity tests according to ER SOP GT.1, (EG&G 1992a). Lithologic logs of core and cuttings of the Rocky Flats Alluvium for all boreholes and monitoring wells within the OU-2 area are contained in Appendix A4. Along with the USCS codes or classifications, the lithologic logs give geologic descriptions of the alluvial materials. Grain-size percentages obtained by sieve analysis are also listed for 1991 and more recent boreholes and monitoring wells. As discussed in Section 2.0, samples of Rocky Flats Alluvium and Arapahoe Formation bedrock materials were analyzed in a geotechnical laboratory for physical property information. The results of the geotechnical analyses are summarized in Table 3.5-2.

Of the fifteen USCS soil classifications or codes, twelve codes are used to describe the geologic materials within the Rocky Flats Alluvium. These twelve USCS soil codes and brief descriptions

are shown in Figure 3.5-11. The USCS is a classification system originally devised to classify unconsolidated materials according to their engineering properties. The system is based on those characteristics of the soil that indicate how it will behave as an engineering construction material. Thus, individual classifications are not necessarily useful in construction of lithofacies or in evaluation of depositional systems and geological processes. To use the USCS in lithofacies construction, classifications were group based upon their similar textural characteristics and probable genetic relationship. For instance, sandy gravels with little to no fines (GW) are probably genetically related to gravelly sands with little to no fines (SW). Both units were probably the depositional product of high velocity flow streams in which winnowing removed most of the fine (silt and clay) fraction.

USCS classifications were grouped into three lithofacies based upon the percent of fines (silt and clay) within the material and probable similarity in depositional process. The lithofacies consist of four individual USCS codes each, but for ease of further discussion, they are referred to by the most dominant lithology comprising the facies. These lithofacies are listed and briefly described below:

- **Sandy Gravel Lithofacies** (USCS codes - GW, GP, SW and SP). Consists of well-graded to poorly-graded gravels, sands and sand/gravel mixtures with little to no fines. Fines generally make up five percent or less of the soil.

- **Clayey Gravel Lithofacies** (USCS codes - GC, GM, SC and SM). Consists of gravels and sands containing various amounts of silt and clay. Total fines generally exceed 20 percent of the soil.

- **Clay Lithofacies** (USCS codes - ML, CL, OL and CH). Consists of clays and silts containing some gravel, sand and/or organic matter.

To illustrate the subsurface distribution of these lithofacies within the area, cross-sections were constructed. Cross-section locations are shown in Figure 3.5-12. Early evaluations of lithofacies distributions revealed that distributions were influenced or controlled in part by the top of bedrock features discussed earlier. Therefore, sections are constructed along the trends of top of bedrock features to best illustrate these relationships. Cross-section AA-AA' (Figure 3.5-13), is a dip line showing the distribution of lithofacies along the trend of the north paleoridge. Cross-section AB-AB' (Figure 3.5-14) is a dip line showing the lithofacies distribution along the medial paleoscour. Cross-section AC-AC' (Figure 3.5-15) is another dip line showing the

distribution of lithofacies along the eastern portion of the south paleoridge, across the bedrock step and across the eastern low. Cross-section AD-AD' (Figure 3.5-16) is a strike line across the OU-2 pediment, perpendicular to the paleoridges and scour, which ties the dip lines together. The three lithofacies and their distribution within the area are discussed in the following text. The averages and ranges of grain size percentages stated in the following descriptions are based upon the lithologic logs from boreholes and monitoring wells shown within the aforementioned lithofacies cross-sections, not upon all lithologic logs within the OU-2 area.

Sandy Gravel Lithofacies: This lithofacies consists predominantly of moderately sorted sandy gravels with lesser amounts of gravelly sands. Gravel ranges in size from pebbles (noted in drill core samples) to cobbles and boulders (observed in the field in excavations or roadcuts). Stones are typically subrounded and consist predominantly of quartzite, granitic and metamorphic rocks. Sand ranges in size from fine to very coarse grained and is usually angular to subrounded. Grains are composed primarily of quartz with some feldspars, rock fragments and traces of mica and dark minerals. Iron staining on stones and sand grains is common. No apparent bedding is discernable in drill core samples. Predominant colors for gravels and sands are browns, yellowish browns and pale to yellowish orange. The average and range of grain size percentages comprising the gravels and sands are as follows:

Gravels (GW, GP):	Average (%)	Range (%)
Gravel -	67	49-95
Sand -	28	5-46
Fines -	5	0-11

Sands (SW, SP):	Average (%)	Range (%)
Sand -	64	50-80
Gravel -	31	15-41
Fines -	5	1-7

The sandy gravel lithofacies is the predominant facies that occurs along the crest of the north paleoridge over the western two thirds of its length (Figure 3.5-13). The facies extends down both flanks of the paleoridge; southward toward the paleoscour and northward until the unit is truncated by the hillside of South Walnut Creek (Figure 3.5-16). The lithofacies also occurs along the south flank of the south paleoridge (Figure 3.5-16). Sandy gravel comprises the bulk

of the Rocky Flats Alluvium in the eastern portion of the OU-2 area (Figures 3.5-14 and 3.5-15).

Clayey Gravel Lithofacies: This lithofacies consists predominantly of poorly sorted clayey gravels and clayey sands with lesser amount of silty gravels and silty sands. Gravel and sand grain size range and other sedimentological properties are the same as listed above for the Sandy Gravel lithofacies. Crude bedding and/or laminations are discernable in some clayey and silty sands. No apparent bedding is discernable in gravels. The colors of these gravels and sands are quite variable . Colors include various shades of brown, pale to grayish orange, yellowish to pinkish gray, blackish red and pale olive. The average and range of grain size percentages comprising the gravels and sands are as follows:

Gravels (GC, GM):	Average (%)	Range (%)
Gravel -	53	33-80
Sand -	22	10-38
Fines -	25	13-46

Sands (SC, SM):	Average (%)	Range (%)
Sand -	60	35-84
Gravel -	13	1-40
Fines -	27	11-43

The clayey gravel lithofacies is the dominant alluvial facies within the medial paleoscour (Figure 3.5-14 and 3.5-16), except for areas along the south flank of the north paleoridge where sandy gravel occurs, as mentioned earlier. The facies onlaps the crest of the adjacent south paleoridge and occurs along the eastern side of the bedrock step (Figures 3.5-15 and 3.5-16). Farther to the east in the vicinity of the eastern low, the facies interfingers with the sandy gravel facies. The facies also occurs along the north paleoridge, east of where the paleoridge rapidly loses elevation along its crest.

Clay Lithofacies: This lithofacies consists predominantly of clay with some silt. Clays are typically gravelly, sandy or silty. Silts are gravelly and sandy. Organic rich silty clay (OL) was observed at the surface based on a drill core sample from monitoring well 05091. Clay rip-up clasts may occur in clay units directly overlying bedrock. No apparent bedding is discernable in drill core samples. Colors range from browns, reddish and yellowish brown to pale orange.

Clay units directly overlying bedrock are typically yellowish to light olive gray in color. The average and range of grain size percentages comprising clays and silts are as follows:

Clays and Silts (ML, CL, OL and CH):	Average (%)	Range (%)
Fines -	70	57-85
Sand -	18	5-39
Gravel -	12	0-21

The clay lithofacies occupies two stratigraphic positions within the OU-2 area. It occurs throughout the area as thin lenses within the other lithofacies, and occurs directly overlying bedrock.

3.5.1.2 High Terrace Alluviums

Several alluvial terrace deposits occur along the hillsides within the OU-2 area. These deposits are located topographically below the Rocky Flats Alluvium, but above the Valley Fill Section 3.5.1.3. Malde (1955) referred to these deposits as terrace gravels and undifferentiated upland deposits. Hurr (1976) and Rockwell International (1987c) named two of these deposits, the Verdos and Slocum Alluviums, placing them into the formal classification system for the Quaternary developed by Scott (1960) The deposits are considered to be Pleistocene (Kansan to Wisconsin) in age (Figure 3.5-2).

During the Phase II field investigations, three widespread alluvial terrace deposits were identified and mapped along the hillsides of OU-2 (Plate 3.5-2). Placement of these alluvial terraces into the formal classification system for the Quaternary (Figure 3.5-2) requires information on physiographic position of terraces relative to stream base, superposition, ancient soil development, presence of fossil mammals and mollusks, absolute age dating and presence of synchronous volcanic ash beds, where available (Scott 1960). Currently, an RFP sitewide Surficial Deposits Mapping Project is underway as a joint effort of DOE and the U.S. Geological Survey (Tim Lovseth, 1993, EG&G, Personal Communication). This investigation may acquire some of the necessary information to correlate these alluvial terrace deposits across RFP and place them into the formal Quaternary classification system.

Placement of the alluvial terrace deposits into the formal classifications system is not crucial to the data needs of the OU-2 Phase II RFI/RI investigation. Therefore, until the Surficial Deposits Mapping Project is complete, these deposits are simply referred to as high terrace

alluviums. Terrace No. 1 (Qt_1) is topographically the highest alluvium; Terrace No.2 (Qt_2) is intermediate in elevation; and Terrace No.3 (Qt_3) is the lowest. While these three terraces are widespread throughout the area, several other terrace alluviums occur at other topographic intervals. Only small remnants remain of these deposits and they are traceable for only short distances along the hillsides. These terraces are referred to as undifferentiated high terrace alluviums (Qt_u). Some of these deposits were mapped and are shown in Plate 3.5-2. The positions of the terrace deposits below the top of the adjoining Rocky Flats Alluvium are summarized in Table 3.5-3.

Erosion by cross drainages along the hillsides has dissected the terrace deposits, leaving only remnants of formerly laterally extensive deposits. Where a remnant is relatively large or wide (perpendicular to the hillside), the deposit exhibits a relatively flat top with adjoining steep flanks (Figure 3.5-17). Where a remnant is small in extent, the deposit displays a knoll or mound morphology. Earlier investigations may have interpreted this knoll morphology developed on some small terrace remnants as surface indications of landslides or slump features. This interpretation will be discussed in Section 3.5.1.6.

Thicknesses of terrace alluvium encountered in boreholes range from about 2 feet (borehole 09291) to 22 feet (well 05991). Thinner sections are probably the result of erosion of the deposit and not original depositional thicknesses. Average thicknesses of terrace alluviums (measured in the field) are listed in Table 3.5-3.

Lithologically, terrace alluvium exhibits a distinct fining upward sequence of lithic units. This vertical stratification distinguishes these deposits from the surrounding non-stratified colluvium or slopewash. Alluvium usually consists of a basal unit of clayey or sandy gravel overlain by sandy clay, clayey sand, or an interbedded sequence of both (Appendix A4; logs 6786 and 09791). Gravel is subangular to rounded and ranges in size from pebbles (noted in drill core samples) to boulders (observed in the field in excavations or roadcuts). Clays and sands commonly contain carbonaceous matter and roots. Calcium carbonate precipitant (caliche) commonly occurs throughout the deposit. Predominant colors of browns and yellow-browns reflect heavy oxidation. Less frequently occurring colors consist of grayish browns, brownish grays, and pale orange.

Within the OU-2 area, Terrace Alluvium is encountered in the boreholes and monitoring wells listed in Table 3.5-4. (See Appendix A4 for lithologic logs.)

3.5.1.3 Valley-Fill Alluvium

Valley-Fill Alluvium (Q_{al}) is defined in this report as Quaternary (Wisconsin to Holocene) age alluvium that occurs beneath and adjacent to the present creeks. This designation includes alluvium forming low (less than 40 feet above the creeks) terraces along the drainages. Various alluviums at this level have been formally named for the Quaternary along the Front Range (Figure 3.5-2). Those which may occur within the Valley-Fill designation used in this report include Post-Piney Creek, Piney Creek, Pre-Piney Creek, Louviers and Broadway alluviums (Figure 3.5-3). Pond sediments within the drainages are also included within the Valley-Fill designation.

Valley-Fill Alluvium is derived by the reworking and redeposition of the Rocky Flats Alluvium, high terrace alluvium, colluvium, and bedrock units exposed along the adjacent hillsides. The distribution of Valley-Fill Alluvium within the OU-2 area is shown in Plate 3.5-2. Upstream from B-5 pond, the deposit is narrowly confined along South Walnut Creek. Along the main trunks of Walnut and Woman Creeks, valley fill covers a broad plain adjacent to the creeks. Where this broad plain is formed, some of the above named low terrace alluviums are recognizable.

Where penetrated by boreholes, Valley-Fill Alluvium ranges in thickness from about 2 feet (well 6491) to 15 feet (well 41691). Lithologically, the Valley-Fill Alluvium consists predominantly of interbedded gravelly sands and sandy to clayey gravels. Gravel is sub-angular to sub-rounded and ranges in size from small pebbles (noted in drill core samples) to boulders (observed in the field in excavations and roadcuts). Clay, silty to sandy clay, and clayey to silty sand occur in lesser amounts. Yellow browns are the predominant color for the gravels and sands. Clay colors are olive to yellow grays, gray brown, and dark yellow brown.

Within the OU-2 area, Valley-Fill Alluvium was encountered in the boreholes and monitoring wells listed in Table 3.5-5. (See Appendix A4 for lithologic logs.)

3.5.1.4 Colluvium

Colluvium is defined as unconsolidated geologic materials that are deposited on slopes or at the base of slopes predominantly by the transporting action of rainwash, sheetwash or slow continuous downslope creep (Bates and Jackson 1980). Colluvial deposits at OU-2 overlie the eroded bedrock surfaces that slope toward the South Walnut and Woman Creek drainages.

Colluvium within the OU-2 area is Holocene in age (Figure 3.5-2) and is the most commonly occurring surficial deposit covering the hillsides of the South Walnut and Woman Creek drainages (Plate 3.5-2).

Lithologically, colluvium consists predominantly of clay, silty clay and sandy clay. The source of this material is the claystones, siltstones and sandstones of the Arapahoe and Laramie Formations that underlie the hillsides. Most of the above lithologies encountered in boreholes contain some (less than 15 percent) pebbles and cobbles scattered throughout the material. This coarse-size material is shed off the Rocky Flats Alluvium and high terrace alluviums where present. Lesser lithologies encountered in boreholes are clayey sand, gravelly clay (greater than 20 percent gravel), and clayey gravel.

In the field, colluvium along and onlaping the base of the Rocky Flats Alluvium is typically coarser than the colluvium located further downslope, reflecting the different source materials. Colluvium typically lacks any apparent bedding structures, is non-stratified and is poorly sorted (well-graded) reflecting its deposition by gravity and absence of winnowing by running water. Lithologic logs for borehole 01191 and monitoring well 02491 illustrate typical colluvial sections for the OU-2 area (Appendix A4).

Calcium carbonate precipitant (caliche) is common throughout the deposit. It occurs as thin layers, discrete nodules, or is disseminated throughout the deposit. Carbonaceous matter is also common in the near surface portions of the deposit. The deposit is usually highly oxidized which is evident by mottled colors of browns, yellow browns, and grayish orange. Colluvium containing a high percentage of organic matter may have a dark gray color (well 11791). Where the deposit is not highly oxidized, gray and olive gray colors reflect the original color of the parent bedrock material.

The thickness of the colluvium along the hillsides of OU-2 is shown in Figure 3.5-18. Thickness data from high terrace alluviums and artificial fill (where present) were also included in construction of the contour map. Thickness varies from about 2 feet (borehole 01091) to 22 feet (well 6286).

The thickness of the colluvium is controlled in large part by the shape of the underlying bedrock surface. In areas where bedrock lows occur along the slopes, the colluvium is thicker. In areas where bedrock highs occur, the colluvium is thinner. An example of this is found south and southeast of the 903 Pad along the north slope of the Woman Creek drainage. Three

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prominent cross-scours or gullies have been eroded into the bedrock in that area (Figure 3.5-5 and 3.5-7). In each of those locations, relatively thick deposits of colluvium occur, infilling the scours. Conversely, relatively thin areas of colluvium overlie the bedrock high areas separating the scours (Figure 3.5-18).

Within the OU-2 area, colluvium was encountered in the boreholes and monitoring wells listed in Table 3.5-6. (See Appendix A4 for lithologic logs.)

3.5.1.5 Debris Fans

Many cross-drainages or transverse gullies (i.e., perpendicular to slope) occur at ground surface along the hillsides within OU-2. Distinct fan-shaped deposits, interpreted as debris fans, are located at the bases of eight of these drainages. Most of these fans are located in the northeastern portion of OU-2 on the hillside adjoining South Walnut Creek, northeast of B-5 pond (Plate 3.5-2). The fans are Holocene in age and onlap or commingle with the adjoining valley fill deposits.

Lithology and thickness of these deposits is presently unknown since no boreholes have been drilled through the deposits. All fans are well vegetated and show no signs of recent seasonal erosion or deposition.

3.5.1.6 Slumps

During the Phase II field investigations, numerous slump features were identified and mapped within the OU-2 area. The majority are located along the hillside adjoining South Walnut Creek (Plate 3.5-2). In this report, slump features belong to two categories: (1) areas along the hillsides which exhibit evidence of mass movement of surficial soil and possibly bedrock materials along relatively distinct ruptures or glide surfaces and (2) areas of hummocky topography reflecting downslope creep of surficial soils but no observable rupture surface.

The majority of slump features in the OU-2 area belong to the first category. Surficial deposits along the hillside are observed to be displaced in these slumps, but the extent of bedrock involvement is unknown due to absence of subsurface control. Detachment scarps are usually developed along the head areas of slump features. Many slump features display multiple scarps recording sequential movement of the slumps. Some scarp faces are relatively fresh (non-

vegetated and moist) suggesting recent movement. Vertical displacements on scarp faces range from several inches to three feet. Typical displacements are one foot or less.

Slumps within the OU-2 area are usually located downgradient from alluvial or bedrock groundwater discharge areas. The discharge of groundwater increases the water saturation within downgradient soils which apparently leads to shear failure of the material.

In two earlier investigations, several potential slump features were identified along the north hillside of Woman Creek (Figure 3.5-19). EG&G (1990c) mapped four potential slump features of various sizes that were located within OU-2. The features were numbered WMCN1 - WMCN4. These features were reportedly located within a "restricted" area (i.e., Radiologically Controlled Area) and access at the time of the study was not feasible. Therefore, the features were located on a base map and qualitatively described from outside this restricted area, presumably from the south side of Woman Creek. DOE (1992i) recognized several large slump features based on interpretation of air photographs. These features were named WMCN1-WMCN6 in accordance with the EG&G 1990c designation. These features were much larger in dimensions than the earlier identified slump features (Figure 3.5-19). The features were not confirmed by field investigation.

During the OU-2 Phase II field investigations, surficial deposits along the Woman Creek hillside were mapped (Plate 3.5-2). The large slump features identified by the DOE (1992i) study could not be verified by field investigation. Two of the smaller slump features identified by the EG&G 1990c study, specifically WMCN2 and WMCN4, spatially correspond with small remnants of high terrace alluvium mapped in this study (Figure 3.5-19). The knoll or mound morphology developed on these small terrace remnants may have been interpreted as slump morphology by the EG&G 1990c investigation. The existence of slump features WMCN1 and WMCN3 could not be verified by field investigations during this study.

3.5.1.7 Man-made Deposits

Man-made deposits within the OU-2 area were identified using information from historical reports; air photography of the OU-2 area covering the years 1955, 1964, 1969, and 1971; and field identification and mapping of deposits during the summers of 1992 and 1993. Three general categories of man-made deposits are identified: soil and debris dumps, disturbed ground, and artificial fill. The locations of these deposits are shown in Figure 3.5-20. Artificial

fill deposits are also shown on Plate 3.5-2. These three categories of man-made deposits are discussed in the following text.

Soil and debris dumps within the OU-2 area consist of irregular shaped mounds or areas of discarded soils and construction debris, such as asphalt or concrete. Three mounds of soil and minor amounts of construction debris are located southwest of B-1 pond (Figure 3.5-20). A dump or surface pour of concrete is located due north of the old practice firing range. Concrete was apparently poured over the pediment edge formed by the Rocky Flats Alluvium. Some disturbance in this area is noticeable as early as 1964. By 1969, the bulk of the concrete appears to have been dumped. A large soil dump area is located within the East Spray Fields, south of Central Avenue. The dump area is noticeable on 1964 and later air photos of the area. Soil appears to have been dumped and then graded to produce a low broad mound.

Disturbed ground within OU-2 consists of areas where surface soils have been removed, graded, or otherwise disturbed during construction or interim remedial activities. During construction of the PA located north of Central Avenue, extensive areas of surface soils were graded. Surface soils within the Mound Area adjacent to the PA were graded after excavation of the Mound Site in 1970. In 1968, the surface soils beneath the 903 Pad were graded prior to placement of the asphalt cap over the area. From 1976 through 1984, the 903 Lip area, located south and east of the 903 Pad, had extensive surface soil removed as part of the interim cleanup efforts to remove plutonium-contaminated soils. After removal, clean topsoil was usually backfilled.

Artificial-fill within the OU-2 area consists of man-made placement of soils and/or aggregate to backfill disposal trenches or to produce earthen structures for various purposes. Thirteen trenches (T1-T11) were backfilled with portions of the soil originally removed from the trenches at the time of excavation. Backfilling usually resulted in a slight mounding of the backfilled soil over the approximate outline of the trench. Through time, backfill in some areas has settled and shifted, resulting now in surface depressions along some portions of the trenches.

Artificial fill consisting of aggregate and soil was used in construction of the dams for the B and C series ponds. Dam fill is shown in Figure 3.5-20 and Plate 3.5-2. Native geologic materials that were excavated along the Woman Creek hillside during construction of the South Interceptor Ditch (SID) were placed all along the south flank of the ditch. During construction of the PA artificial fill was most likely extensively used to level areas for building purposes. The South Walnut Creek topographic drainage was filled with large amounts of soil at two locations

(Figure 3.5-20). Infilling was accomplished in order to bring these areas up to grade for the security fence and road construction.

Artificial fill was placed beneath and west of the old practice firing range along the Woman Creek hillside. Fill was probably used to level the site prior to construction. The lift is several feet thick along the fill area west of the practice range and thickens beneath the range itself. A linear soil berm was placed along the extreme eastern edge of the practice range as a backstop. A small berm of soil was place around the base of a high tension electrical line pole located south of the East Spray Fields (Figure 3.5-20). A small elongate berm of unknown origin is located due south of the old gravel quarry. The berm appears on air photos at the same time as quarry activities and is probably associated with this operation. Several feet of graded artificial fill is located due south of the fence surrounding the 903 Lip area.

3.5.2 Bedrock Geology

Bedrock geologic units investigated in this study consist of claystones, siltstones and sandstones of the Arapahoe Formation and the upper portion of the Laramie Formation (Figure 3.5-1). Several bedrock sandstone nomenclatures have been used in previous investigations that cover the OU-2 area. These investigations have also proposed differing geologic ages for bedrock units within the study area. These past nomenclatures and age assignments are discussed here along with the bedrock designations used in this report.

In 1987, the Phase I remedial investigation of OU-2 (Rockwell International 1987c) defined the shallow bedrock beneath the area as consisting predominantly of claystone with some sandstones, siltstones and occasional lignite deposits. The report states that sandstones are generally lenticular and discontinuous, so correlations between boreholes were tenuous. Sandstone intervals were, therefore, not named or labeled, and the number of intervals encountered beneath the site was not determined. All bedrock units encountered were assigned to the Arapahoe Formation.

In 1991, a shallow, high-resolution seismic investigation of the OU-2 area was completed (DOE 1991e). This investigation defined three anomalous seismic zones which were interpreted as representing sandstone intervals within the shallow bedrock. This report referred to these zones as channel zones A, B, and C. Channel zone A is the shallowest zone and channel zone C is the deepest. Due to the absence of coarse conglomerate within the OU-2 area (characteristic of the base of the Arapahoe Formation), the investigation suggested that the shallow bedrock

beneath OU-2 may be wholly Laramie in age. The Arapahoe Formation was considered to be eroded or not deposited within the area.

Later in 1991, the Final Geologic Characterization Report (DOE 1991d) defined at least five mappable sandstone intervals within the shallow bedrock beneath RFP. This report designated these intervals as Sandstones No. 1 through No. 5. Sandstone No. 1 being the shallowest interval and Sandstone No. 5 being the deepest. The sandstones were said to be lenticular in geometry and may not be present in all boreholes or areas beneath RFP. The base of the Arapahoe formation was tentatively placed at the bottom of the No. 5 Sandstone. This designation made the Arapahoe Formation approximately 150 feet thick in the central portion of the RFP. Phase II (Alluvial and Bedrock) RFI/RI workplans (DOE 1991a; 1991b) used this No.1 through No.5 designation for the sandstones beneath the OU-2 area as well.

In 1992, a palynologic study of bedrock core samples from the RFP site (many from the OU-2 area) was undertaken (DOE 1993e). The study analyzed spores, pollen, dinoflagellates and acritarchs (marine plankton), collected from the bedrock materials for age and environments of deposition determinations. According to C. Dodge (EG&G 1993b, personal communication), this study has tentatively age-dated the geologic units directly beneath the No. 1 Sandstone as lower to middle Maastichtien in age (i.e., part of the Laramie Formation). Analysis of samples collected from the No.1 Sandstone and overlying claystone units did not yield definitive age dates for these units.

Discussions in this report use this current information about the age of bedrock geologic units. The No. 1 Sandstone is still considered the basal portion of the Arapahoe Formation as reported in earlier studies since no current data refutes the age date of the unit. All lower bedrock units investigated in this Phase II RFI/RI are considered to belong to the upper Laramie Formation in accordance with the recent palynologic data.

Subsurface investigations have shown that the No. 1 Sandstone is a distinct bedrock unit separate in geologic characteristics from the underlying Laramie sandstones. These geologic characteristics will be discussed further in the following sections. The former No.1 Sandstone designation is continued in this report. Limited information is available based on current subsurface control to evaluate the geometries and lateral continuity of the lower stratigraphic Laramie sandstones. The sandstones appear to be discontinuous in nature, thus correlations from borehole to borehole are tenuous. In this report, Laramie sandstone/siltstone correlations between boreholes are based solely on like stratigraphic positioning relative to elevation

although lateral continuity between boreholes is unknown. Due to this uncertainty in lateral continuity, the Nos. 2 through 5 designation for Laramie sandstones is discontinued in this report. Rather, the units are referred to as Laramie sandstone/siltstone intervals.

The geologic characteristics of the bedrock units are discussed in the following sections.

3.5.2.1 Arapahoe No. 1 Sandstone

The Final Geologic Characterization Report (DOE 1991d) states that the Arapahoe Formation beneath the RFP site is a fluvial deposit composed of channel, point bar, and overbank deposits. The report also states that most of the Arapahoe sandstones are predominantly fine- to medium-grained and represent deposition in low to moderate flow regime meandering streams.

Pettijohn, Potter, and Siever (1973) list many characteristics of fluvial sands and sandstones. These characteristics include:

- An elongated or channel-shaped geometry. The base of the channel is commonly sharply disconformable with underlying geologic units (i.e., erosional contact). Basal sands or sandstones may contain conglomeratic lenses or scattered pebbles from a distal source as well as locally derived rip-up clay clasts.

- Texturally, sands or sandstones range from poorly- to moderately-sorted. Grain roundness is variable. Grain size, being a function of stream gradient and source area, is also variable. A vertical fining upward sequence of grain size is characteristic. Stacked fining upward sequences are common. These fining upward sequences reflect the waning water flow velocity typical of stream flow influenced by seasonal precipitation fluctuations.

- Internal sedimentary structures consist of cross- and horizontal-bedding, ripple marks and some massive or poorly-developed bedding. Soft sediment deformation features are common.

- Carbonaceous matter and woody debris may occur throughout due to the presence of flora along the stream banks. Fossil faunal content is low to absent.

Phase II RFI/RI data indicate that the Arapahoe No. 1 Sandstone within the area displays most of these fluvial characteristics. These characteristics for the No. 1 Sandstone are discussed below.

A channel shaped geometry for the No. 1 Sandstone is indicated by OU-2 subsurface control (Figure 3.5-21). The geometry of the main channel is clearly indicated by subsurface control just east of the inner east gate and beneath the Northeast Trenches Area. In that area, the channel is about 800 feet wide. North of the East Spray Fields, where there is an absence of subsurface control, the channel location and geometry are extrapolated in Figure 3.5-21. A secondary smaller channel is located just west of the 903 Pad, trends north-northeast, and may join with the main channel in the vicinity of the Mound Area. This secondary channel is approximately 400 feet wide. Closely spaced subsurface control beneath the 903 Pad Area documents the absence of the sandstone beneath most of the 903 Pad Area (Figure 3.5-21).

In Section 3.5.1.1.1, it was mentioned that an earlier study (DOE 1991d) suggests that the bedrock step located beneath the Southeast Trenches may delineate the eastern limit of a north-south oriented meander segment of the underlying No. 1 Sandstone. The closely spaced subsurface control in this area, acquired during the Phase II field program refutes this suggestion and documents the absence of the sandstone in this area. Phase II subsurface control locates the southern sandstone channel boundary due north of the Southeast Trenches (Figure 3.5-21). Therefore, no apparent stratigraphic control for the location and orientation of the bedrock step can be inferred by the data obtained during the Phase II RFI/RI.

The basal contact of the No. 1 Sandstone is usually abrupt and non-gradational. Basal sandstone units commonly contain claystone clasts, although clasts may also occur at higher horizons as well. (See lithologic logs for wells 03691, 03791 and 21091 in Appendix A4.) Clast lithology is similar to claystone units directly underlying the channel and appear to be rip-up material due to scouring along the channel bottom.

Texturally, the No. 1 Sandstone is poorly to well sorted. Grain roundness ranges from sub-angular to rounded. Sand size is predominantly very fine- to fine-grained, but medium to coarse grain size occurs in cleaner (less fines) sandstone intervals. Stacked fining upward sequences in grain size are common. (See lithologic logs for wells 02991, 03391, 03791, 12691, and 20991 in Appendix A4.) A single fining upward sequence typically consists of a lower bed of sandstone or silty sandstone with sand grain size ranging from medium- to very fine-grained overlain by a bed of clayey sandstone or sandy claystone containing predominantly very fine-grained sand.

Internal sedimentary structures consist of inclined to sub-horizontal bedding, as well as massive or poorly-developed bedding. Bedding is usually evident due to the presence of thin clay laminations. Soft sediment deformation features, such as slip planes, load casts, and dewatering structures are abundant. Carbonaceous matter and coalified woody fragments occur scattered throughout the unit.

These above mentioned characteristics of the Arapahoe No. 1 Sandstone indicate a fluvial environment of deposition as defined by Pettijohn, Potter, and Siever (1973). OU-2 Phase II investigations, therefore, support the previous interpretations of depositional environment set forth by DOE (1991d). Other notable lithologic and sedimentological characteristics of the No. 1 Sandstone are mentioned below.

Lithologically, the No. 1 Sandstone consists predominantly of an interbedded sequence of sandstone (less than 20 percent fines), silty to clayey sandstone, and sandy claystone (commonly occurring as a fining upward sequence as mentioned previously). Less frequently occurring lithologies consist of clayey to sandy siltstone and silty claystone.

Compositionally, sand grains consist predominantly of quartz. Feldspars, mafics, and micas occur in trace amounts. Quartz grains commonly have pitted or frosted surfaces. Iron staining of quartz grain surfaces is also common. Sandstone color is typically pale olive to light gray. Oxidized sections are yellowish orange. The sandstone is weakly cemented to non-cemented. Where cementation is present, argillaceous minerals are the agent. Iron oxides may assist in cementation of some intervals. Saturated non-cemented sections commonly flow into open boreholes.

Tectonic fractures are common. Fracture surfaces are typically coated by iron oxides and may be healed due to this coating. Offset of lithic units across fracture planes is small (less than 1 cm) to non-observable.

The thickness of the No. 1 Sandstone encountered in boreholes varies from about 2 feet (well 02091) to 48 feet (well 21091). Thinner sections of sandstone generally occur toward the channel margins, and thicker sections occur toward the center of the channel (Figure 3.5-21).

The Arapahoe No. 1 Sandstone is the stratigraphically highest sandstone encountered within the OU-2 area. It is stratigraphically located from 0 to 20 feet below the overlying Rocky Flats Alluvium or colluvium (Figure 3.5-22). The sandstone directly underlies (i.e., subcrops)

beneath the Rocky Flats Alluvium along the medial paleoscour mentioned in Section 3.5.1. (Figure 3.5-22). Downcutting along the paleoscour prior to Rocky Flats deposition has apparently removed the overlying claystone/siltstone layer in this area. This subcrop area beneath the Rocky Flats Alluvium is apparently an important feature in allowing vertical groundwater flow to the No. 1 Sandstone from the overlying alluvial units and will be discussed further in Section 3.6. Where the sandstone does not directly underlie the Rocky Flats Alluvium, a claystone/siltstone layer overlies it. The claystone/siltstone layer overlying the No. 1 Sandstone is located along the adjoining paleoridges (Figure 3.5-22).

The No. 1 Sandstone is truncated by erosion to the north, south, and east by the South Walnut and Woman Creek drainages (Figure 3.5-22). The No. 1 Sandstone in OU-2 does not extend from the mesa across the eastern OU-2/RFP boundary (i.e., Indiana Street). The Sandstone along the hillside is typically covered by colluvium but outcrops do occur at several locations along man-made ditches (Plate 3.5-2). The presence of subsurface groundwater seepage along areas of the hillsides helps define the location of the sandstone subcrops beneath colluvial cover. Discharge of groundwater along the base of these areas will be discussed further in Section 3.6.

Within the OU-2 area, complete stratigraphic sections of the Arapahoe No. 1 Sandstone are encountered in the boreholes and monitoring wells listed in Table 3.5-7. (See Appendix A4 for lithologic logs.)

3.5.2.2 Upper Laramie Formation

The depositional environment of the Laramie Formation has been defined by Weimer and Land (1975) to be part of a delta plain complex deposited along the western edge of the Western Interior Seaway. Hurr (1976) states that the Laramie Formation is a fresh-to-brackish-water, non-marine deposit. Most recently, a palynological study of the Laramie and Arapahoe Formations (DOE 1993e) suggests a brackish-water, lagoonal depositional setting for most of the Laramie core samples studied.

The depositional environments presented above are interrelated in that fluvial deltas in coastal settings can occur associated with, or in proximity to lagoonal/barrier-island settings. Coleman and Prior (1982), McCubbin (1982), and Elliott (1986) discuss lithofacies and sedimentary features associated with these environments. Characteristics of a lower delta plain, which lies within the zone of river-marine interaction and which can serve as a possible environmental model for the Laramie Formation, are summarized as follows:

- A large percentage of the lower delta plain consists of interdistributary bays, overbank and crevasse splays, marshes and swamps. Distributary channels become more numerous as they bifurcate, showing an anastomosing type of plan view pattern. Seaward gradients of the channels and delta are low.

- Overbank sediments are deposited during floods when channel levees are breached and crevasse splays are formed. The crevasse splay is a lenticular unit that primarily consists of alternating silts, sands, and clays. The silts and sands may display small-scale ripple laminations. Some low-angle scour planes are apparent. Individual beds of a crevasse splay become thinner and finer-grained away from the channel margins.

- The interdistributary bays normally consist of highly burrowed silts and silty clays, whereas marshes and swamps display a sequence of highly burrowed organic clays. Iron carbonate or siderite nodules are common and plant debris is often abundant along with a brackish or freshwater fauna.

- Distributary channels are often thin units of limited lateral extent, reflecting the small scale of the channels. Avulsion commonly occurs on delta plains and leads to channel abandonment which produces a fining-upward trend in the channel-fill sequence. The deposits consist of fine-to-medium grained sands and silts, with some clays. Internal sedimentary structures include cross- and horizontal-bedding and flat-to-rippled laminations.

Data from OU-2 boreholes drilled into the upper Laramie Formation indicate that these bedrock units display many of these lower delta plain characteristics. A network of cross-sections, constructed from lithologic logs in the OU-2 area (Figures 3.5-23 through 3.5-27), reveals predominately thin upper Laramie sandstone/siltstone units (less than 15 feet) with limited lateral and vertical extent. Available deep borehole control in the OU-2 area limits detailed mapping of the upper Laramie sandstone units to define the orientation and geometry of individual channels, as was possible with the Arapahoe No. 1 Sandstone. However, where closely spaced borehole data exist, various sandstone and siltstone units are shown to pinchout over a distance of several hundred feet or less (i.e., Figure 3.5-26, between boreholes B315289 and 21393). Lithologic logging of the upper Laramie units in the OU-2 area, including sandstone units, has shown the units to be comprised of or contain substantial amounts of fine-grained sediments. Both the fine-grained nature of the sediments and the spacial distribution

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of the sandstone/siltstone intervals within the upper Laramie Formation indicate a low-energy depositional environment such as a delta plain.

The most common upper Laramie lithologies encountered in boreholes within the OU-2 area are claystones and silty claystones. Sandy or clayey siltstones and silty or clayey sandstones are the next most abundant lithologies after claystones. Alternating sequences of sandstone and siltstone units are quite common. (See lithologic logs for 1687, B315289, 21293, and 22193 in Appendix A4.) The lithologic and sedimentological characteristics of these upper Laramie units within OU-2 are detailed below.

The claystones and silty claystones are light-to-medium olive-gray, and occasionally dark gray to olive-black due to an abundance of carbonaceous material. The claystones generally have massive bedding, however horizontal and inclined bedding are sometimes present. They are commonly dense, but become quite rubbly in some intervals. Where fractures are observed in core, they are commonly within the claystone intervals. The fractures vary in scale and density, are found as both healed or open, and often possess slickensides along the fracture planes. At one location (near wells 2087 and 22393), substantial fracturing of claystone is observed to depths of about 100 feet. Further discussion on fracture occurrence is found near the end of this section.

Highly weathered claystones are yellowish-orange in color due to iron oxide staining and are generally found directly beneath the surficial sediments or the No. 1 Sandstone of the Arapahoe Formation, where present. Occasional ironstone nodules and possible siderite nodules occur within the claystones. Possible biofeeding structures have been noted in some silty claystone intervals. Thin coal seams are rare and are often less than 0.75 ft thick, however plant debris is abundant in some claystone intervals.

The sandstones within the upper Laramie Formation are primarily light gray and olive-gray, very fine-to-fine grained, moderately sorted, subangular to subrounded, silty, clayey, and quartzitic. Few medium grained, well sorted sandstones are present. Sandstones containing low percentages of the silt and clay fractions, known as "clean" sandstones, are uncommon in the boreholes within the OU-2 area. The upper Laramie siltstones are primarily light gray and olive-gray, and often contain a large percentage of clay. Both the sandstones and siltstones are slightly-to-moderately friable, and primarily are moderately-to well-cemented with argillaceous or calcareous cement. The sandstones and siltstones often contain thin clay laminae and exhibit horizontal to inclined bedding. Small scale cross-laminated beds are less common. Interbeds

of sandstones, siltstones and claystones are common with beds usually less than 1 foot thick. Soft sediment deformation features, such as slump structures and convoluted bedding, are also present. Bioturbation is abundant, whereas burrows are less common. Occurrences of carbonaceous material and iron oxide staining are rare compared to the claystone intervals.

Calcareous cemented siltstone marker beds were identified in borehole logging of cores taken in the upper Laramie Formation during the site-wide drilling program (DOE 1993e). Calcareous siltstone and/or sandstone marker beds were also identified in the cores of the upper Laramie Formation from pilot boreholes drilled in the 1993 revised bedrock field investigation program in OU-2 (Section 2.2). The pilot boreholes contained up to four marker beds that varied in thickness from 0.1 to 2.9 feet. These marker beds are shown on the core and geophysical log composites, Figures 3.5-28 through 3.5-33, for each of the 1993 pilot boreholes.

Cross-sections RB-RB', RC-RC', and RV-RV' (Figures 3.5-25 through 3.5-27) incorporate the lithologic data acquired from drilling and logging of the six pilot boreholes, 21193 through 21693, during the 1993 revised bedrock field investigation (Section 2.2). The lithologic data from the a-series monitoring well boreholes were not included in the cross-sections because of their close proximity and comparable lithologies to the pilot boreholes. However, the screened intervals for the monitoring wells are shown adjacent to the pilot borehole lithologic column. Figures 3.5-28 through 3.5-33 are composites of selected geophysical log curves and generalized core lithologic units for pilot boreholes 21193 through 21693. The screened intervals for the adjacent monitoring wells (i.e., 23193 and 22593, 22093, 22193, 22293, and 23293) are also shown on Figures 3.5-28 through 3.5-33.

The lithologic logs for the 1993 revised bedrock program boreholes and monitoring wells, as well as other boreholes and wells shown on the cross-sections, are in Appendix A4.1. Geologic and well construction information for the wells and boreholes shown on the cross-sections is presented in tabular format in Appendixes A3 and B2.

Two of the cross-sections, RB-RB'(Figure 3.5-25) and RC-RC'(Figure 3.5-26) are north-south strike sections. The third cross-section, RV-RV'(Figure 3.5-27), is a west-east dip section. Figures 3.5-23 and 3.5-24 are a location map and legend, respectively, for the cross-sections. Table 3.5-8 lists the 1993 pilot boreholes and all of the LHSU monitoring wells drilled to date in the OU-2 area, and provides associated data.

Stratigraphically, the units of the upper Laramie Formation are either positioned directly beneath the overlying Rocky Flats Alluvium or colluvium (Figure 3.5-25), or beneath the Arapahoe No. 1 Sandstone where present (Figures 3.5-26 and 3.5-27). In most areas of OU-2, the uppermost Laramie unit is a claystone. However, at several known locations the Arapahoe No. 1 Sandstone channel is believed to have incised into upper Laramie sandstone/siltstone units. Figure 3.5-27 shows one such location at monitoring well 12391. Where this condition has been encountered in boreholes (e.g., 12391), the contact between the Arapahoe No. 1 Sandstone and underlying Laramie sandstone/siltstone units has been identified primarily on color, grain size, competency, apparent moisture content, apparent permeability, lamination and content of carbonaceous material. In addition, several upper Laramie sandstone/siltstone units are believed to subcrop beneath the colluvium along the north hillside of the Woman Creek drainage, as shown in Figures 3.5-25 and 3.5-26.

The upper Laramie sandstone or siltstone intervals are approximately 15 ft thick or less, except where lenses are stacked one on top of another, which results in a thick sandstone sequence interbedded with thinner siltstone and claystone layers (see borehole 21293 in Figures 3.5-25 and 3.5-29). As illustrated in the cross-sections, the sandstones and siltstones are laterally discontinuous and appear to be isolated vertically by relatively thick intervals of claystones. The lateral discontinuity of these sandstones is illustrated in Figure 3.5-26. A contaminated sandstone screened in 00391 was the target for investigation at the WC-3 location drilled during the 1993 bedrock field program (Section 1.4.7). No sandstone, however, was encountered in the target interval in pilot borehole 21393, indicating the sandstone in 00391 does not extend laterally to this location. In another pilot borehole, 21493, an unexpected upper Laramie sandstone interval of approximately 20 feet thick was encountered immediately below the colluvium (i.e., from about 21 ft to 40 ft deep). Based on data from surrounding wells, a claystone had been expected.

These upper Laramie sandstone/siltstone intervals are assumed to have an approximate dip of less than 2 degrees to the east (Figure 3.5-27), consistent with the regional bedrock dip in the RFP area. The sandstones are primarily distributary channel deposits and likely represent the most permeable intervals of the unfractured Laramie bedrock. Results of permeability tests performed on geotechnical samples from various upper Laramie units cored during the 1993 RBWP field investigation are presented in Table 3.5-9. Discussion of these permeability tests and various aquifer tests performed on upper Laramie units is found in Section 3.6 of this report.

Fracture-enhanced permeability of the claystones is theorized to be a possible mechanism for contaminant migration, particularly in the Mound Area of OU-2. Various boreholes previously drilled in the Mound Area have shown a higher occurrence of fractures relative to boreholes drilled in others portions of OU-2. The objective of pilot borehole 21593, drilled as part of the 1993 revised bedrock field program, was to evaluate the mechanism for downward migration of UHSU contaminants into the upper Laramie units screened by well 2087 in the Mound Area (Figures 3.5-25 and 3.5-27).

The lithology of the screened interval in 2087 consists of claystones and silty claystones, with a few, thin clayey and sandy siltstone beds. Fractures were noted in core from the screened interval in 2087 and are shown on the lithologic log (Appendix A4). The boreholes (21593 and 22393) at location WC-5, drilled to evaluate the contamination in 2087, contained significantly more fractures than the other five investigation locations of the 1993 revised bedrock field program. Fractures, described in core samples from 21593 (lithologic log in Appendix A4), were most numerous in the following intervals: 48 to 57 ft; 67 to 77 ft; 81 to 99 ft; 130 to 142 ft; and 157 to 171 ft. The caliper log for 21593 (Figure 3.5-32) shows the effects of a highly fractured interval located just below the isolation casing and extending to a depth of about 59 feet, with a hole diameter greater than 10 inches between 57 feet and 59 feet (off-scale on log as shown). Fractures were detected on the acoustic televiewer log (not shown) in the same intervals described above from core to a depth of 99 feet. Below 99 feet, fewer fractures were detected on the acoustic televiewer when compared to core description which suggests some of the fractures may be healed. The apparent healing of some fractures below 99 feet is consistent with well development observations at WC-5 in a-series monitoring well 22393. Insufficient water was produced from 22393 to meet development criteria in over 4 weeks of development (Section 3.6.3). This indicates that fracture enhancement of permeability in the claystone surrounding the screened interval of 22393 is not significant.

Within the OU-2 area, the boreholes and monitoring wells listed in Table 3.5-10 were reviewed and/or used in the characterization of the upper Laramie units. (Appendix A4 for lithologic logs.)

3.6 HYDROGEOLOGY

3.6.1 Regional Hydrogeology

The Denver groundwater basin underlies a 6,700 square mile area extending from the Front Range on the west to near Limon, Colorado on the east and from Greeley on the north to Colorado Springs on the south. The center of the basin is south of Bennett, Colorado in western Arapahoe and Elbert Counties. Alluvial aquifers 20 to 100 feet thick commonly occur in the valleys of large streams in the basin. The four major bedrock aquifers occurring in the basin from deepest to shallowest are the Laramie-Fox Hills Aquifer, the Arapahoe Aquifer, the Denver Aquifer, and the Dawson Aquifer. The Pierre Shale underlies these units and is considered the base of the bedrock system due to its great thickness (up to 8,000 feet) and its low permeability (Robson et al 1981a and 1981b).

Alluvial groundwater in OU-2 is discussed in Section 3.6.2. Descriptions of the two Denver Basin bedrock aquifers that exist beneath RFP, the Laramie-Fox Hills Aquifer and the Arapahoe Aquifer follow. The Denver and Dawson Aquifers do not occur in the immediate vicinity of RFP.

<u>Laramie-Fox Hills Aquifer</u>

The Laramie-Fox Hills Aquifer is composed of the upper sandstone and siltstone units of the Fox Hills Formation and the lower sandstone units of the Laramie Formation (Figure 3.5-1). The thickness of the aquifer ranges from near zero at the aquifer boundary (the approximate boundary of the Denver Basin) to 200 to 300 feet near the center of the basin (Robson et al 1981b). Although RFP is located near the western boundary of the aquifer, the base of the aquifer dips steeply to the east beneath the site and the aquifer may have substantial thickness in the area. The upper Laramie, which separates the shallow water-bearing units of concern for OU-2 (Section 3.6.2) from the Laramie-Fox Hills Aquifer, consists of several hundred feet of claystones, siltstones, and some clayey or silty sandstones with occasional coal layers (DOE 1992b). The upper Laramie Formation is discussed in more detail in Section 3.5.2.2.

In outcrop and shallow subcrop areas, recharge occurs as infiltration of incident precipitation and as infiltration of groundwater from shallow alluvial aquifers, respectively. Outcrops of the Laramie and Fox Hills Formations in clay pits west of RFP are believed to be recharge areas for the aquifer (Rockwell International 1987c). Toward the interior of the basin, downward

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leakage may also occur through the upper Laramie Formation from the overlying Arapahoe aquifer (Robson et al 1981b). Recharge to the Laramie-Fox Hills Aquifer from vertical leakage through the upper Laramie in the vicinity of RFP is expected to be minimal due to the substantial thickness of claystones and siltstones (up to 400 feet or more) of the upper Laramie beneath RFP.

On a regional scale, groundwater in the Laramie-Fox Hills Aquifer flows from outcrop recharge areas toward discharge areas in the center of the basin. In addition, groundwater discharges to pumping wells in the basin (Robson et al 1981b). In the vicinity of RFP, groundwater flow is generally from west to east.

Arapahoe Aquifer

The Arapahoe Aquifer is defined as the saturated portion of the Arapahoe Formation by Robson and others (1981a). In the central part of the Denver groundwater basin, the Arapahoe Formation consists of a 400 to 700 foot thick sequence of interbedded claystones, siltstones, sandstones, and conglomerates with claystones and shale being more prominent in the northern third of the basin (Robson et al 1981a). Individual sandstone beds are commonly lenticular and range from a few inches to 30 to 40 feet in thickness (Robson et al 1981a). Beneath the plant, only a thin portion (about 60 feet thick) of the Arapahoe Formation is present, and the majority of groundwater occurs in the lenticular sandstones within the claystones (Rockwell International 1987c). The portion of Arapahoe Aquifer present beneath RFP at OU-2 is not significant from a regional aquifer perspective because it is truncated by drainages on RFP and does not extend laterally from RFP to off-site areas.

Recharge to the Arapahoe Aquifer occurs by the same mechanisms described for the Laramie-Fox Hills Aquifer. In outcrop and subcrop areas, recharge occurs from infiltration of incident precipitation and as infiltration of groundwater from shallow alluvial aquifers, respectively. At RFP, the Arapahoe aquifer is recharged from infiltration of groundwater from overlying unconsolidated surficial deposits. On a regional scale, the primary recharge mechanism for the Arapahoe Aquifer occurs through leakage from the overlying Denver Aquifer (Robson et al 1981a). This is not the case at RFP because the Denver Formation and Aquifer do not occur in the vicinity of RFP.

Groundwater flow in the Arapahoe Aquifer is from recharge areas at the edges of the basin toward discharge areas along incised stream valleys. Groundwater also discharges from

pumping wells (Robson et al 1981a). Groundwater flow in the vicinity of RFP is generally from west to east, but may be locally influenced by sandstone channel geometry and ground surface topography.

3.6.2 OU-2 Hydrogeology

This section presents the hydrogeology of the OU-2 area based on information collected as part of the Phase I, Phase II, and other investigations. Those investigations focused on the shallow saturated units within OU-2, including the saturated unconsolidated surficial deposits and the shallow (up to 200 feet deep) saturated bedrock units of the Arapahoe and upper Laramie Formations (Figure 3.5-1). These are considered the hydrogeologic units of concern for the Phase II RFI/RI because of the potential for contamination of these units from RFP site-related activities. Deeper bedrock hydrogeologic units beneath RFP, including the Laramie-Fox Hills water supply aquifer, are not addressed here because the potential for contamination of these units from RFP site-related activities appears to be minimal given their substantial depth below RFP and the substantial thickness of intervening claystones and siltstones (DOE 1992b) (Figure 3.5-1). The results of detailed soil and groundwater sampling in OU-2 support the conclusion that site-related contamination is limited to the unconsolidated surficial materials and uppermost bedrock units (Section 4.0).

Hydrogeologic conditions in the shallow units at OU-2 are strongly influenced by local geologic conditions, local areal recharge, and interactions with South Walnut and Woman Creeks. Groundwater flow is controlled to a high degree by the shape of the top of bedrock surface, and the geometry and lithology of geologic units. Groundwater recharge occurs primarily as a result of local infiltration of snowmelt, rainfall, and surface water within the OU-2 area. The majority of OU-2 groundwater discharges to surface seeps within the boundaries of OU-2 because the major shallow water-bearing units are completely truncated on the north, east, and south by South Walnut and Woman Creeks.

The hydrogeologic system at OU-2 is comprised of two distinct water-bearing zones; the UHSU and the LHSU. The units are defined in Section 3.6.2.1. Physical parameter data used for the evaluation of the hydraulic properties of the UHSU and LHSU were obtained from historical and Phase II (alluvial and bedrock) aquifer test results and geotechnical test results. Descriptions of alluvial and bedrock materials, including grain size distributions, were obtained from boring logs. Groundwater level data were collected from historical, Phase II, and other monitoring wells within the OU-2 area as part of the Rocky Flats Groundwater Monitoring

Program. These data were obtained from RFEDS and are listed in Appendix B3 (Table B3-1.) Groundwater level data were used to create groundwater hydrographs (Appendix B4), and UHSU saturated thickness and potentiometric maps (Figures 3.6-2 through 3.6-4, and 3.6-8 through 3.6-13) for use in the evaluation of groundwater conditions. Potentiometric and saturated thickness maps were prepared using all available data from the first three quarters of 1992 because data from those quarters represent the most complete data sets available. The specific monthly data used for each quarter are listed in Appendix B3 (Table B3-2). These maps are limited in areal extent to the portion of OU-2 west of the East Spray Fields because water level data east of the East Spray Fields are sparse, and groundwater in that area does not appear to have been contaminated (Section 4.4). The evaluation of alluvial and bedrock seeps within the OU-2 area was based on field mapping and observations, review of aerial photographs, and interpretations of sandstone elevations.

3.6.2.1 Definition of Hydrostratigraphic Units

Figure 3.6-1 is a schematic diagram of the UHSU and LHSU units and the conceptual boundary between the UHSU and LHSU. The UHSU within OU-2 consists of saturated portions of unconsolidated surficial deposits (Rocky Flats Alluvium, high terrace deposits, colluvium, and disturbed ground), the Arapahoe No. 1 Sandstone that is in hydraulic communication with saturated surficial materials, and weathered claystones of the Arapahoe and/or Laramie Formations. In addition, Laramie sandstones, where they subcrop in isolated areas beneath the No. 1 sandstone or hillside colluvium, were considered part of the UHSU. The majority of groundwater flow in the UHSU of OU-2 occurs in saturated Rocky Flats Alluvium and in the Arapahoe No. 1 Sandstone. The focus of the UHSU hydrogeologic evaluation was on these two units which appear to be in hydraulic communication throughout much of the area. The UHSU is described in Section 3.6.2.2.

The LHSU is composed of upper Laramie Formation clayey-silty sandstones, claystones, and siltstones that are not in substantial hydraulic communication with the UHSU. The LHSU is described in Section 3.6.2.3.

3.6.2.2 Upper Hydrostratigraphic Unit

Groundwater flow system in the UHSU at OU-2 is complex because of areal variation in groundwater flow directions, interactions between geologic units, and variation in degree of saturation and saturated thickness. Groundwater in the UHSU exists under unconfined

conditions except where portions of the No. 1 Sandstone are overlain by claystone, resulting in confined and unconfined conditions within the sandstone. Groundwater flow is influenced by the presence of lows and scours (Section 3.5.1.1) in the top of the bedrock surface beneath the Rocky Flats Alluvium and by the degree of direct contact between the alluvium and underlying No. 1 Sandstone (Figure 3.5-22). Cross-gullies, which are incised into the top of bedrock beneath colluvium (Figure 3.5-5) also influence colluvial groundwater flow and saturated thickness along the OU-2 hillsides. The geometry and distribution of the No. 1 Sandstone strongly influences groundwater flow in that geologic unit.

Saturated groundwater conditions within the colluvium, high terrace deposits, and other unconsolidated deposits, which mantle the hillsides of OU-2, appear to occur in to those areas immediately downslope of alluvial and No. 1 Sandstone seeps. Those saturated areas appear to be are limited in areal extent and are relatively thin due to the limited thickness of the surficial deposits on the hillsides (Figures 3.6-2 through 3.6-4).

The hydrogeology of the Rocky Flats Alluvium component of the UHSU, including associated seeps, is described in Section 3.6.2.2.1. The hydrogeology of the No. 1 Sandstone is discussed in Section 3.6.2.2.2. Subcropping Laramie sandstones are discussed briefly in Section 3.6.2.2.3 and in more detail in Section 3.6.3. The hydrogeology of the hillside deposits (colluvium, terrace deposits, and disturbed ground) is discussed in Section 3.6.2.2.4. The UHSU system interactions are discussed in Section 3.6.2.2.5.

3.6.2.2.1 **Rocky Flats Alluvium.** Groundwater flow within the Rocky Flats Alluvium is strongly influenced by the top of bedrock features and the geometry and lithology of alluvial geologic units discussed in Section 3.5.1.1. Saturated alluvial conditions within the Rocky Flats Alluvium occur predominantly within lows and scours in the top of the Arapahoe and/or Laramie Formation bedrock materials. The largest of the scours, the medial paleoscour (Section 3.5.1.1.1) contains and transmits most of the alluvial groundwater in OU-2. This paleoscour appears to originate in the vicinity of the 903 Pad and trends predominantly from southwest to northeast (Figures 3.5-5 and 3.5-6 and Plate 3.5-1). Paleoridges, capped by claystone, to the north and south of the medial paleoscour and a claystone high west of the paleoscour apparently bound the lateral extent of saturated alluvium across much of OU-2 west of the East Spray Fields. It is believed that alluvial groundwater inflow to OU-2 from the west is restricted by the claystone high just west of the 903 Pad. Well 1087 (located west of the 903 Pad) and well 37691 (southwest of the 903 Pad) are generally either dry or the saturated thickness in the

unconsolidated materials at these wells is small (less than 2 feet). Thus, it appears that inflow of water in the alluvium from the west, if it occurs at all, is not substantial.

The north and south paleoridges restrict groundwater outflow from the alluvium to the north and south, particularly during the drier seasons when groundwater levels are at their lowest. As described in Section 3.5, the medial paleoscour is believed to truncate along the South Walnut Creek hillside. Alluvial groundwater flowing within the scour discharges along the head of a well-developed surface drainage gully on the hillside, probably as a result of this truncation of the paleoscour along the hillside. This discharge is indicated by a seepage observed along the head of the surface drainage gully (Plate 3.6-1).

Based on available water level and top of bedrock data, it appears that the bedrock step feature does not substantially influence alluvial groundwater flow. This is apparently because the south paleoridge separates the saturated alluvium in the medial paleoscour from the bedrock step. East of the bedrock step, the lateral extent of saturated alluvium increases due to the presence of the eastern bedrock low feature and discontinuation of the south paleoridge.

The areal extent and thickness of the saturated alluvium within the medial paleoscour varies considerably with the season. Figures 3.6-2, 3.6-3, and 3.6-4 show the areal extent and thickness of the saturated alluvium in the first, second, and third quarters of 1992, respectively. Figures 3.6-5 and 3.6-6 depict the first and second quarter conditions with a relief perspective. First quarter conditions (March 1992) represent the low groundwater level conditions for the year (Figures 3.6-2 and 3.6-5). During this period, the areal extent of saturated alluvium was mostly confined to the central portion of the medial scour, and the maximum saturated thickness was approximately 8 feet. Second quarter conditions (May 1992) represent the high groundwater level conditions for the year (Figures 3.6-3 and 3.6-6). The areal extent of the saturated alluvium in May was, in general, still bounded by the adjacent paleoridges over much of the scour length, but was much larger, with the estimated width of the saturated zone increasing by as much as 250 feet from low to high flow conditions. The maximum saturated thickness of alluvium during second quarter 1992 was estimated to be greater than 17 feet. Third quarter (July 1992) conditions represent an intermediate flow condition (Figure 3.6-4) with the areal extent and thickness of the saturated alluvium at an intermediate level between those measured in first and second quarter.

As shown on Figures 3.6-2 through 3.6-4, an area of saturated alluvium occurs in the vicinity of well 2687 (south of the Southeast Trenches Area) during second and third quarter 1992 that was

not observed during first quarter. Saturated thickness in the alluvium at well 2687 in first and second quarter 1992 was about 7 feet and 3.5 feet, respectively. A review of the hydrograph for well 2687 (Appendix B4) indicated that, prior to second quarter 1992, the alluvium at this well location has been essentially dry since January of 1989. A comparison of the location of well 2687 relative to the crest of the south paleoridge (see the boundary of the underground groundwater collection basin on Figures 3.6-2 through 3.6-4) indicates that the saturated alluvium in the vicinity of well 2687 is south of the south paleoridge crest. Based on the groundwater elevations in the saturated alluvium within the medial paleoscour relative to the elevation of the south paleoridge crest elevation, it appears that the saturated alluvium in the vicinity of well 2687 is separate from the saturated alluvium within the medial paleoscour. This is supported by contamination data for the alluvium that indicate that VOCs were not detected in well 2687 in second or third quarter 1992. If the saturated alluvium at well 2687 was originating from the medial paleoscour, it would be expected to exhibit elevated VOC concentrations, as occurred in the alluvium in the medial paleoscour. The lateral extent of this saturated alluvium area is unknown. However, it is believed to be limited based on the limited indication of subsurface seepage at the alluvium/bedrock contact south of well 2687.

Recharge. Groundwater recharge to the Rocky Flats Alluvium within the OU-2 area occurs due to local direct infiltration of precipitation, and by seepage from surface water features such as ditches. The rate of recharge to the alluvium is generally highest during the spring when precipitation is high and evapotranspiration is low. The effects of increased temperature and evapotranspiration in summer months tend to minimize the recharge rate during summer. Recharge is also minimal during fall and winter months due to the low precipitation that occurs during those months. As discussed previously, inflow of alluvial water to OU-2 from the west is believed to be minimal or does not occur.

The dominance of localized areal recharge on the OU-2 UHSU groundwater system is indicated by the large groundwater level fluctuations that occur in response to springtime precipitation events. Alluvial groundwater levels typically rise rapidly in the spring due to recharge and then decrease until spring of the following year when the seasonal cycle begins again, as shown in alluvial well hydrographs (e.g., wells 1587, 1787, 4286, B218789) presented in Appendix B4. Observed water level changes due to recharge were as great as 14 feet (well 1787) during the period March 1992 to May 1992, a period during which 3.5 inches of precipitation was recorded at RFP. The period of rapid water level rise is followed in some wells (1587, 1787, B218789) by a period in which water levels fall rapidly, presumably due to discharge from the alluvial system to seeps and to the No. 1 Sandstone. This period is generally followed by a period of

slower water level decline (beginning in early summer), during which discharge from alluvium occurs at a lower rate.

Water level fluctuations tend to be greater in wells located in the medial paleoscour than in wells located near the paleoridges. This phenomenon is believed to be related to collection of recharging groundwater within the scour, which acts as an underground groundwater collection basin in much the same way that a surface watershed acts as a collection mechanism for surface flow. The approximate boundary of the collection basin, shown in Figures 3.6-2 through 3.6-4, is defined to the north and south by the crest of the claystone capped paleoridges and to the west by the presence of a claystone high (Figure 3.5.5). The area of the collection basin, in general, is larger than the area of saturated alluvium within it. Thus, most of the precipitation infiltrating over the collection basin area either moves directly downward to the saturated alluvium area or moves downward through unsaturated alluvium until it reaches the bedrock surface and then flows along that surface until it reaches the saturated alluvium area (Figure 3.6-7). As a result, water levels in wells completed within the central portion of the scour may rise substantially in response to recharge, while wells completed nearer the margins of the scour may remain dry, even after substantial recharge.

It has also been observed that increases in groundwater elevation in response to recharge events are greater in alluvial wells located west of the bedrock step (wells 1787, B218789, 4286) than in areas east of the bedrock step (wells 04591, 05091, 05191). This phenomenon is believed to be a combination of two factors. First, top of bedrock surface relief is greater west of the bedrock step than east of the step (Figures 3.5-5 and 3.5-7 and Plate 3.5-1). Therefore, the effect of recharge collection in the scour is more pronounced west of the step. Second, the alluvial materials in the paleoscour west of the step appear to contain more clay than alluvial materials in the area east of the bedrock step. Therefore, the specific yield of subsurface materials west of the step is expected to be lower, resulting in a greater increase in water level for a given recharge event.

The evidence for a higher clay content west of the step is based on comparison of lithologic data collected from borings drilled east and west of the step. The soil types (Section 3.5) in the saturated alluvial zone throughout the area vary from fine-grained materials (silty clay, sandy clay) to gravelly sands and gravels. Lithologic descriptions of saturated alluvium encountered in borings for wells 06691, 06891, 06991, and 1787, located west of the bedrock step, range from clays with silt (92 percent clay) to clayey gravels (24 percent clay). Lithologic descriptions of saturated alluvial materials observed in borings drilled east of the step (wells 05691, 05091, and

05191) range from gravelly sands with clay to well graded gravels (less than 10 percent clay), indicating a lower percentage of clay.

Groundwater Flow Conditions. As noted above, alluvial groundwater levels are generally at their lowest level during the first quarter of the year. Figure 3.6-8 shows the alluvial groundwater levels for first quarter (March) of 1992. The flow direction of alluvial groundwater in March 1992 was generally to the northeast following the medial paleoscour, with a hydraulic gradient of about 0.018 feet/foot. A small branch of southward flow toward Woman Creek also occurred just east of the 903 Pad, possibly through a small gap in the south paleoridge.

Figure 3.6-9 shows the water level conditions in second quarter (May) 1992, which represents the high water table condition for that year. The flow direction in May 1992 was similar to March 1992, with the exception of the saturated area just east of the 903 Pad. Under the high water level conditions in May 1992, the alluvial water level in this area rose sufficiently to overtop a large portion of the south paleoridge, resulting in substantial southward flow over a wide area toward Woman Creek. The hydraulic gradient in the alluvium along the paleoscour during May 1992 was approximately 0.022 feet/foot.

Third quarter (July) 1992 alluvial groundwater elevations are shown in Figure 3.6-10. Third quarter water level conditions are intermediate of those observed in March and May. Groundwater flow direction along the scour is similar to May flow. Groundwater flow toward the south in the vicinity and east of the 903 Pad is greater than in March 1992, but less than in May 1992.

As discussed previously in this section, an area of saturated alluvium in the vicinity of well 2687 occurred during second and third quarter 1992. This area of saturated alluvium is apparently separate from the saturated alluvium in the medial paleoscour, and is located on the south flank of the south paleoridge. It is inferred from the southeastward sloping top of bedrock surface at this location that the groundwater flow direction in the saturated alluvium in this area is toward the south or southwest. This is supported by the presence of deciduous trees rooted near the alluvial/bedrock contact south of well 2687 that may be indicative of a limited degree of subsurface seepage from the alluvium (Plate 3.6-1).

As described in Section 3.5.1.1.3, the Rocky Flats Alluvium has been segregated into a number of lithofacies based on variations in soil types related to depositional environments. Based on the water level maps discussed above, the distribution of lithofacies within the alluvium does not

appear to substantially influence groundwater levels and flow directions on a macro scale. In general, the hydraulic head distribution within the alluvium indicates the aquifer behaves as relatively homogenous system on a large scale. Thus, the details of the alluvial lithofacies are relatively unimportant when assessing the overall hydrogeology of the OU-2 system.

Hydraulic Properties and Estimated Flow Velocities. Estimates of hydraulic conductivity for the Rocky Flats Alluvium at the OU-2 site are based on aquifer testing activities (drawdown-recovery tests) on 1986 wells during the initial CEARP Phase 2 site characterization, slug tests performed on 1986 and 1987 wells during the 1987 Phase I RFI/RI and from aquifer pumping tests conducted in 1992 as part of the Phase II RFI/RI. Results of the 1986 and 1987 tests are summarized in Table 3.6-1. The results of the 1992 tests are summarized in Table 3.6-2.

Hydraulic conductivity values estimated for the Rocky Flats Alluvium from the 1986 and 1987 investigations ranged from 5×10^{-2} cm/s to 4×10^{-5} cm/s (Rockwell International 1987c). The geometric mean for the 1986 and 1987 investigation results is 4×10^{-4} cm/s.

Aquifer pumping tests were conducted during April-June 1992 at OU-2 as part of the Phase II RFI/RI. The testing approach and procedures were specified in the Final Phase II RFI/RI Aquifer Test Work Plan (Alluvial), Technical Memorandum 3 (TM3), for Operable Unit 2 (DOE 1992g). Aquifer pumping tests were conducted at three sites at OU-2, two of which tested saturated alluvium (Sites 2 and 3). Details of the field procedures, analysis methods and procedures, and the results of the aquifer tests are presented in the Phase II RFI/RI Aquifer Test Report (DOE 1992h).

Estimated values of hydraulic conductivity for the Rocky Flats Alluvium from the pumping test conducted at the Site 2 well cluster (wells 05691, 11491, 20291, and 20491) range from 8×10^{-4} cm/s to 4×10^{-3} cm/s. Estimated values of hydraulic conductivity from the pump test at the Site 3 well cluster (wells 1787, 20591, and 20691) range from 6×10^{-5} cm/s to 9×10^{-4} cm/s. The geometric mean of the estimated values from the 1992 tests is 8×10^{-4} cm/s.

In addition to the aquifer pumping tests and slug tests, samples of Rocky Flats Alluvium material collected from boreholes drilled during the Phase II RFI/RI Alluvial programs were submitted for geotechnical laboratory permeability testing. Vertical fixed wall falling head permeability tests for four borehole samples of Rocky Flats Alluvium yielded vertical hydraulic conductivity values ranging from 1.2×10^{-8} cm/sec to 1.3×10^{-7} cm/sec (Table 3.5-2). The lower values of hydraulic conductivity obtained during the laboratory tests may be reflective of the fact

that the vertical permeability of the samples is often affected by layering within the samples. Also, the vertical permeability samples are only representative of conditions in the immediate vicinity of the sample location. Due to the highly heterogeneous nature of alluvial materials, average hydraulic conductivity for the alluvium may differ substantially from the local sample conditions. As such, the laboratory estimated hydraulic conductivity values are considered less reliable than the field test results as indicators of large-scale lateral hydraulic conductivity within the alluvium.

Potential average groundwater flow velocity (average linear velocity) was estimated for the Rocky Flats Alluvium based on the estimated mean hydraulic conductivity, estimated hydraulic gradient, and assumed effective porosity. Using the geometric mean value for estimated hydraulic conductivity from the 1986, 1987, and 1992 aquifer tests (6×10^{-4} cm/s); the estimated average hydraulic gradient for the alluvium from the 1992 water level measurements (about 0.020 feet/foot); and an assumed effective porosity of 10 percent; the estimated potential average linear groundwater flow velocity is about 120 feet/year.

To investigate the water production capabilities of the near surface aquifer materials within OU-2 including the Rocky Flats Alluvium, several transient-pumping computer simulations were performed. The simulations were performed using the USGS MODFLOW numerical groundwater flow program (McDonald and Harbaugh 1988). The analysis approach, procedures, and results are presented in OU-2 Domestic Water Supply Simulations (EG&G 1992f). The results of this analysis for the Rocky Flats Alluvium indicated that the simulated alluvial aquifer went dry after one to two hours of pumping at a rate of 1.5 gpm. These results indicate that the Rocky Flats Alluvium is not capable of producing water at a rate sufficient to support the water needs (240 gallons per day) of a four-member household.

Rocky Flats Alluvium Seeps. Because the Rocky Flats Alluvium is completely truncated to the north, east, and south within the OU-2 area (see Plate 3.6-1), all alluvial groundwater is discharged to surface and subsurface seeps along the slopes of the drainages, with the exception of alluvial groundwater which migrates vertically into the underlying No. 1 Sandstone. Groundwater seepage from the Rocky Flats Alluvium occurs where saturated alluvium is truncated along the hillsides at the contact between Rocky Flats Alluvium and bedrock. At these locations, discharged seep water infiltrates the colluvium and high terrace alluvium downslope from the seepage face. The resultant increase in soil moisture in these downslope geologic materials allows characteristic vegetation to develop that is distinct from the surrounding tall and short prairie grasses common to RFP. This seep-related vegetation

typically consists of cattails, baltic rushes, woody bushes and other phreatophytes. At one location, south of well 2687, deciduous trees may also be indicative of subsurface seepage. The locations of these alluvial seeps and associated downslope vegetated areas were mapped by visual field observations during the summers of 1992 and 1993. High terrace alluvium and bedrock seep locations were also mapped. Field methods used in this mapping are described in Section 2.1.4. Observed seeps and associated vegetated areas are shown in Plate 3.6-1. On this plate, the upslope edge of the vegetated areas is the approximate location and extent of the seepage face. The geologic units from which seep water discharges are also shown.

During high groundwater flow periods, usually the spring season, the majority of the vegetated areas associated with alluvial seeps exhibit moist or wet surface soils. Some of the vegetated areas may also contain areas of standing and/or flowing surface water. As groundwater flow decreases, usually beginning in early summer, the majority of the vegetated areas dry out and remain dry throughout much of the year.

Two alluvial seep areas have been identified within the OU-2 area as being large relative to other OU-2 seeps. One of these areas occurs along and surrounding the head area of a surface drainage gully located south-southwest of Pond B-5 (Plate 3.6-1). As discussed earlier, the majority of the alluvial groundwater within OU-2 is contained and transmitted along the medial paleoscour (a top of bedrock feature). This bedrock feature is believed to be truncated along the South Walnut Creek drainage at the head area of the above mentioned surface drainage gully. Alluvial groundwater flowing within the paleoscour discharges at seeps along the head of this gully. This alluvial seep water supplies surface water flow to the drainage gully. This surface water in turn flows downslope within the gully and discharges to South Walnut Creek approximately 300 feet west of Pond B-5. In April and May 1993, surface water flow measurements were obtained within this drainage gully. (See Plate 3.6-1 for measurement location.) The average flow rate measured on April 10, 1993 was approximately 1 gallons per minute (gpm). The average flow rate measured on May 28, 1993 was 0.18 gpm.

Field observations have confirmed that groundwater within the paleoscour seeps into the head area of the surface drainage gully during the spring and summer months of the year, but year round observational data are not available. Monitoring well 06091 is screened across alluvium within the medial paleoscour, and is located near the head area of the surface drainage gully. According to water level measurements collected within this monitoring well (Appendix B4), alluvium within the paleoscour, at this location, stays saturated year round. This observation suggests that perennial seep discharge to the surface drainage gully may occur.

The second relatively large OU-2 alluvial seep area is located southeast of the 903 Pad (Plate 3.6-1). Groundwater flow within this seep area is heavily influenced by seasonal variations in alluvial groundwater elevations. During high groundwater flow periods, groundwater within the Rocky Flats Alluvium overtops a large portion of the south paleoridge, and flows southward and discharges from the base of the alluvium seep line where the alluvium is truncated by the Woman Creek drainage. As alluvial groundwater elevations decrease, usually beginning in early summer, groundwater elevations drop below the crest of the south paleoridge, limiting southward flow of alluvial groundwater toward the seepline. As a result, the vegetated areas associated with the seep area dry out and remain dry for much of the year. An exception to this scenario occurs in the extreme eastern portion of this seep area. At that location, perennial seep flow may occur. This apparently sustained flow has been attributed to groundwater discharge from a subcropping portion of the No. 1 Sandstone in this area and not to alluvial groundwater discharge (Plate 3.6-1). No. 1 Sandstone seepage in this area will be discussed in a following section.

Two large areas associated with past alluvial groundwater seepage and surface water runoff are located due south of the East Spray Fields (Plate 3.6-1). Presently, the majority of surface soils within these areas stay dry throughout the year and dead seep-related vegetation is being replaced by thistle and other dry soil weeds. From the early 1980s to early 1990, the East Spray fields were used to distribute treated sanitary sewer effluent for evaporation (DOE 1992). According to Koffer (1989), significant amounts of effluent sprayed on the field infiltrated the alluvium and recharged the underlying alluvial groundwater system. Surface water runoff also occurred in areas where a caliche layer, located approximately 18 to 24 inches beneath the surface, inhibited the infiltration of effluent. During winter months, frozen near-surface soils also inhibited effluent infiltration and lead to some surface water runoff. Alluvial monitoring wells 4186 and 2787 are located within the East Spray Field Area (Plate 1.3-2). Hydrographs for these wells (Appendix B4) show that during spray field operations, saturated alluvial thicknesses ranged from approximately 3 to 24 feet beneath the area. After spray field operations were ceased in early 1990, the alluvial groundwater level beneath the fields dropped substantially. As a result, alluvial groundwater seepage in the area south of the East Spray Fields has apparently ceased.

Other Rocky Flats Alluvium seeps occur along the hillsides of the South Walnut Creek and Woman Creek drainages in portions of OU-2 east of the surface drainage gully and East Spray Fields (Plate 3.6-1). The seep areas in the eastern portions of OU-2 are considered less

important from the standpoint of the Phase II RFI/RI because they occur in areas where groundwater has not been affected by site-related contamination.

3.6.2.2.2 **Arapahoe No. 1 Sandstone.** As discussed in Section 3.5, the Arapahoe No. 1 Sandstone is the uppermost sandstone unit within OU-2. The No. 1 Sandstone is a fluvial sandstone channel which incised into the surrounding claystone bedrock deposits. The saturated No. 1 Sandstone is bounded in areal and vertical extent by the surrounding bedrock deposits, which are mostly claystone, or by the South Walnut Creek drainage, which has eroded away the northern edge of the sandstone channel. Figures 3.6-11, 3.6-12, and 3.6-13 show the areal extent of saturated No. 1 Sandstone in the portion of OU-2 west of the East Spray Fields. East of that area, subsurface control for the No. 1 Sandstone is limited or non-existent.

The No. 1 Sandstone directly subcrops beneath the Rocky Flats Alluvium in some locations and is separated from the alluvium by claystone in others (Figure 3.5-22). The majority of groundwater in the No. 1 Sandstone occurs under unconfined conditions, but it does occur in some limited areas under confined conditions. Where it subcrops directly beneath the alluvium, groundwater within the No. 1 Sandstone is unconfined. Where the sandstone is separated from the alluvium by claystone it may occur under confined or unconfined conditions (Figure 3.6-1). Generally, the confined conditions occur where the sandstone is overlain by claystone but is near an area where it subcrops beneath the alluvium and receives recharge from the alluvium at that location. In addition, confined conditions may occur seasonally during high flow periods when recharge from the alluvium is at a maximum. As the flow conditions and recharge decrease, water levels in the sandstone may also decrease, resulting in unconfined conditions.

Recharge. Recharge to the No. 1 Sandstone in OU-2 probably occurs as a result of infiltration of precipitation and surface water through overlying unsaturated deposits, vertical flow from overlying saturated alluvium, and inflow to the area from upgradient portions of the sandstone west of OU-2. The No. 1 Sandstone is the uppermost water bearing zone in areas of OU-2 outside the saturated alluvium zone.

The No. 1 Sandstone is believed to receive recharge due to downward vertical flow from overlying saturated alluvium in areas where the alluvium and sandstone are in direct contact, or where they are separated by only a few feet of weathered and/or fractured claystone (Figure 3.5-22). Downward vertical flow between the alluvium and No. 1 Sandstone is indicated by downward vertical gradients between the units, as discussed in Section 3.6.2.2.6. Evidence for recharge in the contact zone along the medial paleoscour northeast of the 903 Pad is

indicated by a potentiometric high within the sandstone in that area and contaminant data that indicate migration of contamination from the alluvium to the sandstone (Section 4.4). In addition, evaluation of groundwater geochemical data for wells screened in the Rocky Flats Alluvium and wells screened in the No. 1 Sandstone indicates that the two units have similar groundwater geochemistry (i.e., both are calcium-bicarbonate type waters and have low total dissolved solids) (Figure 4.4-1). This supports the conclusion that the No. 1 Sandstone receives recharge from the overlying alluvium. Discussion of UHSU groundwater geochemistry within OU-2 is presented in Section 4.4.

Water level data indicate that recharge to the No. 1 Sandstone within OU-2 also occurs as inflow from the west where the No. 1 Sandstone crosses the western boundary of OU-2 (Figures 3.6-11 through 3.6-13). This groundwater flow is the only apparent source of groundwater recharge into the UHSU of OU-2 that is not directly related to infiltration from precipitation falling on OU-2.

In areas where the No. 1 Sandstone is in hydraulic communication with saturated alluvium, the response to recharge in terms of increased groundwater elevation in wells is similar to that of the alluvium (refer to the hydrograph for well cluster 13291 [alluvial well] and 6591 and 13191 [sandstone wells] in Appendix B5). The rise of the groundwater level is rapid and occurs during spring recharge periods. In areas where the units are in less hydraulic communication, the response of water levels is less and there is a longer delay between the initial recharge event and the response of the sandstone water level (refer to the hydrograph for well cluster 5391 [alluvial well] and 12391 [sandstone well] in Appendix B5).

Groundwater Flow Conditions. Groundwater flow direction within the No. 1 Sandstone is controlled by the geometry of the sandstone unit and its interaction with the overlying alluvium and South Walnut and Woman Creek drainages. Potentiometric maps for the first three quarters of 1992 for No. 1 Sandstone (Figures 3.6-11 through 3.6-13) indicate that the primary direction of flow within the sandstone is to the north-northeast, with some flow to the southeast. The hydraulic gradient in the No. 1 Sandstone varies from approximately 0.028 feet/foot to as much as 0.1 feet/foot.

As noted above, in the contact area between the Rocky Flats Alluvium and the No. 1 Sandstone along the medial paleoscour east of the 903 Pad (Figure 3.5-22), the potentiometric surface of the No. 1 Sandstone appears to be mounded, apparently causing flow in the sandstone to diverge, with most flow moving to the north and northeast and some flow moving to the

southeast. Flow is primarily to the northeast or north in the area beneath and to the north of the medial paleoscour. Groundwater flowing north and northeast discharges to subsurface sandstone seeps where the sandstone subcrops beneath colluvium along the southern slope of the South Walnut Creek drainage. To the south of the medial scour, the No. 1 Sandstone is laterally bounded along much of its length by claystone, which limits southeastward flow toward Woman Creek. The exception to this is in the area south of the Northeast Trenches, where the sandstone channel is truncated by the Woman Creek drainage. In this area, groundwater in the sandstone flows southward from the groundwater potentiometric high and is discharged at subsurface seeps on the northern slope of the Woman Creek drainage.

The bedrock step feature identified in Section 3.5.1.1 does not appear to influence groundwater flow within the No. 1 Sandstone, as shown on Figures 3.6-11 through 3.6-13. The No. 1 Sandstone does not extend southward to the location of the bedrock step (Figures 3.5-5 and 3.5-6).

Groundwater flow downward from the No. 1 Sandstone to the underlying LHSU is believed to be minimal due to the low permeability of the LHSU units. This is supported by the results of field investigations conducted in 1993 for the TM8 (DOE 1993a). The hydrogeology of the LHSU is discussed in Section 3.6.2.3.

Hydraulic Properties and Estimated Flow Velocities. Estimates of hydraulic conductivity for the No. 1 Sandstone at the OU-2 site are based on aquifer testing activities conducted in 1987 and 1992. The results from the 1987 tests are summarized in Table 3.6-3. The results from the 1992 tests are summarized in Table 3.6-4.

Hydraulic conductivity values estimated for the No. 1 Sandstone from the 1987 investigations ranged from 3×10^{-3} cm/s to 2×10^{-4} cm/s (Rockwell International 1987c). The geometric mean of the 1987 investigation results is 1×10^{-3} cm/s.

An aquifer pumping test was conducted in the No. 1 Sandstone during April-June 1992 at OU-2 as part of the Phase II RFI/RI. The testing approach and procedures were specified in the Final Phase II RFI/RI Aquifer Test Work Plan (Alluvial), Technical Memorandum 3 (TM3), for Operable Unit 2 (DOE 1992g). An aquifer pumping test entirely within the No. 1 Sandstone was conducted at one site at OU-2 (Site 1). Details of the field procedures, analysis methods and procedures, and the results of the aquifer test are presented in the Phase II RFI/RI Aquifer Test Report (DOE 1992h).

Calculated values of hydraulic conductivity for the No. 1 sandstone from pumping test measurements conducted at the Site 1 well cluster (wells 3687, 20991, and 21091, and 20891) range from 3.7 x 10^{-4} to 6.2 x 10^{-4} cm/sec (Table 3.6-4). The geometric mean of the 1992 investigation results is 4.8 x 10^{-4} cm/s.

In addition to the aquifer pumping tests and slug tests, samples of No. 1 Sandstone collected from boreholes drilled during the Phase II RFI/RI Alluvial program were submitted for geotechnical laboratory permeability testing. Vertical fixed wall falling head permeability tests for ten borehole samples of the No. 1 sandstone yielded vertical hydraulic conductivity values ranging from 3.1 x 10^{-9} to 1.1 x 10^{-4} cm/sec (Table 3.5-2). As for the alluvial samples, the laboratory estimated hydraulic conductivity values for the No. 1 Sandstone are considered less reliable than the field test results as indicators of large-scale lateral hydraulic conductivity within the sandstone.

Potential groundwater flow velocities (average linear velocities) were estimated for the No. 1 Sandstone based on the estimated mean hydraulic conductivity, estimated hydraulic gradient range, and assumed effective porosity. Based on the geometric mean value for estimated hydraulic conductivity from the 1987 and 1992 aquifer tests (7 x 10^{-4} cm/s), the measured hydraulic gradient range from the 1992 water level measurements (0.028 to 0.1 feet/foot), and an assumed effective porosity of 10 percent, the estimated potential average linear groundwater flow velocity ranged from 730 ft/year to 200 ft/year.

To investigate the water production capabilities of the No. 1 Sandstone, transient-pumping computer simulation scenarios were also run for the sandstone. The analysis approach, procedures, and results are presented in OU-2 Domestic Water Supply Simulations (EG&G 1992f). The results of this analysis for the No. 1 Sandstone indicated that the simulated sandstone aquifer was capable of producing water at a rate sufficient to support the long term water needs of ten four-member households.

Arapahoe No. 1 Sandstone Seeps. Because the No.1 Sandstone is entirely truncated to the north, east, and south by the South Walnut and Woman Creek drainages, no direct off-site groundwater pathway within the sandstone exists from OU-2 to off-site locations. Therefore, virtually all No. 1 Sandstone groundwater within OU-2 is discharged to seeps along the slopes of the drainages.

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It is believed that the No.1 Sandstone subcrops beneath colluvium along the South Walnut Creek hillside. This is based on projections of elevations of the No. 1 Sandstone encountered in monitoring wells and boreholes located on the pediment top close to the hillside. Outcrops in some man-made ditches along the hillside also confirm the subcrop position of the sandstone. The location of the base of the No. 1 Sandstone projected into the hillside from nearby subsurface control is shown in Plate 3.6-1. Seep areas and associated downslope vegetated areas that occur near this projected base are attributed to groundwater discharge from the sandstone. In contrast to the localized alluvial seep discharge from the medial paleoscour discussed earlier, groundwater subsurface seepage associated with the No.1 Sandstone along the South Walnut Creek hillside tends to be spread over a wide area and discharges at a low flow rate. The absence of a visible seepline along the entire subcrop length of the sandstone may be explained by the following reasons. In some places, subsurface seeps may be obscured by thick colluvial cover or overlying high terrace alluviums. In other areas, the close proximity of the base of the sandstone and the shoreline of adjacent b-series ponds makes recognition of groundwater subsurface seepage based on vegetation difficult because shoreline vegetation and seep-related vegetation are very similar. In still other areas, low groundwater discharge rates may allow evapotranspiration to remove a large majority of the soil moisture so that distinct seep-related vegetation does not develop. Regardless of the reasons for the lack of visual evidence of a continuous seep line, based on elevation data and outcrops that indicate that the sandstone subcrops along the drainage, subsurface seepage from the subcrops is expected even in areas where it is not visually obvious.

No. 1 Sandstone subsurface seepage is also believed to occur along the hillside of the Woman Creek drainage where the sandstone subcrops beneath colluvium covering the slopes (Plate 3.6-1). The extreme eastern portion of the alluvial seep located southeast of the 903 Pad may flow perennially, as mentioned earlier. Since the alluvial seepage is seasonal in this area, the No. 1 Sandstone is probably responsible for the sustained subsurface seep flow observed in this area.

3.6.2.2.3 Subcropping Laramie Sandstones. Laramie sandstones are known to subcrop beneath colluvium on the north slope of the Woman Creek drainage (Figures 3.5-24 through 3.5-26) and may also subcrop beneath the No. 1 Sandstone in limited areas of OU-2. At those locations, the Laramie sandstones are in some degree of hydraulic communication with the colluvium or No. 1 Sandstone and are, thus, locally part of the UHSU. In all cases, this is expected to be a local condition. Away from the subcrops, the sandstones are not believed to be in substantial hydraulic communication with UHSU units and are part of the LHSU.

In the case of Laramie sandstones that subcrop beneath the colluvium on the hillsides of Woman Creek, interaction with the UHSU colluvium is believed to occur only in the immediate vicinity of the subcrops. Chemical data for groundwater samples collected from certain wells screened in the sandstones at or near subcrop locations indicate that the sandstones are contaminated at those locations (Sections 4.4 and 4.5). However, the results of the revised bedrock field investigation indicate that this is a local condition in the vicinity of the subcrops related to localized recharge of the sandstones by infiltrating contaminated colluvial water. Thus, in the vicinity of the subcrops, the sandstones are considered to be part of the UHSU. Upgradient of the subcrops (i.e., further into the OU-2 pediment), the sandstones are not in communication with the colluvium and are part of the LHSU.

In some limited areas beneath the central part of the OU-2 pediment (e.g., Wells 03091 and 03391), the No. 1 Sandstone may directly overlie lower Laramie sandstones. This is believed to be an uncommon condition because in most locations where bedrock well data exist, the No. 1 Sandstone is underlain by claystone. In those limited areas where direct sandstone contact does exist, some degree of hydraulic communication between the sandstones is possible, and the lower Laramie sandstones could be considered part of the UHSU. This condition is expected to be localized in the direct contact areas because the low permeability and discontinuous nature of the Laramie sandstone units beneath the No. 1 Sandstone makes substantial and wide-spread hydraulic communication unlikely. This is discussed further in Section 3.6.3.

3.6.2.2.4 Weathered Claystone. Weathered and/or fractured claystones of the Arapahoe and Laramie Formations are considered to be part of the UHSU where these units subcrop beneath saturated alluvium or colluvium. Typically, where wells were screened in alluvium or colluvium, the screened intervals extend into the underlying claystones from about 1 to 2 feet or less. Some wells were screened across Arapahoe claystone units within the No. 1 Sandstone channel as well (e.g., well 01991).

3.6.2.2.5 Colluvium. Colluvium consisting of generally fine-grained materials (clay) with some gravel covers the hillsides of OU-2. Observed groundwater levels in colluvial wells on the northern slope of the Woman Creek drainage indicate that colluvial groundwater generally flows downslope toward Woman Creek in small paleogullies developed on top of the underlying surface, although some flow may occur outside these small channels. These paleogullies are illustrated in Figure 3.5-5. Saturated colluvial areas along the Woman Creek hillside are shown in Figures 3.6-2 to 3.6-4. No monitoring wells have been installed in colluvium on the southern

hillside of the South Walnut Creek drainage, however colluvial groundwater flow toward South Walnut Creek is expected. The primary source of recharge to colluvial groundwater is groundwater discharging from alluvial and bedrock seeps located along the higher portions of hillsides. Direct recharge to the colluvium from precipitation is expected to be limited based on the steep angle of the hillsides and the fine-grained nature of the colluvial deposits.

The hydraulic conductivity of colluvium is expected to be low because of the high clay content of the material. The estimated horizontal hydraulic conductivity in colluvium from the only available aquifer test results (from a slug test conducted at well 3586) was 1 x 10^{-4} cm/sec (Rockwell International 1987c).

3.6.2.2.6 <u>UHSU System Interaction.</u> Where the No. 1 Sandstone and Rocky Flats Alluvium are in direct contact or are separated by a thin layer of claystone, their water levels are similar, indicating a substantial degree of hydraulic communication. Where the alluvium and sandstone are separated by a substantial thickness of claystone, they become less hydraulically connected and behave as more separate systems with different flow directions and water levels.

Saturated Rocky Flats Alluvium and the No. 1 Sandstone appear to be in hydraulic communication in much of OU-2 where the sandstone and alluvium are in contact or in close vertical proximity. On the west side of the 903 Pad, where the sandstone subcrops beneath the alluvium, observed groundwater elevations in the alluvium and sandstone differed by less than 1 foot in April and May at well 06591 (screened in sandstone) and well 13291 (screened in alluvium), an indication that these units are in hydraulic communication. Downward vertical gradient between the screened intervals of these two wells in second quarter 1992 was about 0.02 feet per foot. In the subcrop area northeast of the 903 Pad, along the medial paleoscour, paired wells 1991 (sandstone) and 13491 (alluvial) also have very similar water levels and appear to be in hydraulic communication. Downward vertical gradient between the screened intervals of these two wells in first quarter 1993 and second quarter 1992 were 0.003 and 0.019 feet per foot, respectively.

Groundwater elevation observations indicate that the Rocky Flats Alluvium and No. 1 Sandstone are in less hydraulic communication in areas where they are separated by claystone; for example in the Northeast Trenches Area, several hundred feet northeast and downgradient of 1991 and 13491 along the paleoscour. Water levels in wells 03191 (alluvial) and 12691 (sandstone) differ by 8 to 9 feet in March and May 1992 observations. At the well 05391 (alluvial) and well 12391 (sandstone) well pair, the observed water levels differed by 14 to 15 feet in March and May

1992. Several feet of claystone separates the sandstone and alluvium at both of these locations. Downward vertical gradient ranges across these two well pairs in first quarter and second quarter 1992 were 0.25 to 0.21 feet per foot and 0.42 to 0.45 feet per foot, respectively. The higher vertical gradients for these two pairs relative to the gradients reported for the pairs above (i.e., pairs 6591/13291 and 1991/13491) are also indicative of a lower degree of hydraulic communication. In addition, there appears to be a longer delay in the water level response of Well 12391 to recharge events than occurs in well 05391 (refer to hydrographs for 05391 and 12391 in Appendix B4). The response delay may result because well 05391 receives direct recharge from precipitation, while Well 12391 receives recharge from upgradient areas of the No. 1 Sandstone. This is further evidence that the sandstone and alluvium have limited vertical hydraulic communication in this area.

As stated earlier, downward vertical flow occurs from the Rocky Flats Alluvium to the No. 1 Sandstone in contact areas between the units and where they are separated by small amounts of weathered and/or fractured claystone. However, in the sandstone subcrop area just west of the 903 Pad, near the western edge of the saturated alluvial zone (Figures 3.5-22 and 3.6-2 through 3.6-4), there are indications that the No. 1 Sandstone may provide groundwater recharge to the alluvium during high water periods. In this area, the sandstone channel subcrops along the head of the medial paleoscour. The groundwater flow direction within the sandstone (Figures 3.6-11 through 3.6-13) and alluvium both appear to have an eastward component (i.e., laterally from the sandstone toward the alluvium), and the hydraulic heads are similar, indicating potential hydraulic communication.

Interaction between the colluvium and Rocky Flats Alluvium and No. 1 Sandstone occurs where the saturated alluvium is truncated upslope of colluvium and where sandstone subcrops beneath the colluvium. In most cases, flow is from the alluvium and sandstone to the colluvium. In limited areas, however, localized recharge of subcropping sandstones from colluvial water may occur, as already discussed.

3.6.2.3 Lower Hydrostratigraphic Unit

As discussed in Section 3.5.2.2, the LHSU rock types at OU-2 consist of Laramie Formation clayey-silty sandstones, claystones, and siltstones. Groundwater is generally observed to flow only into boreholes and wells that are open to sandstones and siltstones due to their relatively higher permeability (i.e., relative to LHSU claystones). LHSU claystones have low permeability and generally do not produce water to boreholes and wells at substantial rates unless the

claystones are highly fractured. Quantitative and qualitative evidence for the low permeability of LHSU claystones, and of LHSU units in general, is presented in later parts of this section.

Based on available water level data for LHSU wells (Appendix B3), groundwater in the sandstone and siltstone units of the LHSU generally occurs under confined conditions. In some cases (e.g., wells 2287, 4086, and 22093) available water level data indicate that unconfined groundwater conditions may also occur in LHSU units, however, those data are probably not representative of static water levels in the surrounding bedrock formation due to influences from routine well purging and sampling activities. Most of the wells are sampled on a quarterly basis, and recovery of water levels between purging and sampling events is incomplete for some wells due to the low permeability of bedrock surrounding their screened intervals. Therefore, water levels reported for those wells are lower than static water levels in the surrounding bedrock.

Recharge. Recharge to the LHSU of OU-2 occurs from vertical migration of water from the UHSU to the LHSU. Lateral inflow of water into OU-2 within the LHSU also occurs from the west. In general, the rate of recharge or inflow to the LHSU from both sources is expected to be low due to the low permeability of the LHSU units. The highest vertical recharge rates from the UHSU are expected to occur where LHSU sandstones or siltstones subcrop immediately beneath UHSU alluvium or No. 1 Sandstone, or are separated from UHSU alluvium or sandstones by a thin layer of claystone. Such conditions are known to occur within OU-2 (e.g.,in the vicinity of wells 3687, 03091, B217489 and 23193) but are believed to relatively uncommon. As shown on the geologic cross-sections presented in Section 3.5.2.2 (Figures 3.5-24 through 3.5-26), in general, the UHSU is underlain by claystone. Where the UHSU is underlain by thick sections of unfractured LHSU claystone, vertical recharge rates are expected to be minimal due to the low permeability of the claystone. Where the claystone is highly fractured, however, the permeability of the claystone may be enhanced, potentially resulting in higher recharge rates from the UHSU.

An evaluation of the geochemistry of groundwater in the UHSU and LHSU supports the observation that recharge rate from the UHSU to LHSU is low. Figure 4.4-1 presents geochemical Stiff diagrams for groundwater samples from selected UHSU and LHSU wells. Stiff diagrams illustrate similarities and differences in general groundwater geochemistry (i.e., major anions and cations) and can be useful in evaluating the degree of hydraulic communication between hydrogeologic units. As shown in Figure 4.4-1, 17 out of 17 of the plotted alluvial (green) and No. 1 Sandstone (purple) wells indicate UHSU groundwater is a

calcium-bicarbonate type water. This indicates a high degree of communication between those units. On the other hand, six of ten of the plotted Laramie Formation (red and blue) wells (1487, 2287, 3487, 1687, 4086, and 22293) show the LHSU water is sodium/potassium-bicarbonate or sodium/potassium-sulfate type water, indicating a limited degree of hydraulic communication with the UHSU at those locations.

Of the four Laramie Formation locations plotted as calcium-bicarbonate waters (1187, 00391, 22913, and 23193), two (1187 and 00391) are screened in Laramie Formation sandstones that are apparently locally recharged by colluvial water near where the sandstones subcrop beneath saturated colluvium on the hillside of Woman Creek; and one (23193) is screened in a Laramie Formation sandstone that is separated from the No. 1 Sandstone by only a thin layer of claystone (Section 4.5.1). Thus, most of the geochemical results support the interpretation that recharge from the UHSU to Laramie Formation units is limited except where Laramie Formation sandstone/siltstone units subcrop immediately below the UHSU or are separated from UHSU units by a thin claystone layer.

Lateral inflow of water within LHSU units across the western boundary of OU-2 is also expected to be limited due to the low permeability of the LHSU units and the discontinuous nature of LHSU sandstones and siltstones. Available data for several of the boreholes near the western boundary of OU-2 indicate a relative absence of sandstones and siltstones in some areas. Figure 3.5-26 is a west-east cross-section that extends on its western end within about 450 feet from the western boundary of OU-2. As shown in that figure, only a few thin discontinuous sandstone and siltstone units are present in that area. Data from well 42892, which is in the immediate vicinity of the western OU-2 boundary, indicates only one thin siltstone unit is present at that location; the remainder of the borehole encountered claystone. In other boreholes (e.g., 4587 and 2287), some sandstones and siltstones are present; however, inflow rate in those areas is still expected to be low due to the relatively low permeability of the LHSU sandstones and siltstones.

Groundwater Flow Conditions. As previously discussed, although groundwater occurs within the LHSU units, the rate of flow from the UHSU to the LHSU, and within the LHSU, is limited due to the distribution and nature of the LHSU rocks. As shown in Figures 3.5-24 through 3.5-26 and discussed in Section 3.5.2.2, LHSU sandstone and siltstone units, which are expected to be the most permeable unfractured LHSU rocks, are laterally discontinuous and are often separated vertically and horizontally by relatively thick intervals of claystone. Where sandstone and siltstone units occur, they are often interbedded with claystone layers. As shown

on the cross-sections and as observed during drilling activities, the lithology of the LHSU units can change substantially over a few tens of feet. During drilling of well clusters for the 1993 revised bedrock field investigations, it was not uncommon for sandstone intervals observed in pilot boreholes to have changed to siltstone or claystone intervals in adjacent a-series and b-series well boreholes located 10 to 15 feet away. The result is that overall groundwater flow rates within the LHSU are low because they are controlled by the low permeability claystone intervals separating the sandstones and siltstones, rather than by the permeabilities of the sandstones and siltstones.

In addition to their discontinuous nature, LHSU sandstone and siltstone units, in general, contain substantial amounts of fine-grained materials (i.e., silt and clay in sandstone units, and clay in siltstone units), resulting in relatively low permeability for those units as well. Appendix A4 contains the lithologic logs for LHSU boreholes drilled in OU-2. In general, those logs, which are based on field logging in accordance with ER SOP GT.1, describe most of the sandstones as silty or clayey sandstones, and many of the siltstones as having substantial clay contents. Table 3.5-9 summarizes the results of geotechnical laboratory grain size analyses conducted on LHSU core samples collected from pilot boreholes drilled during the 1993 revised bedrock field investigation. Those core samples were specifically collected to be representative of the major different lithologic types (i.e., sandstones, siltstones, and claystones) encountered in the boreholes as described based on field logging. Thirty-five samples were submitted for analysis, of which 4 were described in the field as sandstones, 5 as siltstones, 19 as claystones, and 6 as interbedded sandstones, siltstones, and claystones. Of those 35 samples, 34 were classified by the laboratory as silts or clays (i.e., ML or CL). The remaining sample was classified as silty sand (i.e., SM). These results demonstrate the high content of fine-grained material in the LHSU units and, thus, support the expected low flow rates, even for units described in the field as sandstones and siltstones.

The areal distribution of LHSU geologic and water level data are not sufficient to estimate LHSU horizontal groundwater flow directions in detail, as was done for the UHSU. However, based on the topography of OU-2 (i.e., a ridge bounded to the north and south by drainages), horizontal groundwater flow direction within the LHSU units that are in close vertical proximity to the UHSU is expected to range from north/northeast to south/southeast toward the drainages. A comparison of third quarter 1993 water levels for three well pairs investigated during the 1993 revised bedrock field investigation (22093/1187, 22193/00391, and 22293/1487) was performed to evaluate apparent hydraulic gradient direction and magnitude in LHSU units that subcrop along the north slope of the Woman Creek drainage. These three wells pairs

(Figures 3.5-25 and 3.5-26) were selected to investigate the potential scenario in which contaminants migrate in groundwater from the central portion of the pediment to the Woman Creek drainage through LHSU migration pathways (i.e., scenario 2, Figure 2.2-4). Water levels indicate apparent horizontal gradients of 0.007, 0.05, and 0.005 feet per foot toward the Woman Creek drainage for the 22093/1187, 22193/00391, and 22293/1487 well pairs, respectively. Because these gradient measurements are based on data from only two wells each, it is not possible to conclude that these gradients are maximum gradients and thus, indicative of groundwater flow direction. However, they do indicate that a component of horizontal groundwater flow is toward the drainages.

Implicit in this evaluation is the assumption that each well of a given well pair is screened in a LHSU unit that is laterally continuous between these wells. If not, the calculated apparent gradients may not be meaningful due to the influence of downward gradients across the LHSU.

Downward vertical hydraulic gradients are believed to exist between the UHSU and LHSU, consistent with the interpretation that recharge occurs from the UHSU to LHSU. Such downward gradients are expected in a regional recharge area such as RFP. However, estimates of downward gradient magnitude based on some available OU-2 water level data for UHSU and LHSU wells may not be reliable due to groundwater purging and sampling affects on the LHSU water level data. As noted before, quarterly sampling is performed in most LHSU wells and water level recovery between sampling events may not be complete due to the low permeability of the bedrock surrounding the screened intervals of the wells.

A review of hydrographs for 11 selected UHSU/LHSU well pairs (00191/1687, 1587/3087, 1787/1887, 1987/2087, 2187/2287, 2787/2887, 3287/3187, 3387/3487, 3586/3486, 4186/4086, and 4487/4587) indicates that seven of the LHSU wells (1687, 3087, 1887, 2087, 2887, 3487 and 4087) exhibit cyclical water level fluctuations on a quarterly basis consistent with the interpretation that measured water levels have not fully recovered between water level measurement periods. Vertical hydraulic gradients measured for clusters including these LHSU wells range from 0.5 to 0.9 ft/foot, however these estimates may be higher than actual gradients in some cases due to the incomplete water level recovery. The remaining four LHSU wells (2287, 3187, 3486, and 4587) may fully recover between sampling events. Vertical hydraulic gradients measured for clusters including these wells range from about 0.7 to 0.9 ft/foot.

Hydraulic Properties

Observations during well development activities support the interpretation that the permeability of the LHSU units is low. During development of wells installed during the 1993 revised bedrock field program, flow rates into wells were generally very low, requiring several weeks to produce sufficient water to meet development criteria. Two of the wells (22393 and 23293) failed to produce sufficient water to meet development criteria even after 4 to 5 weeks.

Estimates of hydraulic conductivity of LHSU units based on aquifer testing also generally support the interpretation that the permeability of LHSU units is low. Estimates of hydraulic conductivity for the LHSU units at the OU-2 site are based on aquifer testing activities (slug tests, drawdown-recovery tests, and packer tests) conducted in 1986 and 1987, and slug tests conducted as part of the revised bedrock field investigation in 1993. Results of the 1986 and 1987 tests are summarized in Table 3.6-5. The results of the 1993 slug tests are summarized in Table 3.6-6.

Hydraulic conductivity values were estimated for LHSU sandstone, siltstone, and claystone during the 1986 and 1987 tests (Rockwell International 1987c). Hydraulic conductivity values estimated for LHSU sandstones from slug tests, drawdown-recovery tests, and packer tests range from 8×10^{-5} to 1×10^{-7} cm/s (Table 3.6-5). The value estimated for siltstone from a slug test at well 3487 is 1×10^{-5} cm/s, and the value estimated for claystone from a packer test at well 2087 is 1×10^{-7} cm/s. Hydraulic conductivity values estimated for interbedded sandstone/siltstone/claystone from a slug test (well 1487) and packer test (well 2287) range from 2×10^{-6} to 2×10^{-5} cm/s. The geometric mean for the 1986 and 1987 aquifer test results is 4×10^{-6} cm/s.

Slug tests were conducted in four LHSU monitoring wells (22093, 22193, 22293, and 23193) as part of the 1993 revised bedrock field investigation activities (Table 3.6-6). The details of the analyses of the slug tests are presented in Appendix B1). The tested lithologic units consisted of interbedded sandstones, siltstones, and claystones. The estimated hydraulic conductivity values from the 1993 slug tests range from 9.7×10^{-5} to 2.2×10^{-8} cm/s. The geometric mean of the 1993 values is 2×10^{-6} cm/s.

In addition to the aquifer tests, samples of LHSU material collected from the pilot boreholes during the 1993 revised bedrock field investigation were submitted for geotechnical laboratory permeability testing. The tested lithologies (based on field logging per ER SOP GT.1) include

sandstone, siltstone, claystone, and interbedded sequences of those units. Permeability values were reported for 34 vertical fixed wall falling head permeability tests and 27 horizontal (radial) permeability tests (Table 3.5-9). The permeability values from the vertical permeability tests range from 8.8×10^{-6} to 1.4×10^{-9} cm/s. The geometric mean of the vertical permeability tests is 4.8×10^{-8} cm/s. The permeability values from the horizontal (radial) permeability tests range from 3.4×10^{-6} to 5.0×10^{-9} cm/s. The geometric mean of the horizontal permeability tests is 8.0×10^{-8} cm/s.

In general, the hydraulic conductivity of LHSU claystones is believed to be very low (i.e., on the order of 1×10^{-7} to 1×10^{-8} cm/s based on 1993 horizontal (radial) permeability tests and one 1987 packer test). However, the permeability of claystones can be enhanced substantially if the claystones are fractured and the fractures are open and interconnected. Such a condition appears to occur in the vicinity of wells 2087 and 22393 in the Mound Area. Substantial fracturing of claystones is noted in the lithologic logs for both wells, and is indicated by the results of borehole geophysical logging conducted in pilot borehole 21593, adjacent to well 22393 (Section 3.5.2.2). Fractures were observed in drill core from 21593 throughout the borehole depth and exhibited iron staining on the fracture surfaces to a depth of about 60 feet, indicating water movement through the fractures to at least that depth. During drilling of 21593, several highly fractured intervals were encountered above about 60 feet, resulting in loss of drilling mud circulation. This indicates substantial permeability of the claystones in this interval. Below approximately 100 feet in 21593, the fracture occurrence appeared to decrease, and acoustic televiewer log results indicate the fractures may be healed. This is consistent with well development observations for 22393 (screened over a depth interval of 108 to 118 feet) that indicated that the permeability of the claystone at that depth was very low. Despite attempts to develop 22393 over a 5 week period, the well failed to produce sufficient water to meet development criteria and could not be sampled or slug tested.

UHSU/LHSU System Interaction

As discussed earlier, in general, hydraulic communication between the UHSU and LHSU appears to be limited by the low permeability and discontinuous nature of the LHSU materials. Where LHSU sandstones and siltstones are in close vertical proximity to the UHSU, there is the potential for groundwater to migrate into the LHSU sandstones and siltstones at low rates. However, once in the sandstone and siltstone units, lateral or downward migration of the water within the LHSU is inhibited by the low permeability of the sandstone and siltstone units and by the claystone intervals separating those units.

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Evidence to support the conclusion that limited hydraulic communication occurs between the UHSU and LHSU includes:

- The discontinuous nature of LHSU sandstone and siltstone units (Figures 3.5-23, 3.5-26, and 3.5-27).

- The substantial thickness of claystone that underlies much of the UHSU and horizontally and vertically separates LHSU sandstone and siltstone units (Figures 3.5-25, 3.5-26, and 3.5-27).

- Observation of limited inflow of water to LHSU boreholes during drilling.

- Extended periods of time to develop LHSU wells due to low inflow rates (up to 4 weeks or more; two 1993 revised bedrock program wells never met development criteria even after 5 weeks).

- Water level records that indicate many LHSU wells do not recover to static water levels for weeks or more after well purging and sampling events.

- Mean hydraulic conductivity for the LHSU based on aquifer tests (3×10^{-6} cm/s) that is approximately 2 orders of magnitude lower than for the UHSU (7×10^{-4} cm/s).

- Groundwater geochemical data that indicate the LHSU water type (Na/K-bicarbonate) is substantially different than the UHSU water type (Ca-bicarbonate).

Although the bulk of the field data indicate communication between the UHSU and LHSU is limited, in some areas a higher degree of communication may exist. Well 23193, installed in the Northeast Trenches Area (work plan location WC-1) during the 1993 revised beedrock field program, is screened in an interbedded sequence of Laramie siltstone and claystones in close vertical proximity to the UHSU (Figure 3.5-27). Hydraulic communication between this unit and the UHSU is indicated by the presence of low concentrations (about 10 µg/L) of TCE in samples from this well (Section 4.6), and by geochemical data that indicate the water in this unit is similar to the UHSU water. Although the conditions observed at 23193 are somewhat unique with respect to conditions observed at other LHSU wells, they do indicate that enhanced

communication between the UHSU and LHSU can occur in limited areas, particularly where Laramie sandstones and siltstones are in close vertical proximity to the UHSU.

Where the LHSU sandstone and siltstone units are separated from the UHSU by substantial thicknesses of claystone that is not highly fractured, the degree of hydraulic communication between the UHSU to LHSU appears to be minimal due to the low permeability of the claystone. However, in areas where substantial quantities of open, interconnected fractures exist in the claystone (e.g., the Mound Area near wells 2087 and 22393), permeability and hydraulic communication between the UHSU and LHSU may be enhanced.

As discussed in Sections 3.5.2.2 and 3.6.2.2.3, Laramie sandstones and siltstones subcrop along the north hillside of Woman Creek (Figures 3.5-25 and 3.5-26). Based on the results of investigations conducted at three locations (TM8 locations WC-2, WC-3, and WC-4) during the revised bedrock field program, the subcropping sandstones and siltstones are believed to be in direct hydraulic communication with the UHSU colluvium in the immediate vicinity of the subcrop locations. Away from the subcrops, the sandstones and siltstones do not appear to be in communication with the UHSU. Therefore, the interaction is believed to be limited in area and not significant in terms of contamination migration pathways. This is discussed further in Section 6.0.

3.7 SURFACE WATER HYDROLOGY

The surface water hydrology description contained in this section provides an overview of drainage patterns in OU-2. South Walnut and Woman Creeks drain the OU-2 site. The drainage basins of South Walnut and Woman Creeks are represented on Figure 3.7-1. South Walnut and Woman Creeks flow eastward.

3.7.1 South Walnut Creek

The headwaters of South Walnut Creek were filled during construction of plant facilities. As a result of this, flow originates from a buried culvert located west of Building 991. The discharge from the corrugated metal pipe is augmented by flow from a concrete pipe (SW-59) at a point north of the Mound Area. The flow from the concrete pipe originates as seepage from the hillside south of Building 991 and flows into a ditch along the slope. The combined flow then enters the South Walnut Creek retention pond system. A discussion of the origin of SW-59 is presented in Section 4.6.2.

Below the retention ponds, South Walnut Creek, Walnut Creek, and an unnamed tributary join within the buffer zone before flowing into Great Western Reservoir. Great Western Reservoir is located approximately one mile east of this confluence. The South Walnut Creek retention pond system consists of five ponds (B-1, B-2, B-3, B-4, and B-5) that retain surface water runoff and plant discharges for the purpose of monitoring before downstream release of these waters. All flow in the pond system is eventually retained in Pond B-5 where it is monitored for quality before discharge in accordance with the Plant's National Pollutant Discharge Elimination System (NPDES) permit (discharge point 0006). Ponds B-1 and B-2 are reserved for spill control, surface water runoff, or treated sanitary waste of questionable quality. Pond B-3 is used as a holding pond for sanitary sewage treatment plant effluent. The normal discharge of Pond B-3 is to Pond B-4. Pond B-4 and B-5 receive surface water runoff from the central portion of the Plant. The surface water runoff received by Pond B-4 is collected by Central Avenue Ditch and upper reaches of South Walnut Creek.

3.7.2 Woman Creek

Woman Creek is located south of the Plant with headwaters in largely undisturbed Rocky Flats Alluvium. A portion of the storm runoff and groundwater seepage from the southern part of the Plant is collected in the South Interceptor Ditch (located north of the creek) and delivered downstream to Pond C-2; the remainder discharges to Woman Creek. Pond C-1 is diverted around Pond C-2 where approximately two-thirds of the water is diverted from Woman Creek's main channel into an unnamed ditch to Mower Reservoir. The remaining flow continues into the Woman Creek channel downstream. Water to Pond C-2 is discharged in Woman Creek in accordance with the Plant NPDES permit (discharge point 007).

Flow in Woman Creek and the South Interceptor Ditch is ephemeral. During 1986 and 1987, there was no visible surface flow in Woman Creek downstream on Pond C-2.

3.8 ECOLOGY

3.8.1 General Setting

The natural environment of RFP and vicinity is influenced primarily by its proximity to the Front Range of the Southern Rocky Mountains. RFP is located less than 2 miles east of the north-south trending Front Range and approximately 16 miles east of the Continental Divide. This transition zone between prairie and mountains is referred to as the Colorado Piedmont

section of the Great Plains province (Thornbury 1965; Hunt 1967). The Colorado Piedmont is an area of dissected topography formed by folding and faulting along the edge of the Front Range uplift, subsequent pediment erosion and burial by fluvial processes, and more recent incision of drainages and removal of a portion of the alluvial cap. Rocky Flats is the most extensive pediment surface in the area. RFP occupies the eastern edge of the pediment, which extends approximately 5 miles northeast from the mouth of Coal Creek Canyon at an elevation of approximately 6,000 feet. In eastern portions of Rocky Flats, the gently sloping pediment gives way to low, rolling hills.

Downcutting of streams flowing eastward across Rocky Flats has resulted in differences in microclimate related to slope, aspect, and soil parent material. The most important microclimatic factor is soil moisture, which is influenced by angle of insolation, wind desiccation, snow accumulation, soil texture, depth to groundwater, and proximity to surface water.

3.8.2 Vegetation

RFP is located immediately below the elevation at which plains grasslands grade abruptly into lower montane (foothills) forests. The present vegetation of Rocky Flats is dominated by mixed prairie showing some residual influence of previous grazing (see Marr 1964; Clark et al 1980). Vegetation within OU-2 is typical for RFP.

Flat-topped ridges that form the divides between drainages (such as Woman Creek and South Walnut Creek) are relatively dry, primarily because of wind exposure and the generally coarse, well-drained substrate. Native vegetation on most of the ridgetops has been mapped as xeric grassland. Dominant grasses in this vegetation type include blue grama, buffalo grass, red three-awn, needle-and-thread, spike dropseed, spike muhly, and mountain muhly.

Hillsides sloping from the ridgetops toward the drainages are generally more moist, owing to protection from the wind, loamier soils, and (in the case of north-facing slopes) lower angles of insolation. Most of the hillsides are mapped as mesic grassland, which is typified by blue grama, side-oats grama, prairie junegrass, western wheatgrass, Canada bluegrass, native Kentucky bluegrass, and green needlegrass.

Within either xeric or mesic grasslands, localized areas of greater moisture may support species more typically associated with tallgrass prairie, such as big bluestem, little bluestem, switchgrass, and yellow Indiangrass. The latter two species are most common in mesic grassland on

floodplains, such as along Woman Creek. Fringed sage, Louisiana sage, common sage, wild tarragon, broom snakeweed, and a low-growing form of rubber rabbitbrush are locally abundant in native grassland communities throughout RFP. Yucca and cacti are abundant on sites with shallow, rocky soils. In northern and western portions of RFP, ponderosa pine and associated foothills species may occur as scattered individuals or small clumps. This habitat type does not occur in OU-2.

Vegetation types along streams, ditches, and retention ponds are mostly either tall marsh (consisting of either broadleaf or narrowleaf cattails) or a riparian shrubland/woodland complex. Tall (cattail) marshland is prevalent around both the B-series ponds on South Walnut Creek and the C-series ponds on Woman Creek and the South Interceptor Ditch (SID). Riparian shrubland is generally dominated by sandbar willow or leadplant; snowberry and prickly rose are locally abundant just outside the riparian zone. Riparian woodland is mapped where trees such as plains cottonwoods and peachleaf willows protrude above the shrub canopy. Narrow ribbons of riparian trees are well developed in some stream segments, such as the stretch of Woman Creek adjacent to OU-2. Riparian trees are less numerous along South Walnut Creek.

In the northern portion of RFP (i.e., the Rock Creek drainage), wild plum, chokecherry, hawthorn, and golden currant are common along the valley floor, as well as on rocky sideslopes. Skunkbrush sumac and mountain ninebark, two shrub species more characteristic of the lower foothills, are also common in the Rock Creek area.

Seeps and springs emerge at several points along the contact between the Rocky Flats Alluvium and underlying bedrock strata. These wet areas generally support short marsh communities dominated by rushes, sedges, wetland grasses, and associated forbs. The largest or most persistent seeps and springs support tall marsh (cattail) communities.

Interspersed within the native communities are areas mapped as disturbed land or reclaimed grassland. Disturbed land is dominated by a variety of weedy forbs, as well as cheatgrass, Japanese brome, and bottlebrush squirreltail. Reclaimed grassland consists of introduced pasture grasses (smooth brome, intermediate wheatgrass, and crested wheatgrass) previously planted to reclaim disturbed land, increase forage and reduce soil erosion in degraded range, or support hay production.

3.8.3 Wildlife

As in most of the Front Range Urban Corridor, the wildlife of Rocky Flats has been greatly influenced by the increase in human activity and disturbance over the past 100 years. Most notable have been reductions in the number and diversity of ungulates (hoofed animals) and predators. However, the relative isolation and habitat diversity of Rocky Flats have resulted in a fairly rich animal community.

The Rocky Flats EIS (DOE 1980) reported that eight species of small mammals were captured during a live-trapping program in 1975. These species were listed as the deer mouse, harvest mouse, meadow vole, thirteen-lined ground squirrel, northern pocket gopher, hispid pocket mouse, silky pocket mouse, and house mouse. More recent studies have documented the occurrence of Mexican woodrats, prairie voles, western jumping mice, and meadow jumping mice and demonstrated that both the plains harvest mouse and western harvest mouse are present. Black-tailed jackrabbits, white-tailed jackrabbits, and desert cottontails also occur.

The most abundant large mammal is the mule deer, with an estimated population of more than 170. White-tailed deer also occur, but in very low numbers. Riparian areas such as along Woman Creek and portions of South Walnut Creek provide thermal cover, hiding cover, and browse for these species. Carnivores present include coyotes, red foxes, gray foxes, bobcats, raccoons, badgers, long-tailed weasels, and striped skunks.

Common grassland birds at RFP include western meadowlarks, horned larks, vesper sparrows, grasshopper sparrows, and both western and eastern kingbirds. Tall marsh and riparian shrubland communities support song sparrows, common yellowthroats, red-winged blackbirds, common snipe, and sora rails. Black-billed magpies, northern orioles, yellow warblers, warbling vireos, American robins, indigo buntings, blue grosbeaks, and lesser and American goldfinches (among other species) nest in cottonwoods or other mature riparian trees. Wooded draws in the Rock Creek drainage attract foothills species, including MacGillivray's warblers, yellow-breasted chats, black-headed grosbeaks, green-tailed and rufous-sided towhees, and lazuli buntings. Prevalent songbirds during the winter include horned larks in grasslands, pine siskins in wooded areas, and dark-eyed juncos in brushy habitats.

Common birds of prey in the area include American kestrels, northern harriers, red-tailed hawks, Swainson's hawks, great horned owls, and long-eared owls. Golden eagles, ferruginous

hawks, and prairie falcons also occur, as do rough-legged hawks, short-eared owls, and occasional bald eagles during the winter.

The most abundant reptiles at RFP are the bullsnake, yellow-bellied racer, western terrestrial gartersnake, and prairie rattlesnake. Amphibians are described in Section 3.8.4.

Prevalent terrestrial arthropods captured at RFP have included four major classes: Diplopoda (millipedes), Crustacea (isopods or pill bugs), Arachnida (spiders and allies), and Insecta (insects). Of these, insects are the most abundant and taxonomically diverse. Prevalent insect taxa include leafhoppers, treehoppers, and spittlebugs (Homoptera); seed bugs and leaf bugs (Hemiptera); leaf beetles and ladybird beetles (Coleoptera); grasshoppers and crickets (Orthoptera); and ants (Hymenoptera). All of the most abundant arthropod groups are herbivorous, except for ants, which are omnivorous, and ladybird beetles and spiders, which are predacious.

3.8.4 Aquatic Organisms

Surface waters at RFP support a variety of aquatic macroinvertebrates, including snails and several orders of insects and crustaceans. The benthic macroinvertebrate community of Woman Creek is strongly influenced by low and nonpersistent flows and the generally fine-textured sediment. Benthic macroinvertebrate communities within the creek are generally dominated by larvae of true flies (Diptera), especially midges and craneflies, or mayflies (Ephemeroptera). Other taxa present include amphipods and snails.

Pond C-1 differs from Woman Creek in that aquatic earthworms (Oligochaeta) are the dominant macroinvertebrates in the fine substrate; diptera (mostly midge) larvae are the only other group present in detectable numbers within the sediment. Pond C-2 supports a more diverse benthic macroinvertebrate community, although oligochaetes and midges are by far the most abundant organisms.

As with benthic macroinvertebrates, low and intermittent flows along most stretches of Woman Creek greatly limit its ichthyofauna. The two stream sites on Woman Creek above Pond C-1 support only two fish species, both of which are members of the minnow family: the creek chub, found at both stations, and the stoneroller, captured only at the downstream station. The creek chub feeds on a variety of small insect prey; the stoneroller is primarily a bottom-feeder, consuming insect larvae, small crustaceans, and algae.

Fish species present in Woman Creek below Pond C-1 include the fathead minnow and largemouth bass, the latter occurring as juvenile fish. The fathead minnow, like the creek chub, is widespread within its range but may inhabit ponds as well as streams with silty bottoms. Fathead minnows feed primarily on plankton. Juvenile largemouth bass feed on a variety of insects, crustaceans, and fish small enough to be consumed.

Sampling at Pond C-1 has yielded seven species: the stoneroller, creek chub, fathead minnow, golden shiner, white sucker, green sunfish, and largemouth bass. Of these, the golden shiner is the most abundant. Golden shiners feed on aquatic insects, small mollusks, and algae and may themselves be an important prey species for larger fish or water birds. Sunfish and bass consume a variety of insects, crustaceans, and small fishes. Pond C-2 supports a very limited ichthyofauna; the only species captured to date is the fathead minnow, which is present in very large numbers owing to the absence of a predatory fish.

The SID also provides some aquatic habitat. The SID collects surface and shallow subsurface flows from the hillside south of Woman Creek and carries the water into Pond C-2, which is isolated from Woman Creek itself. No fish were captured in the SID. The muddy substrate and very low flows afford poor habitat for fish; physical barriers would probably impede colonization from Pond C-2, even if habitat were more suitable.

The ponds and creeks at RFP attract water birds such as mallards, gadwall, green-winged and blue-winged teal, pied-billed grebes, spotted sandpipers, killdeer, great blue herons, black-crowned night-herons, and double-crested cormorants. Muskrats and western painted turtles are common in some water bodies at RFP. Additionally, aquatic habitats support use by a variety of terrestrial species, primarily as sources of drinking water or cover, and provide breeding habitat for amphibians. Amphibians observed at RFP include the Woodhouse's toad, northern leopard frog, northern chorus frog, and tiger salamander. Larvae of the last species, commonly known as "mudpuppies," are common in some ponds at RFP. Northern chorus frogs are widespread in wetland habitats along pond margins and intervening stream reaches.

3.8.5 Sensitive Habitats and Endangered Species

Federally listed endangered species potentially of interest in the Rocky Flats area are the black-footed ferret, peregrine falcon, and bald eagle (ASI 1991). Black-footed ferrets are not known to occur in the vicinity of RFP. Critical habitat for the black-footed ferrets consists primarily of colonies of its major food item, the prairie dog. Prairie dogs occur in only small numbers

on or near RFP. Bald eagles occur occasionally in the RFP area, primarily as irregular visitors during the winter or migration seasons. No roost areas or nest sites exist at RFP; however, a pair of bald eagles exhibited courtship and nest-building behavior in an area of cottonwoods between RFP and Stanley Reservoir in 1993. Peregrine falcons may occur as migrants, and a pair nested approximately 10 kilometers to the northwest in 1991. It is possible that the hunting territory of nesting peregrines could include Rocky Flats, although suitable habitat occurs closer to the nest area.

Three "Category 2" species have been reported at RFP: the ferruginous hawk, long-billed curlew, and Preble's meadow jumping mouse. Ferruginous hawks have been observed throughout the year and appear to be vagrants. The species may nest near RFP and use the site for hunting. Potential nest sites in the vicinity of RFP include scattered trees and rocky ridgetops. The long-billed curlew is a grassland species, although a member of the sandpiper family. A long-billed curlew was reported in the Buffer Zone of RFP during fall migration in 1993.

Preble's meadow jumping mice were captured in small numbers along Woman Creek in 1991, and one individual was captured in reclaimed grassland within the OU-2 study area. As a result of the discovery of Preble's jumping mouse at RFP, an intensive survey for the species was undertaken in 1992 (EG&G 1992i) and repeated in 1993. Surveys were conducted during the summer, because jumping mice become inactive by early fall. The 1992 program resulted in live captures of ten Preble's jumping mice, including two along Woman Creek below Pond C-1. The areas where Preble's jumping mice were captured were dominated by shrubs, such as sandbar willow, leadplant, and snowberry, with relatively lush grasses and forbs.

Other Category 2 wildlife species potentially present at RFP include the white-faced ibis, mountain plover, and swift fox (ASI 1991). To date, these species have not been documented at RFP.

Four plant species of special concern reported by ASI (1991) as potentially present include one threatened species (Ute lady's tresses), one Category 2 species (Colorado butterfly plant), and two species of concern in Colorado (forktip three-awn, toothcup). None of these species was found at RFP during the ASI (1991) survey. However, the forktip three-awn was reported along Woman Creek in 1973 and was documented in the same area during intensive vegetation investigations of OU5 (Woman Creek) in 1991. The toothcup has been reported from a temporary pool about 4 miles east of Boulder, and the Ute lady's tresses has been reported near

Clear Creek to the south of RFP and near South Boulder Creek to the north of RFP (ASI 1991). The Colorado butterfly plant has not been reported near RFP, but wetlands along the major creeks represent suitable habitat for both this species and the Ute lady's tresses. Neither species was found during surveys of appropriate habitat in 1992 or 1993.

The discovery of large populations of Ute lady's tresses on City of Boulder Open Space only a few miles from RFP led to initiation of a survey for this species in suitable moist habitats in 1992; the survey was repeated and expanded in 1993. Surveys for Ute lady's tresses are performed during late summer, when the plant is most easily detected and identified by its spike of small, white flowers. Ute lady's tresses were not observed at RFP during the 1992 survey (EG&G 1992j) or in 1993. The report concluded that some sites at RFP contained the appropriate degree of moisture, based on the presence of commonly associated plant species, such as blue vervain, great lobelia, and swamp milkweed.

Several wetlands identified at RFP come under the protection of state and federal laws. Wetlands at RFP were identified in conjunction with the National Wetlands Inventory (FWS 1979) and field-checked by U.S. Army Corp of Engineers personnel to verify their jurisdictional status. These wetlands consist of emergent, intermittently flooded stream channels and artificial, semipermanent ponds. Wetlands along drainages in most areas of RFP are dominated by a narrow band of cattails, leadplant, or sandbar willows with emergent trees and mesophytic or hydrophytic grasses and forbs. Prominent riparian trees include plains cottonwoods, hybrid (lanceleaf) cottonwoods, white poplars, and peachleaf willows; Siberian elms and Russian-olives are also common. Many of the same woody and herbaceous species occur along margins of ponds, particularly those with more stable water levels such as Pond C-1.

3.8.6 Location of OU-2 IHSSs Relative to Habitat Types

IHSSs within OU-2 are situated on the ridge between the Woman Creek and South Walnut Creek drainages (Figure 3.8-1). The Mound area (IHSSs 108, 113, 153, and 154) is located in a highly disturbed area of the ridgetop that is routinely mown and provides little or no wildlife habitat. The East Trenches (IHSSs 110 and 111.1 - 111.8) are in an area of xeric grassland composed primarily of native species. However, parts of the area have been disturbed by mowing or other activities. The East Spray Fields (IHSSs 216.2 and 216.3) are within an area that probably was xeric grassland in the past but currently is vegetated primarily by weedy non-native grasses and forbs. The area adjacent to the 903 Pad (IHSS 155) appears to be xeric grassland that is recovering from prior disturbance; the 903 Pad itself is asphalt.

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IHSSs 109, 183, and 140 are on the south-facing hillside below the 903 Pad. This area would probably be mesic grassland under natural conditions but currently is dominated by species that reflect prior disturbance and reclamation efforts. The area known as the Americium Zone is located east of the 903 Pad. Most of the Americium Zone is either xeric grassland on the ridgetop or mesic grassland on the south-facing hillside between the ridge and Woman Creek. However, this large area includes some weedy (disturbed) sites and stands of reclaimed grassland, primarily smooth brome.

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TABLE 3.2-1
SUMMARY OF POPULATION SECTORS IN THE ROCKY FLATS PLANT AREA

Sector	1989 Population	1989 Household No.	2010 Population	2010 Household No.
1	0	0	0	0
2	0	0	0	0
3	51	15	51	17
4	633	193	2,263	950
5	8,439	2,508	23,773	9,957
10	307,567	109,859	408,821	171,141

Source: DOE 1990d

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TABLE 3.3-1
1991 ANNUAL CLIMATIC SUMMARY

	Temperature (°F)			Dewpoint (°F)	Precipitation (inches)	Wind Data (mph)		Pressure (mbars)
	High	Low	Mean	Mean	Total	Mean	Maximum	Mean
January	55.9	-5.8	29.8	11.3	0.19	10.7	72.7	809
February	58.3	14	40.5	13.8	0.04	9.4	60.2	812
March	64.4	16.9	39.7	-999	0.41	11.6	83.7	804
April	68.4	16.5	42.1	22.3	1.5	8.9	53	808
May	79.7	27.7	55	31.3	3.77	8.7	47.9	810
June	91.6	45	64.4	39.6	2.3	7.6	40.7	813
July	90.5	50.9	68.7	45.5	2.47	7.2	41.2	818
August	86.2	52.2	67.8	48	2.45	6.9	46.1	819
September	79.7	34.7	59.7	36.7	0.84	7.4	49	813
October	82.9	3.5	49.8	23.5	0.31	8.1	46.8	813
November	66.9	-2.7	36.1	18.3	1.72	9.2	69.3	811
December	63.0	5.7	36.3	12.9	0.6	8.7	65.1	811

Source: EG&G 1992d

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TABLE 3.3-2
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX A

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+-----WIND SPEED CLASSES (KNOTS)-----+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.00045	.00182	.00000	.00000	.00000	.00000	.00227	4.60
NNE	.00114	.00295	.00000	.00000	.00000	.00000	.00409	4.33
NE	.00227	.00534	.00000	.00000	.00000	.00000	.00761	4.52
ENE	.00238	.00500	.00000	.00000	.00000	.00000	.00738	4.49
E	.00284	.00795	.00000	.00000	.00000	.00000	.01079	4.50
ESE	.00375	.00863	.00000	.00000	.00000	.00000	.01238	4.48
SE	.00272	.00761	.00000	.00000	.00000	.00000	.01033	4.44
SSE	.00125	.00238	.00000	.00000	.00000	.00000	.00363	4.39
S	.00068	.00079	.00000	.00000	.00000	.00000	.00148	4.13
SSW	.00045	.00011	.00000	.00000	.00000	.00000	.00057	2.50
SW	.00068	.00011	.00000	.00000	.00000	.00000	.00079	3.75
WSW	.00011	.00034	.00000	.00000	.00000	.00000	.00045	4.41
W	.00023	.00023	.00000	.00000	.00000	.00000	.00045	3.75
WNW	.00079	.00057	.00000	.00000	.00000	.00000	.00136	3.88
NW	.00068	.00034	.00000	.00000	.00000	.00000	.00102	3.75
NNW	.00034	.00034	.00000	.00000	.00000	.00000	.00068	3.74
TOTAL	.02078	.04450	.00000	.00000	.00000	.00000	.06528	
AVG SPD	3.34981	4.89210	.00000	.00000	.00000	.00000		4.40

Number of Calm Hours - 0
Frequency of Calms - .00000
Number of Hours of Data - 575

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TABLE 3.3-2 (continued)
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX B

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+------WIND SPEED CLASSES (KNOTS)-------+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.00125	.00477	.00159	.00011	.00000	.00000	.00772	5.82
NNE	.00148	.00613	.00159	.00011	.00000	.00000	.00931	5.81
NE	.00227	.00806	.00136	.00000	.00000	.00000	.01169	5.40
ENE	.00170	.00556	.00091	.00000	.00000	.00000	.00817	5.48
E	.00159	.00522	.00091	.00000	.00000	.00000	.00772	5.38
ESE	.00148	.00908	.00102	.00000	.00000	.00000	.01158	5.53
SE	.00227	.00988	.00148	.00000	.00000	.00011	.01374	6.37
SSE	.00045	.00556	.00068	.00011	.00000	.00000	.00681	5.97
S	.00068	.00114	.00045	.00000	.00000	.00000	.00227	5.29
SSW	.00079	.00148	.00034	.00000	.00000	.00000	.00261	4.75
SW	.00045	.00114	.00011	.00000	.00000	.00000	.00170	5.45
WSW	.00011	.00125	.00068	.00023	.00000	.00000	.00227	7.19
W	.00011	.00057	.00034	.00011	.00000	.00000	.00114	7.58
WNW	.00045	.00125	.00057	.00023	.00011	.00000	.00261	6.83
NW	.00045	.00114	.00045	.00011	.00000	.00000	.00216	5.63
NNW	.00148	.00261	.00079	.00000	.00000	.00000	.00488	5.30
TOTAL	.01703	.06483	.01328	.00102	.00011	.00011	.09639	
AVG SPD	3.24443	5.68967	7.76263	13.68854	17.86437	105.46670		5.76

Number of Calm Hours - 0
Frequency of Calms - .00000
Number of Hours of Data - 849

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TABLE 3.3-2 (continued)
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX C

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+------WIND SPEED CLASSES (KNOTS)-------+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.00148	.00545	.00636	.00068	.00000	.00000	.01396	7.08
NNE	.00159	.00420	.00545	.00079	.00000	.00000	.01203	7.14
NE	.00170	.00488	.00284	.00034	.00000	.00000	.00976	6.36
ENE	.00125	.00159	.00125	.00000	.00000	.00000	.00409	5.64
E	.00136	.00250	.00091	.00000	.00000	.00000	.00477	5.38
ESE	.00193	.00375	.00204	.00011	.00000	.00000	.00783	5.70
SE	.00182	.00443	.00477	.00000	.00000	.00000	.01101	6.34
SSE	.00159	.00522	.00443	.00023	.00000	.00000	.01147	6.54
S	.00114	.00227	.00148	.00068	.00000	.00000	.00556	6.63
SSW	.00079	.00431	.00102	.00011	.00000	.00000	.00624	3.77
SW	.00023	.00182	.00125	.00057	.00000	.00000	.00386	8.48
WSW	.00102	.00204	.00136	.00023	.00011	.00000	.00477	6.48
W	.00091	.00193	.00329	.00114	.00011	.00000	.00738	8.35
WNW	.00136	.00114	.00409	.00238	.00057	.00000	.00954	9.18
NW	.00125	.00136	.00375	.00102	.00011	.00000	.00749	8.05
TOTAL	.02089	.04893	.04837	.00886	.00091	.00000	.12795	
AVG SPD	3.16072	5.30101	8.86867	12.15883	19.03560	.00000		6.87

Number of Calm Hours - 0
Frequency of Calms - .00000
Number of Hours of Data - 1127

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TABLE 3.3-2 (continued)
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX D

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+------WIND SPEED CLASSES (KNOTS)-------+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.00443	.01317	.01226	.00840	.00125	.00034	.03985	8.54
NNE	.00250	.00658	.00545	.00522	.00057	.00011	.02044	8.60
NE	.00079	.00284	.00272	.00159	.00045	.00000	.00840	8.35
ENE	.00136	.00272	.00182	.00011	.00000	.00000	.00602	6.17
E	.00227	.00193	.00034	.00000	.00000	.00000	.00454	4.63
ESE	.00091	.00227	.00068	.00000	.00000	.00000	.00386	5.38
SE	.00136	.00397	.00284	.00045	.00000	.00000	.00863	6.53
SSE	.00193	.00658	.00670	.00227	.00000	.00000	.01748	7.34
S	.00159	.00874	.00942	.00193	.00000	.00000	.02168	7.22
SSW	.00182	.00920	.00602	.00057	.00023	.00000	.01782	6.59
SW	.00250	.00931	.01135	.00170	.00000	.00000	.02486	7.23
WSW	.00238	.01010	.01181	.00715	.00136	.00023	.03304	9.00
W	.00363	.01555	.01090	.01362	.00556	.00352	.05279	10.93
WNW	.00318	.01340	.01465	.02657	.01249	.00988	.08015	13.56
NW	.00182	.01079	.01374	.01306	.00329	.00102	.04371	10.23
TOTAL	.03451	.13022	.12500	.08958	.02611	.01521	.42064	
AVG SPD	3.19772	5.55985	8.72034	13.408971	9.06328	26.45159		9.57

Number of Calms - 0
Frequency of Calms - .00000
Number of Hours of Data - 3705

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TABLE 3.3-2 (continued)
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX E

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+------WIND SPEED CLASSES (KNOTS)-------+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.00341	.00556	.00363	.00000	.00000	.00000	.01260	5.65
NNE	.00216	.00352	.00193	.00000	.00000	.00000	.00761	5.38
NE	.00204	.00148	.00045	.00000	.00000	.00000	.00397	4.60
ENE	.00170	.00125	.00023	.00011	.00000	.00000	.00329	4.72
E	.00159	.00114	.00011	.00000	.00000	.00000	.00284	4.03
ESE	.00114	.00057	.00000	.00000	.00000	.00000	.00170	3.54
SE	.00068	.00204	.00011	.00000	.00000	.00000	.00284	4.79
SSE	.00136	.00500	.00057	.00000	.00000	.00000	.00693	5.13
S	.00386	.00658	.00284	.00000	.00000	.00000	.01328	5.30
SSW	.00307	.00942	.00658	.00000	.00000	.00000	.01907	6.01
SW	.00556	.01147	.00761	.00000	.00000	.00000	.02464	5.88
WSW	.00454	.01476	.01249	.00011	.00000	.00000	.03190	6.30
W	.00545	.01169	.00227	.00023	.00023	.00000	.01987	5.31
WNW	.00590	.01010	.00170	.00057	.00000	.00000	.01828	5.16
NW	.00477	.01362	.00431	.00023	.00000	.00000	.02293	5.50
NNW	.00465	.01010	.00738	.00000	.00000	.00000	.02214	6.02
TOTAL	.05188	.10831	.05223	.00125	.00023	.00000	.21390	
AVG SPD	3.14997	5.46329	8.1750413	.2262217	.77003	.00000		5.62

Number of Calm Hours - 0
Frequency of Calms - .00000
Number of Hours of Data - 1884

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TABLE 3.3-2 (continued)
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX F

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+------WIND SPEED CLASSES (KNOTS)------+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.00216	.00079	.00000	.00000	.00000	.00000	.00295	3.51
NNE	.00182	.00068	.00000	.00000	.00000	.00000	.00250	3.20
NE	.00148	.00068	.00000	.00000	.00000	.00000	.00216	3.19
ENE	.00114	.00034	.00000	.00000	.00000	.00000	.00148	3.43
E	.00148	.00068	.00000	.00000	.00000	.00000	.00216	3.91
ESE	.00272	.00068	.00000	.00000	.00000	.00000	.00341	3.33
SE	.00204	.00114	.00000	.00000	.00000	.00000	.00318	3.78
SSE	.00204	.00136	.00000	.00000	.00000	.00000	.00341	3.81
S	.00318	.00136	.00000	.00000	.00000	.00000	.00454	3.67
SSW	.00250	.00148	.00000	.00000	.00000	.00000	.00397	3.67
SW	.00443	.00318	.00000	.00000	.00000	.00000	.00761	3.78
WSW	.00477	.00318	.00000	.00000	.00000	.00000	.00795	3.69
W	.00454	.00295	.00000	.00000	.00000	.00000	.00749	3.62
WNW	.00420	.00238	.00000	.00000	.00000	.00000	.00658	3.67
NW	.00658	.00329	.00000	.00000	.00000	.00000	.00988	3.57
NNW	.00477	.00182	.00000	.00000	.00000	.00000	.00658	3.48
TOTAL	.04984	.02600	.00000	.00000	.00000	.00000	.07584	
AVG SPD	3.06587	4.65980	.00000	.00000	.00000	.00000		3.61

Number of Calm Hours - 0
Frequency of Calms - .00000
Number of Hours of Data - 668

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TABLE 3.3-2 (concluded)
ROCKY FLATS
WEST BUFFER ZONE
JOINT FREQUENCY DISTRIBUTION
(WIND SPEED, DIRECTION, AND STABILITY)

STABILITY INDEX ALL

FROM JANUARY 1, 1992 THROUGH DECEMBER 31, 1992

	+------WIND SPEED CLASSES (KNOTS)-------+							AVERAGE
DIRECTION	0-3	4-6	7-10	11-16	17-21	>21	TOTAL	WIND SPEED
N	.01317	.03156	.02384	.00920	.00125	.00034	.07936	7.26
NNE	.01067	.02407	.01442	.00613	.00057	.00011	.05597	6.83
NE	.01056	.02327	.00738	.00193	.00045	.00000	.04360	5.85
ENE	.00954	.01646	.00420	.00023	.00000	.00000	.03043	5.21
E	.01113	.01941	.00227	.00000	.00000	.00000	.03281	4.77
ESE	.01192	.02498	.00375	.00011	.00000	.00000	.04076	4.96
SE	.01090	.02906	.00920	.00045	.00000	.00011	.04973	5.73
SSE	.00863	.02611	.01238	.00261	.00000	.00000	.04973	6.20
S	.01113	.02089	.01419	.00261	.00000	.00000	.04882	6.12
SSW	.00942	.02600	.01396	.00068	.00023	.00000	.05030	5.65
SW	.01385	.02702	.02032	.00227	.00000	.00000	.06347	6.28
WSW	.01294	.03168	.02634	.00772	.00148	.00023	.08038	7.18
W	.01487	.03292	.01680	.01510	.00590	.00352	.08912	8.77
WNW	.01589	.02884	.02100	.02975	.01317	.00988	.11853	11.10
NW	.01555	.03054	.02225	.01442	.00341	.00102	.08719	7.85
NNW	.01476	.02997	.02657	.00749	.00091	.00011	.07981	7.01
TOTAL	.19494	.42280	.23887	.10070	.02736	.01533	1.00000	
AVG SPD	3.16763	5.39943	8.57790	13.29961	19.04666	27.03689		7.22

Number of Calm Hours - 0
Frequency of Calms - .00000
Number of Missing Hours - 0
Number of Hours of Data - 8808

Note: Analysis of data performed by computer program based on algorithms presented in U.S. EPA 1987 On-site Meteorological Program Guidance for Regulatory Modeling Application.

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TABLE 3.4-1
SOIL MAP UNITS AT
OPERABLE UNIT NO. 2

Series	Family	Phase	Mimimum-Maximum Slope (%)	Infiltration Rate
Denver-Kutch-Midway	Torretic Argiustolls	clay loam	9-25	slow
Flatirons	Aridic Paleustolls	very cobbly sandy loam	0-3	slow
Denver	Torretic Argiustolls	clay loam	5-9	slow
Nederland	Aridic Argiustolls	very cobbly sandy loam	15-50	moderate
Haverson	Ustic Torrifluventis	loam	0-3	slow
Nunn	Aridic Argiustolls	clay loam	0-2	slow
Denver-Kutch	Torretic Argiustolls	clay loam	5-9	slow
Midway	Ustic Torriorthents	clay loam	9-30	slow
Englewood	Torretic Argiustolls	clay loam	2-5	slow
Leyden-Primen-Standley	Aridic Argiustolls	cobbly clay loam	15-50	slow
Standley-Nunn	Aridic Argiustolls	gravelly clay loam	0-5	slow

Source: Department of Agriculture 1980

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TABLE 3.5-1
OU-2 SUBSURFACE STRATIGRAPHIC CONTROL

Year	Subsurface Stratigraphic Information Obtained From		
	Monitoring Wells	Boreholes***	Trenches
1971-1974	Plant-wide Hydrogeologic Investigations		
	4	0	0
1981	Geologic and Seismologic Investigations For Rocky Flats Plant (Dames and Moore, 1981)		
	0	0	3
1986	Plant-wide Hydrogeologic Investigations (Rockwell International, 1986b)		
	17	0	0
1987	Phase I OU-2 RFI\RI Investigation (Rockwell International, 1987c)		
	31	41	0
1989	Task 3 Shallow, High Resolution Seismic Reflection Profiling In OU-2 (DOE, 1991e)		
	10	9	0
1990	French Drain Geotechnical Investigation (EG&G, 1990c)		
	4*	4	0
1991	Phase II OU-2 RFI\RI Alluvial Investigation (This Study)		
	99**	37	0
1991	Phase III OU-1 RFI\RI Investigation (DOE, 1992i)		
	3	5	0
1991-1992	On-going Site-wide Geologic and Hydrogeologic Characterization		
	4	5	0
1992	Well Abondonment and Restoration Program		
	3	0	0
1993	Phase II OU-2 RFI\RI Bedrock Investigation (This Study)		
	7	10	0
	Totals: **182**	**111**	**3**

* - Piezometers
** - Includes Ten Aquifer Test Pumping and Observation Wells
*** - Includes Abandoned Monitoring Well Installation Attempts
All Monitoring Well and Borehole Locations are shown in Plates 1.1-1 and 1.1-2.

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TABLE 3.5-2
OU-2 GEOTECHNICAL RESULTS
(ROCKY FLATS ALLUVIUM AND ARAPAHOE FORMATION)

New Site Number	Work Plan Site Number	Sample Depth (ft BGS)	Sample Strat.	Moisture Content (%)	Dry Density (pcf)	Gradation			Atterberg Limits			Perm.(1) (cm/sec)	Sample Description (USCS Symbol)
						Grave (%)	Sand (%)	Silt & Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plastic. Index (%)		
03091	30-91	43.7	Ka (No.1)	10.5	129.4	0	54	46	27	15	12	3.1E-9	Clayey Sand, Grey-Brown(SC)
03091	30-91	53.5	Ka (cs)	13.8	114.2	0	5	95	39	14	25	--	Lean Clay, Grey-Black(CL)
03591	35-91	26.5	Qrf	11.4	119.6	0	66	34	33	12	21	--	Clayey Sand, Light Red-Brown(SC)
03591	35-91	37.5	Ka (cs)	18.9	101.8	0	2	98	55	16	39	1.7E-8	Fat Clay, Grey-Brown(CH)
04491	44-91	19.8	Qrf	16.6	94.4	11	45	44	51	16	35	--	Clayey Sand, Orange-Brown(SC)
04491	44-91	26.8	Qrf	18.8	114.3	12	32	56	60	16	44	--	Sandy Fat Clay, Orange-Brown(CH)
05191	51-91	30.5	Qrf	13.3	116.5	0	50	50	40	14	26	1.9E-8	Clayey Sand, Orange-Brown(SC)
05191	51-91	48.5	Ka (cs)	15.1	110.7	0	40	60	36	15	21	--	Sandy Lean Clay, Light Grey(CL)
05191	51-91	50.5	Ka (cs)	20.6	106.9	0	11	89	42	15	27	--	Lean Clay, Grey(CL)
05291	52-91	13.3	Qrf	9.1	104.0	53	30	17	38	16	22	--	Clayey Gravel With Sand, Orange-Brown(GC)
05291	52-91	22.6	Qrf	12.5	119.2	14	56	30	47	16	31	--	Clayey Sand With Gravel, Orange-Brown(SC)
05291	52-91	29.6	Qrf	24.3	95.0	0	35	65	67	20	47	--	Sandy Fat Clay, Orange-Brown(CH)
05291	52-91	31.6	Qrf	18.4	109.4	0	49	51	40	15	25	--	Sandy Lean Clay, Orange-Brown(CL)
06191	61-91	1.6	Qrf	17.2	102.2	12	55	33	41	21	20	--	Clayey Sand, Orange(SC)
06191	61-91	10.7	Qrf	8.8	118.6	34	43	23	--	--	--	--	Clayey Sand With Gravel, Brown(SC)
06191	61-91	23.5	Qrf	5.5	114.8	48	40	12	--	--	--	--	Clayey Gravel With Sand, Orange-Brown(GC)
08591	5-91/BH419	40.7	Qrf	17.0	114.8	14	30	56	44	13	31	--	Sandy Lean Clay With Gravel, Olive-Brown(CL)
10291	BH3091	8.4	Qrf	5.2	--	51	35	14	--	--	--	--	Clayey Gravel With Sand, Orange-Brown(GC)
10291	BH3091	17.8	Ka (cs)	4.9	--	0	35	65	--	--	--	--	Sandy Lean Clay, Brown-Olive(CL)
10291	BH3091	21.8	Ka (cs)	11.5	119.5	0	50	50	30	13	17	--	Sandy Lean Clay, Grey-Brown(CL)
10291	BH3091	37.8	Ka (No.1)	10.3	121.5	0	81	19	28	11	17	3.7E-8	Clayey Sand, Orange-Grey(SC)
10291	BH3091	43.8	Ka (No.1)	14.0	115.3	0	52	48	NP	NP	NP	1.1E-8	Clayey Sand, Light Brown(SC)
10291	BH3091	47.8	Ka (No.1)	12.6	117.8	0	85	15	NP	NP	NP	--	Clayey Sand, Grey-Brown(SC)
10291	BH3091	51.8	Ka (No.1)	14.2	119.5	0	31	69	36	13	23	5.0E-9	Sandy Lean Clay, Brown(CL)
10291	BH3091	57.8	Ka (No.1)	12.3	121.9	0	20	80	35	18	17		Lean Clay With Sand, Grey(CL)
10391	BH3191	35.8	Ka (No.1)	17.9	111.8	0	92	8	NP	NP	NP	1.1E-4	Sand With Clay, Grey(SP-SC)
10391	BH3191	61.8	Ka (No.1)	11.2	124.5	0	51	49	29	15	14	7.3E-8	Clayey Sand, Brown(SC)
10691	BH4291	29.0	Qrf	16.2	117.1	49	33	18	--	--	--	--	Clayey Gravel With Sand, Olive-Brown(GC)

TABLE 3.5-2
OU-2 GEOTECHNICAL RESULTS
(ROCKY FLATS ALLUVIUM AND ARAPAHOE FORMATION)

New Site Number	Work Plan Site Number	Sample Depth (ft BGS)	Sample Strat.	Moisture Content (%)	Dry Density (pcf)	Gradation			Atterberg Limits			Perm.(1) (cm/sec)	Sample Description (USCS Symbol)
						Grave (%)	Sand (%)	Silt & Clay (%)	Liquid Limit (%)	Plastic Limit (%)	Plastic. Index (%)		
10791	BH4391	28.4	Qrf	8.8	116.6	17	55	28	--	--	--	--	Clayey Sand With Gravel, Orange-Brown(SC)
10791	BH4391	33.8	Qrf	20.3	107.5	0	47	53	49	15	34	--	Sandy Lean Clay, Brown-Olive(CL)
10791	BH4391	37.3	Qrf	12.7	118.8	10	58	32	29	13	16	--	Clayey Sand, Orange-Brown(SC)
10891	BH4491	16.7	Qrf	15.4	105.7	15	52	33	45	17	28	--	Clayey Sand, Orange-Brown(SC)
10891	BH4491	25.8	Qrf	16.3	111.3	0	58	42	40	16	24	1.2E-8	Clayey Sand, Orange-Brown(SC)
20091	NA	28.1	Qrf	10.2	124.9	0	61	39	35	14	21	1.3E-7	Clayey Sand, Brown(SC)
20091	NA	40.7	Ka (No.1)	11.9	121.4	0	45	55	29	22	7	5.4E-8	Sandy Silty Clay, Brown(CL-ML)
20091	NA	49.6	Ka (No.1)	12.3	119.1	0	53	47	24	19	5	1.5E-7	Silty Clayey Sand, Brown(SC-SM)
20791	NA	15.3	Qrf	13.1	109.1	16	65	19	38	15	23	2.2E-8	Clayey Sand With Gravel, Brown(SC)
20791	NA	20.9	Qrf	8.0	147.2	56	36	8	34	16	18	--	Gravel With Clay and Sand, Brown(GP-GC)
20991	NA	42.8	Ka (No.1)	15.1	113.7	55	41	4	NP	NP	NP	1.1E-6	Gravel With Sand, Brown(GP)
20991	NA	56.8	Ka (No.1)	13.4	117.1	0	49	51	29	14	15	6.8E-8	Sandy Lean Clay, Brown(CL)
20991	NA	60.5	Ka (No.1)	--	--	42	51	7	--	--	--	--	Sand With Clay & Gravel, Yellow-Brown(SP-SC)

Notes :

BGS - Below Ground Surface
BH - Borehole
(cs) - Claystone
Qrf - Rocky Flats Alluvium
Ka - Arapahoe Formation
NA - Not Applicable
No. 1 - No. 1 Sandstone
NP - Non-Plastic
Perm. - Permeability
Plastic. Index - Plasticity Index
Sample Strat. - Sample Stratigraphy

The symbol "--" indicates that the tests were not conducted on that sample.

(1) Permeability tests were conducted using the fixed-wall, falling-head method at 20 degrees C.

TABLE 3.5-3
HIGH TERRACE ALLUVIUM INFORMATION

Terrace Designation	Position Below Top of Adjoining RFA (in feet)	Thickness*** (in feet)	Named by Previous Investigations
Qt1	20-35 (SWC) 20 (WC)	35-45 (SWC) 10-15 (WC)	Not previously mapped
Qt2	70-90(SWC) 45-60 (WC)	10-20	Verdos Alluvium* and Terrace gravel and Upland Deposit**
Qt3	70-125 (SWC) 100-110 (SWC)	12-20	Slocum Alluvium* and Upland Deposit**
Qtu	Various levels	10-20	Not previously mapped

RFA - Rocky Flats Alluvium

SWC - S. Walnut Creek Hillside
WC - Woman Creek Hillside
* - Hurr 1976 and Rockwell International 1987c
** - Malde 1955
*** - Measured in the Field

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TABLE 3.5-4

TERRACE ALLUVIUM BOREHOLES AND MONITORING WELLS

BOREHOLES	MONITORING WELLS
BH1687*	6786
BH1787*	4487*
BH2587*	4587*
BH2787*	00491**
00591*	00691
07491*	00891
07591*	00991
07691*	05991***
09291*	07391*
09391*	
09491*	
09591*	
09791*	
12791*	
40591*	

* Upper portion of section may be disturbed by man-made activity.

** Upper portion of section is artificial fill.

*** May be colluvium filling bedrock low.

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TABLE 3.5-5

VALLEY-FILL ALLUVIUM BOREHOLES AND MONITORING WELLS

BOREHOLES	MONITORING WELLS
11091	0286
40391	0386
40691	3386*
	3486*
	3586*
	6486*
	BH217289
	BH317189
	06491
	40491
	40791
	41591
	41691

* Core from these wells may contain artificial fill or be disturbed by man-made activity.

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TABLE 3.5-6
COLLUVIUM BOREHOLES AND MONITORING WELLS

BOREHOLES	MONITORING WELLS
0687A	3686
1287A*	3786
1387A	6286
BH2687*	6386
BH2887*	0687
BH6187**	1187
B300190	1287*
B300290	1487
B300390	2187*
B303790	2287*
01091	2987
01191	3087
31191	5087**
32691	B213789
	B3003390
	B3003490
	B3003590
	B3003690
	00391
	00791
	01291
	02291
	02491
	09691*
	11791
	34591*
	34791*

* Upper portion of section may be disturbed by man-made activity.

** Upper portion of section is artificial fill.

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TABLE 3.5-7
ARAPAHOE NO. 1 SANDSTONE BOREHOLES AND MONITORING WELLS

BOREHOLES	MONITORING WELLS
BH3187	0987
B217389	2387
10191	2587
10291	3687
10391	B217489
11391*	B217689
20091**	B315289
42792	00291
21193	01491
21693	02091
	02291
	02491
	02991
	03091
	03391
	03691
	03791
	12391
	12691
	20191***
	20891***
	20991***
	21091***
	46792

* Abandoned monitor well installation attempt.
** Abandoned borehole from failed monitoring well installation attempt.
*** Test wells.

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TABLE 3.5-8
SUMMARY OF EXISTING OU-2 LHSU MONITORING WELLS AND 1993 PILOT BOREHOLES

Well Number	Borehole/ Monitor Well Designation	Concrete Pad/Ground Elev.(1)(ft.)	Total Depth (BGS)(4) (ft)	Isolation Casing Depth(4) (BGS)(ft)	Top of Well Casing Elevations (ft)	Well Casing Stickup (1) (ft)	Depth of Screened Interval(1)(ft)	Elevation of Screened Interval(1)(ft)	Lithology of Screened Interval	Depth to Groundwater(2)(3) (ft)	Groundwater Elevation (2) (ft)
903 Pad Area											
1687	MW	5969.49	174.0	49.17	5970.79	1.30	100.00-125.00	5869.49-5844.49	Kl (silt)	84.43	5886.36
3087	MW	5810.12	110.0	45.00	5811.77	1.65	85.79-94.35	5724.33-5715.77	Kl (silt)	27.64	5784.13
4587	MW	5949.32	112.0	58.77	5950.91	1.59	89.50-101.05	5859.82-5848.27	Kl (ss)	91.40	5859.51
B315289	MW	5963.20	220.0	75.00	5965.21	2.01	91.00-98.00	5872.20-5865.20	Kl (ss, silt)	57.76	5907.45
21293	BH	5946.18	148.8	26.40	NA	NA	NA	NA	NA	NA	NA
21393	BH	5960.78	209.8	45.00	NA	NA	NA	NA	NA	NA	NA
21493	BH	5883.60	130.4	43.00	NA	NA	NA	NA	NA	NA	NA
22093	MW	5945.00	67.5	24.10	5947.43	2.43	48.00-63.00	5897.00-5882.00	Kl(silt,ss)	49.28	5898.15
22193	MW	5960.90	59.7	44.00	5963.36	2.46	49.40-56.40	5911.50-5904.50	Kl(ss,cs,silt)	40.04	5923.32
22293	MW	5881.50	84.5	51.00	5884.12	2.62	67.00-82.00	5814.50-5799.50	Kl(ss,silt)	41.33	5842.79
Mound Area											
3486	MW	5912.00	100.0	NA	5913.95	1.95	44.24-56.25	5867.76-5855.75	Kl (ss)	21.33	5892.62
1887	MW	5967.99	148.0	52.70	5969.49	1.50	127.00-133.45	5840.99-5834.54	Kl (silt)	127.73	5841.76
2087	MW	5968.66	126.2	51.64	5970.14	1.48	107.26-116.11	5861.40-5852.55	Kl (cs)	94.30	5875.84
2287	MW	5930.70	111.0	43.59	5931.18	0.48	81.41-88.46	5849.29-5842.24	Kl (ss, silt)	80.37	5850.81
21593	BH	5969.35	175.0	24.30	NA	NA	NA	NA	NA	NA	NA
22393	MW	5969.30	121.0	58.30	5972.14	2.84	108.00-118.00	5861.30-5851.30	Kl(cs)	Dry	NA
S.E. Trenches Area											
4086	MW	5943.85	124.8	NA	5944.89	1.04	88.00-111.50	5855.85-5832.35	Kl (cs)	103.09	5841.80
2887	MW	5947.56	207.0	55.50	5949.90	2.34	187.37-197.37	5760.19-5750.19	Kl (ss, silt)	188.20	5761.70
3187	MW	5945.31	140.0	57.60	5947.46	2.15	110.66-129.41	5834.65-5815.90	Kl (ss)	100.19	5847.27
3487	MW	5945.60	124.0	55.30	5947.22	1.62	97.29-104.29	5848.31-5841.31	Kl (silt)	58.97	5888.25
B217789	MW	5954.90	220.1	45.00	5956.85	1.95	52.00-63.84	5902.90-5891.06	Kl(cs)	52.19	5904.66
B317189	MW	5725.00	220.4	36.00	5726.64	1.64	60.60-75.10	5664.40-5649.90	Kl (ss)	Dry	NA

TABLE 3.5-8 (concluded)
SUMMARY OF EXISTING OU-2 LHSU MONITORING WELLS AND 1993 PILOT BOREHOLES

Well Number	Borehole/ Monitor Well Designation	Concrete Pad/Ground Elev.(1)(ft.)	Total Depth (BGS)(4) (ft)	Isolation Casing Depth(4) (BGS)(ft)	Top of Well Casing Elevations (ft)	Well Casing Stickup (1) (ft)	Depth of Screened Interval(1)(ft)	Elevation of Screened Interval(1)(ft)	Lithology of Screened Interval	Depth to Groundwater(2)(3) (ft)	Groundwater Elevation (2) (ft)
N.E. Trenches Area											
B217289	MW	5777.50	220.0	46.19	5779.10	1.60	109.80-134.20	5667.70-5643.30	Kl (ss,silt)	70.40	5708.70
B217489	MW	5961.20	220.0	61.00	5963.23	2.03	142.03-146.43	5819.17-5814.77	Kl ss)	128.64	5834.59
B217589	MW	5952.90	221.3	75.00	5954.89	1.99	85.23-90.74	5867.67-5862.16	Kl (cs)	40.78	5914.11
B217689	MW	5960.53	220.1	69.00	5961.87	1.34	98.52-102.91	5862.01-5857.62	Kl (ss)	50.94	5910.93
46692	MW	5956.20	90.1	60.30	5958.25	2.05	72.30-87.30	5883.90-5868.90	Kl (ss)	31.93	5926.32
46792	MW	5956.30	118.8	64.50	5958.44	2.14	97.10-112.10	5859.20-5844.20	Kl (silt)	66.74	5891.70
46892	MW	5956.70	165.2	60.00	5958.36	1.66	147.40-162.40	5809.30-5794.30	Kl (ss, silt)	102.89	5855.47
21193	BH	5948.70	160.2	66.80	NA	NA	NA	NA	NA	NA	NA
21693	BH	5955.17	163.0	47.00	NA	NA	NA	NA	NA	NA	NA
21993	AMW	5948.00	66.6	64.80	NA	NA	NA	NA	NA	NA	NA
22493	AMW	5955.36	52.3	52.30	NA	NA	NA	NA	NA	NA	NA
22593	MW	5947.60	99.5	80.00	5950.13	2.53	85.00-95.00	5860.60-5852.60	K1(cs,ss,silt)	86.38	5863.75
23193	MW	5948.20	77.0	65.00	5950.46	2.26	66.80-73.80	5881.40-5869.00	K1(ss,cs)	37.69	5912.77
23293	MW	5955.60	89.5	45.00	5958.02	2.42	77.70-87.70	5877.90-5867.90	K1(silt,cs)	Dry	NA

Explanation

ss = sandstone
silt = siltstone
cs = claystone
K1 = Laramie Formation
ft = feet

AMW - Abandoned Monitoring Well
BGS - Below Ground Surface
BH - Borehole
MW - Monitoring Well
NA - Not Applicable

(1) Measured from ground elevation for 1993 wells; measured from top of concrete pad (6" thick) for all other wells.
(2) Measured from top of casing.
(3) Groundwater levels obtained in 3rd quarter 1993 for all wells except 1993 wells; groundwater levels obtained in 4th quarter 1993 for 1993 wells. Some water levels may not have fully recovered from well development and/or sampling activities.
(4) Data from draft boring logs.

TABLE 3.5-9
OU-2 GEOTECHNICAL RESULTS
(LARAMIE FORMATION)

Site Number	Work Plan Site Number	Sample Number	Sample Depth* (ft BGS)	Sample Strat.**	Moisture Content (%)	Dry Density (pcf)	Bulk Density*** (pcf)	Void Ratio	Porosity (%)	Saturation (%)	Gradation				Specific Gravity	Vertical Perm.(1) (cm/sec)	Horiz. Perm.(2) (cm/sec)	Sample Description (USCS Symbol)
											Grave (%)	Sand (%)	Silt (%)	Clay (%)				
21193	WC-1BH	BH20294WC	65.8-66.5	Kl(cs)	6.5	109.3	145.7	0.525	34.4	33.3	0.0	20.6	42.5	36.9	2.67	8.4E-8	!	Silt with Sand, Dark Gray (ML)
21193	WC-1BH	BH20295WC	69.0-70.6	Kl(sltst)	7.5	128.2	214.4	0.295	22.8	67.2	0.0	17.4	53.5	29.1	2.66	1.4E-9	2.3E-7	Silt with Sand, Dark Gray (ML)
21193	WC-1BH	BH20296WC	78.3-79.4	Kl(cs)	12.8	119.8	216.1	0.439	30.5	80.4	0.0	7.6	18.6	73.8	2.76	1.8E-8	1.3E-7	Lean Clay, Dark Gray (CL)
21193	WC-1BH	BH20297WC	86.3-93.8	Kl(sltst)	8.0	118.1	178.4	0.422	29.7	51.1	0.0	12.0	64.3	23.7	2.69	7.1E-8	3.4E-6	Silt, Dark Gary (ML)
21193	WC-1BH	BH20298WC	107.4-110.8	Kl(cs)	10.0	127.9	236.5	0.318	24.1	84.9	0.0	0.2	44.0	55.8	2.70	1.4E-7	!	Lean Clay, Dark Gray (CL)
21193	WC-1BH	BH20393WC	125.1-125.8	K1(cs)	–	–	–	–	–	–	–	–	–	–	–	–	3.3E-8	Lean Clay, Dark Gray (CL)
21293	WC-2BH	BH20353WC	58.4-63.0	Kl(sltst,ss)	9.3	124.4	215.0	0.34	25.4	72.8	0.0	39.1	33.3	27.7	2.67	2.0E-8	6.8E-7	Sandy Silt, Gray (ML)
21293	WC-2BH	BH20354WC	89.5-94.9	Kl(cs)	5.7	131.2	200.3	0.294	22.7	52.7	0.0	2.3	43.2	54.5	2.72	1.4E-7	9.8E-8	Lean Clay, Gray (CL)
21293	WC-2BH	BH20355WC	110.7-115.4	Kl(ss)	9.7	126.6	226.0	0.336	25.2	78.5	0.0	23.5	51.6	25.0	2.71	9.9E-8	5.1E-8	Silt with Sand, Gray (ML)
21293	WC-2BH	BH20356WC	141.6-143.8	Kl(ss)	11.4	110.3	175.3	0.517	34.1	58.9	0.0	77.1	12.3	10.6	2.68	8.8E-6	!	Silty Sand, Gray (SM)
21293	WC-2BH	BH20536WC	138.2-141.1	Kl(ss)		–	–	–	–	–	–	–	–	–	–	–	1.6E-7	Lean Clay, Brown (CL)
21393	WC-3BH	BH20299WC	49.0-50.3	Kl(cs)	7.9	130.7	219.6	0.323	24.4	68.0	0.0	0.0	35.4	64.6	2.77	1.3E-8	1.8E-8	Lean Clay, Dark Gray (CL)
21393	WC-3BH	BH20300WC	51.5-52.8	Kl(sltst)	4.6	123.8	168.0	0.342	25.5	35.7	0.0	9.0	55.2	35.8	2.66	3.8E-8	!	Silt, Light Gray, (ML)
21393	WC-3BH	BH20301WC	58.4-62.2	Kl(cs)	12.8	121.0	224.5	0.409	29.0	85.5	0.0	0.4	29.7	69.9	2.73	2.1E-8	!	Lean Clay, Dark Gray (CL)
21393	WC-3BH	BH20302WC	69.2-70.0	Kl(sltst)	6.5	130.2	210.3	0.285	22.2	61.5	0.0	5.2	70.8	24.0	2.68	1.4E-7	6.0E-7	Silt, Light Gray (ML)
21393	WC-3BH	BH20303WC	84.5-86.0	Kl(cs)	11.7	126.9	243.9	0.348	25.8	92.2	0.0	1.3	51.0	47.7	2.74	3.0E-8	!	Silt, Dark Gray (ML)
21393	WC-3BH	BH20396WC	93.0-93.6	Kl(cs)	–	–	–	–	–	–	–	–	–	–	–	–	5.0E-9	Silt, Dark Gray (ML)
21393	WC-3BH	BH20304WC	94.3-95.9	Kl(sltst)	5.7	125.3	181.9	0.34	25.4	45.2	0.0	9.5	59.9	30.7	2.69	2.5E-7	!	Silt, Light Gray (ML)
21393	WC-3BH	BH20397WC	97.4-97.8	Kl(sltst)	–	–	–	–	–	–	–	–	–	–	–	–	7.3E-8	Silt, Light Gray (ML)
21393	WC-3BH	BH20305WC	124.6-125.7	Kl((cs)	8.4	133.2	242.6	0.28	21.9	82.1	0.0	1.2	44.0	54.8	2.73	4.2E-8	!	Lean Clay, Gray (CL)
21393	WC-3BH	BH20398WC	130.3-130.7	Kl(cs)	–	–	–	–	–	–	–	–	–	–	–	–	3.6E-8	Lean Clay, Gray (CL)
21393	WC-3BH	BH20306WC	145.4-157.4	Kl(ss)	6.1	122.4	176.6	0.372	27.1	44.3	0.0	43.5	35.3	21.2	2.69	4.2E-8	1.2E-8	Sandy Silt, Light Gray (ML)
21493	WC-4BH	BH20331WC	60.0-61.6	Kl(cs)	13.6	118.9	223.5	0.418	29.0	88.0	0.0	1.1	26.7	72.2	2.70	5.4E-9	!	Lean Clay, Gray (CL)
21493	WC-4BH	BH20332WC	73.0-76.6	Kl(ss)	7.9	128.2	215.4	0.315	24.0	68.0	0.0	27.6	46.9	25.6	2.70	1.3E-8	7.5E-9	Silt with Sand, Gray (ML)
21493	WC-4BH	BH20333WC	105.2-106.7	Kl(cs)	10.8	124.1	223.4	0.363	27.0	80.0	0.0	2.8	39.4	57.7	2.71	1.3E-7	2.0E-8	Lean Clay, Gray (CL)
21493	WC-4BH	BH20334WC	120.3-121.8	Kl(ss,cs)	8.6	123.9	203.2	0.361	27.0	64.0	0.0	12.6	64.0	23.4	2.70	4.7E-8	2.9E-7	Silt, Gray (ML)
21493	WC-4BH	BH20335WC	124.5-127.7	Kl(cs)	8.0	134.4	250.0	0.25	20.0	86.0	0.0	1.0	52.3	46.7	2.69	1.3E-7	4.7E-8	Silt, Gray (ML)
21593	WC-5BH	BH20336WC	40.9-42.2	Kl(cs)	13.9	116.7	210.1	0.476	32.0	80.0	0.0	2.7	37.3	60.1	2.76	2.7E-9	3.2E-8	Lean Clay, Yellow-Brown (CL)
21593	WC-5BH	BH20337WC	74.8-76.2	Kl(cs)	12.2	124.3	234.9	0.377	27.0	89.0	0.0	0.8	33.5	65.8	2.74	9.1E-8	!	Lean Clay, Gray (CL)
21593	WC-5BH	BH20338WC	109.8-113.0	Kl(cs, sltst)	7.9	133.7	238.0	0.28	22.0	78.0	0.0	5.3	46.7	48.0	2.74	5.3E-8	1.4E-8	Lean Clay, Gray (CL)
21593	WC-5BH	BH20339WC	128.9-131.3	Kl(cs)	7.2	147.1	283.9	0.222	18.0	93.0	0.0	4.3	44.0	51.7	2.88	2.7E-9	4.7E-7	Lean Clay, Gray (CL)
21593	WC-5BH	BH20340WC	146.6-151.8	Kl(ss,cs)	6.4	123.0	180.8	0.366	27.0	47.0	0.0	29.7	46.2	24.1	2.69	9.1E-8	3.1E-7	Silt wtih Sand, Gray (ML)
21593	WC-5BH	BH20341WC	159.0-163.8	Kl(cs)	9.3	130.7	245.7	0.285	22.0	88.0	0.0	1.1	40.3	58.6	2.69	7.7E-8	3.0E-7	Lean Clay, Gray (CL)
21693	WC-6BH	BH20357WC	63.4-68.7	Kl(ss,cs)	6.8	130.1	218.4	0.266	21.0	67.9	0.0	9.5	49.2	41.2	2.64	7.6E-8	2.6E-8	Silt, Gray (ML)
21693	WC-6BH	BH20358WC	83.6-84.9	Kl(ss,cs)	6.0	127.6	194.0	0.306	23.5	52.0	0.0	1.7	66.5	31.9	2.67	3.2E-7	!	Silt, Gray (ML)

TABLE 3.5-9
OU-2 GEOTECHNICAL RESULTS
(LARAMIE FORMATION)

Site Number	Work Plan Site Number	Sample Number	Sample Depth* (ft BGS)	Sample Strat.**	Moisture Content (%)	Dry Density (pcf)	Bulk Density*** (pcf)	Void Ratio	Porosity (%)	Saturation (%)	Gradation				Specific Gravity	Vertical Perm.(1) (cm/sec)	Horiz. Perm.(2) (cm/sec)	Sample Description (USCS Symbol)
											Grave (%)	Sand (%)	Silt (%)	Clay (%)				
21693	WC-6BH	BH20359WC	94.0-101.8	Kl(cs)	12.0	123.1	234.3	0.354	26.1	90.3	0.0	2.3	31.3	66.3	2.67	2.0E-8	!	Lean Clay, Gray (CL)
21693	WC-6BH	BH20360WC	106.3-108.0	Kl(cs)	6.9	134.2	231.6	0.256	20.4	72.6	0.0	0.3	53.1	46.5	2.70	4.3E-8	3.2E-8	Silt, Gray (ML)
21693	WC-6BH	BH20361WC	119.9-143.7	Kl(cs)	9.4	131.9	249.2	0.288	22.3	88.9	0.0	0.7	16.4	82.9	2.72	1.9E-8	1.0E-7	Lean Clay, Gray (CL)
21693	WC-6BH	BH20362WC	151.8-154.7	Kl(cs)	6.6	129.5	206.4	0.297	22.9	59.4	0.0	5.2	59.5	35.3	2.69	2.4E-7	2.1E-7	Silt, Gray (ML)

Notes :

BGS - Below Ground Surface
BH - Borehole
(cs) - Claystone
(sltst) - Siltstone
(ss) - Sandstone
Kl - Laramie Formation
Sample Strat. - Sample Stratigraphy
Perm. - Permeability
pcf - pounds per cubic foot
* Reflects entire interval selected for geotechnical analyses.
** Logged in field according to SOP GT.1.
*** Bulk density (Pb) was calculated from dry density (Pd) and moisture content (Wc) using the formula Pb=Pd (1+Wc)

! Samples were too small or were disturbed upon arrival at laboratory, or samples shattered during sample preparation.

The symbol "--" indicates that the tests were not conducted on that sample.

(1) Permeability tests were conducted using the flexible-wall, falling-head method.
(2) Permeability tests were conducted using the radial flexible-wall method.

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TABLE 3.5.-10
LARAMIE UNITS BOREHOLES AND MONITORING WELLS

BOREHOLES

Northeast Trenches					
	3687	03091	11391	20191	21693
	B217389	03391	12491	20991	21993
	B218589	10291	12691	21091	22493
	02991	10491	20091	21193	
Mound Area					
		09991			
		21593			
		21893			
Southeast Trenches					
		BH5287	B318889		
		B218689	40591		
		B218989	40691		
903 Pad Area					
	687	BH2587	01191	09291	21393
	67A	3087	05991	09791	21493
	1287	5087	06591	42892	21793
	1387A	BH6187	07391	21293	

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TABLE 3.5.-10 (concluded)
LARAMIE UNITS BOREHOLES AND MONITORING WELLS

MONITORING WELLS

NE Trenches Area				
	B217289	B217689	46692	22593
	B217489	06491	46792	23193
	B217589	12391	46892	23293
Mound Area				
	1887			
	2087			
	2287			
	22393			
SE Trenches Area				
	2887			
	3187			
	3487			
	B217789			
	B317189			
903 Pad Area				
	1187	3087	00391	11791
	1487	4587	00991	22093
	1687	B315289	09691	22193
				22293

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TABLE 3.6-1
ESTIMATED HYDRAULIC CONDUCTIVITY OF
ROCKY FLATS ALLUVIUM
BASED ON RESULTS OF 1986 AND 1987 AQUIFER TESTS

Site/Well Number	Hydraulic Conductivity from Pump Test (cm/sec)	Hydraulic Conductivity from Slug Tests (cm/sec)
3986	4E-05	
4186	9E-05	
4286		5E-02
1787		6E-05
3287		1E-03

Source: Rockwell International 1987c

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TABLE 3.6-2
ESTIMATED HYDRAULIC CONDUCTIVITY OF ROCKY FLATS ALLUVIUM BASED ON RESULTS OF 1992 AQUIFER TESTS

Site/Well Number	Hydraulic Conductivity from Pump Test (cm/sec)
Site 2	
11491 (Alluvial)	1.6E-3 to 1.8E-3
05691 (Alluvial)	1.80E-03
20491 (Alluvial)	3.1E-3 to 3.6E-3
20291 (Alluvial)	8.1E-4 to 8.8E-4
Site 3	
1787 (Alluvial)	1.6E-4 to 9.2E-4
20591 (Alluvial)	5.5E-5 to 8.6E-4
20691 (Alluvial)	1.2E-4 to 4.4E-4

Source: DOE 1992h

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TABLE 3.6-3
ESTIMATED HYDRAULIC CONDUCTIVITY OF
ARAPAHOE NO. 1 SANDSTONE
BASED ON RESULTS OF 1987 AQUIFER TESTS

Well Number	Hydraulic Conductivity from Slug Tests (cm/s)
987	3E-03
2387	2E-04
2587	2E-03
3687	1E-03

Source: Rockwell International 1987c

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TABLE 3.6-4
ESTIMATED HYDRAULIC CONDUCTIVITY OF ARAPAHOE NO. 1 SANDSTONE BASED ON RESULTS OF 1992 AQUIFER TESTS

SITE/WELL NUMBER	HYDRAULIC CONDUCTIVITY FROM PUMP TEST
Site 1	
3687 (Bedrock)	4.2E-04 to 4.8E-04
20991 (Bedrock)	3.7E-04 to 6.2E-04
21091 (Bedrock)	4.7E-04 to 5.1E-04
20891 (Bedrock)	4.7E-04 to 6.0E-04

Source: DOE 1992h

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TABLE 3.6-5
ESTIMATED HYDRAULIC CONDUCTIVITY OF LHSU UNITS BASED ON RESULTS OF 1986 AND 1987 AQUIFER TESTS

		HYDRAULIC CONDUCTIVITY VALUES		
Well Number	Lithology	Slug Test Results (cm/s)	Drawdown-Recovery Test Results (cm/s)	Packer Test Results*
386	Sandstone	---	8.0E-05	--
3486	Sandstone	5.3E-6**	2.0E-05	--
6286	Sandstone	6.0E-06	--	--
1687	Sandstone	2.0E-06	--	3.0E-07
3187	Sandstone	2.0E-06	--	--
3487	Siltstone	1.0E-06	--	--
2087	Claystone	--	--	1.0E-07
1487	Sandstone/siltstone	2.0E-05	--	--
2287	Sandstone/silstone/claystone	--		2.0E-06

Source: Rockwell International 1987c

* Geometric mean of packer test results for screened interval
** EG&G reanalysis (5/93)

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TABLE 3.6-6
ESTIMATED HYDRAULIC CONDUCTIVITY OF LHSU UNITS BASED ON RESULTS OF 1993 RBWP SLUG TESTS

Well Number	Lithology	Hydraulic Conductivity from Slug Test Results (cm/s)
22093	Sandstone/siltstone	1.1E-07 to 2.2E-08
22193	Sandstone/siltstone/claystone	9.7E-05 to 1.2E-05
22293	Sandstone/siltstone	2.0E-05 to 4.1E-06
23192	Sandstone/claystone	2.7E-06 to 8.6E-07

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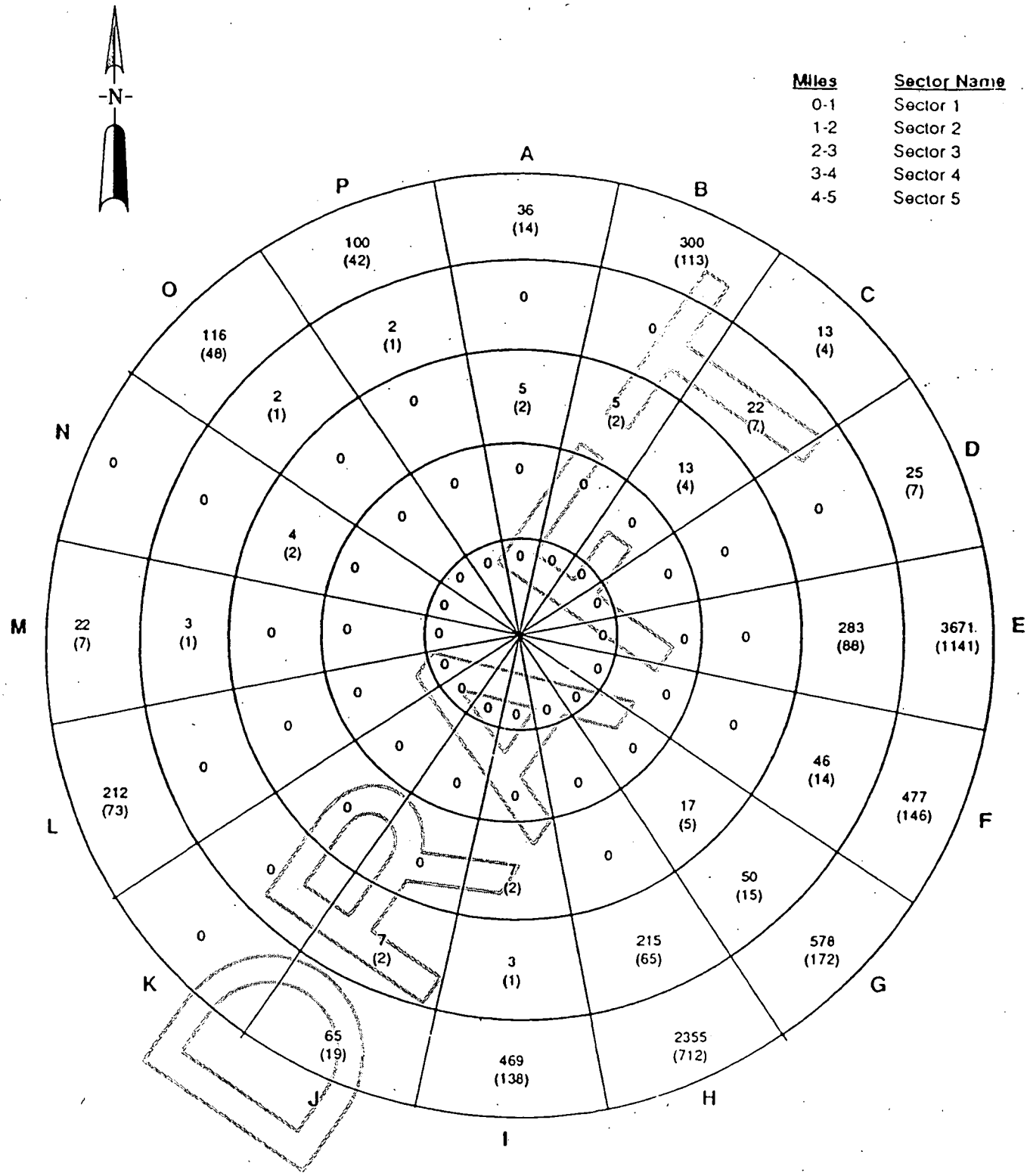

SOURCE: DOE 1990.d

U.S. DEPARTMENT OF ENERGY
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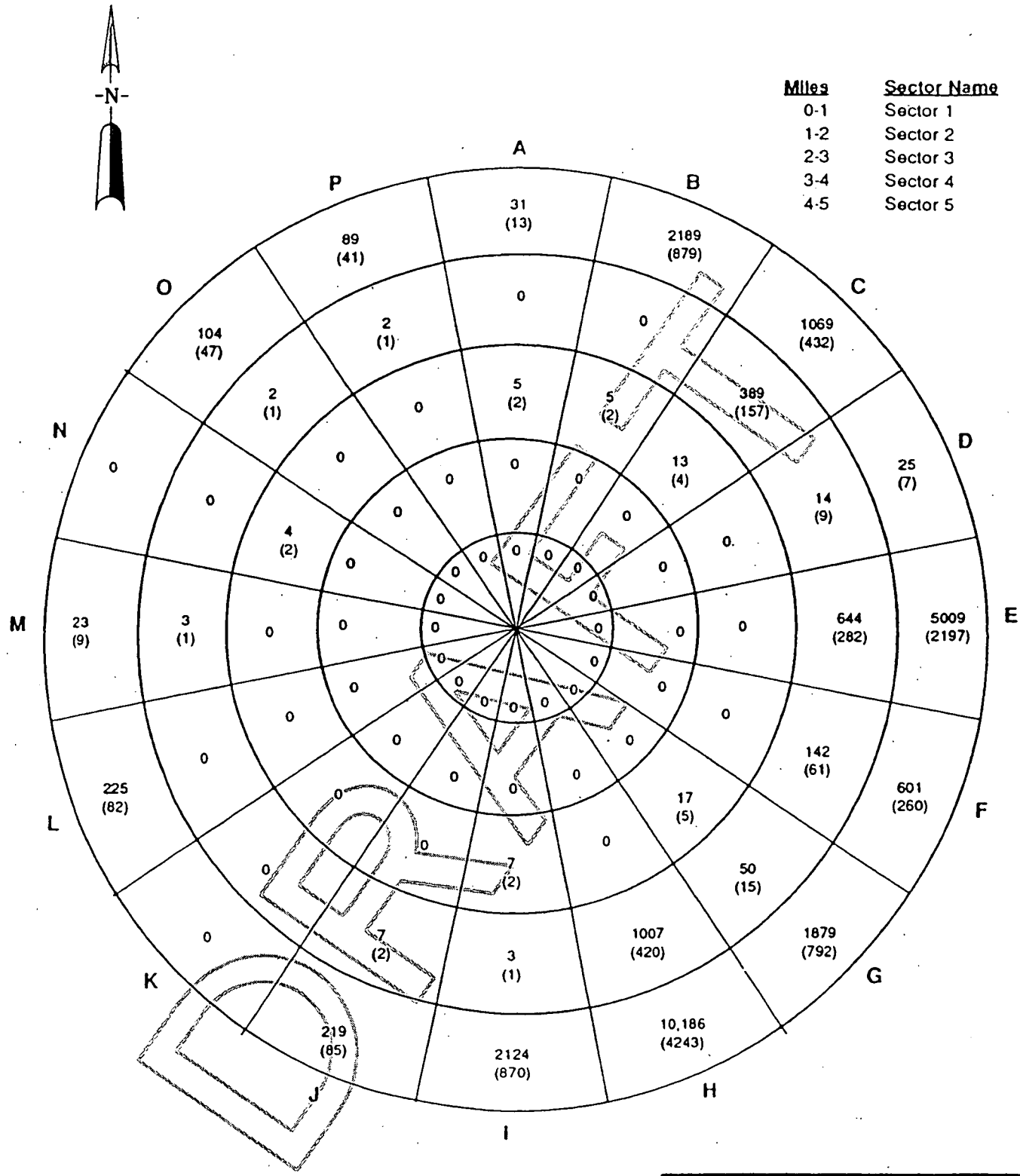
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

1989 POPULATION AND
(HOUSEHOLDS) SECTOR 1-5

FIGURE 3.2-1 OCTOBER 1993

OU2R297 1-1



SOURCE: DOE 1990.d

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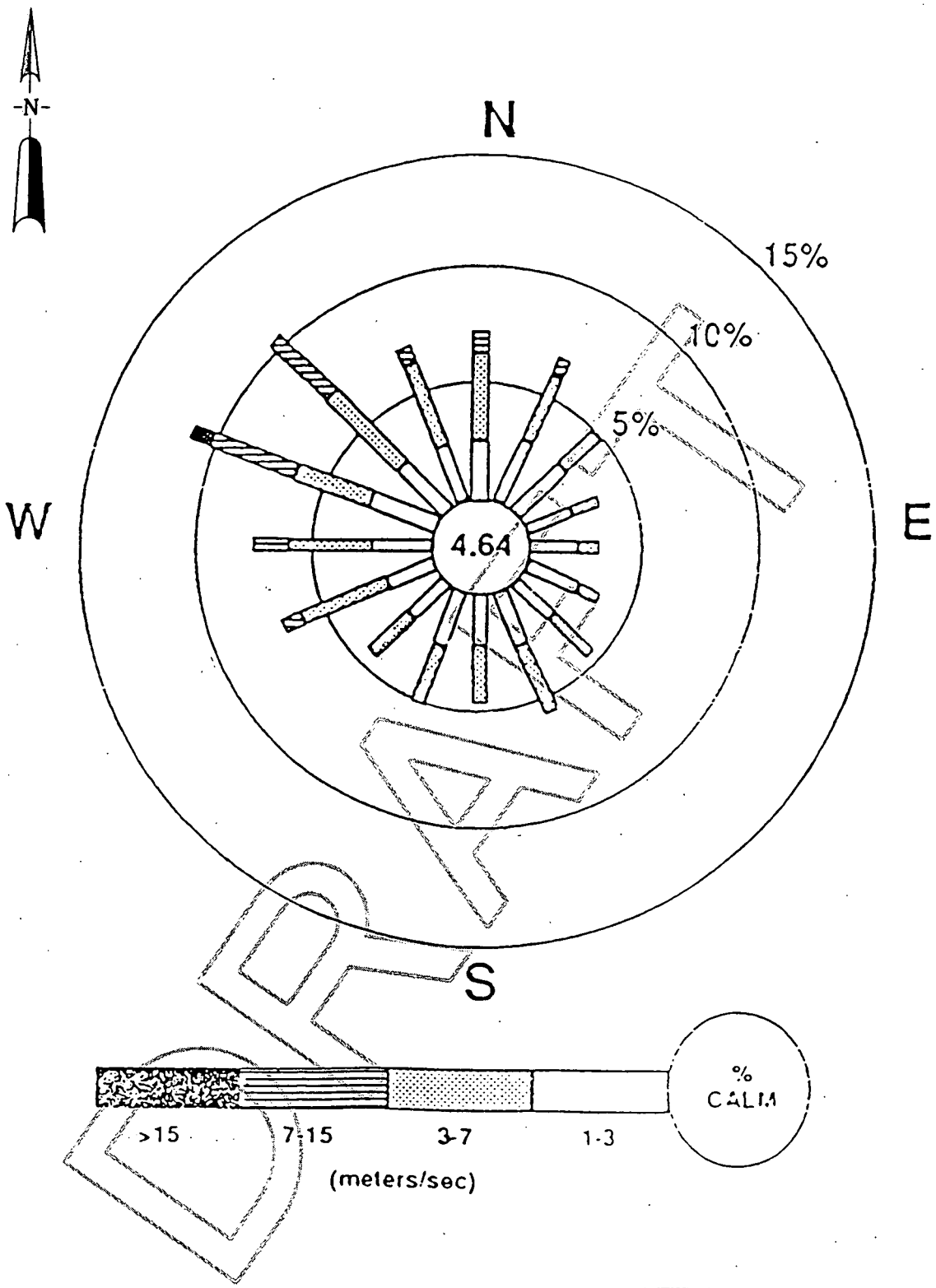
2010 POPULATION AND
(HOUSEHOLDS) SECTOR 1–5

FIGURE 3.2–2

OCTOBER 1993

OU2RI298 1=1



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SOURCE: EG&G, 1991d.

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1990 ANNUAL WIND ROSE
FOR THE ROCKY FLATS PLANT

FIGURE 3.3-1 OCTOBER 1993

OU2R299 1-1

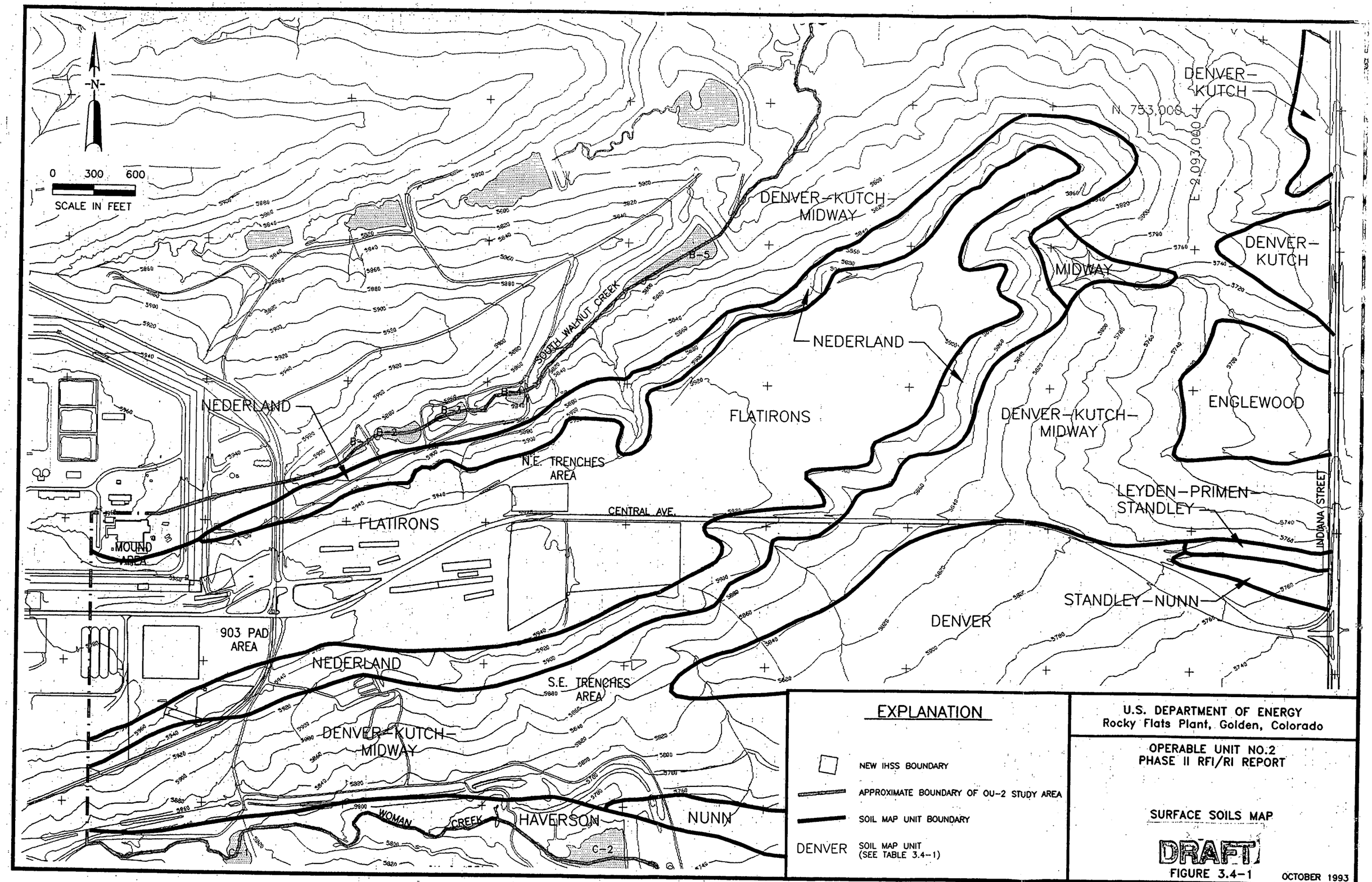
-N-
0 300 600
SCALE IN FEET
DENVER-KUTCH
N 753,000
E 2,093,000
DENVER-KUTCH-MIDWAY
DENVER-KUTCH
MIDWAY
NEDERLAND
ENGLEWOOD
FLATIRONS
DENVER-KUTCH-MIDWAY
SOUTH WALNUT CREEK
B-5
B-4
B-3
B-2
N.E. TRENCHES AREA
CENTRAL AVE.
LEYDEN-PRIMEN-STANDLEY
INDIANA STREET
MOUND AREA
STANDLEY-NUNN
DENVER
903 PAD AREA
S.E. TRENCHES AREA
WOMAN CREEK
HAVERSON
NUNN
C-2
EXPLANATION
NEW IHSS BOUNDARY
APPROXIMATE BOUNDARY OF OU-2 STUDY AREA
SOIL MAP UNIT BOUNDARY
DENVER SOIL MAP UNIT (SEE TABLE 3.4-1)
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT
SURFACE SOILS MAP
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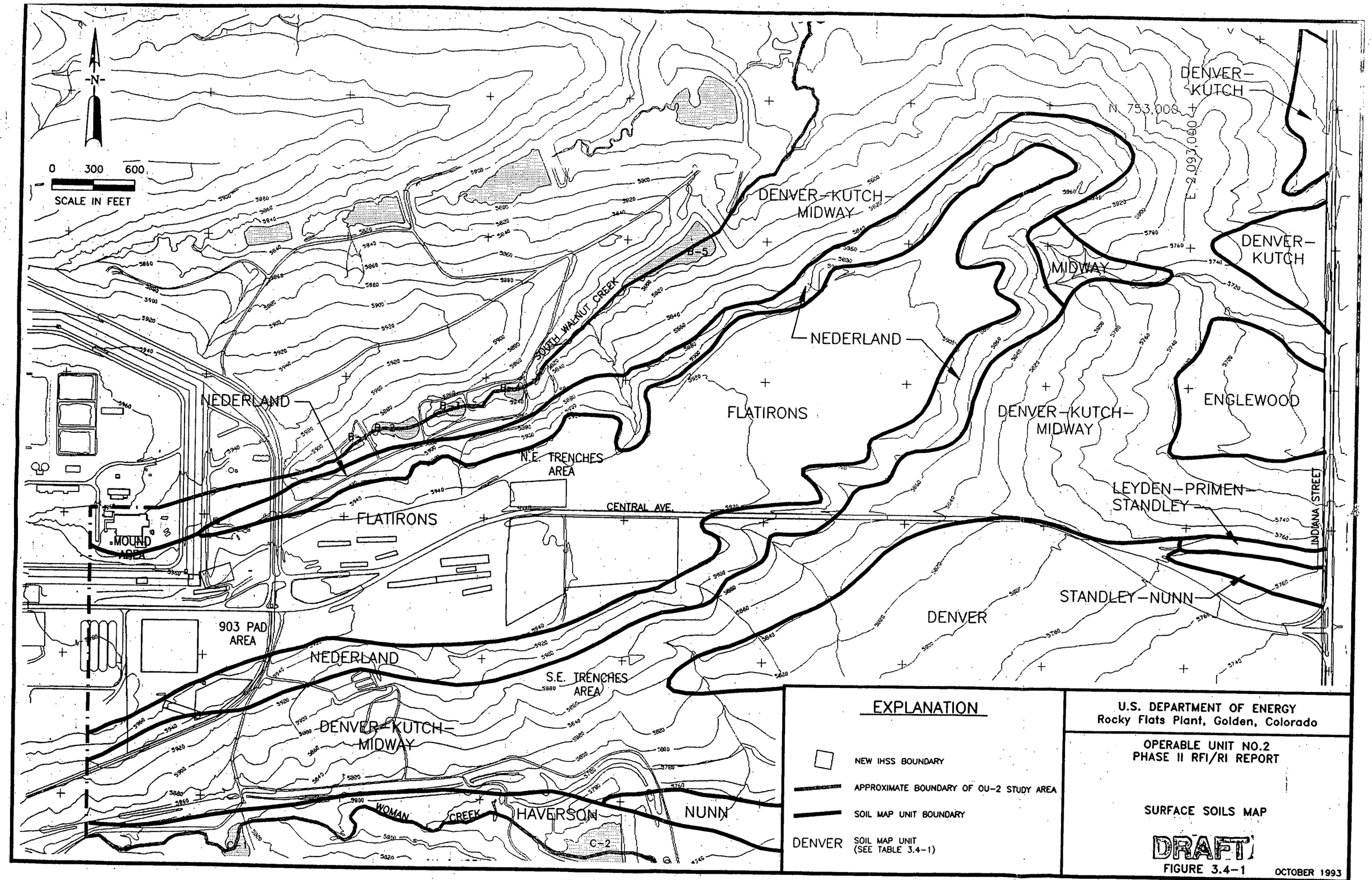
FIGURE 3.4-1
OCTOBER 1993
OU2RI221 1=600


-N-
0 300 600
SCALE IN FEET
DENVER-KUTCH
N 753,000
E 2,093,000
DENVER-KUTCH-MIDWAY
DENVER-KUTCH
MIDWAY
NEDERLAND
ENGLEWOOD
SOUTH WALNUT CREEK
FLATIRONS
DENVER-KUTCH-MIDWAY
N.E. TRENCHES AREA
CENTRAL AVE.
LEYDEN-PRIMEN-STANDLEY
INDIANA STREET
MOUND AREA
STANDLEY-NUNN
DENVER
903 PAD AREA
S.E. TRENCHES AREA
DENVER-KUTCH-MIDWAY
WOMAN CREEK
HAVERSON
NUNN
C-2
EXPLANATION
NEW IHSS BOUNDARY
APPROXIMATE BOUNDARY OF OU-2 STUDY AREA
SOIL MAP UNIT BOUNDARY
DENVER SOIL MAP UNIT (SEE TABLE 3.4-1)
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado
OPERABLE UNIT NO.2
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SURFACE SOILS MAP
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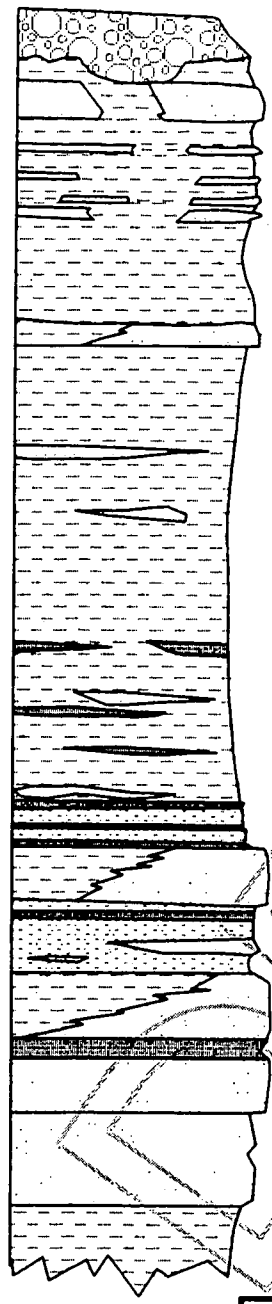
FIGURE 3.4-1
OCTOBER 1993
OU2RI221 1=600



PERIOD	DEPTH FT. (approx.)	STRATIGRAPHY	LITHOLOGIC UNIT & APPROXIMATE THICKNESS	DESCRIPTION
QUATERNARY			ROCKY FLATS ALLUVIUM 0–45'	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
			ARAPAHOE FORMATION 60'(?)	CLAYSTONE, SILTSTONES, CLAYEY SANDSTONES, SANDSTONE– light to medium olive–gray with some dark olive–black claystone and silty claystone. Weathered intervals may be yellowed, and basal sand is often conglomeratic
CRETACEOUS		LARAMIE FORMATION (600–800')	upper interval 300–500'	CLAYSTONES, SILTSTONES, AND COAL– kaolinitic, light to medium gray claystone and siltstone and some dark gray to black carbonaceous claystone, thin (2') coals and thin discontinuous very fine–to–medium grained, moderately sorted sandstone intervals
			lower interval 300'	SANDSTONES 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
			FOX HILLS SANDSTONE 80'	SANDSTONES– grayish–orange to light gray, calcareous, fine–grained, subrounded, glauconitic, feldspathic, friable sandstone
			PIERRE SHALE & OLDER UNITS	

MODIFIED AFTER DOE 1992b

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EXPLANATION

- ALLUVIUM
- FINE–GRAINED & COARSER SANDSTONE
- FINE GRAINED SANDSTONE
- SILTSTONE & CLAYSTONE
- COAL
- SILTY SANDSTONE

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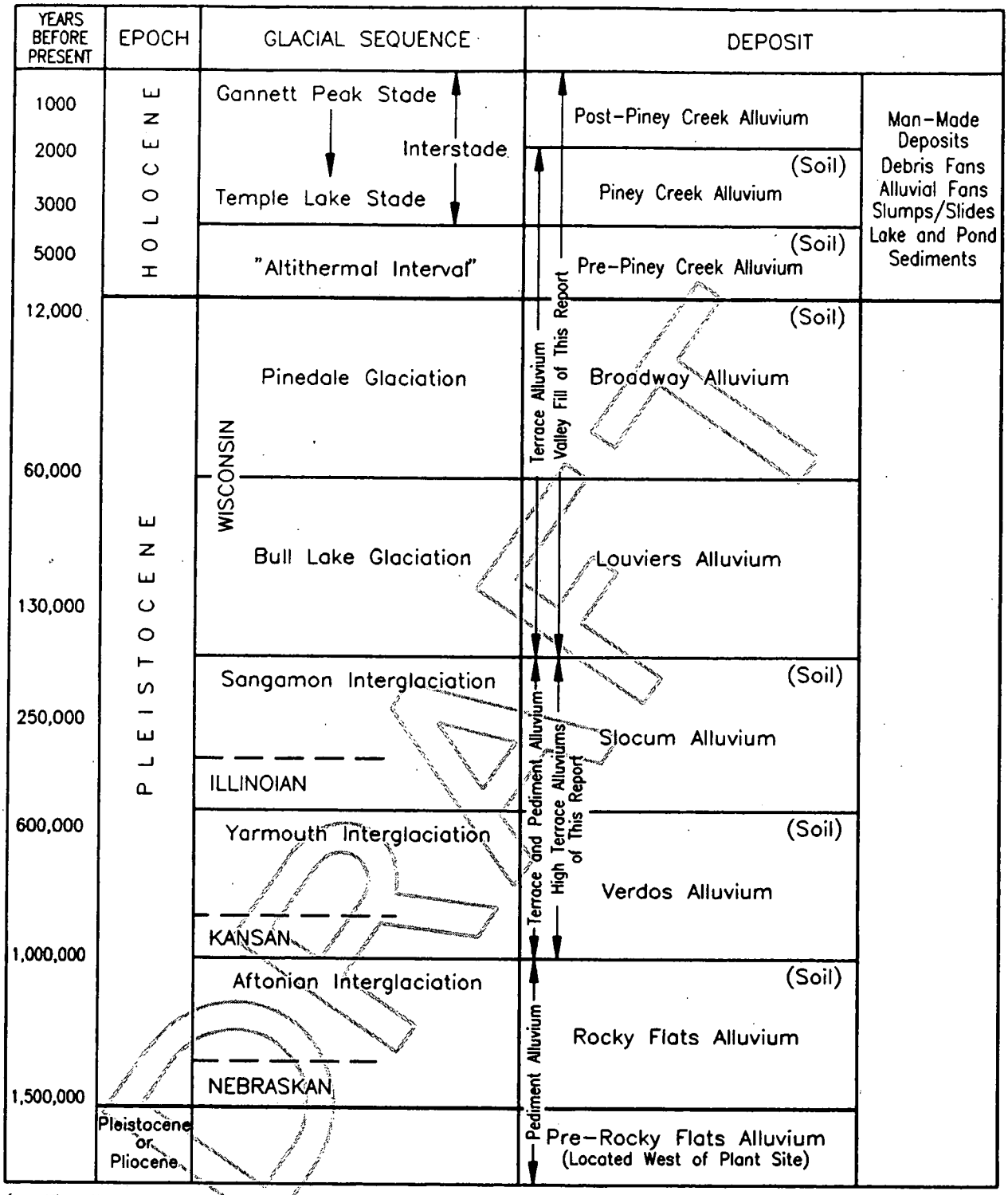
LOCAL STRATIGRAPHIC COLUMN OF THE OU–2 AREA, ROCKY FLATS PLANT

FIGURE 3.5–1 OCTOBER 1993

OU2R071 1=1



(Modified From: Van Horn, 1976; and Scott, 1965)

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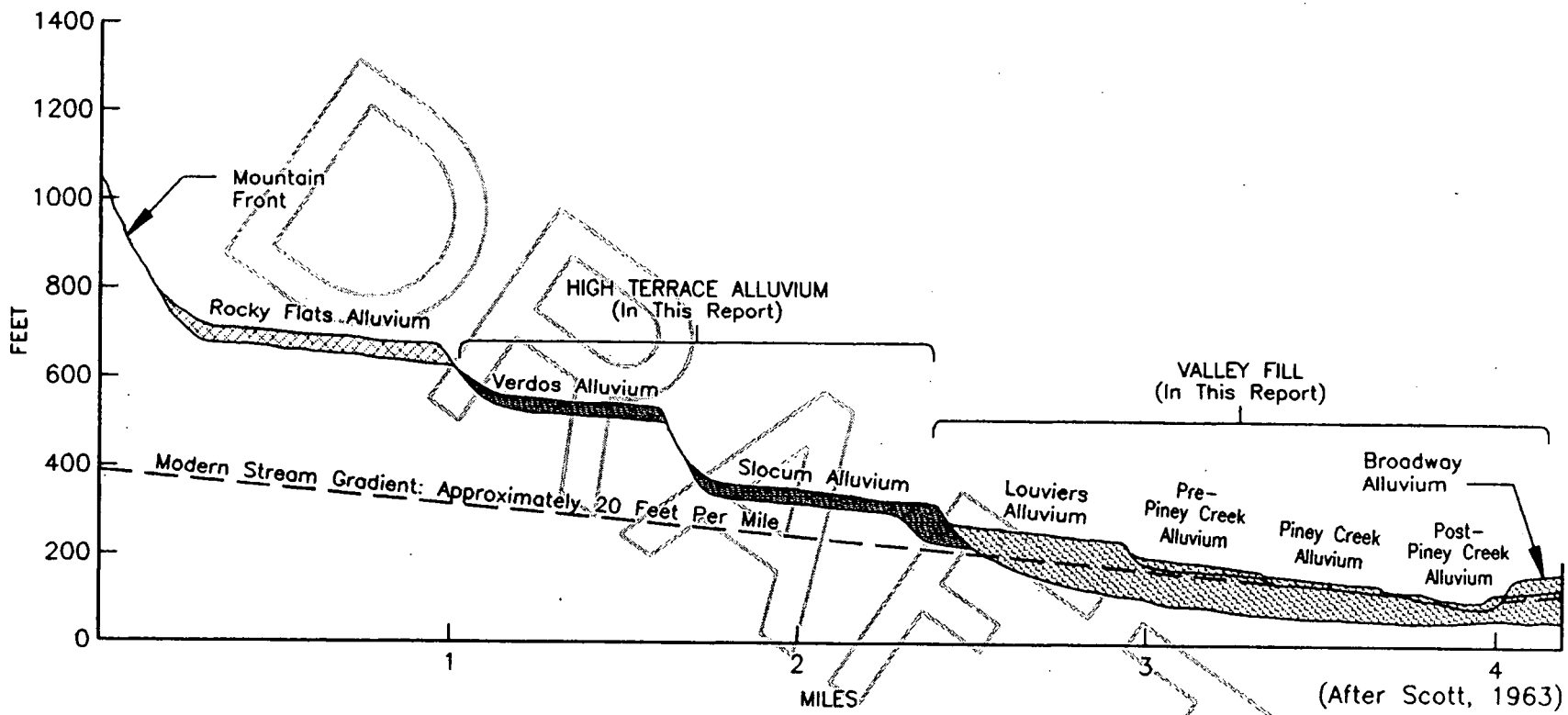
SURFICIAL DEPOSITS IN THE ROCKY FLATS PLANT AREA

FIGURE 3.5-2 OCTOBER 1993

OU2RI120 1=1



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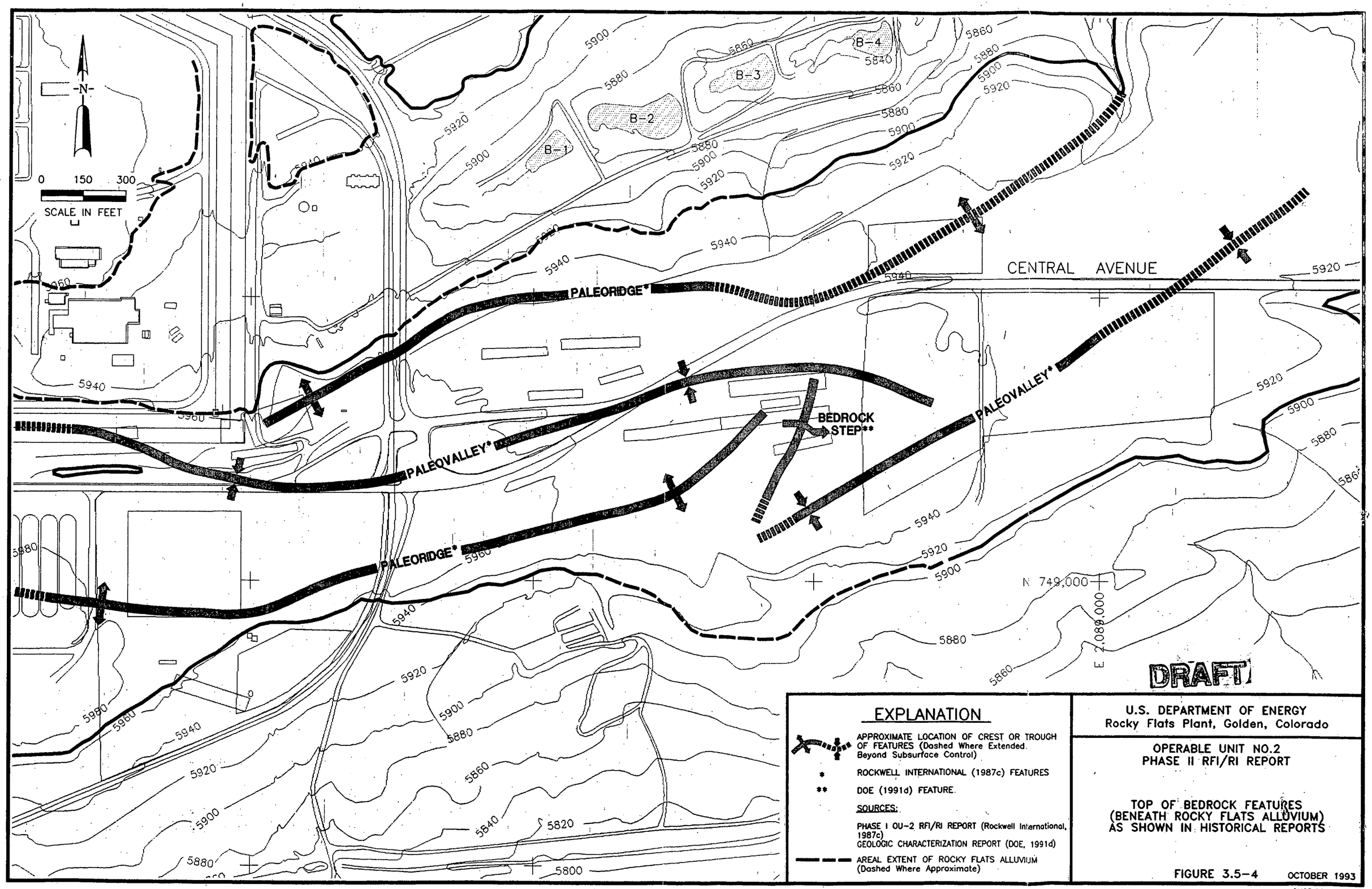
DIAGRAMATIC CROSS-SECTION SHOWING STRATIGRAPHIC RELATIONSHIPS OF QUATERNARY DEPOSITS IN THE VICINITY OF THE ROCKY FLATS PLANT

FIGURE 3.5-3 OCTOBER 1993

0U2R111 1=400



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OPERABLE UNIT NO.2
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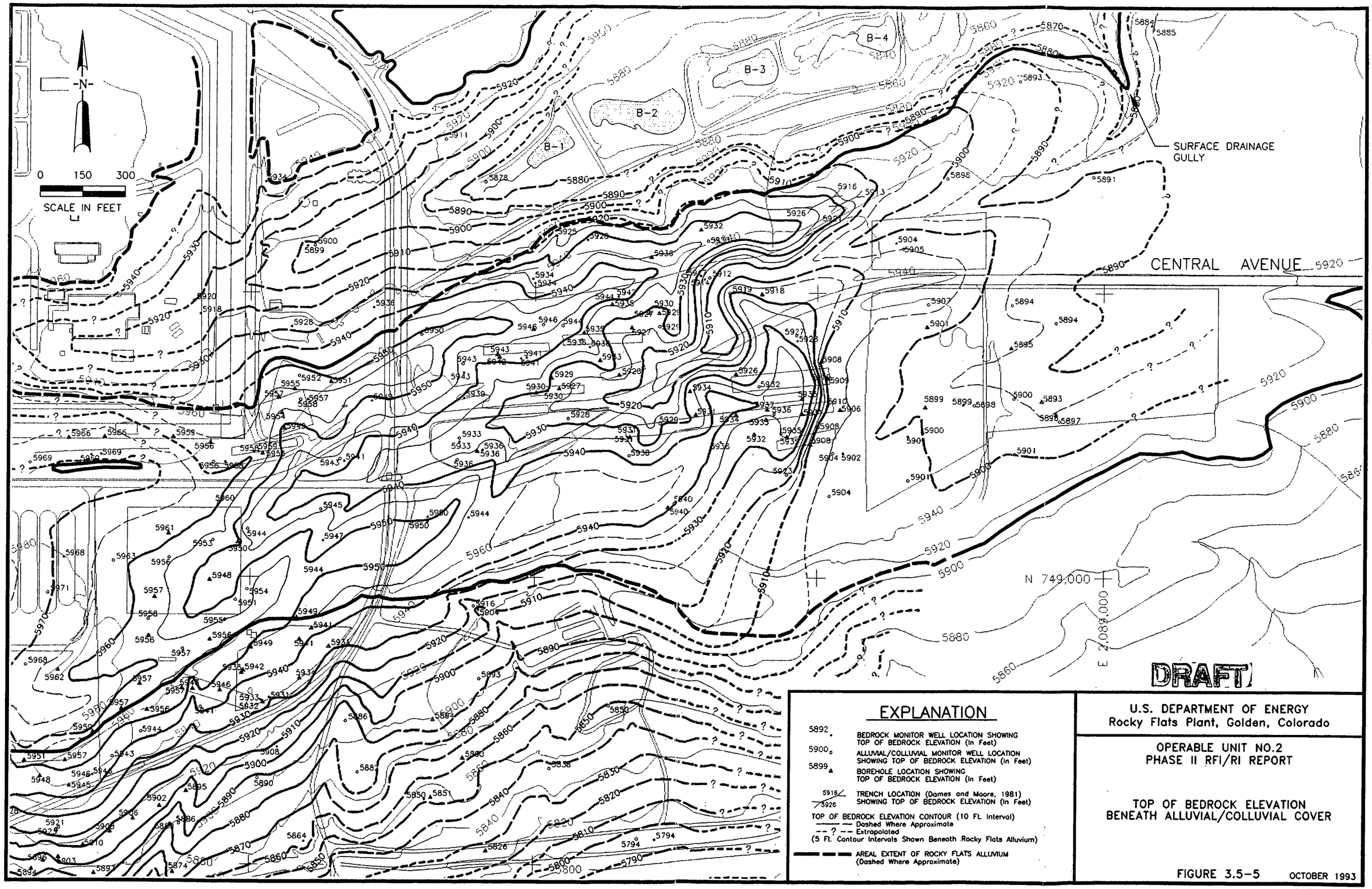
TOP OF BEDROCK FEATURES
(BENEATH ROCKY FLATS ALLUVIUM)
AS SHOWN IN HISTORICAL REPORTS

FIGURE 3.5-4 OCTOBER 1993

OU2RI021 1=300

230



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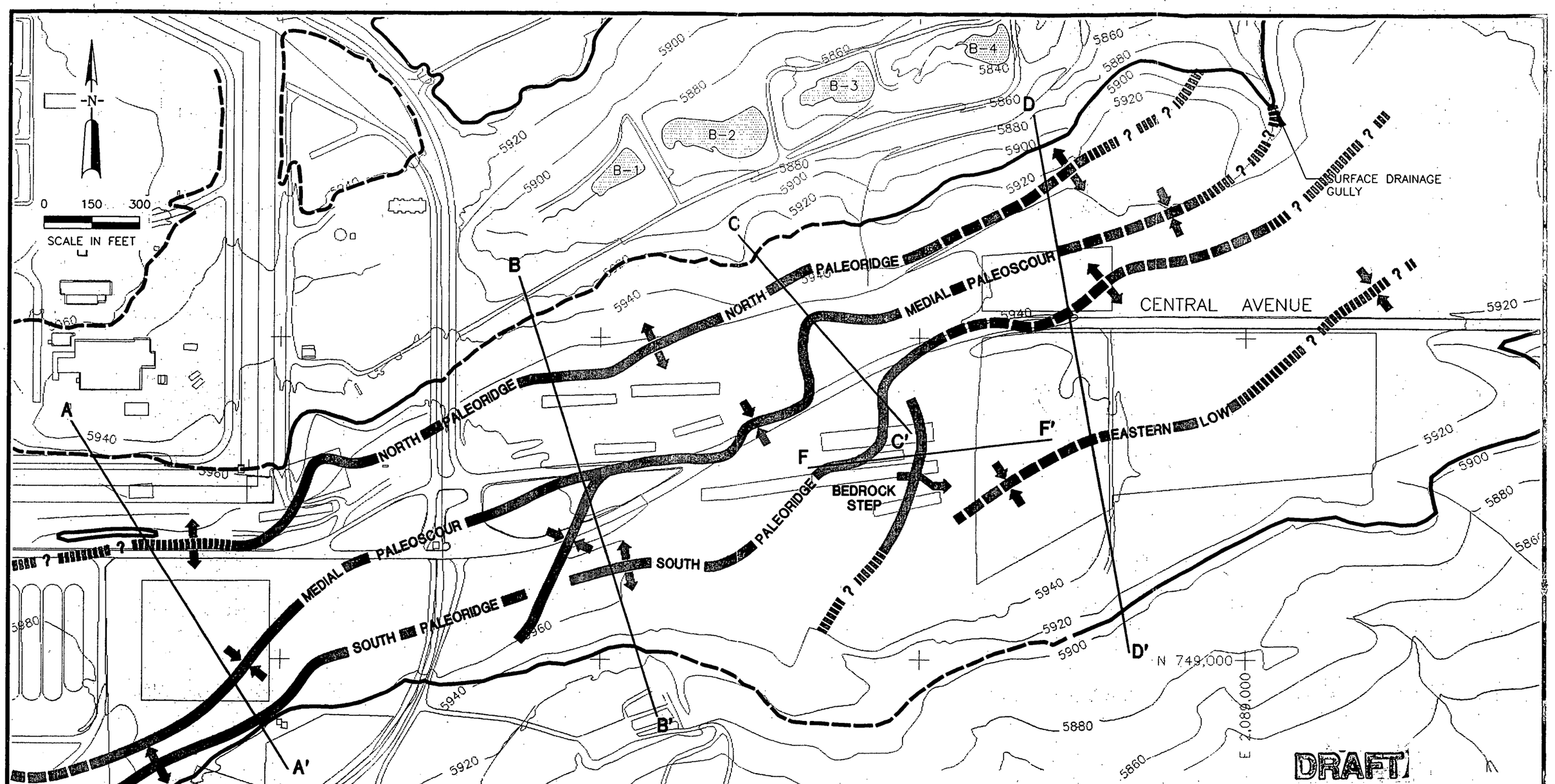
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

TOP OF BEDROCK ELEVATION
BENEATH ALLUVIAL/COLLUVIAL COVER

FIGURE 3.5-5 OCTOBER 1993

0U2RI005 1=300



EXPLANATION

LOCATION OF CREST OR TROUGH OF TOP OF BEDROCK FEATURES

Dashed Where Approximate

Extrapolated

A — A' TOP OF BEDROCK PROFILE AND ALLUVIAL THICKNESS CROSS-SECTION LOCATIONS

AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)

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

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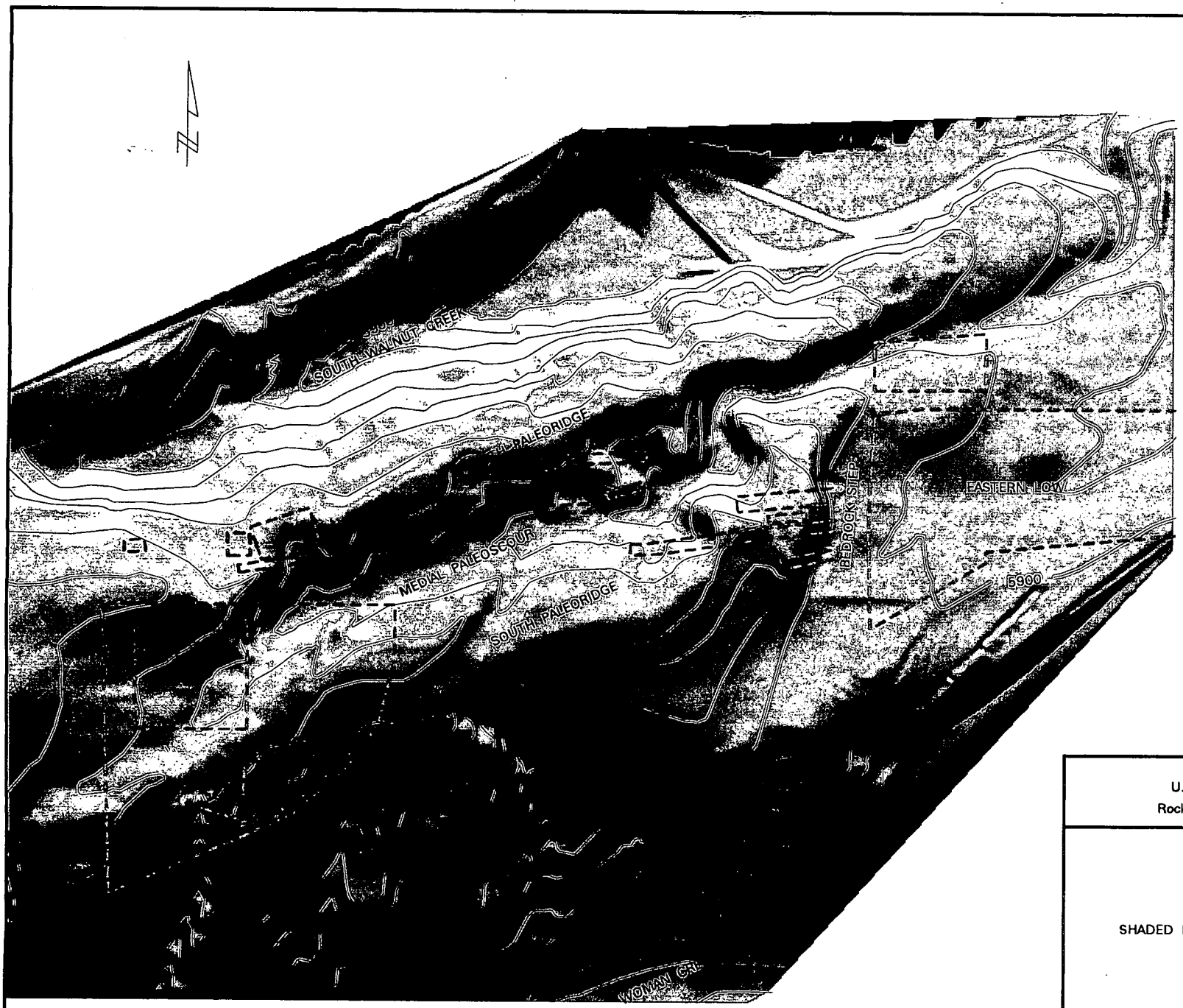
PHASE II RFI/RI REPORT

TOP OF BEDROCK FEATURES
(BENEATH ROCKY FLATS ALLUVIUM) AS REVISED
BASED ON PHASE II FIELD PROGRAM

FIGURE 3.5-6 OCTOBER 1993

OU2RI059 1=300



DRAFT

Top of Bedrock Contours

Projection of Outline of IHSS boundary onto top of bedrock

Contour interval = 10 ft.

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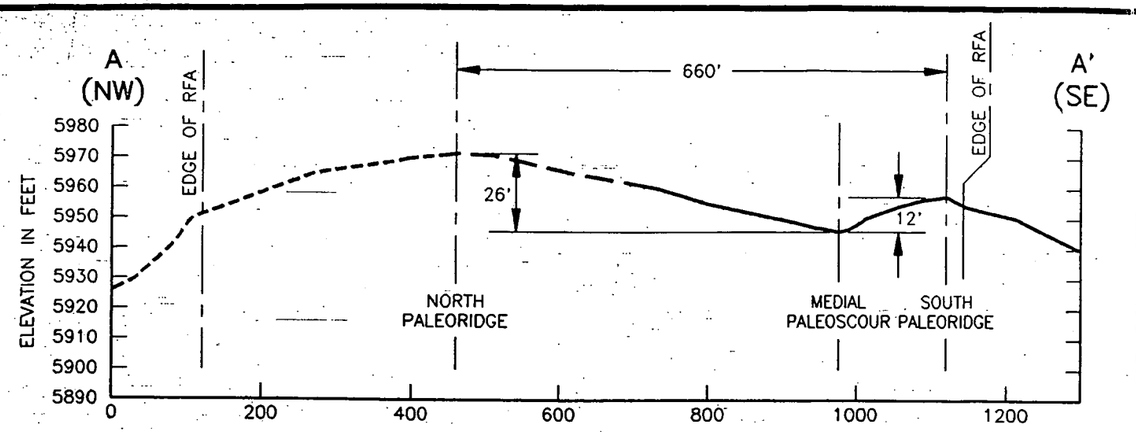
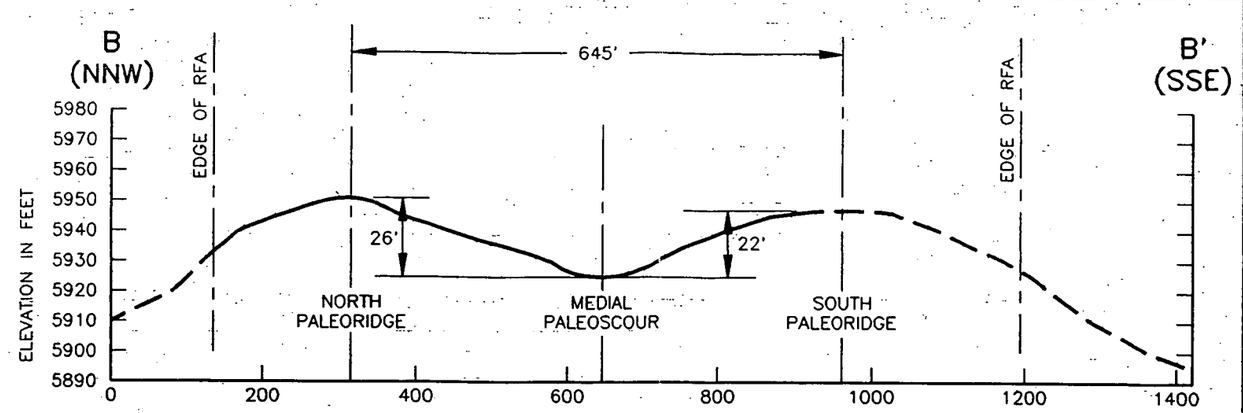
SHADED RELIEF VIEW OF TOP OF BEDROCK

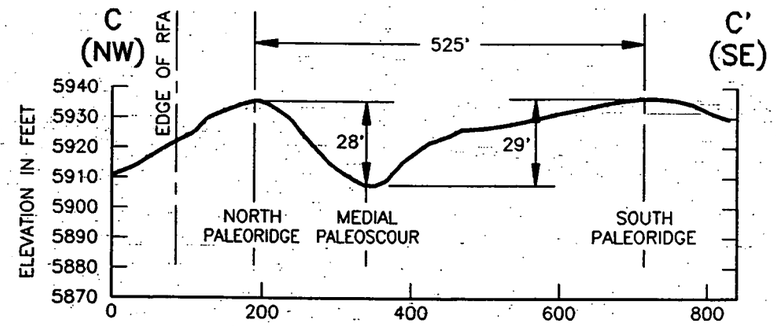
FIGURE 3.5-7 October 1993



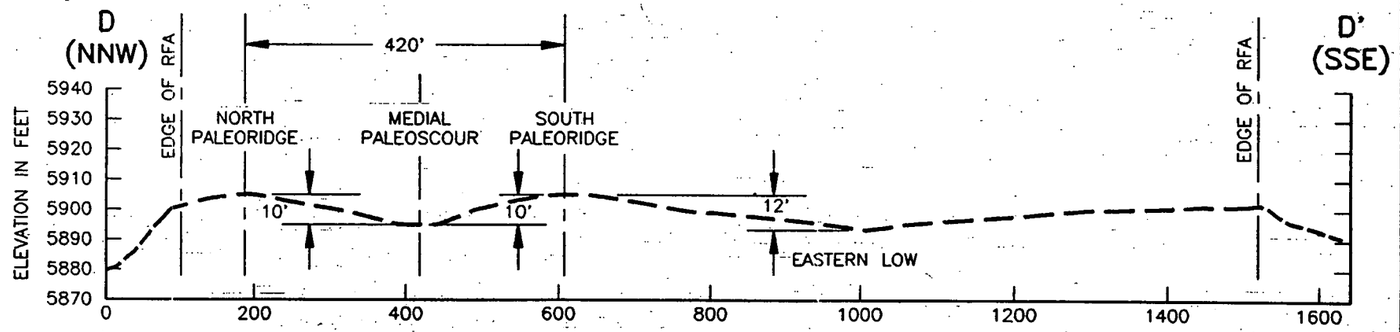
SECTION A–A'



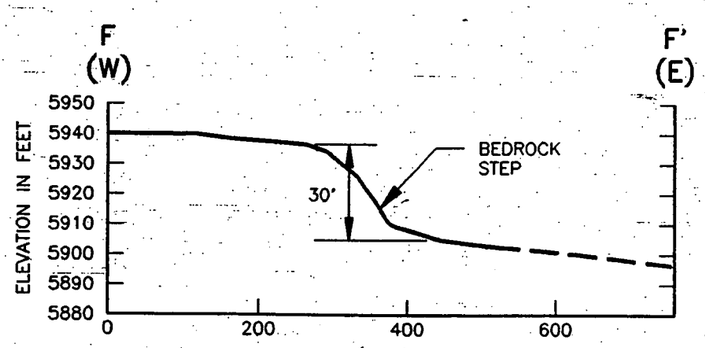
SECTION B–B'



SECTION C–C'

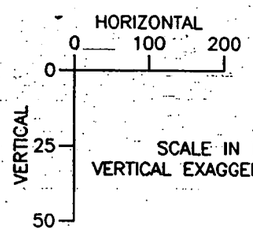


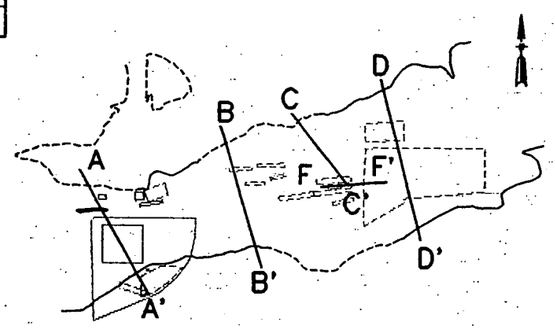
SECTION D–D'



SECTION F–F'

DRAFT





CROSS-SECTION LOCATION MAP

EXPLANATION

TOP OF BEDROCK SURFACE
Dashed Where Approximate
Extrapolated

12' APPROXIMATE RELIEF FROM RIDGE CREST TO SCOUR TROUGH

RFA ROCKY FLATS ALLUVIUM

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Rocky Flats Plant, Golden, Colorado

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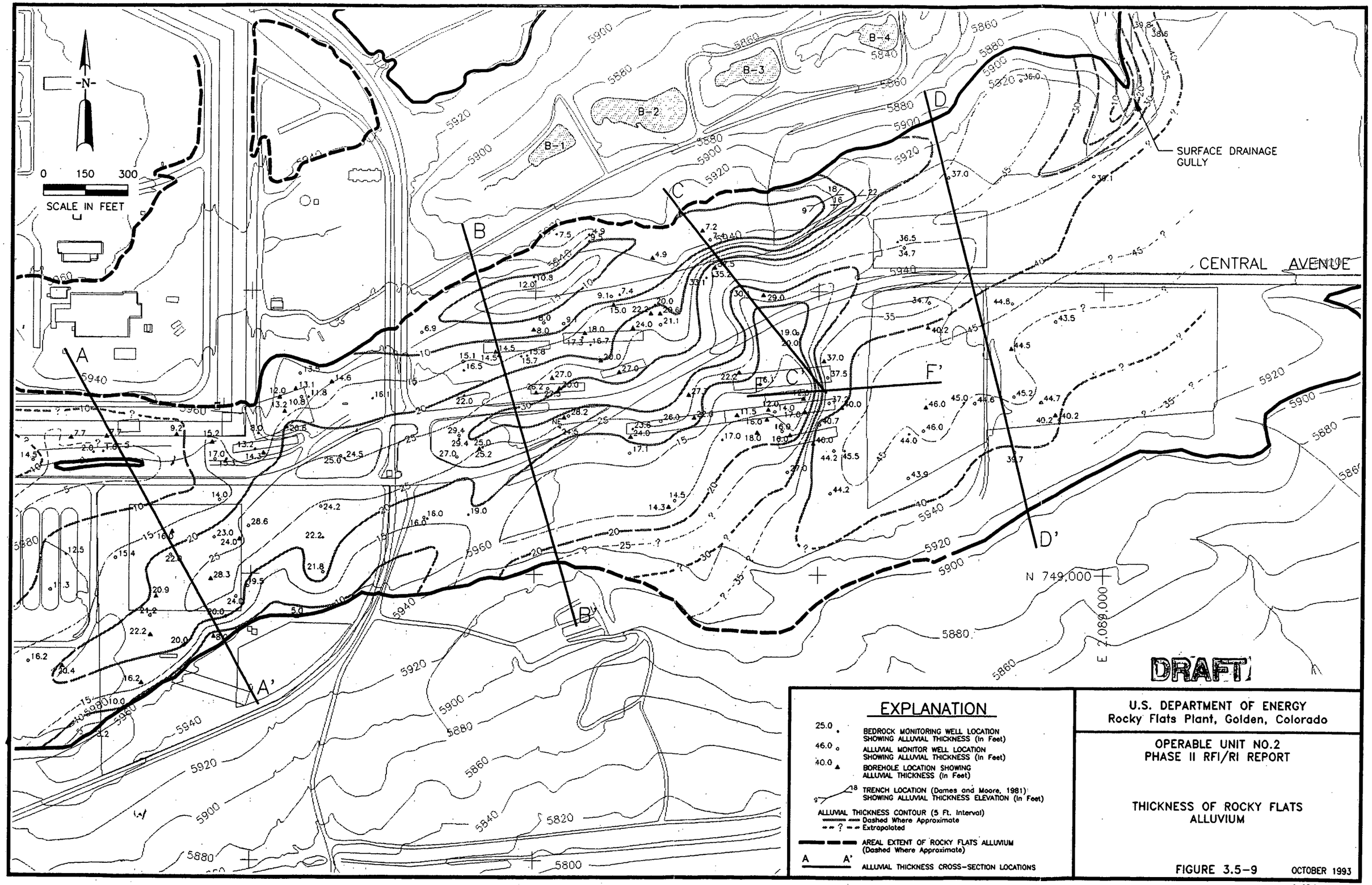
TOP OF BEDROCK PROFILES
SHOWING MAJOR FEATURES
BENEATH ROCKY FLATS ALLUVIUM

FIGURE 3.5–8 OCTOBER 1993

OU2RI009 1=200



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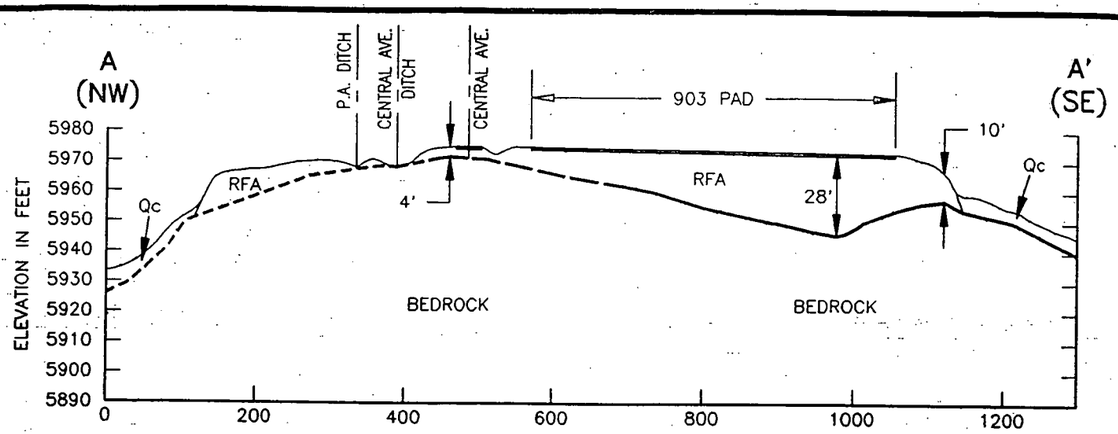
PHASE II RFI/RI REPORT

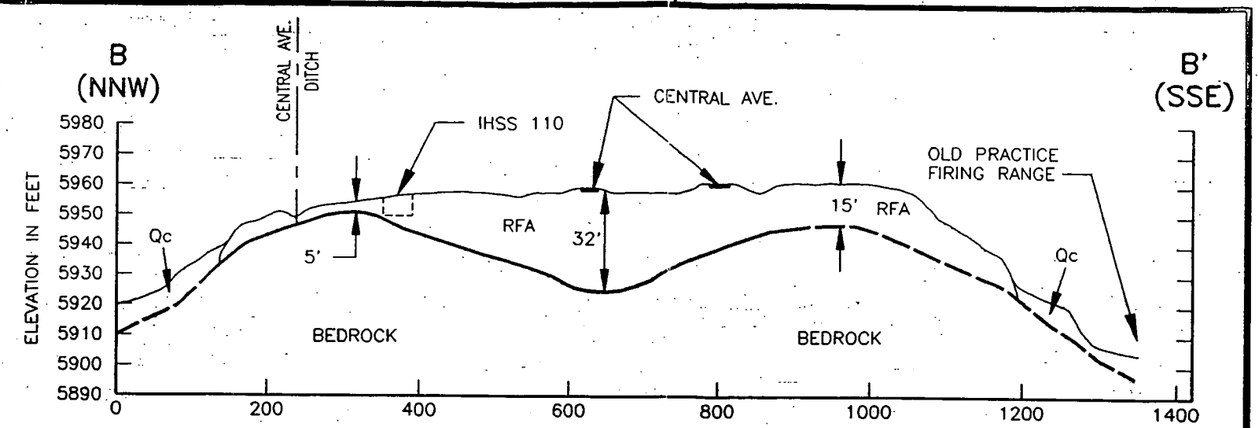
THICKNESS OF ROCKY FLATS ALLUVIUM

FIGURE 3.5-9 OCTOBER 1993

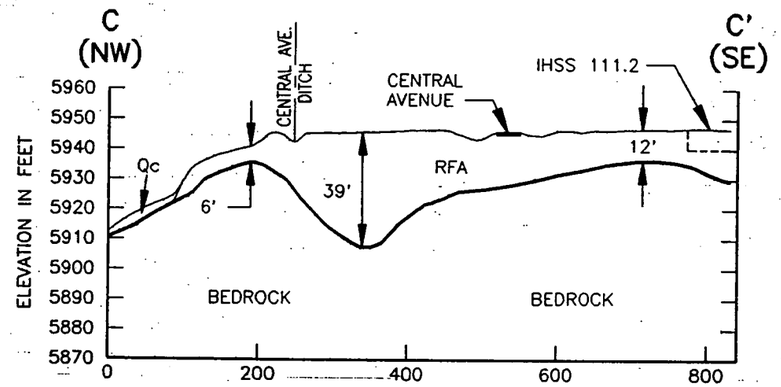
OU2RI006 1=300



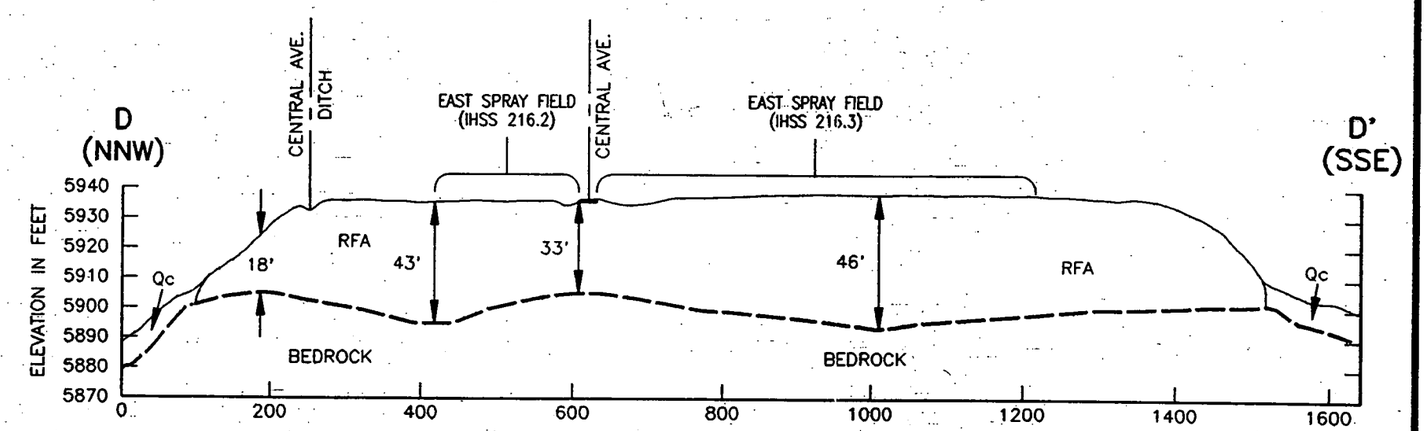
SECTION A–A'



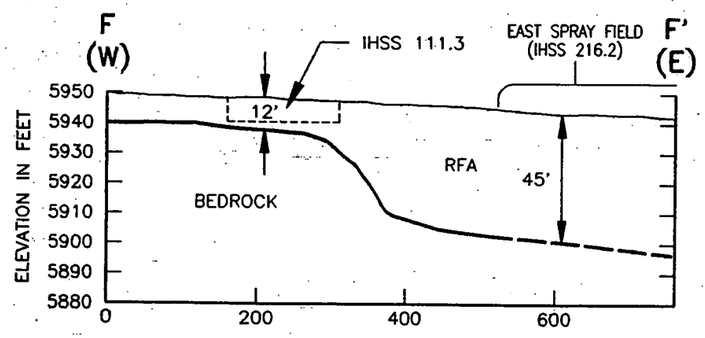
SECTION B–B'



SECTION C–C'



SECTION D–D'

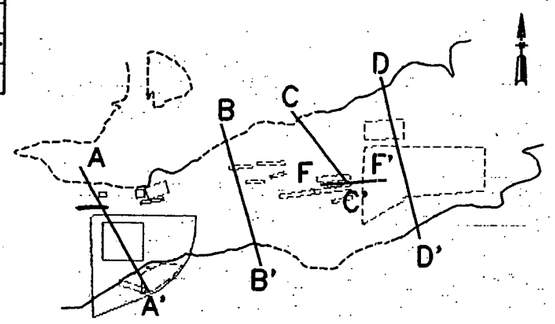


SECTION F–F'

HORIZONTAL
0 100 200

VERTICAL
0
25
50

SCALE IN FEET
VERTICAL EXAGGERATION (4x)



CROSS-SECTION LOCATION MAP

EXPLANATION

TOP OF BEDROCK SURFACE
Dashed Where Approximate
Extrapolated

20' APPROXIMATE THICKNESS OF ROCKY FLATS ALLUVIUM

RFA ROCKY FLATS ALLUVIUM

Qc COLLUVIUM

DRAFT

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Rocky Flats Plant, Golden, Colorado

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CROSS SECTIONS SHOWING THICKNESS OF ROCKY FLATS ALLUVIUM

FIGURE 3.5–10 OCTOBER 1993

OU2RI062 1=200

U.S.C.S. CODES

SANDY GRAVEL LITHOFACIES

- GW WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- GP POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- SW WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
- SP POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES

U.S.C.S. CODES

CLAY LITHOFACIES

- ML INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- CL INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS SILTY CLAYS, LEAN CLAYS
- OL ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
- CH INORGANIC CLAYS OR HIGH PLASTICITY, FAT CLAYS

U.S.C.S. CODES

CLAYEY GRAVEL LITHOFACIES

- GM SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
- GC CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
- SM SILTY SANDS, SAND-SILT MIXTURES
- SC CLAYEY SANDS, SAND-CLAY MIXTURES

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Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT 2
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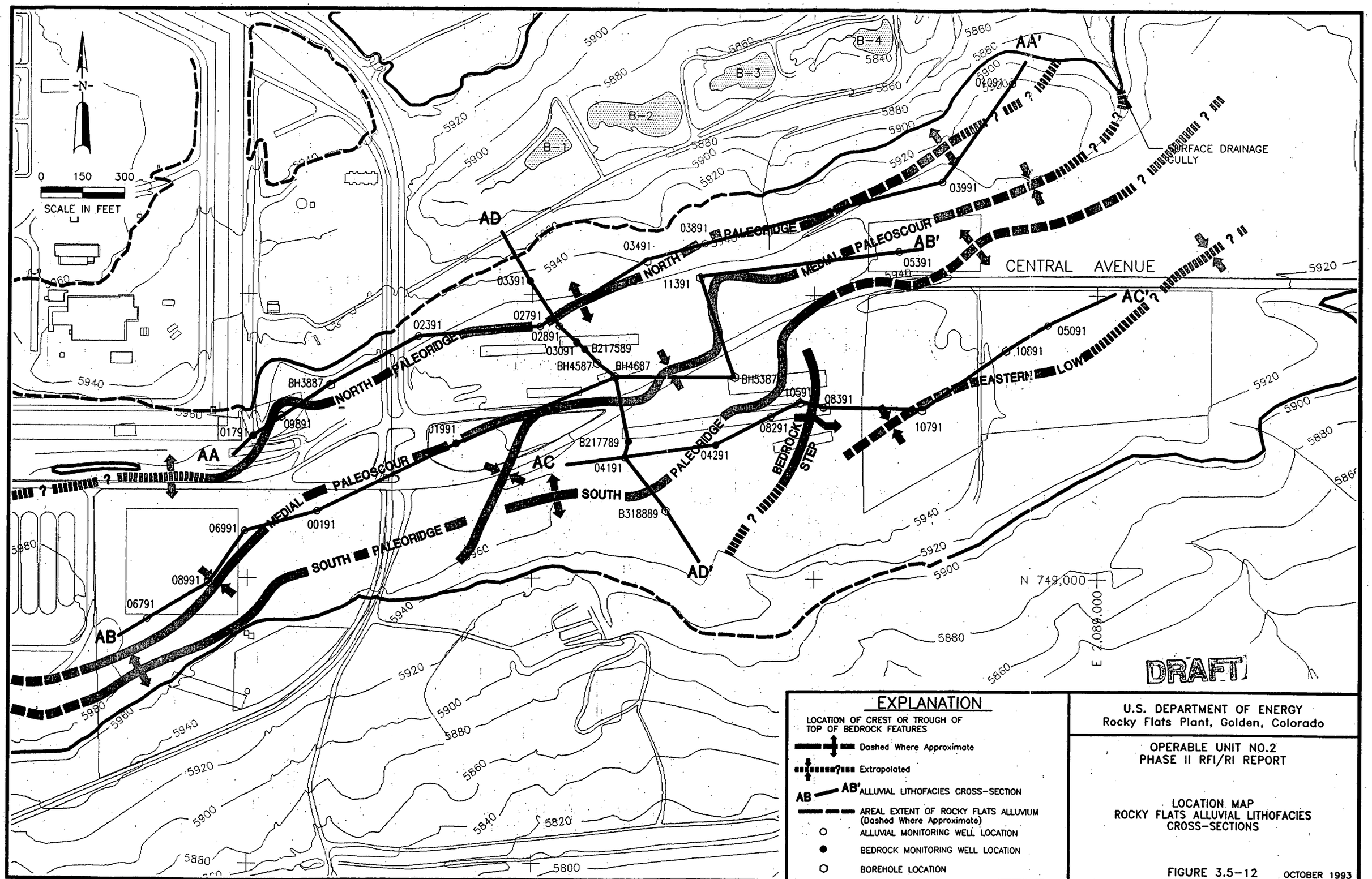
ROCKY FLATS ALLUVIAL LITHOFACIES WITH INCORPORATED U.S.C.S. CODES

FIGURE 3.5-11 OCTOBER 1993

236

OU2RI233 1=1



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

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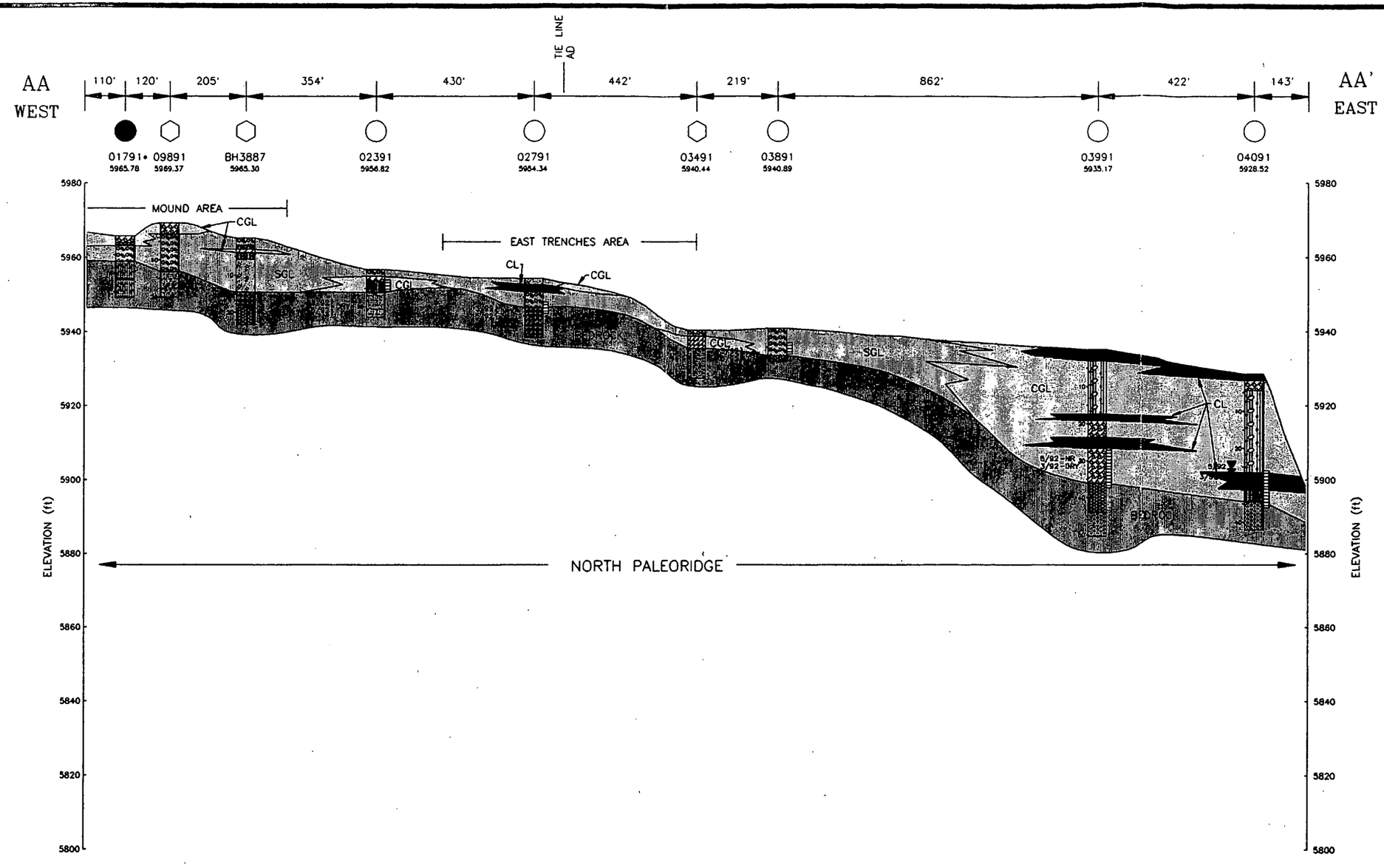
PHASE II RFI/RI REPORT

LOCATION MAP
ROCKY FLATS ALLUVIAL LITHOFACIES
CROSS-SECTIONS

FIGURE 3.5-12 OCTOBER 1993

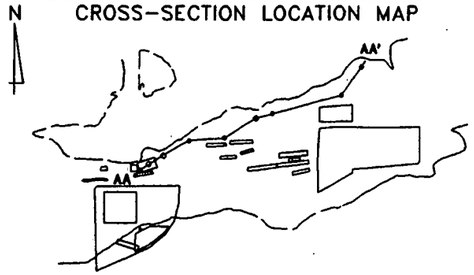
OU2RI232 1=300



* – FULL EXTENT OF LITHOLOGIC LOGS THROUGH BEDROCK MATERIAL NOT SHOWN

HORIZONTAL
150 300 600
SCALE IN FEET
VERTICAL
0
10
20

CROSS-SECTION LOCATION MAP



EXPLANATION

- ALLUVIAL MONITORING WELL
- BEDROCK MONITORING WELL
- BOREHOLE
- 03491 — WELL NUMBER – LAST 2 DIGITS INDICATE YEAR OF DRILLING OR INSTALLATION
- 5940.44 — GROUND SURFACE ELEVATION (FT)
- SCREENED INTERVAL OF ALLUVIAL MONITORING WELL
- 5/92 — STATIC WATER LEVEL AND MEASUREMENT DATA
- 3/92-NR — STATIC WATER LEVEL NOT REPORTED
- SGL — SANDY GRAVEL LITHOFACIES
- CGL — CLAYEY GRAVEL LITHOFACIES
- CL — CLAY LITHOFACIES

GRAPHIC PATTERNS SHOWN IN LITHLOGIC LOGS CORRESPOND TO U.S.C.S CLASSIFICATIONS (SEE FIGURE 3.5-11). COLORS SHOWN CORRESPOND TO LITHOFACIES

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

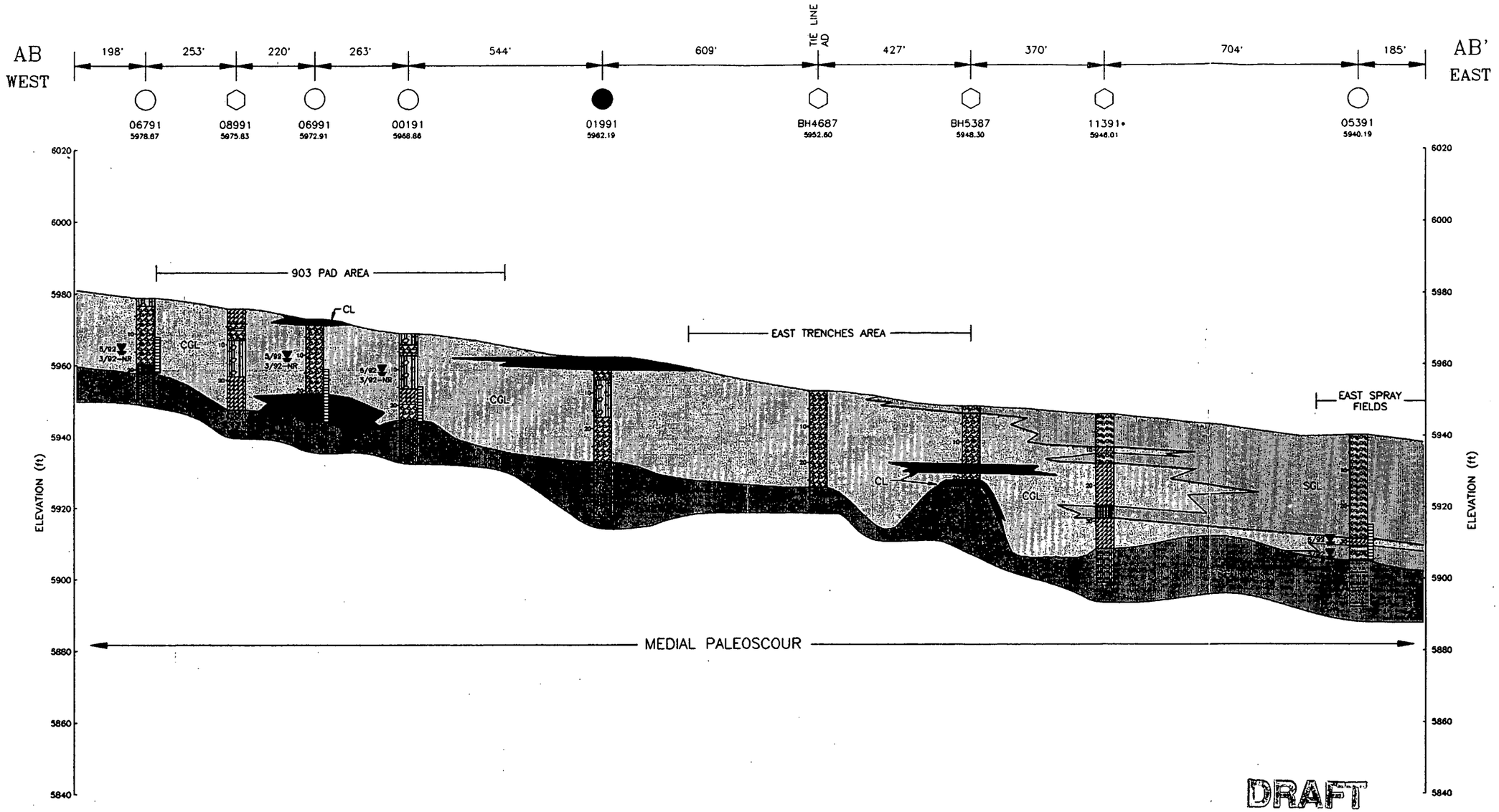
OPERABLE UNIT 2
PHASE II RFI/RI REPORT

ROCKY FLATS ALLUVIAL LITHOFACIES CROSS-SECTION AA-AA' (ALONG NORTH PALEORIDGE)

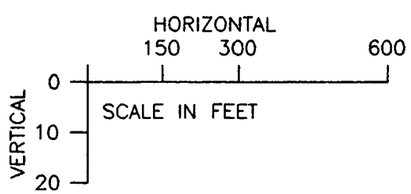
FIGURE 3.5-13

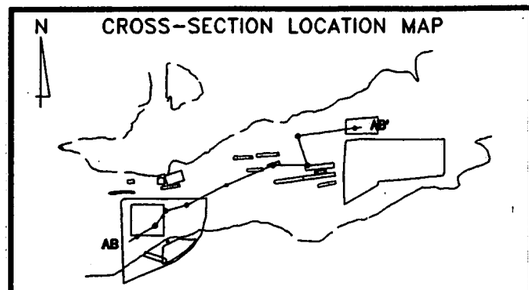
OCTOBER 1993

OU2RI217 1=1



• – FULL EXTENT OF LITHOLOGIC LOGS THROUGH BEDROCK MATERIAL NOT SHOWN.





EXPLANATION

- ALLUVIAL MONITORING WELL
- BEDROCK MONITORING WELL
- BOREHOLE
- 03491 — WELL NUMBER – LAST 2 DIGITS INDICATE YEAR OF DRILLING OR INSTALLATION
- 5940.44 — GROUND SURFACE ELEVATION (FT)
- SCREENED INTERVAL OF ALLUVIAL MONITORING WELL
- 5/92 ▼ — STATIC WATER LEVEL AND MEASUREMENT DATA
- 3/92–NR — STATIC WATER LEVEL NOT REPORTED
- SGL — SANDY GRAVEL LITHOFACIES
- CGL — CLAYEY GRAVEL LITHOFACIES
- CL — CLAY LITHOFACIES

GRAPHIC PATTERNS SHOWN IN LITHLOGIC LOGS CORRESPOND TO U.S.C.S CLASSIFICATIONS (SEE FIGURE 3.5-11). COLORS SHOWN CORRESPOND TO LITHOFACIES

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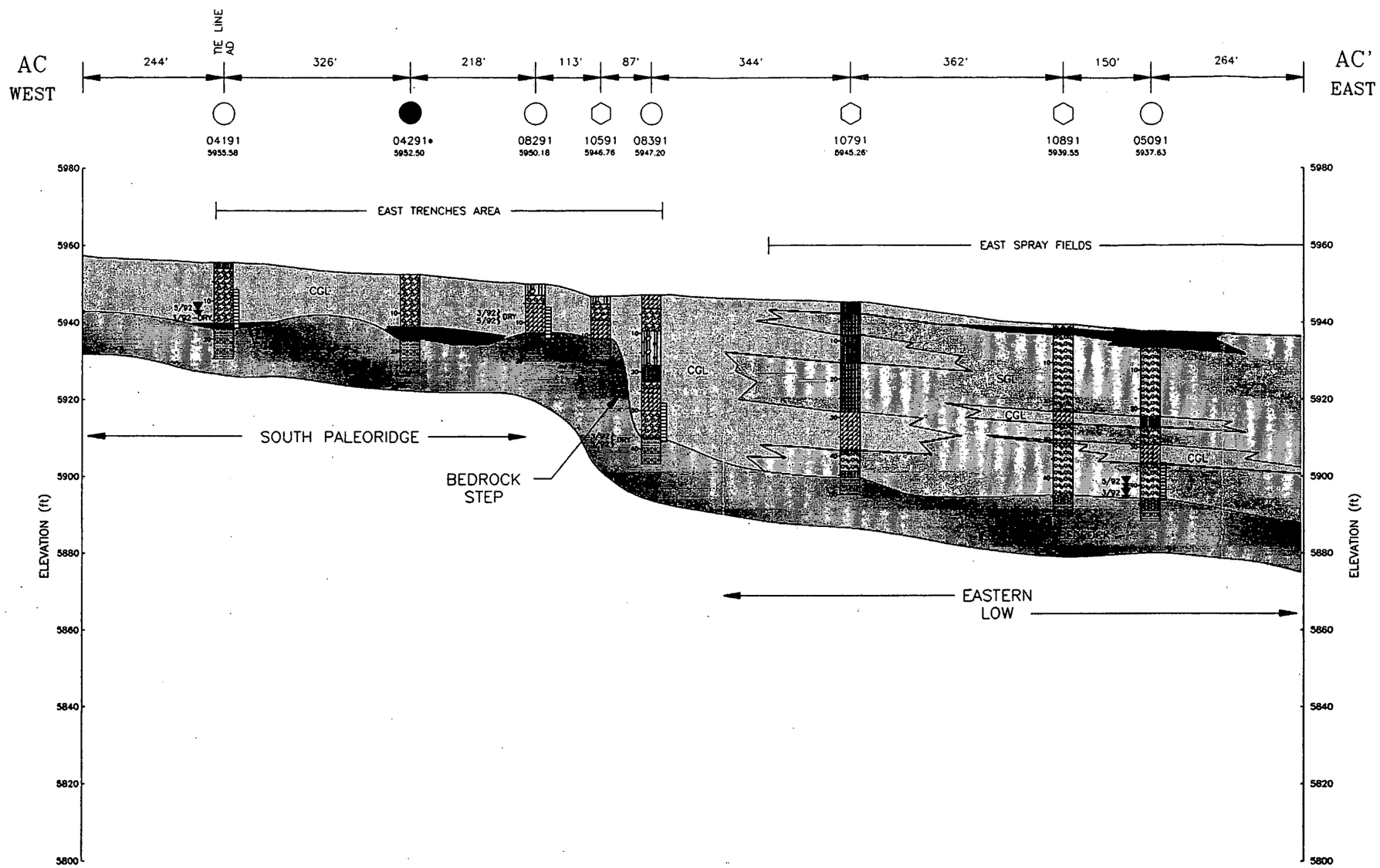
PHASE II RFI/RI REPORT

ROCKY FLATS ALLUVIAL LITHOFACIES CROSS-SECTION AB–AB' (ALONG MEDIAL PALEOSCOUR)

FIGURE 3.5–14 OCTOBER 1993

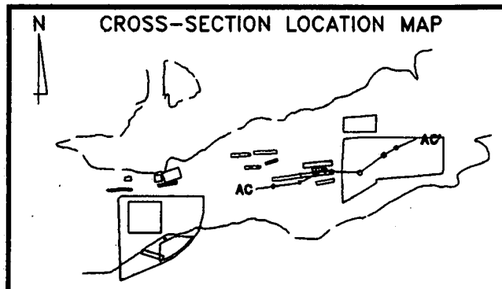
OU2RI218 1=1



DRAFT

• – FULL EXTENT OF LITHOLOGIC LOGS THROUGH BEDROCK MATERIAL NOT SHOWN

HORIZONTAL
100 200 400
0
SCALE IN FEET
VERTICAL
10
20



EXPLANATION

- ALLUVIAL MONITORING WELL
- BEDROCK MONITORING WELL
- BOREHOLE
- 03491 — WELL NUMBER – LAST 2 DIGITS INDICATE YEAR OF DRILLING OR INSTALLATION
- 5940.44 — GROUND SURFACE ELEVATION (FT)
- SCREENED INTERVAL OF ALLUVIAL MONITORING WELL
- 5/92 — STATIC WATER LEVEL AND MEASUREMENT DATA
- 3/92–NR — STATIC WATER LEVEL NOT REPORTED
- SGL — SANDY GRAVEL LITHOFACIES
- CGL — CLAYEY GRAVEL LITHOFACIES
- CL — CLAY LITHOFACIES

GRAPHIC PATTERNS SHOWN IN LITHLOGIC LOGS CORRESPOND TO U.S.C.S CLASSIFICATIONS (SEE FIGURE 3.5–11). COLORS SHOWN CORRESPOND TO LITHOFACIES

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Rocky Flats Plant, Golden, Colorado

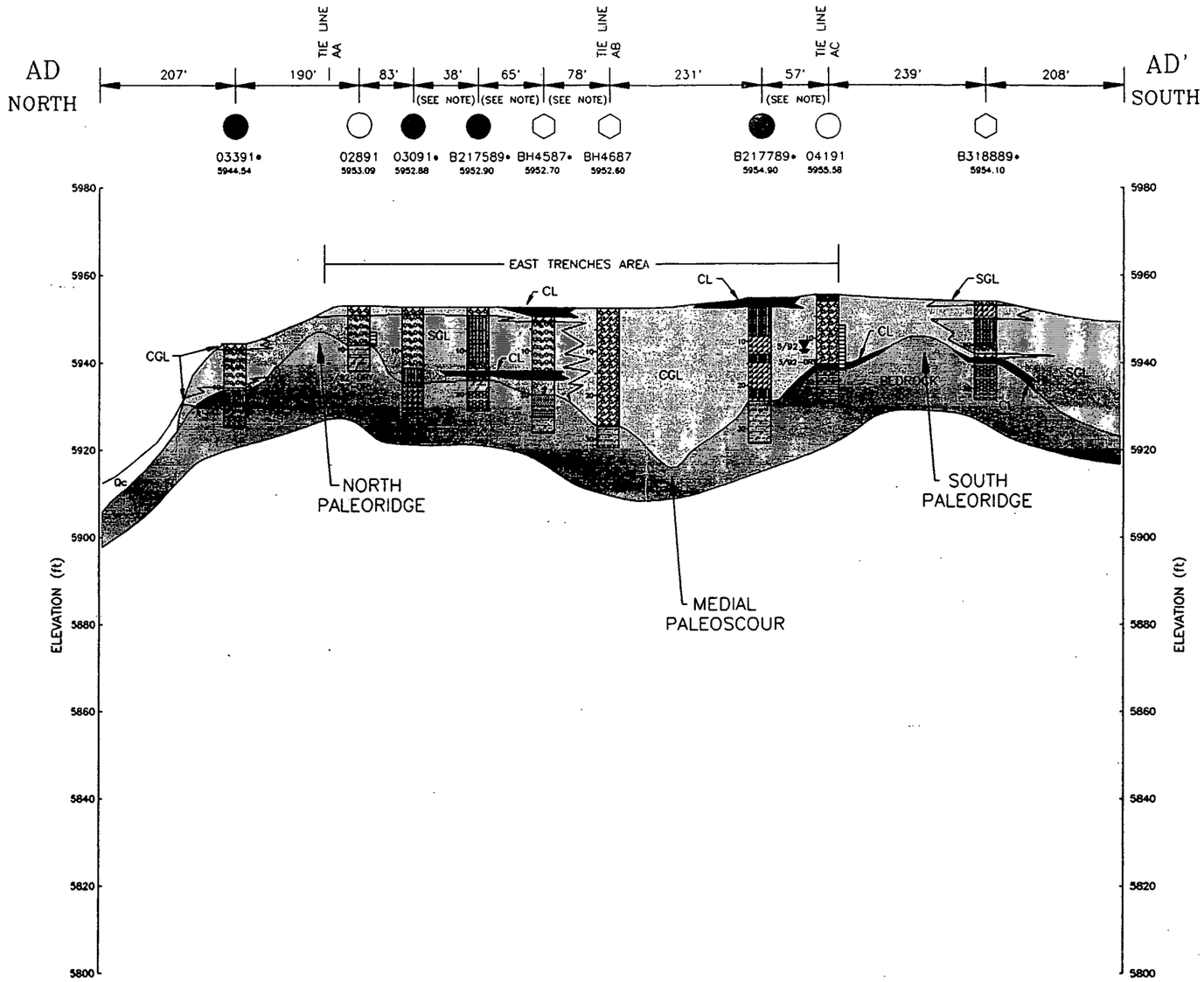
OPERABLE UNIT 2
PHASE II RFI/RI REPORT

ROCKY FLATS ALLUVIAL LITHOFACIES CROSS-SECTION AC–AC' (ALONG SOUTH PALEORIDGE AND ACROSS BEDROCK STEP)

FIGURE 3.5–15 OCTOBER 1993

240

OU2RI219 1=1



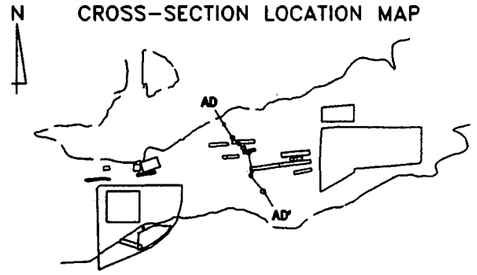
DRAFT

• – FULL EXTENT OF LITHOLOGIC LOGS THROUGH BEDROCK MATERIAL NOT SHOWN

HORIZONTAL
100 200 400
0
SCALE IN FEET
VERTICAL
10
20

NOTE: DISTANCE SHOWN BETWEEN WELLS 03091, B217589, BH4587, BH4687 AND WELLS B217789 AND 04191 IS NOT TO HORIZONTAL SCALE.

CROSS-SECTION LOCATION MAP



EXPLANATION

- ALLUVIAL MONITORING WELL
- BEDROCK MONITORING WELL
- BOREHOLE
- 03491 WELL NUMBER – LAST 2 DIGITS INDICATE YEAR OF DRILLING OR INSTALLATION
- 5940.44 GROUND SURFACE ELEVATION (FT)
- SCREENED INTERVAL OF ALLUVIAL MONITORING WELL
- 3/92 STATIC WATER LEVEL AND MEASUREMENT DATA
- 3/92–NR STATIC WATER LEVEL NOT REPORTED
- SGL SANDY GRAVEL LITHOFACIES
- CGL CLAYEY GRAVEL LITHOFACIES
- CL CLAY LITHOFACIES
- Qc COLLUVIUM

GRAPHIC PATTERNS SHOWN IN LITHLOGIC LOGS CORRESPOND TO U.S.C.S CLASSIFICATIONS (SEE FIGURE 3.5-11). COLORS SHOWN CORRESPOND TO LITHOFACIES

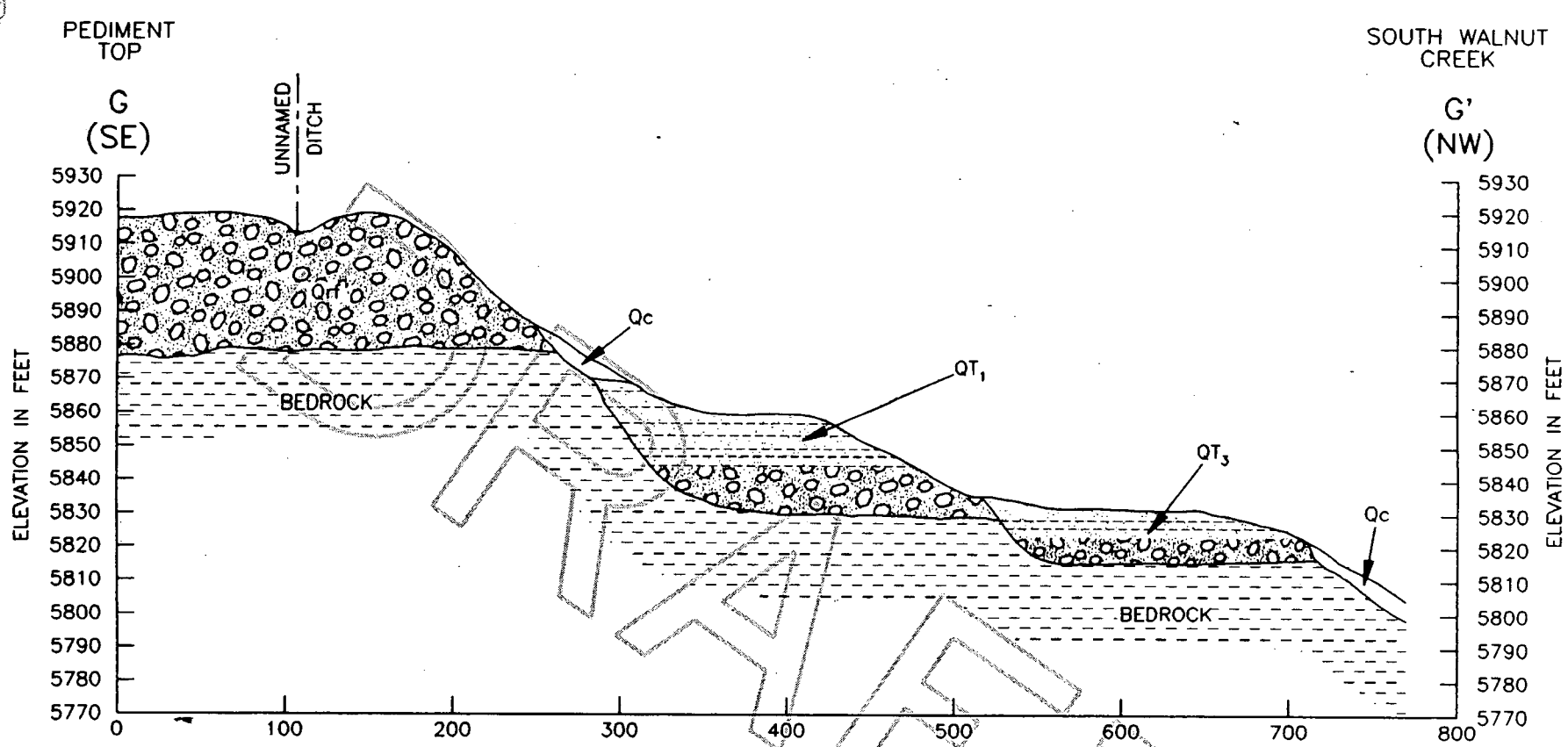
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT 2
PHASE II RFI/RI REPORT

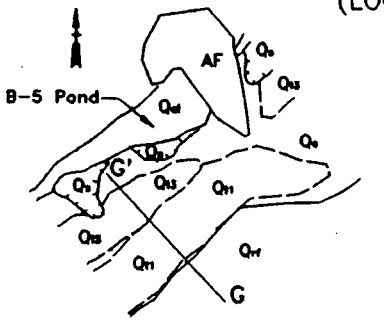
ROCKY FLATS ALLUVIAL LITHOFACIES CROSS-SECTION AD-AD' (ACROSS PEDIMENT)

FIGURE 3.5-16 OCTOBER 1993

OU2RI220 1=1



CROSS-SECTION G-G'
(LOOKING SOUTHWEST)



CROSS-SECTION LOCATION MAP

HORIZONTAL
0 50 100

VERTICAL
0
25
50

SCALE IN FEET
VERTICAL EXAGGERATION (2x)

EXPLANATION

	GRAVEL
	SAND AND CLAY
	CLAYSTONE
Qrf	ROCKY FLATS ALLUVIUM
QT_1	HIGH TERRACE ALLUVIUM NO.1
QT_3	HIGH TERRACE ALLUVIUM NO.3
Qc	COLLUVIUM
Qs	SLUMPS
AF	ARTIFICIAL FILL

U.S. DEPARTMENT OF ENERGY
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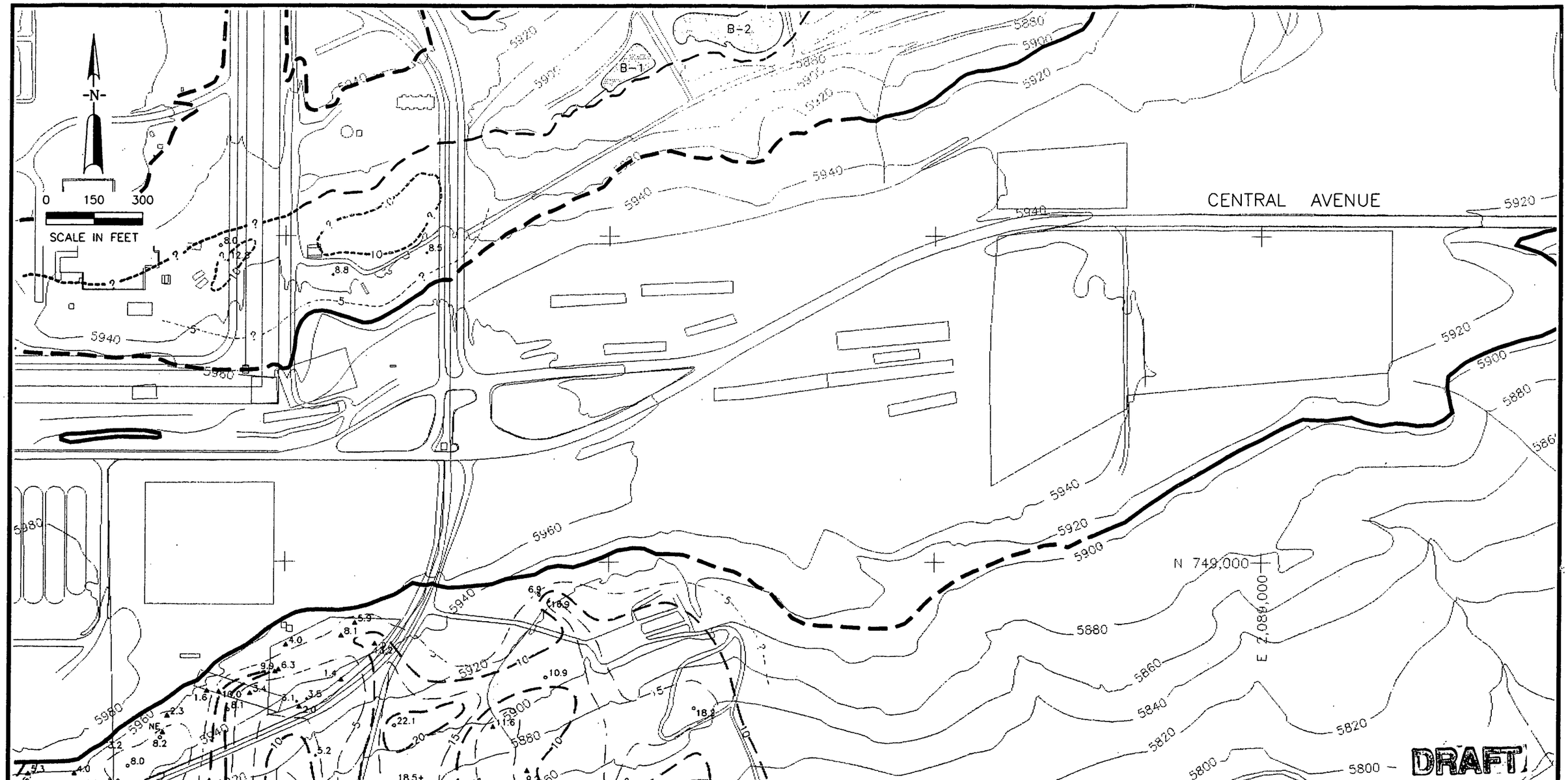
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

SCHEMATIC GEOLOGIC CROSS-SECTION THROUGH HIGH TERRACE ALLUVIUMS ALONG SOUTH WALNUT CREEK HILLSIDE

FIGURE 3.5-17 OCTOBER 1993

OU2R109 1=100

DRAFT



EXPLANATION

22.0 • BEDROCK MONITORING WELL LOCATION SHOWING COLLUVIAL THICKNESS (In Feet)

13.2 ○ COLLUVIAL MONITORING WELL LOCATION SHOWING COLLUVIAL THICKNESS (In Feet)

1.4 ▲ BOREHOLE LOCATION SHOWING COLLUVIAL THICKNESS (In Feet)

COLLUVIAL THICKNESS CONTOUR
— Approximate
- ? - Extrapolated

EDGE OF VALLEY FILL ALLUVIUM
— Approximate
- ? - Extrapolated

AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)

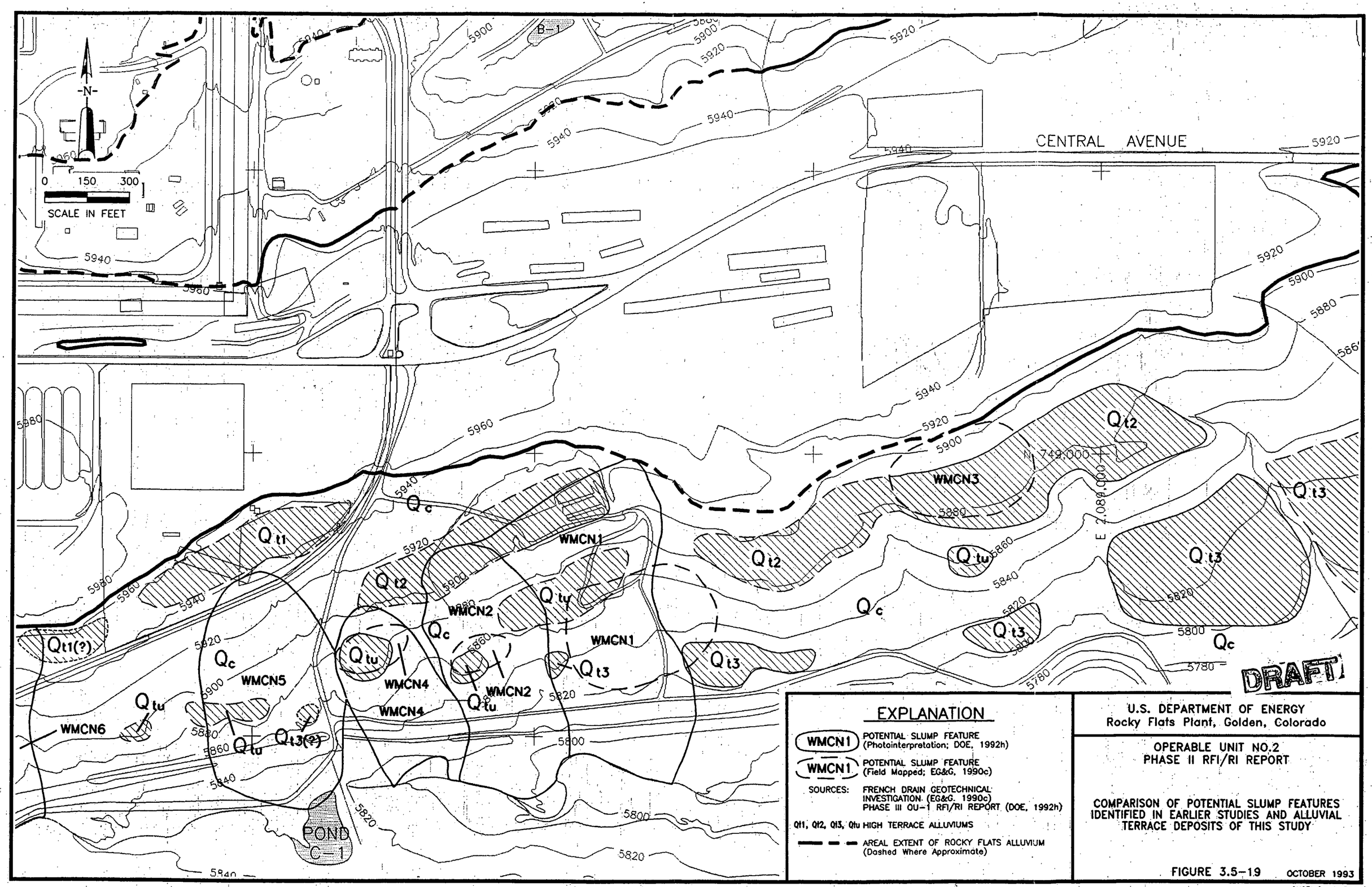
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

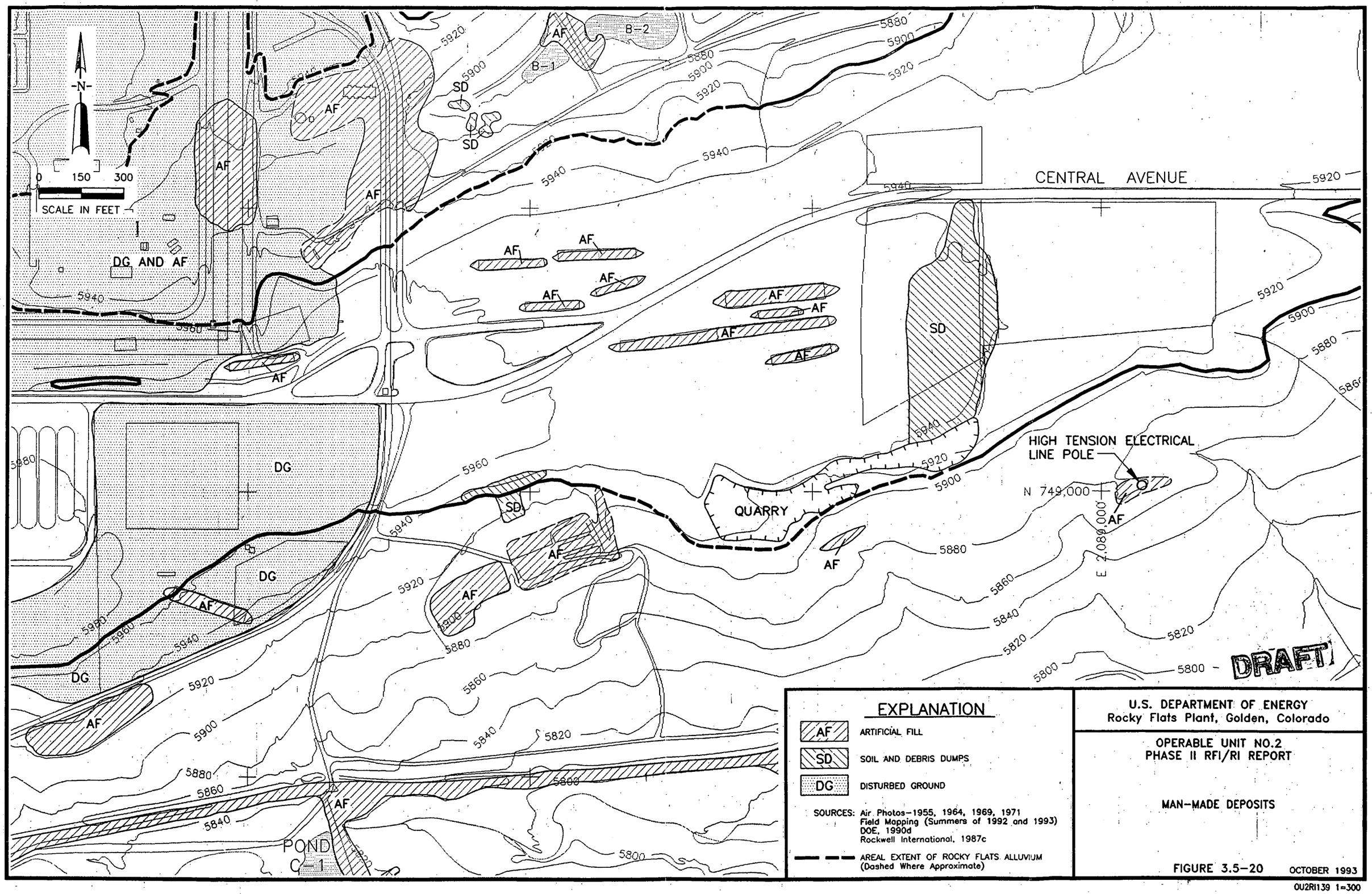
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

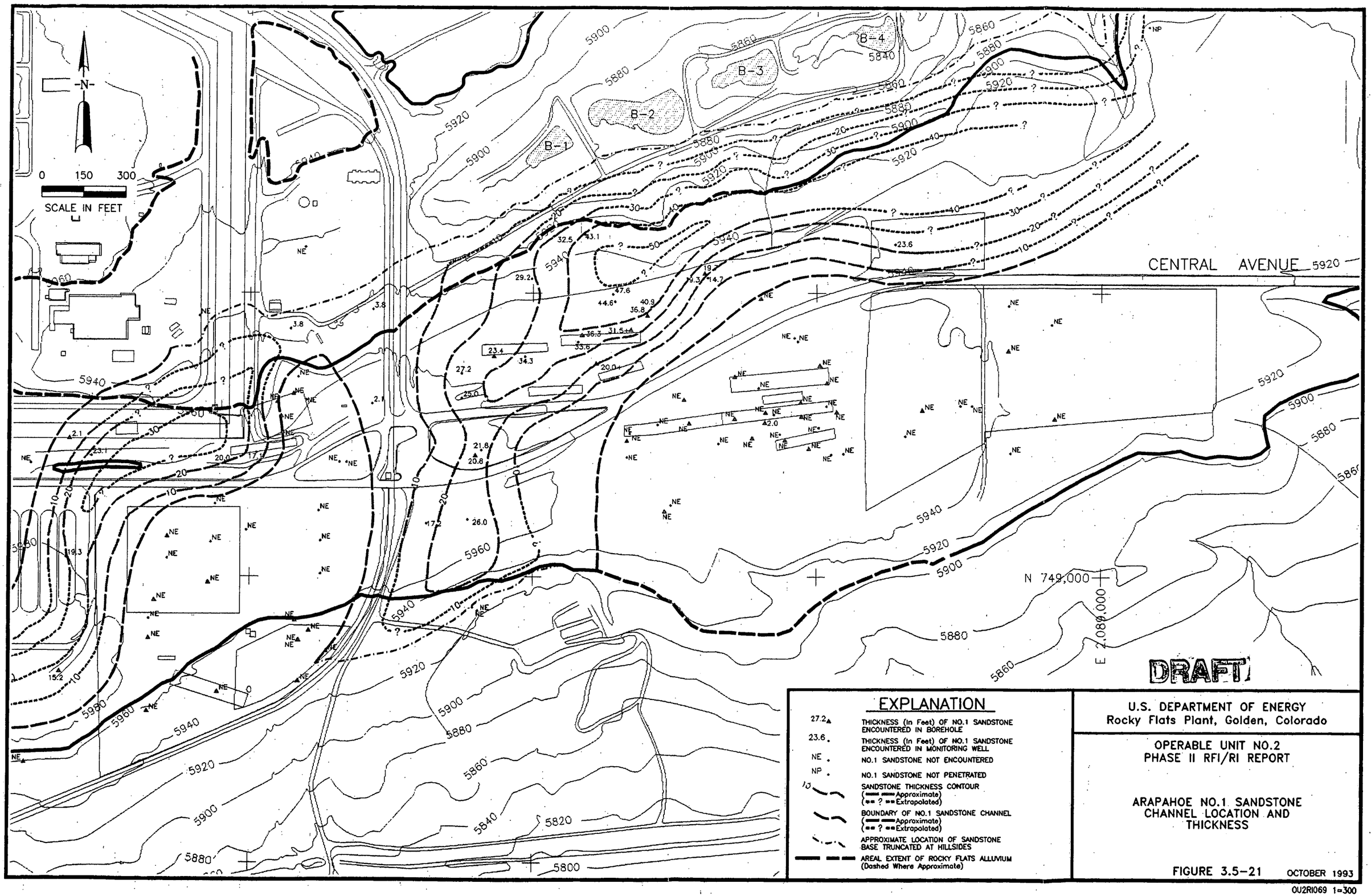
THICKNESS OF COLLUVIUM
(Includes High Terrace Alluvium and Artificial Fill Where Present)

FIGURE 3.5-18 OCTOBER 1993

OU2RI110 1=300


-N-
0 150 300
SCALE IN FEET
CENTRAL AVENUE
B-1
Qt1
Qt1(?)
Qt2
Qt3
Qt3(?)
Qc
Qtu
WMCN1
WMCN2
WMCN3
WMCN4
WMCN5
WMCN6
POND C-1
N 749,000
E 2,084,000
DRAFT
EXPLANATION
WMCN1 POTENTIAL SLUMP FEATURE (Photointerpretation; DOE, 1992h)
WMCN1 POTENTIAL SLUMP FEATURE (Field Mapped; EG&G, 1990c)
SOURCES: FRENCH DRAIN GEOTECHNICAL INVESTIGATION (EG&G, 1990c)
PHASE III OU-1 RFI/RI REPORT (DOE, 1992h)
Qt1, Qt2, Qt3, Qtu HIGH TERRACE ALLUVIUMS
AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT
COMPARISON OF POTENTIAL SLUMP FEATURES IDENTIFIED IN EARLIER STUDIES AND ALLUVIAL TERRACE DEPOSITS OF THIS STUDY
FIGURE 3.5-19
OCTOBER 1993
OU2RI121 1=300


-N-
0 150 300
SCALE IN FEET
CENTRAL AVENUE
DG AND AF
DG
AF
SD
B-1
B-2
QUARRY
HIGH TENSION ELECTRICAL LINE POLE
N 749,000
E 2,089,000
POND C-1
DRAFT
EXPLANATION
AF ARTIFICIAL FILL
SD SOIL AND DEBRIS DUMPS
DG DISTURBED GROUND
SOURCES: Air Photos-1955, 1964, 1969, 1971
Field Mapping (Summers of 1992 and 1993)
DOE, 1990d
Rockwell International, 1987c
AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT
MAN-MADE DEPOSITS
FIGURE 3.5-20
OCTOBER 1993
OU2RI139 1=300



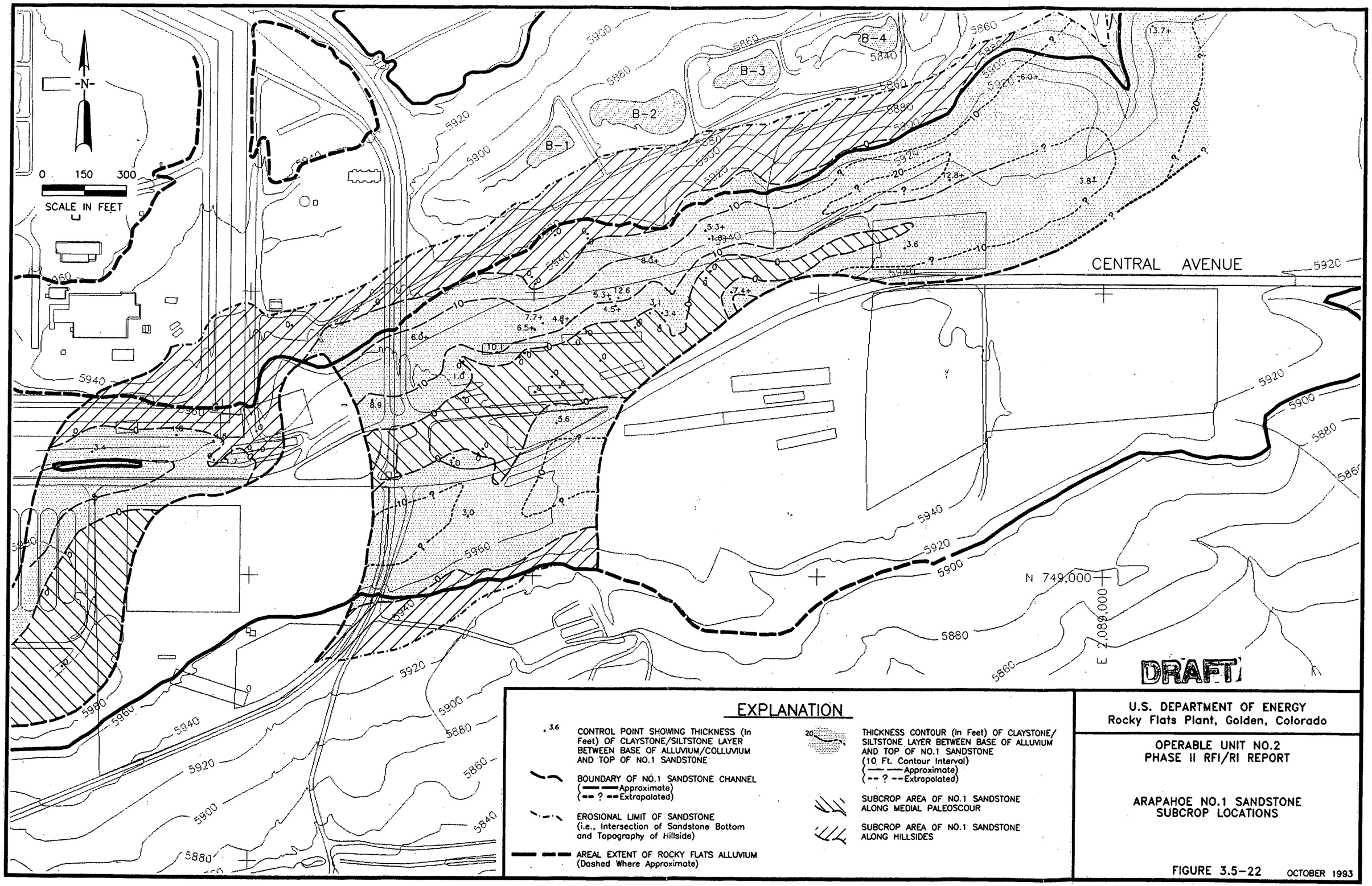
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

ARAPAHOE NO.1 SANDSTONE CHANNEL LOCATION AND THICKNESS

FIGURE 3.5-21 OCTOBER 1993

OU2RI069 1=300



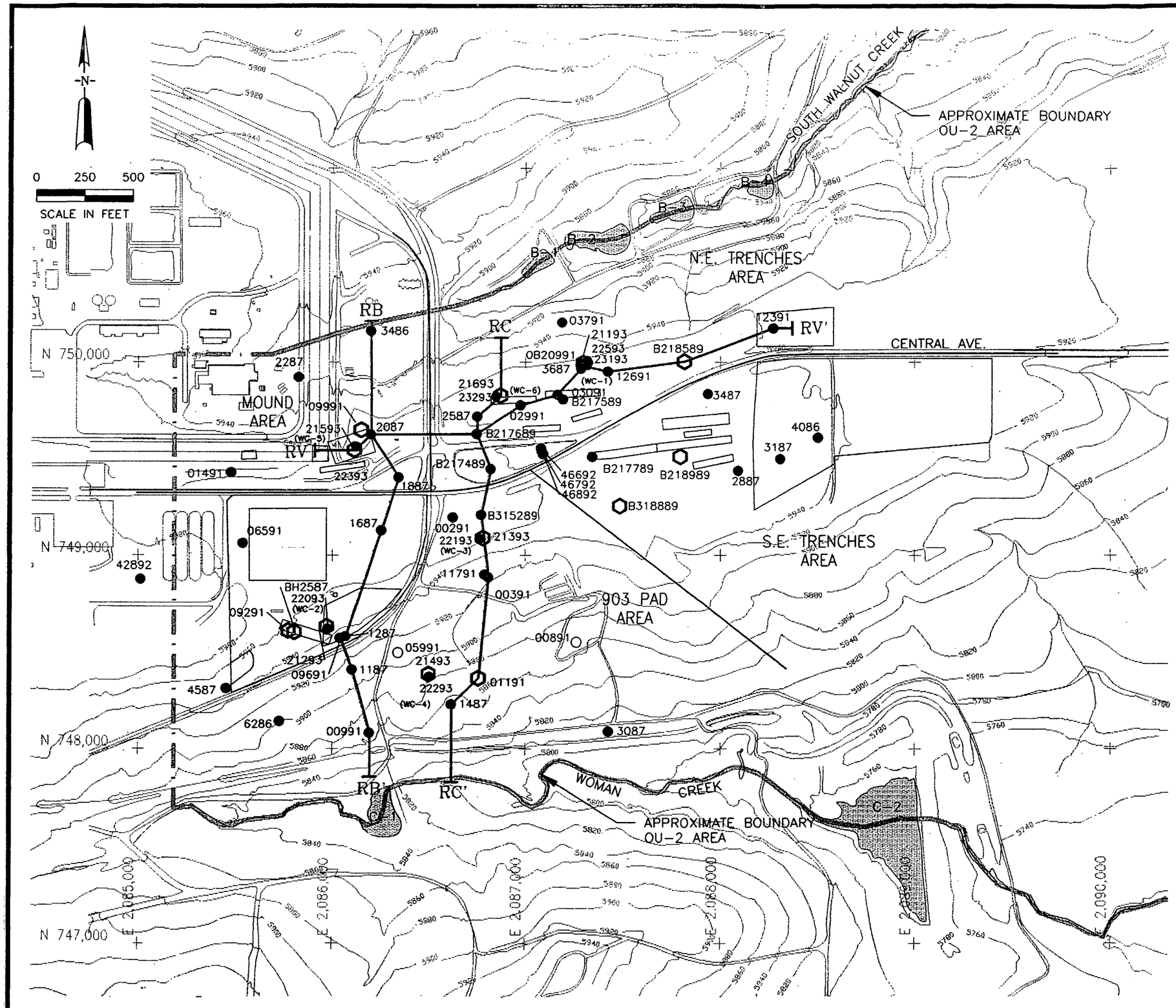
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

ARAPAHOE NO.1 SANDSTONE
SUBCROP LOCATIONS

FIGURE 3.5-22 OCTOBER 1993

OU2RI070 1=300



EXPLANATION

- ALLUVIAL MONITORING WELL
- 22093 BEDROCK MONITORING WELL
- 21193 BOREHOLE
- BEDROCK OBSERVATION WELL
- (WC-3) RBWP WELL CLUSTER LOCATIONS
- INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
- APPROXIMATE BOUNDARY OF OU-2 STUDY AREA
- BOUNDARY BETWEEN HISTORICAL CHARACTERIZATION AREAS
- CROSS-SECTION LINE

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Rocky Flats Plant, Golden, Colorado

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LOCATION MAP
GEOLOGIC CROSS-SECTIONS

FIGURE 3.5-23 OCTOBER 1993

OU2RI215 1=500

SOIL SYMBOLS

- GW WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- GP POORLY-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES
- GM SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
- GC CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
- SW WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
- SP POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
- SM SILTY SANDS, SAND-SILT MIXTURES
- SC CLAYEY SANDS, SAND-CLAY MIXTURES
- ML INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
- CL INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
- CH INORGANIC CLAYS OR HIGH PLASTICITY, FAT CLAYS

BEDROCK SYMBOLS

- SANDSTONE
- SILTY SANDSTONE
- CLAYEY SANDSTONE
- SILTSTONE
- SANDY SILTSTONE
- CLAYEY SILTSTONE
- CLAYSTONE
- SANDY CLAYSTONE
- SILTY CLAYSTONE
- CALICHE
- NO RECOVERY OR SAMPLED INTERVAL NOT LOGGED

WELL CONSTRUCTION SYMBOLS

- CONCRETE SURROUNDING SOLID WELL PIPE
- BENTONITE SEAL SURROUNDING SOLID WELL PIPE
- SAND FILTER PACK SURROUNDING SOLID WELL PIPE
- GROUT SURROUNDING SOLID WELL PIPE
- SAND FILTER PACK SURROUNDING WELL SCREENED INTERVAL
- CONCRETE FILL
- BENTONITE FILL
- A-SERIES OR B-SERIES WELL SCREEN INTERVAL (SHOWN ADJACENT TO PILOT BOREHOLE LITHOLOGIC COLUMN)

WATER LEVEL AND LOCATION SYMBOLS

- 4/92 STATIC WATER LEVEL AND MEASUREMENT DATE
- ALLUVIAL MONITORING WELL
- BEDROCK MONITORING WELL
- BEDROCK OBSERVATION WELL
- BOREHOLE
- 01491 WELL NUMBER. LAST 2 DIGITS INDICATE YEAR IN WHICH WELL WAS INSTALLED

NOTE: NO COLOR IS ADDED TO THAT PORTION OF A BOREHOLE EXTENDING ABOVE THE GROUND SURFACE FOR BOREHOLES THAT ARE PROJECTED INTO THE LINE OF THE CROSS-SECTION.

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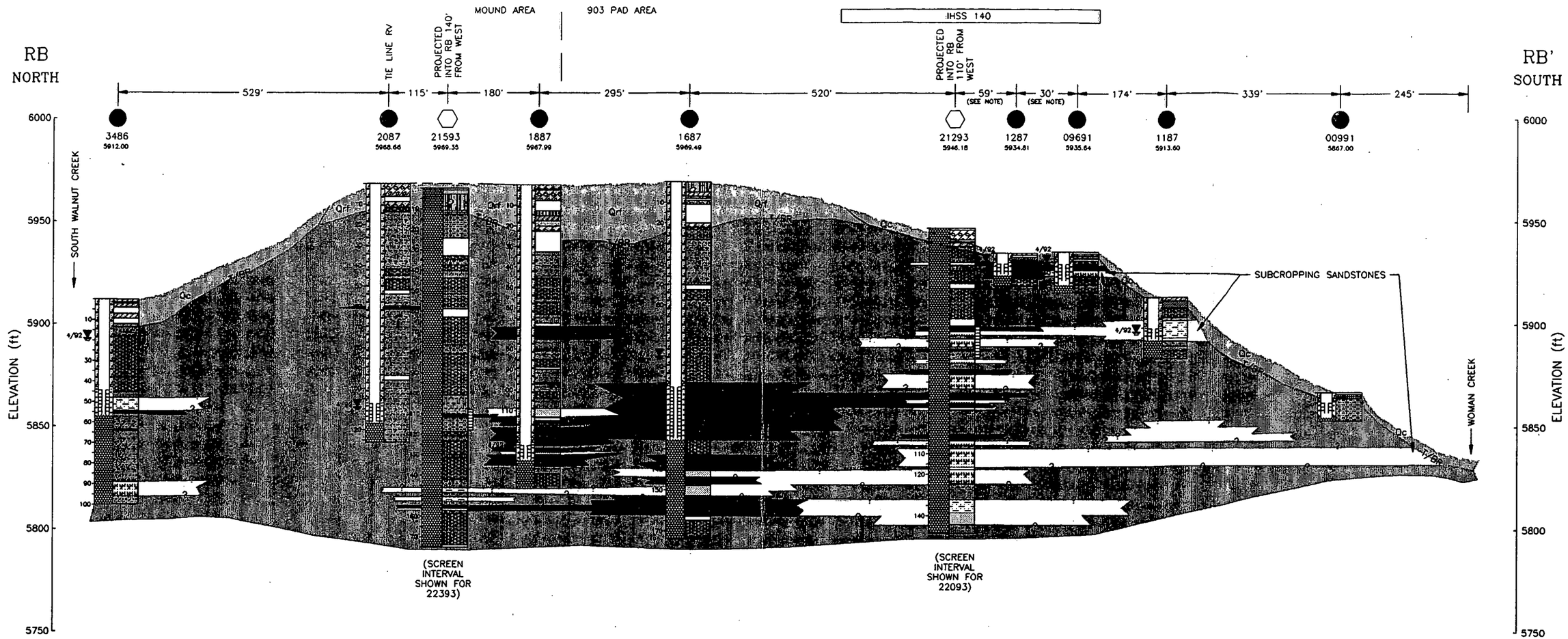
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT 2
PHASE II RFI/RI REPORT

GEOLOGIC CROSS-SECTIONS LEGEND

FIGURE 3.5-24 OCTOBER 1993

OU2RI216 1=1

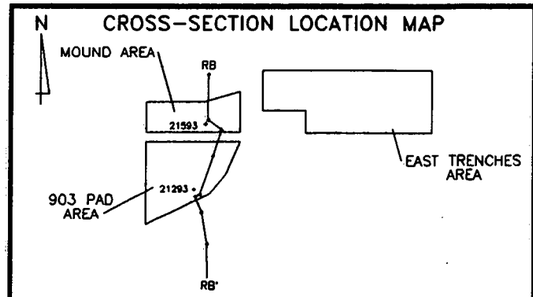


DRAFT

HORIZONTAL
0 100 200
VERTICAL
25
50
SCALE IN FEET
VERTICAL EXAGGERATION (4x)

NOTE:
DISTANCE SHOWN BETWEEN WELLS 21293, 1287 AND 09691 IS NOT TO HORIZONTAL SCALE.

CROSS-SECTION LOCATION MAP



EXPLANATION

Qal = STREAM ALLUVIUM
Qc = COLLUVIUM
Qrf = ROCKY FLATS ALLUVIUM
No.1 = ARAPAHOE FORMATION (FM) SANDSTONE
ALL SANDSTONES BELOW THE BASE OF THE No.1 SANDSTONE (ARAPAHOE FM) ARE LARAMIE FM SANDSTONES
T/BR = TOP OF BEDROCK
● = LOCATION SYMBOL
3486 = LOCATION NAME
5912.00 = GROUND SURFACE ELEVATION (ft)
(SEE LEGEND PAGE FOR MORE ON SYMBOLS)

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

OPERABLE UNIT 2
PHASE II RFI/RI REPORT

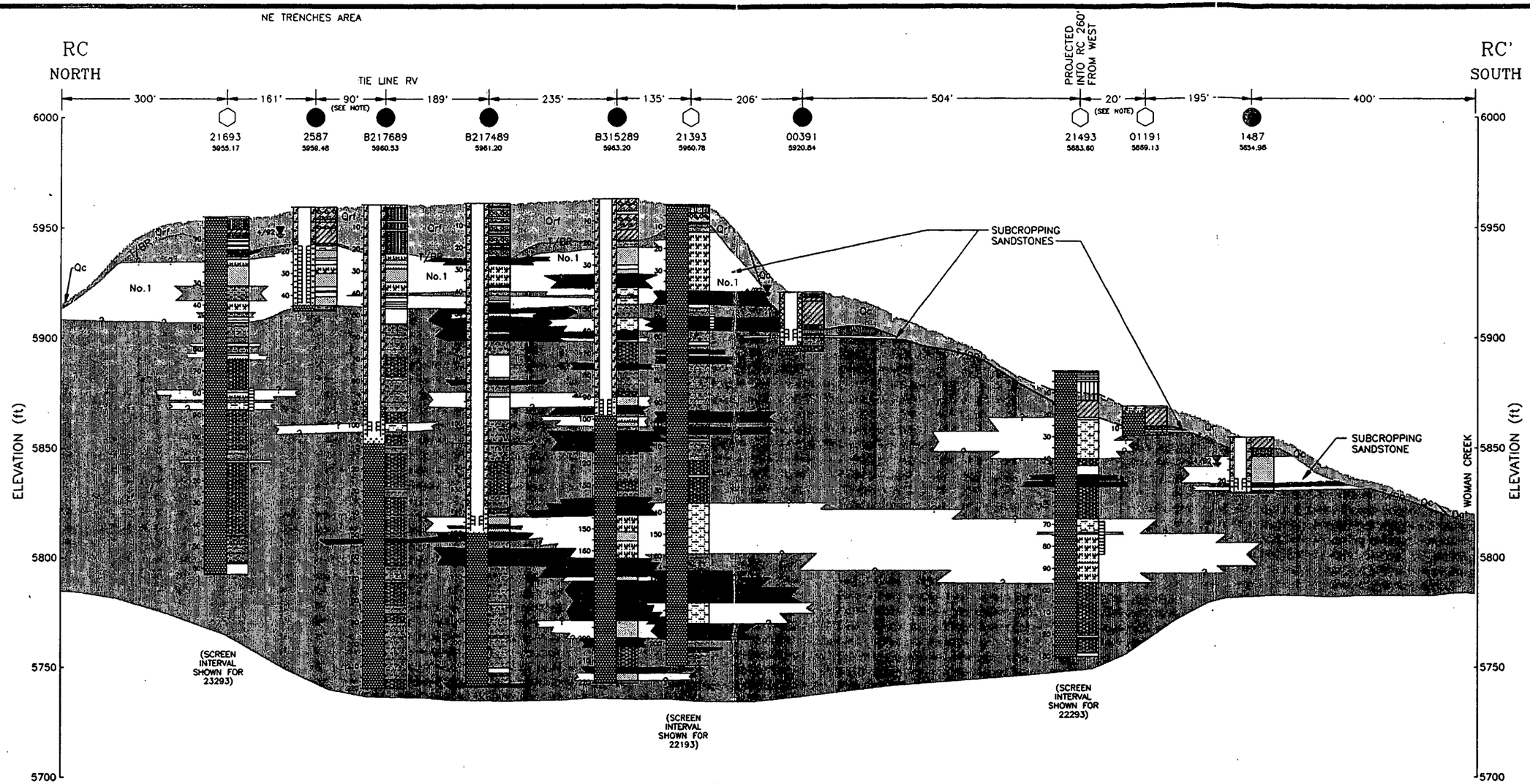
GEOLOGIC CROSS-SECTION RB-RB'

(Revised BB-BB' Cross-Section From Technical Memorandum No. 8)

FIGURE 3.5-25 OCTOBER 1993

OU2RI142 1=1

250

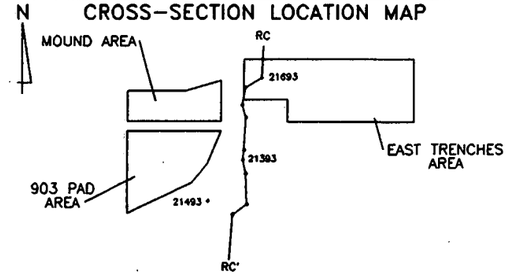


DRAFT

HORIZONTAL
0 100 200
VERTICAL
25
50
SCALE IN FEET
VERTICAL EXAGGERATION (4x)

NOTE: DISTANCE SHOWN BETWEEN WELLS 2587, B217689 AND 21493, 01191 IS NOT TO HORIZONTAL SCALE.

CROSS-SECTION LOCATION MAP



EXPLANATION

Qal = STREAM ALLUVIUM
Qc = COLLUVIUM
Qrf = ROCKY FLATS ALLUVIUM
No.1 = ARAPAHOE FORMATION (FM) SANDSTONE
ALL SANDSTONES BELOW THE BASE OF THE No.1 SANDSTONE (ARAPAHOE FM) ARE LARAMIE FM SANDSTONES
T/BR = TOP OF BEDROCK
● = LOCATION SYMBOL
3486 = LOCATION NAME
5912.00 = GROUND SURFACE ELEVATION (ft)
(SEE LEGEND PAGE FOR MORE ON SYMBOLS)

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

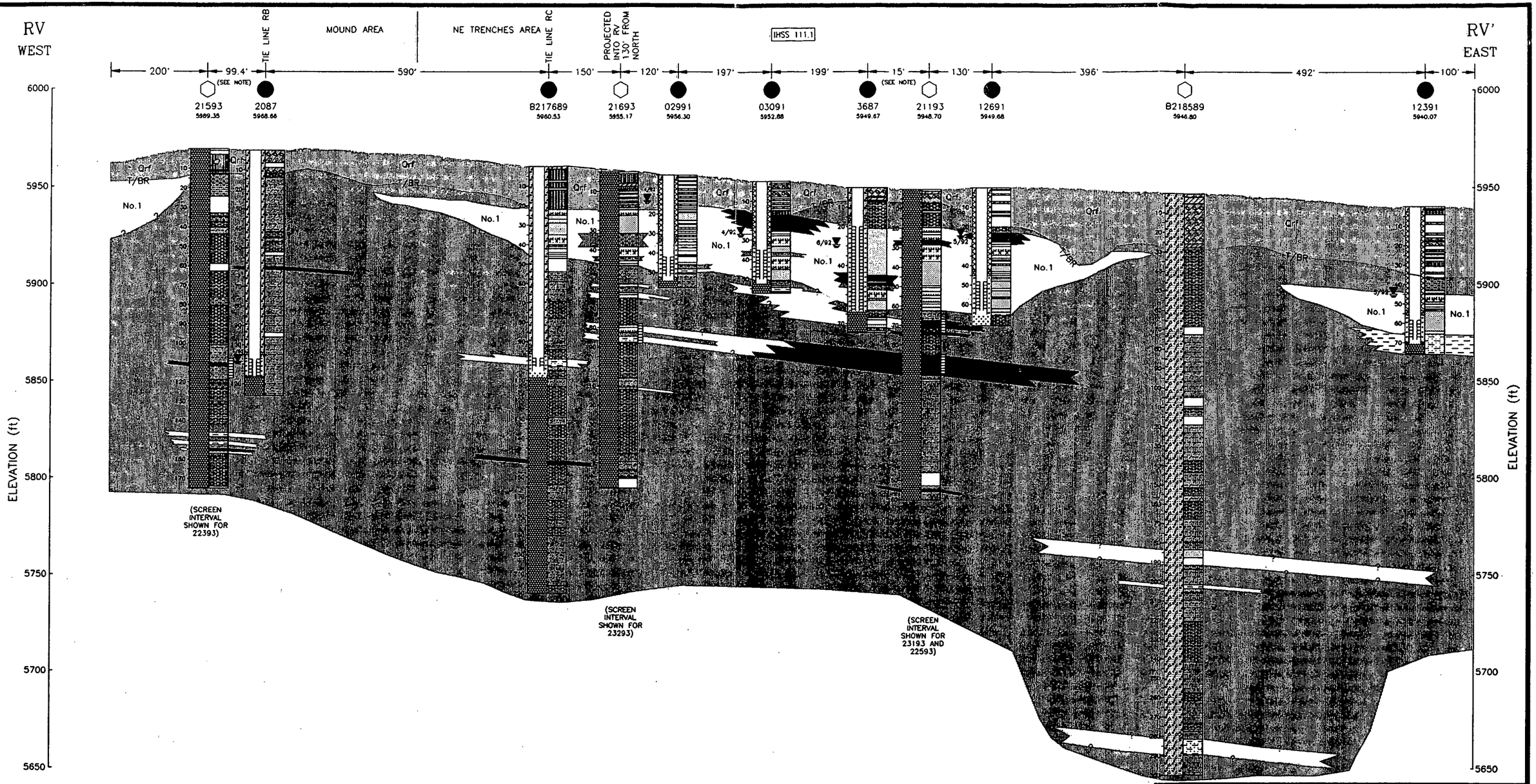
OPERABLE UNIT 2
PHASE II RFI/RI REPORT

GEOLOGIC CROSS-SECTION RC-RC'

(Revised BC-BC' Cross-Section From Technical Memorandum No. 8)

FIGURE 3.5-26 OCTOBER 1993

OU2RI143 1=1



HORIZONTAL
0 100 200

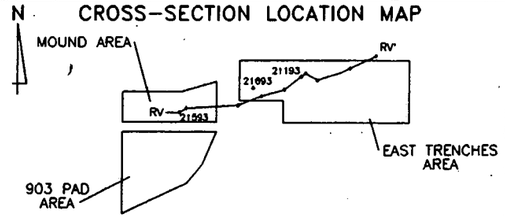
VERTICAL
0 25 50

SCALE IN FEET

VERTICAL EXAGGERATION (4x)

NOTE
DISTANCE SHOWN BETWEEN WELLS 21593, 2087 AND 3687, 21193 IS NOT TO HORIZONTAL SCALE.

CROSS-SECTION LOCATION MAP



EXPLANATION

Qal = STREAM ALLUVIUM
Qc = COLLUVIUM
Qrf = ROCKY FLATS ALLUVIUM
No.1 = ARAPAHOE FORMATION (FM) SANDSTONE
ALL SANDSTONES BELOW THE BASE OF THE No.1 SANDSTONE (ARAPAHOE FM) ARE LARAMIE FM SANDSTONES
T/BR = TOP OF BEDROCK
● = LOCATION SYMBOL
3486 = LOCATION NAME
5912.00 = GROUND SURFACE ELEVATION (ft)
(SEE LEGEND PAGE FOR MORE ON SYMBOLS)

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Rocky Flats Plant, Golden, Colorado

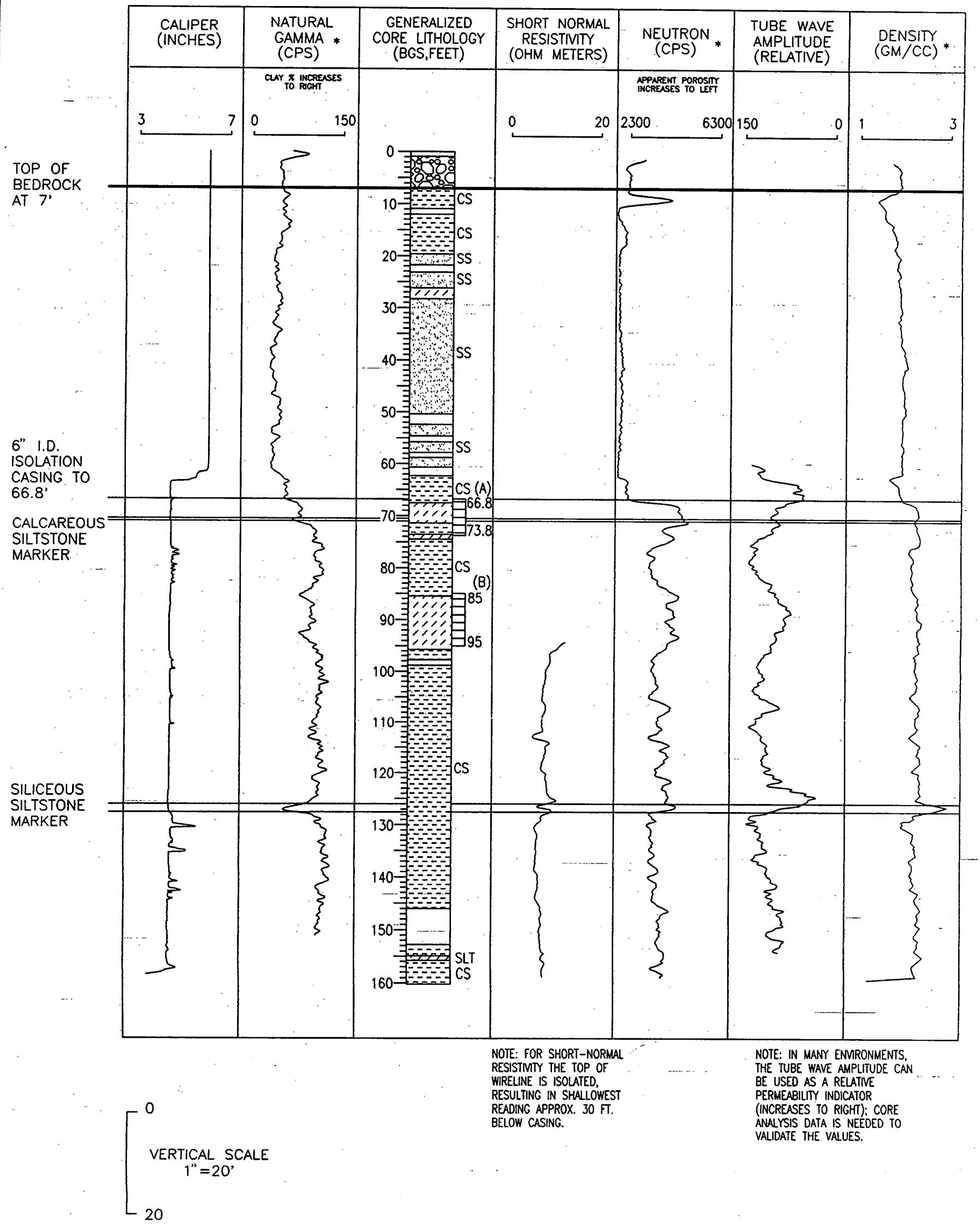
OPERABLE UNIT 2
PHASE II RFI/RI REPORT

GEOLOGIC CROSS-SECTION RV-RV'

(Revised BV-BV' Cross-Section From Technical Memorandum No. 8)

FIGURE 3.5-27 OCTOBER 1993

OU2RI144 1=1



NOTE: FOR SHORT-NORMAL RESISTIVITY THE TOP OF WIRELINE IS ISOLATED, RESULTING IN SHALLOWEST READING APPROX. 30 FT. BELOW CASING.

NOTE: IN MANY ENVIRONMENTS, THE TUBE WAVE AMPLITUDE CAN BE USED AS A RELATIVE PERMEABILITY INDICATOR (INCREASES TO RIGHT); CORE ANALYSIS DATA IS NEEDED TO VALIDATE THE VALUES.

0

VERTICAL SCALE
1"=20'

20

LEGEND

- UNCONSOLIDATED SEDIMENTS (QUATERNARY)
- SANDSTONE
- SILTSTONE
- CLAYSTONE
- NO RECOVERY INTERVAL OR NOT SAMPLED
- SCREENED INTERVAL FROM (A) A-SERIES AND (B) B-SERIES WELL PROJECTED ONTO PILOT BOREHOLE LITHOLOGIC COLUMN

* LOG VALUES ABOVE 66.8' ARE ATTENUATED BY ISOLATION CASING.

DRAFT

EXPLANATION

BGS	BELOW GROUND SURFACE
(CPS)	COUNTS PER SECOND
(GM/CC)	GRAMS PER CUBIC CENTIMETER
SS	SANDSTONE
SLT	SILTSTONE
CS	CLAYSTONE

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

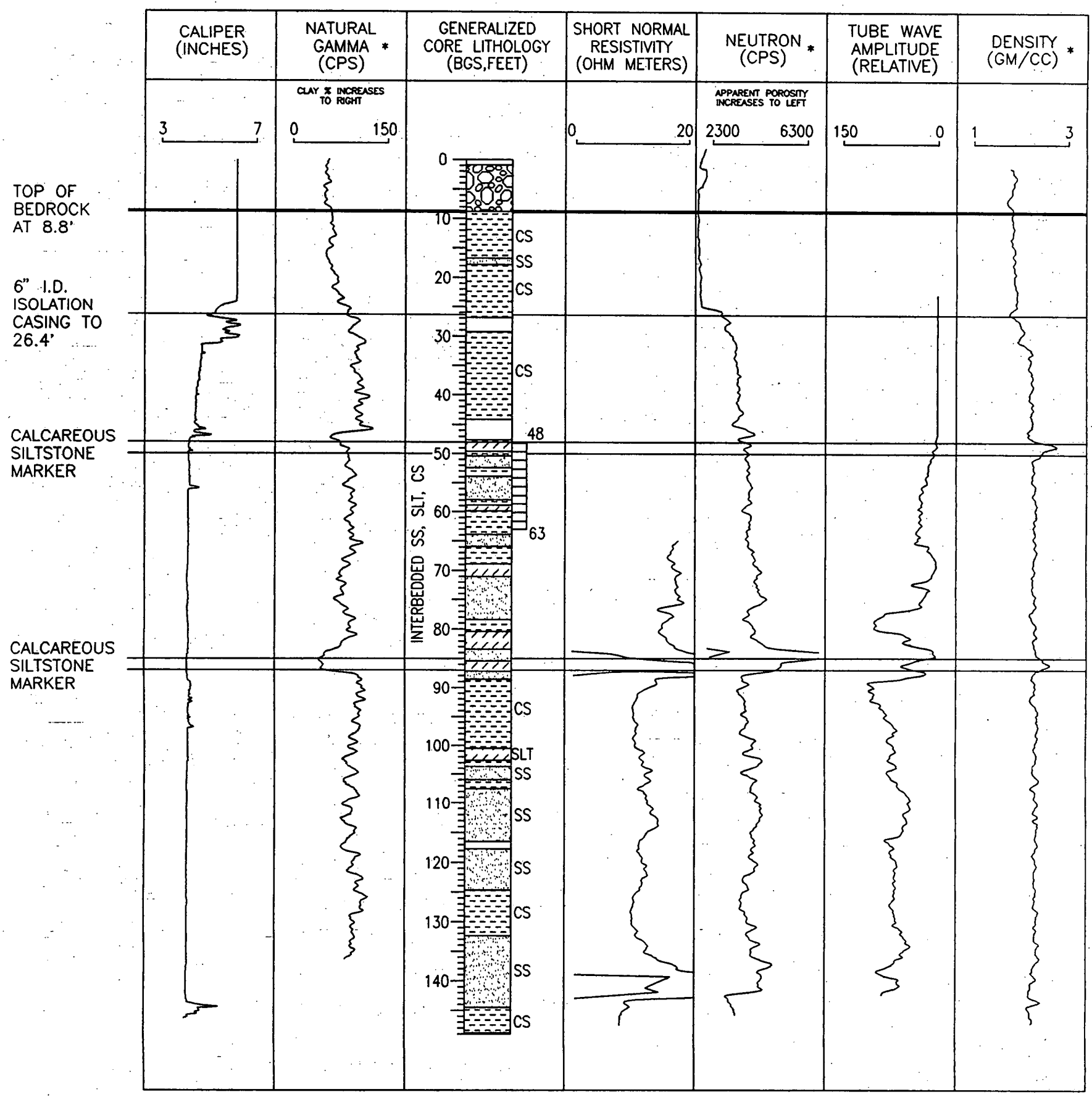
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

GENERALIZED CORE LITHOLOGY AND GEOPHYSICAL LOGS COMPOSITE FOR PILOT BOREHOLE 21193

FIGURE 3.5-28

OCTOBER 1993

OU2RI023 1=20



NOTE: FOR SHORT-NORMAL RESISTIVITY THE TOP OF WIRELINE IS ISOLATED, RESULTING IN SHALLOWEST READING APPROX. 30 FT. BELOW CASING.

NOTE: IN MANY ENVIRONMENTS, THE TUBE WAVE AMPLITUDE CAN BE USED AS A RELATIVE PERMEABILITY INDICATOR (INCREASES TO RIGHT); CORE ANALYSIS DATA IS NEEDED TO VALIDATE THE VALUES.

0

VERTICAL SCALE
1"=20'

20

LEGEND

- UNCONSOLIDATED SEDIMENTS (QUATERNARY)
- SANDSTONE
- SILTSTONE
- CLAYSTONE
- NO RECOVERY INTERVAL OR NOT SAMPLED
- SCREENED INTERVAL FROM A-SERIES WELL PROJECTED ONTO PILOT BOREHOLE LITHOLOGIC COLUMN

* LOG VALUES ABOVE 26.4' ARE ATTENUATED BY ISOLATION CASING.

DRAFT

EXPLANATION

BGS	BELOW GROUND SURFACE
(CPS)	COUNTS PER SECOND
(GM/CC)	GRAMS PER CUBIC CENTIMETER
SS	SANDSTONE
SLT	SILTSTONE
CS	CLAYSTONE

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

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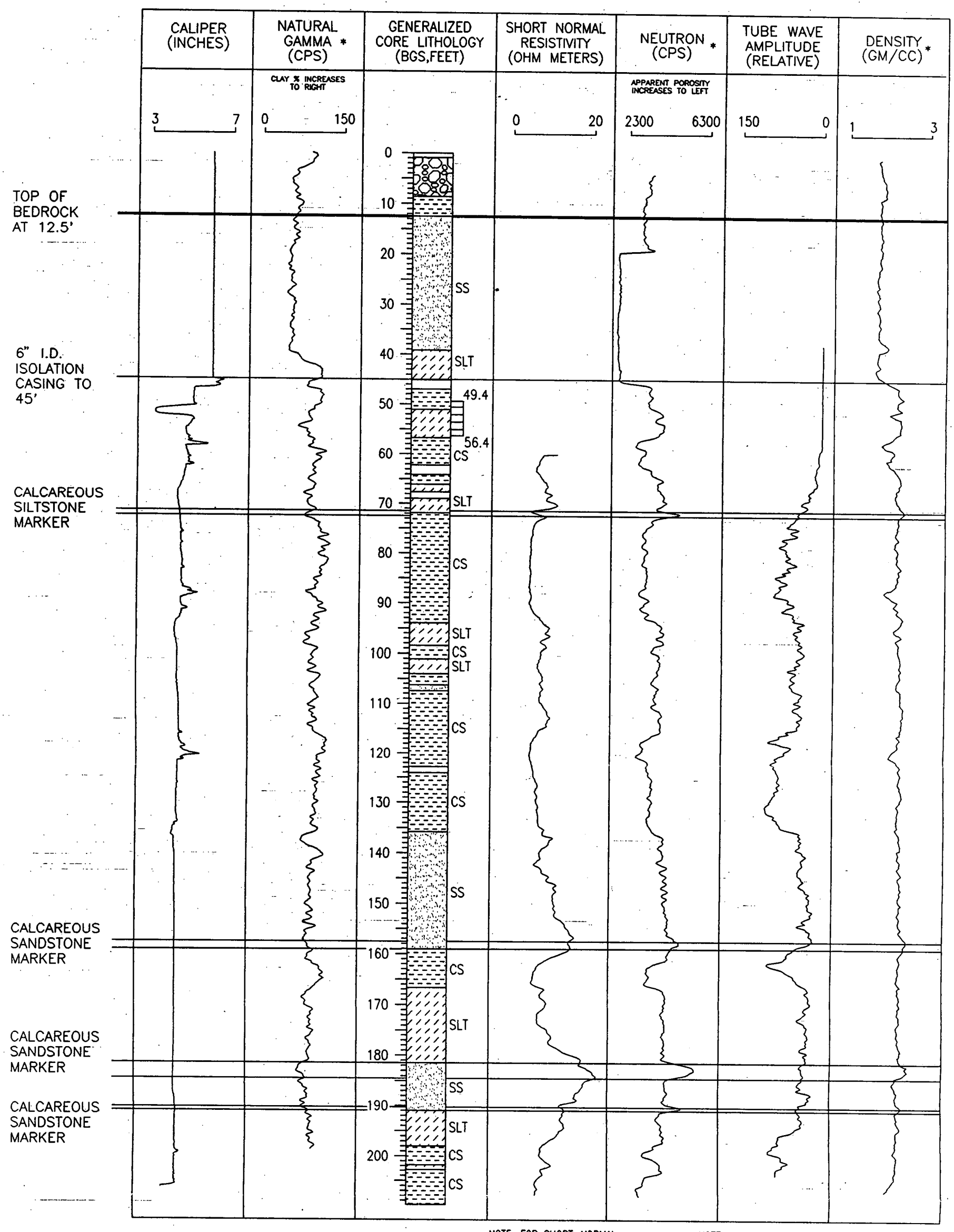
PHASE II RFI/RI REPORT

GENERALIZED CORE LITHOLOGY AND GEOPHYSICAL LOGS COMPOSITE FOR PILOT BOREHOLE 21293

FIGURE 3.5-29 OCTOBER 1993

OU2RI222 1=20



NOTE: FOR SHORT-NORMAL RESISTIVITY THE TOP OF WIRELINE IS ISOLATED, RESULTING IN SHALLOWEST READING APPROX. 30 FT. BELOW CASING.

NOTE: IN MANY ENVIRONMENTS, THE TUBE WAVE AMPLITUDE CAN BE USED AS A RELATIVE PERMEABILITY INDICATOR (INCREASES TO RIGHT); CORE ANALYSIS DATA IS NEEDED TO VALIDATE THE VALUES.

0 — VERTICAL SCALE 1"=20' — 20

LEGEND

- UNCONSOLIDATED SEDIMENTS (QUATERNARY)
- SANDSTONE
- SILTSTONE
- CLAYSTONE
- NO RECOVERY INTERVAL OR NOT SAMPLED
- SCREENED INTERVAL FROM A-SERIES WELL PROJECTED ONTO PILOT BOREHOLE LITHOLOGIC COLUMN

* LOG VALUES ABOVE 45' ARE ATTENUATED BY ISOLATION CASING.

EXPLANATION

BGS	BELOW GROUND SURFACE
(CPS)	COUNTS PER SECOND
(GM/CC)	GRAMS PER CUBIC CENTIMETER
SS	SANDSTONE
SLT	SILTSTONE
CS	CLAYSTONE

DRAFT

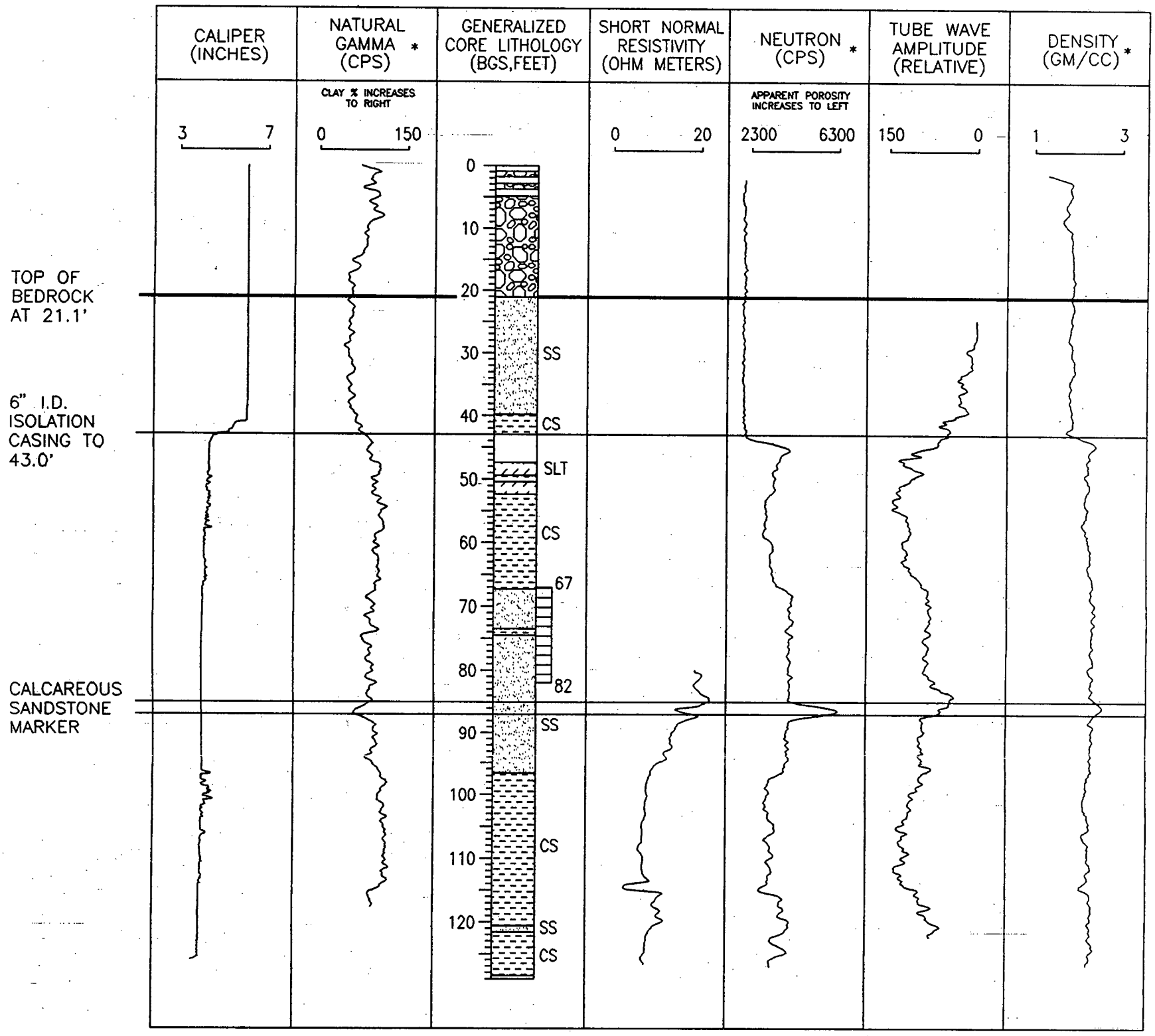
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

GENERALIZED CORE LITHOLOGY AND GEOPHYSICAL LOGS COMPOSITE FOR PILOT BOREHOLE 21393

FIGURE 3.5-30 OCTOBER 1993

OU2RI024 1-20



NOTE: FOR SHORT-NORMAL RESISTIVITY THE TOP OF WIRELINE IS ISOLATED, RESULTING IN SHALLOWEST READING APPROX. 30 FT. BELOW CASING.

NOTE: IN MANY ENVIRONMENTS, THE TUBE WAVE AMPLITUDE CAN BE USED AS A RELATIVE PERMEABILITY INDICATOR (INCREASES TO RIGHT); CORE ANALYSIS DATA IS NEEDED TO VALIDATE THE VALUES.

0

VERTICAL SCALE
1"=20'

20

LEGEND

- UNCONSOLIDATED SEDIMENTS (QUATERNARY)
- SANDSTONE
- SILTSTONE
- CLAYSTONE
- NO RECOVERY INTERVAL OR NOT SAMPLED
- SCREENED INTERVAL FROM A-SERIES WELL PROJECTED ONTO PILOT BOREHOLE LITHOLOGIC COLUMN

* LOG VALUES ABOVE 43' ARE ATTENUATED BY ISOLATION CASING.

DRAFT

EXPLANATION

BGS	BELOW GROUND SURFACE
(CPS)	COUNTS PER SECOND
(GM/CC)	GRAMS PER CUBIC CENTIMETER
SS	SANDSTONE
SLT	SILTSTONE
CS	CLAYSTONE

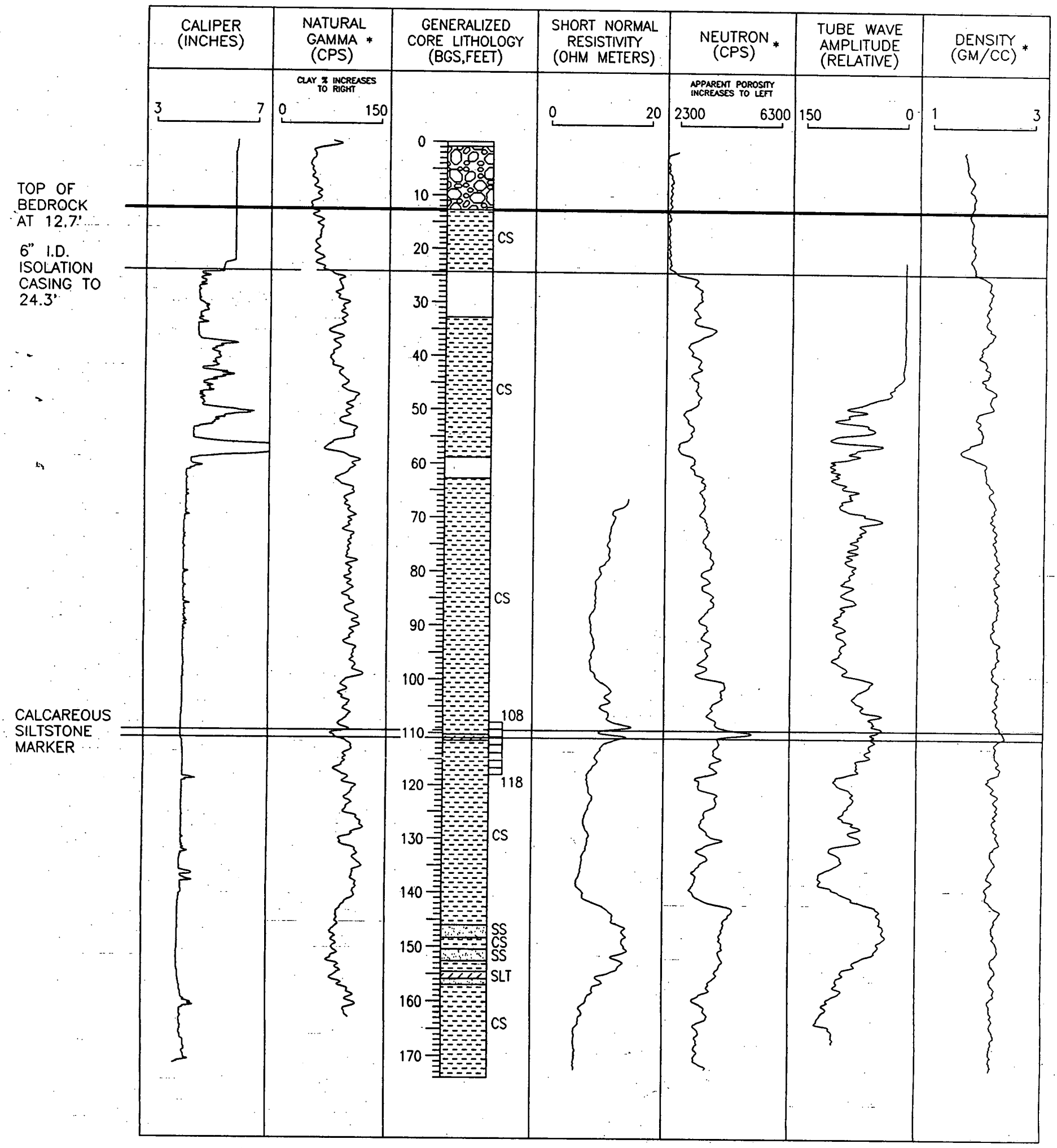
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

GENERALIZED CORE LITHOLOGY AND GEOPHYSICAL LOGS COMPOSITE FOR PILOT BOREHOLE 21493

FIGURE 3.5-31 OCTOBER 1993

OU2PI225 1=20



NOTE: FOR SHORT-NORMAL RESISTIVITY THE TOP OF WIRELINE IS ISOLATED, RESULTING IN SHALLOWEST READING APPROX. 30 FT. BELOW CASING.

NOTE: IN MANY ENVIRONMENTS, THE TUBE WAVE AMPLITUDE CAN BE USED AS A RELATIVE PERMEABILITY INDICATOR (INCREASES TO RIGHT); CORE ANALYSIS DATA IS NEEDED TO VALIDATE THE VALUES.

0

VERTICAL SCALE 1"=20'

20

LEGEND

- UNCONSOLIDATED SEDIMENTS (QUATERNARY)
- SANDSTONE
- SILTSTONE
- CLAYSTONE
- NO RECOVERY INTERVAL OR NOT SAMPLED
- SCREENED INTERVAL FROM A-SERIES WELL PROJECTED ONTO PILOT BOREHOLE LITHOLOGIC COLUMN

* LOG VALUES ABOVE 24.3' ARE ATTENUATED BY ISOLATION CASING.

DRAFT

EXPLANATION

BGS	BELOW GROUND SURFACE
(CPS)	COUNTS PER SECOND
(GM/CC)	GRAMS PER CUBIC CENTIMETER
SS	SANDSTONE
SLT	SILTSTONE
CS	CLAYSTONE

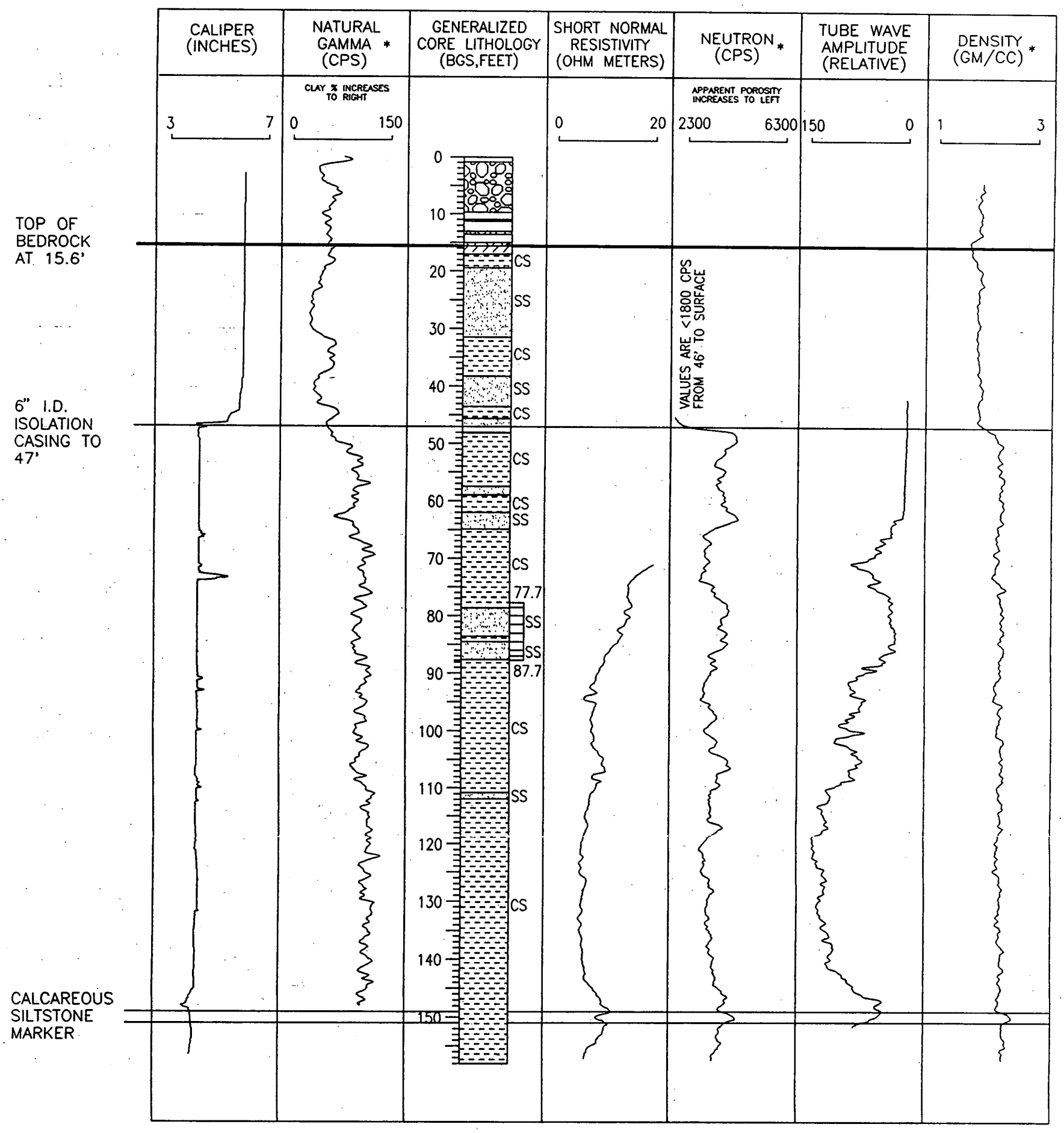
U.S. DEPARTMENT OF ENERGY
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

GENERALIZED CORE LITHOLOGY AND GEOPHYSICAL LOGS COMPOSITE FOR PILOT BOREHOLE 21593

FIGURE 3.5-32 OCTOBER 1993

OU2RI226 1=20



NOTE: FOR SHORT-NORMAL RESISTIVITY THE TOP OF WIRELINE IS ISOLATED, RESULTING IN SHALLOWEST READING APPROX. 30 FT. BELOW CASING.

NOTE: IN MANY ENVIRONMENTS, THE TUBE WAVE AMPLITUDE CAN BE USED AS A RELATIVE PERMEABILITY INDICATOR (INCREASES TO RIGHT); CORE ANALYSIS DATA IS NEEDED TO VALIDATE THE VALUES.

0

VERTICAL SCALE
1"=20'

20

LEGEND

- UNCONSOLIDATED SEDIMENTS (QUATERNARY)
- SANDSTONE
- SILTSTONE
- CLAYSTONE
- NO RECOVERY INTERVAL OR NOT SAMPLED
- SCREENED INTERVAL FROM A-SERIES WELL PROJECTED ONTO PILOT BOREHOLE LITHOLOGIC COLUMN

* LOG VALUES ABOVE 47' ARE ATTENUATED BY ISOLATION CASING.

DRAFT

EXPLANATION

BGS	BELOW GROUND SURFACE
(CPS)	COUNTS PER SECOND
(GM/CC)	GRAMS PER CUBIC CENTIMETER
SS	SANDSTONE
SLT	SILTSTONE
CS	CLAYSTONE

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

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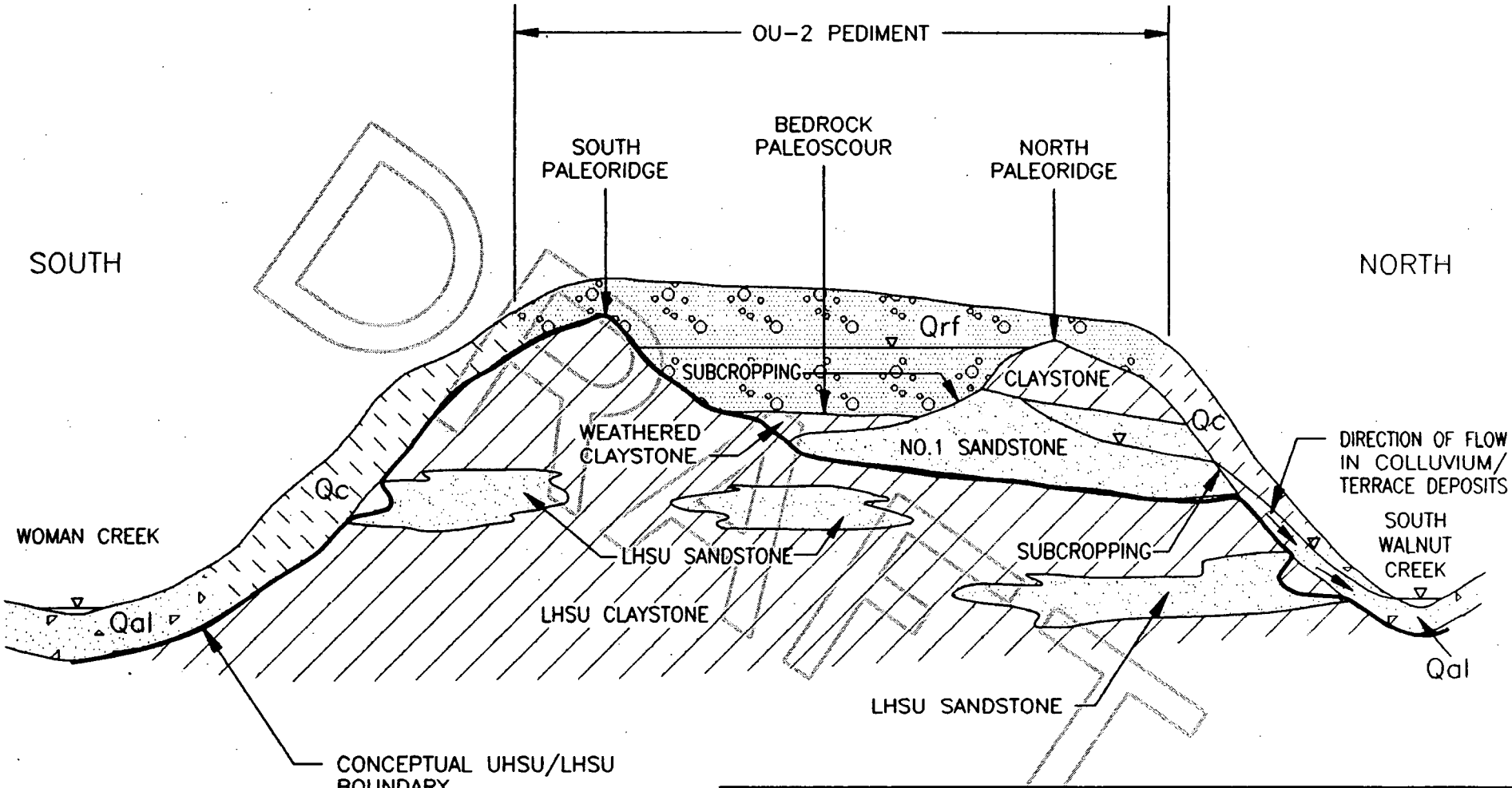
PHASE II RFI/RI REPORT

GENERALIZED CORE LITHOLOGY AND GEOPHYSICAL LOGS COMPOSITE FOR PILOT BOREHOLE 21693

FIGURE 3.5-33 OCTOBER 1993

OU2RI227 1=20



EXPLANATION	
Qrf	ROCKY FLATS ALLUVIUM
Qc	COLLUVIUM/TERRACE DEPOSITS
Qal	VALLEY FILL ALLUVIUM
UHSU	UPPER HYDROSTRATIGRAPHIC UNIT
LHSU	LOWER HYDROSTRATIGRAPHIC UNIT
	CONCEPTUAL UHSU/LHSU BOUNDARY

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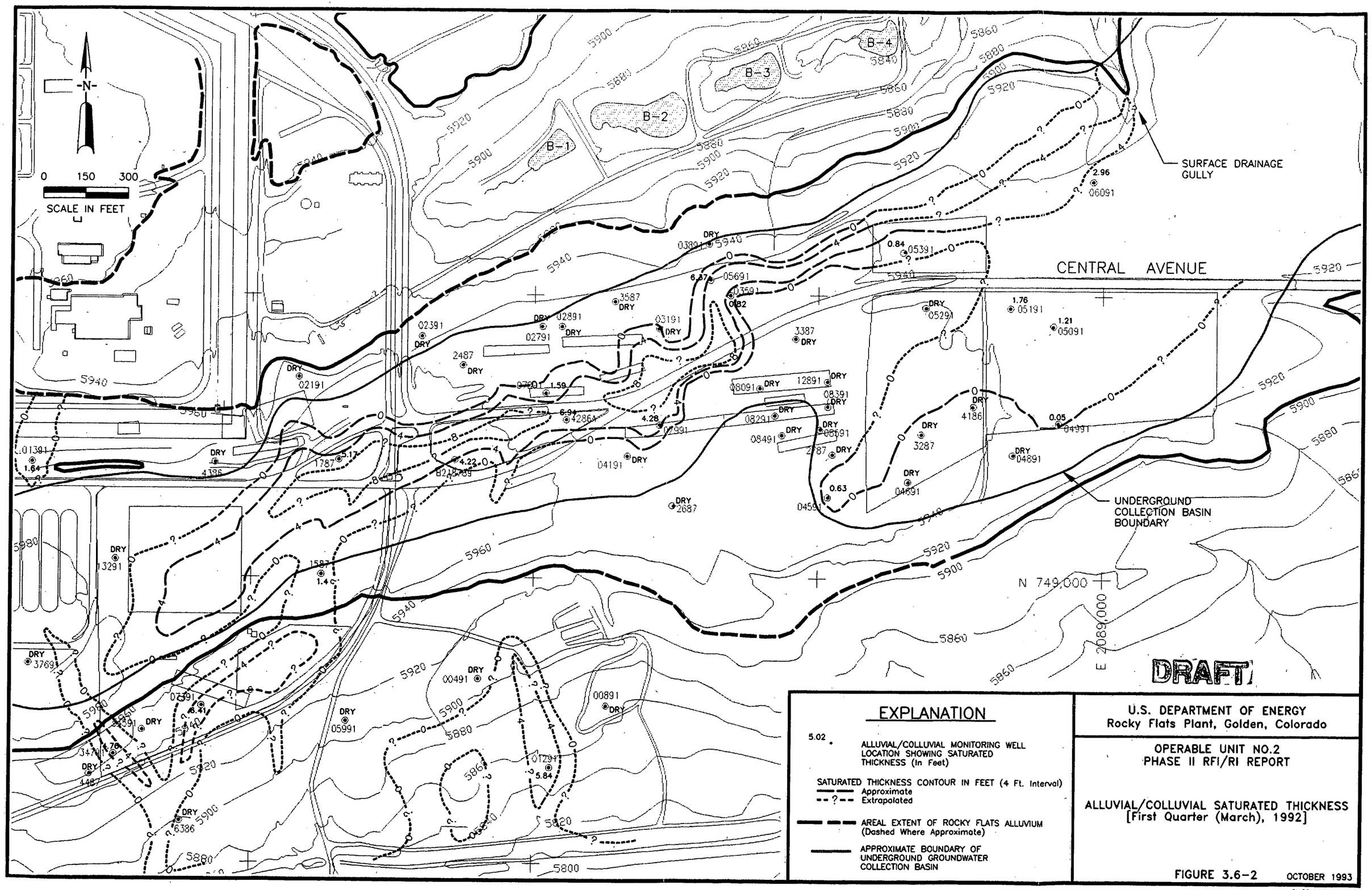
SCHEMATIC CROSS-SECTION OF HYDROSTRATIGRAPHY AT OU-2

FIGURE 3.6-1 OCTOBER 1993

OU2RI168 1-1



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

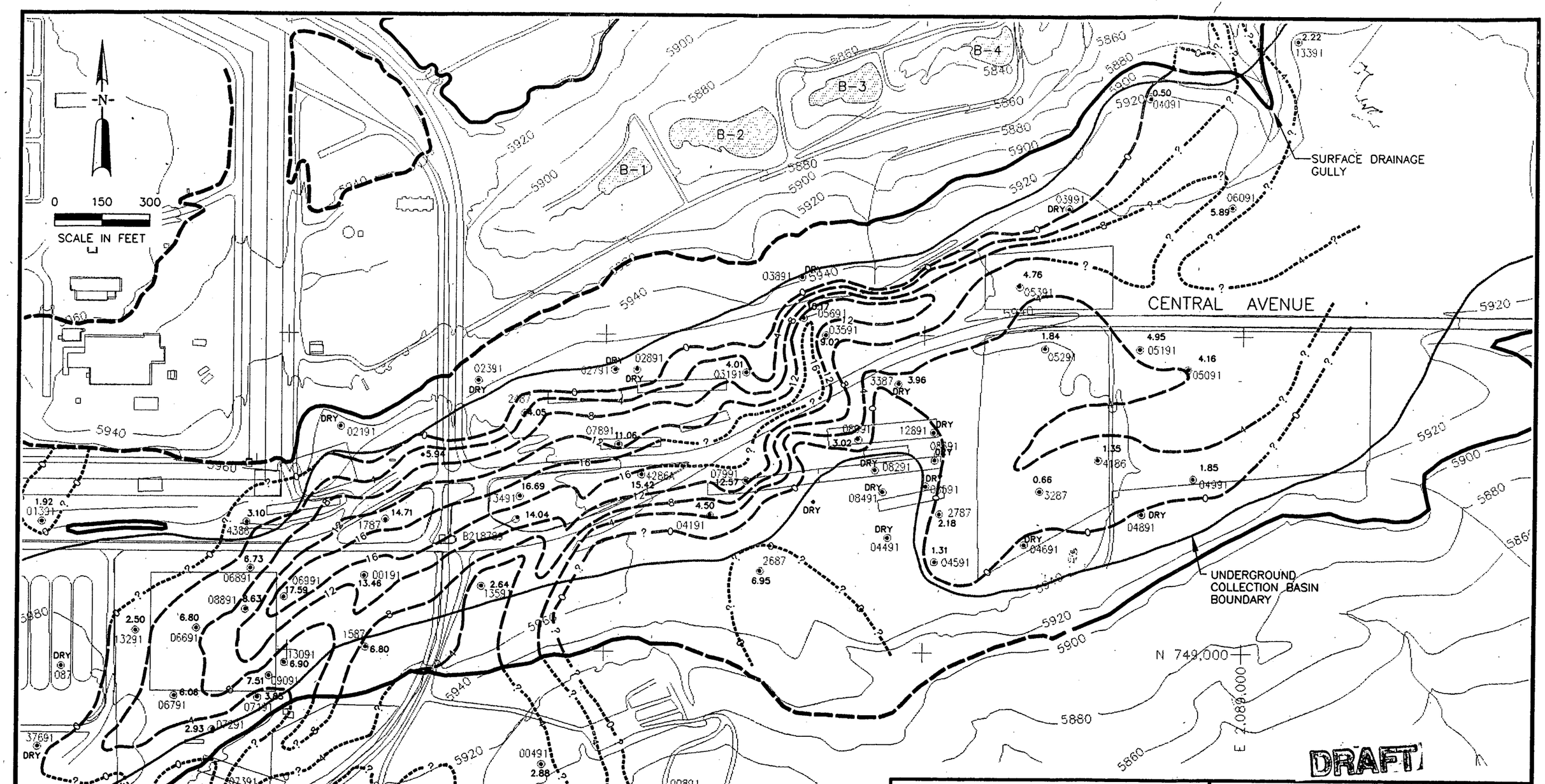
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

ALLUVIAL/COLLUVIAL SATURATED THICKNESS
[First Quarter (March), 1992]

FIGURE 3.6-2 OCTOBER 1993

OU2RI007 1=300

960



EXPLANATION

5.02 • ALLUVIAL/COLLUVIAL MONITORING WELL LOCATION SHOWING SATURATED THICKNESS (In Feet)

SATURATED THICKNESS CONTOUR IN FEET (4 Ft. Interval)
- Approximate
- ? Extrapolated

AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)

APPROXIMATE BOUNDARY OF UNDERGROUND GROUNDWATER COLLECTION BASIN

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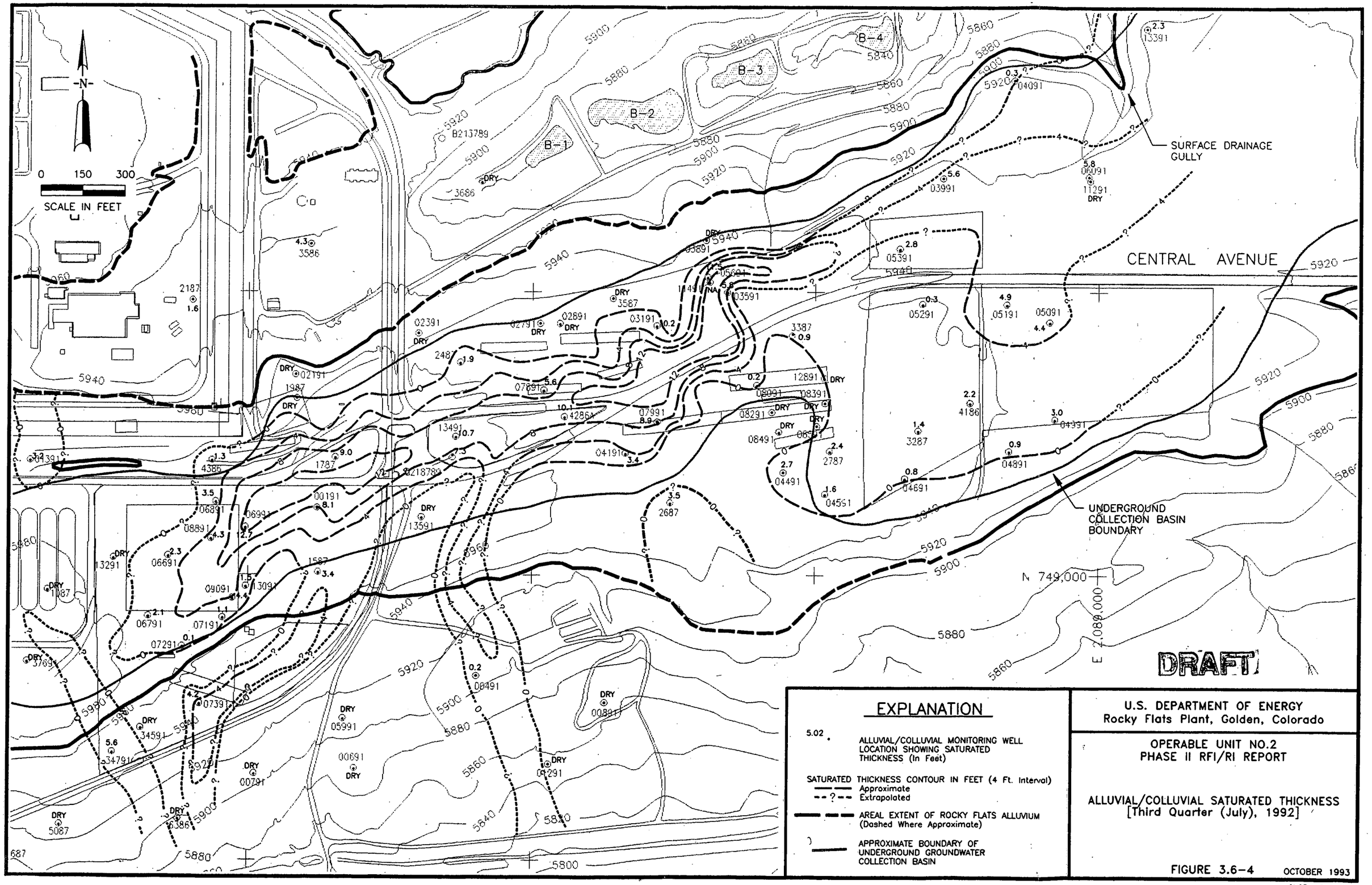
Rocky Flats Plant, Golden, Colorado

OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

ALLUVIAL/COLLUVIAL SATURATED THICKNESS
[Second Quarter (May), 1992]

FIGURE 3.6-3 OCTOBER 1993

OU2RI060 1=300



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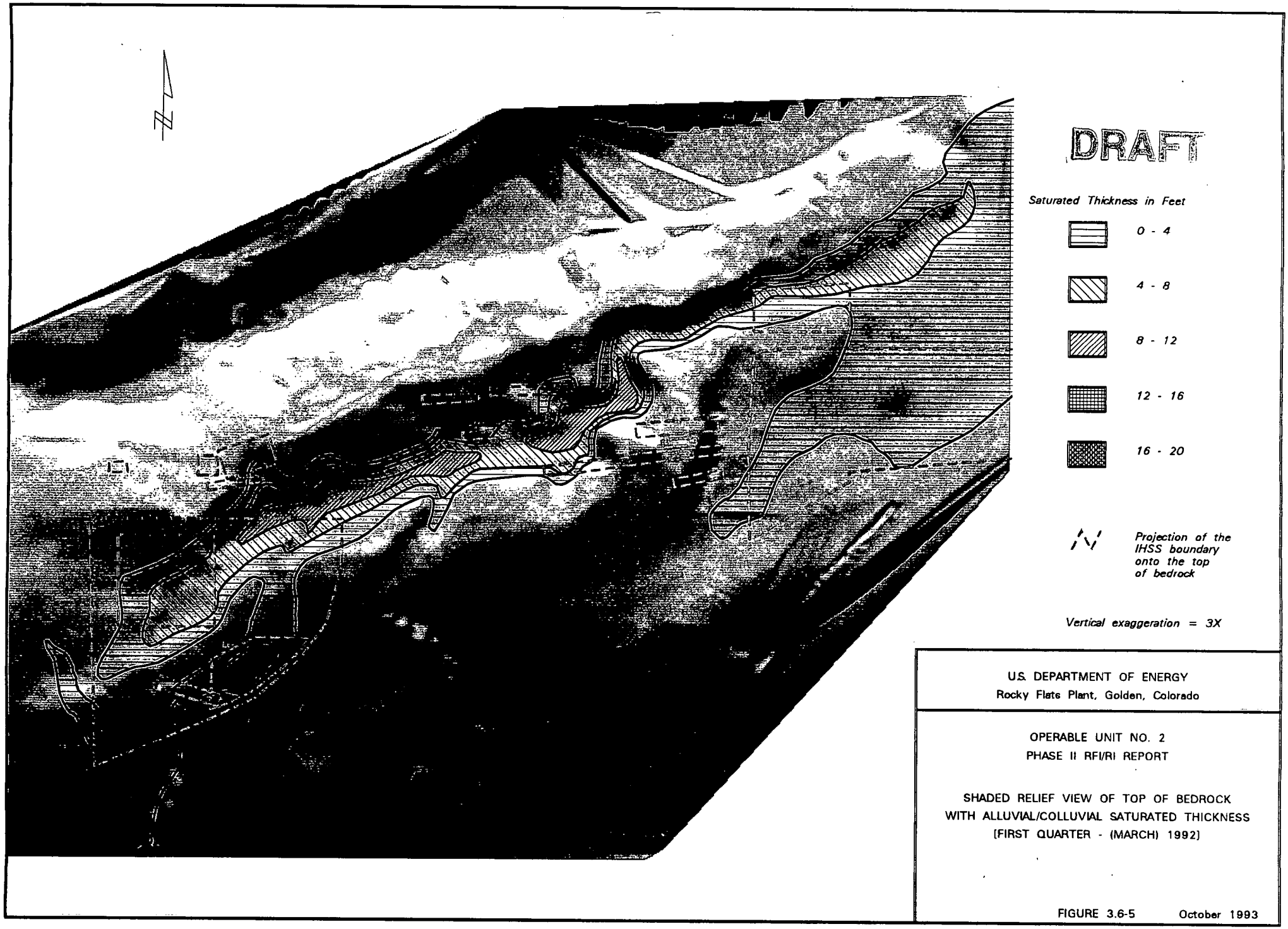
ALLUVIAL/COLLUVIAL SATURATED THICKNESS
[Third Quarter (July), 1992]

FIGURE 3.6-4 OCTOBER 1993

OU2RI113 1=300



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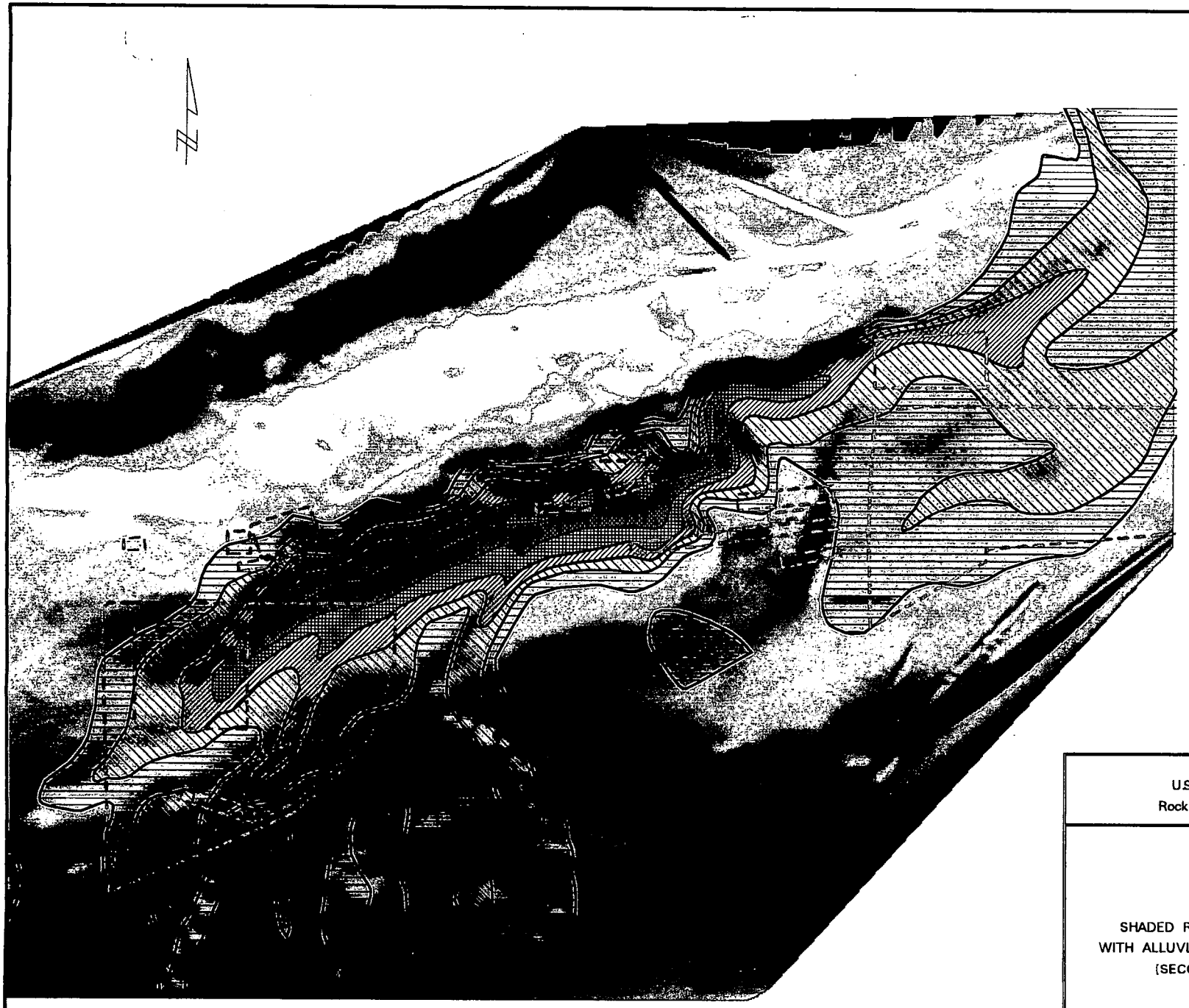
SHADED RELIEF VIEW OF TOP OF BEDROCK
WITH ALLUVIAL/COLLUVIAL SATURATED THICKNESS
[FIRST QUARTER - (MARCH) 1992]

FIGURE 3.6-5 October 1993



DRAFT

Saturated Thickness in Feet

- *0 - 4*
- *4 - 8*
- *8 - 12*
- *12 - 16*
- *16 - 20*

Projection of the IHSS boundary onto the top of bedrock

Vertical exaggeration = 3X

U.S. DEPARTMENT OF ENERGY
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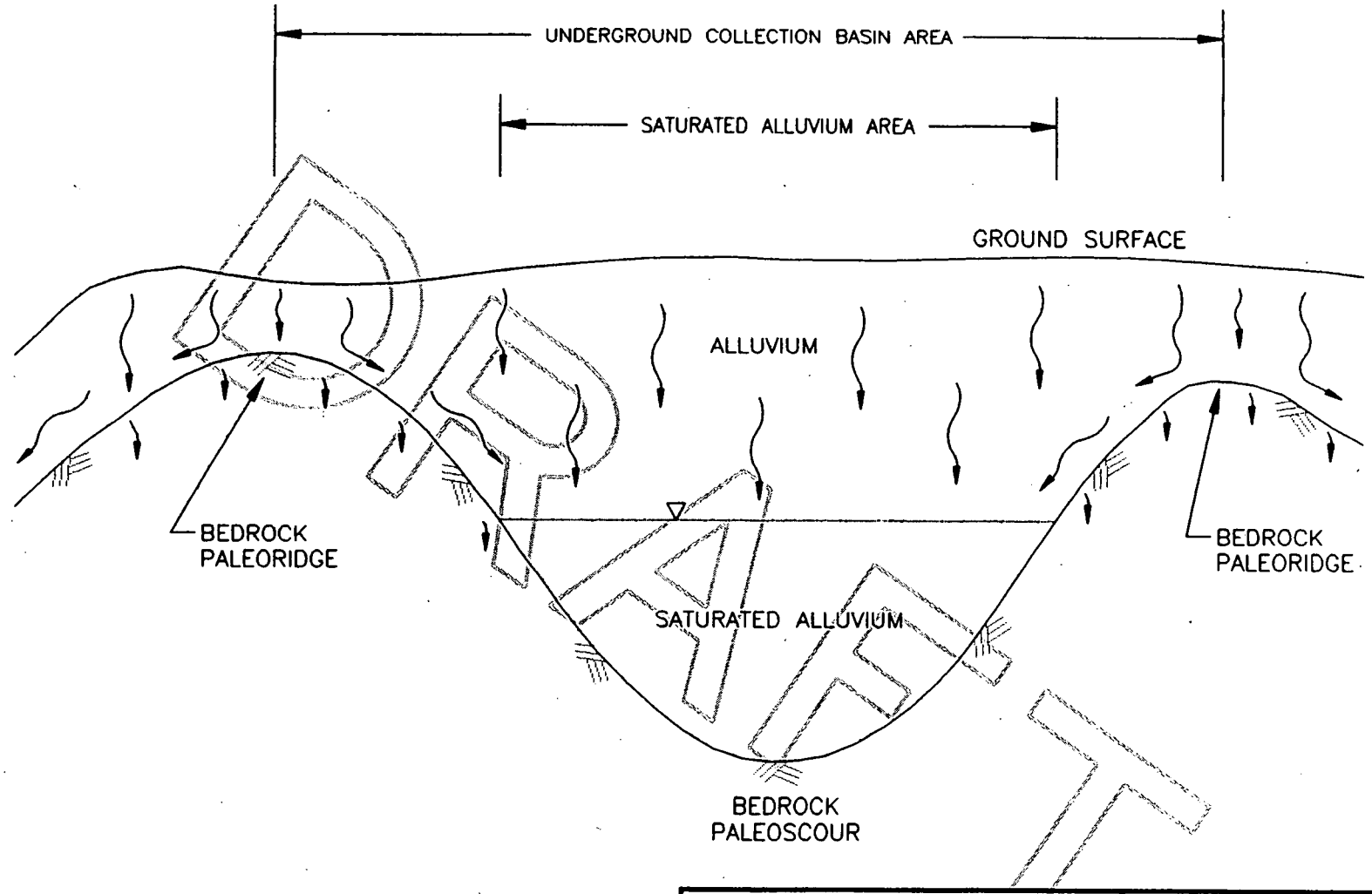
PHASE II RFI/RI REPORT

SHADED RELIEF VIEW OF TOP OF BEDROCK
WITH ALLUVIAL/COLLUVIAL SATURATED THICKNESS
(SECOND QUARTER - (MAY) 1992)

FIGURE 3.6-6 October 1993



EXPLANATION

INFILTRATING PRECIPITATION

WATER TABLE

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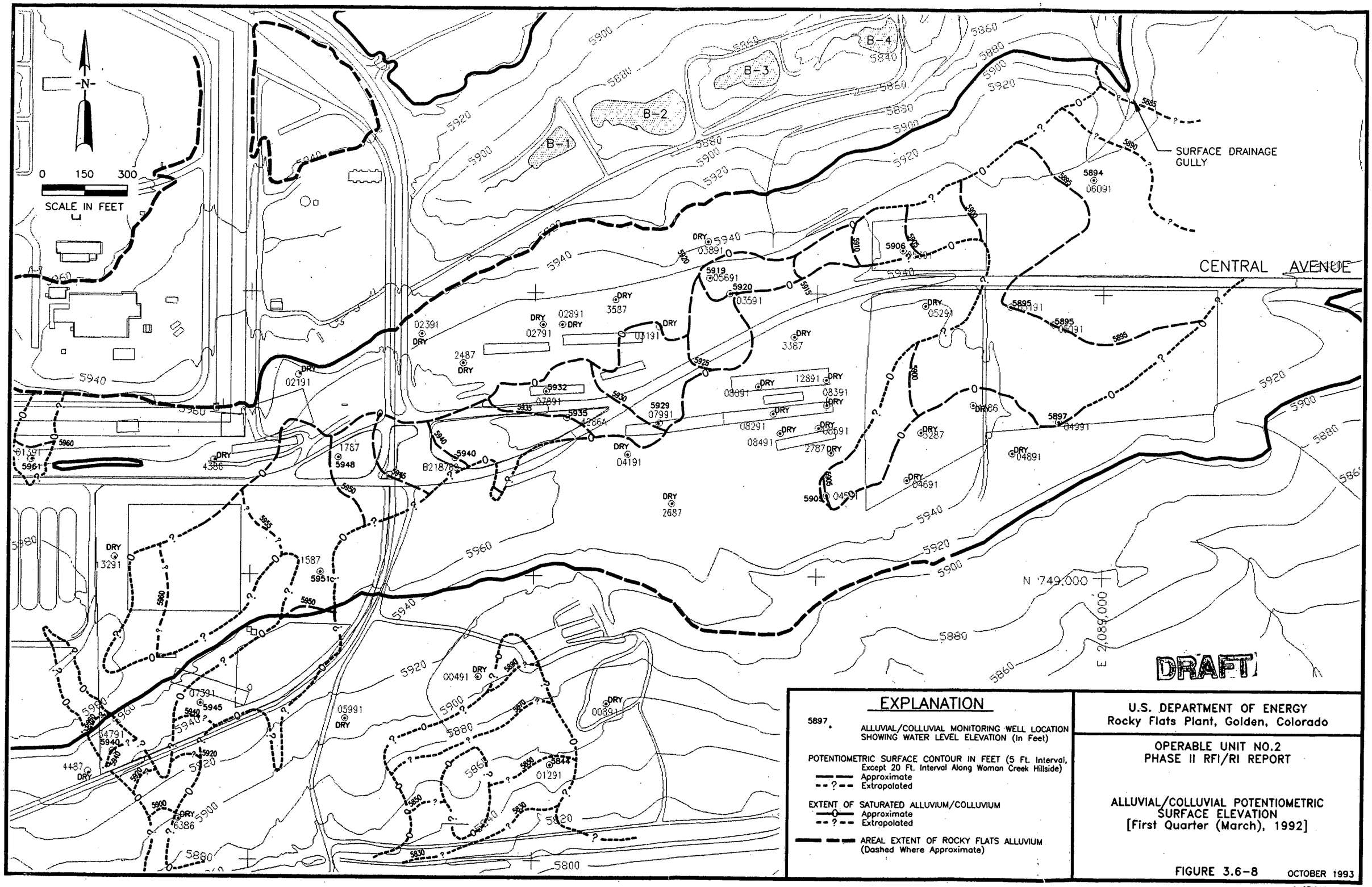
SCHEMATIC DIAGRAM OF RELATIONSHIP OF UNDERGROUND COLLECTION BASIN AREA TO SATURATED ALLUVIUM

FIGURE 3.6-7 OCTOBER 1993

OU2R0085 1-1



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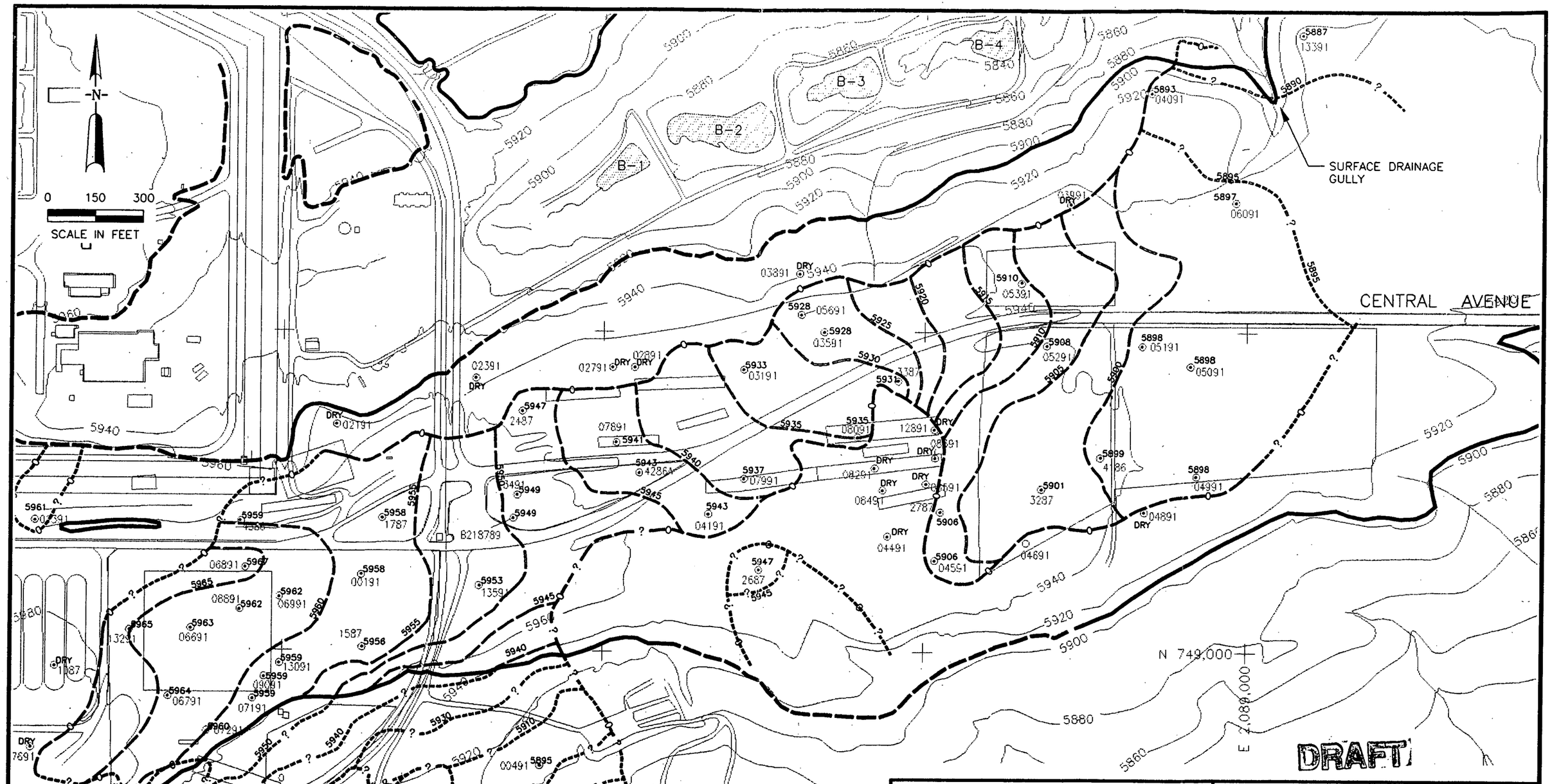
ALLUVIAL/COLLUVIAL POTENTIOMETRIC SURFACE ELEVATION
[First Quarter (March), 1992]

FIGURE 3.6-8 OCTOBER 1993

OU2RI008 1=300



EXPLANATION

5897 • ALLUVIAL/COLLUVIAL MONITORING WELL LOCATION SHOWING WATER LEVEL ELEVATION (In Feet)

POTENTIOMETRIC SURFACE CONTOUR IN FEET (5 Ft. Interval, Except 20 Ft. Interval Along Woman Creek Hillside)
- Approximate
- ? Extrapolated

EXTENT OF SATURATED ALLUVIUM/COLLUVIUM
- Approximate
- ? Extrapolated

AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)

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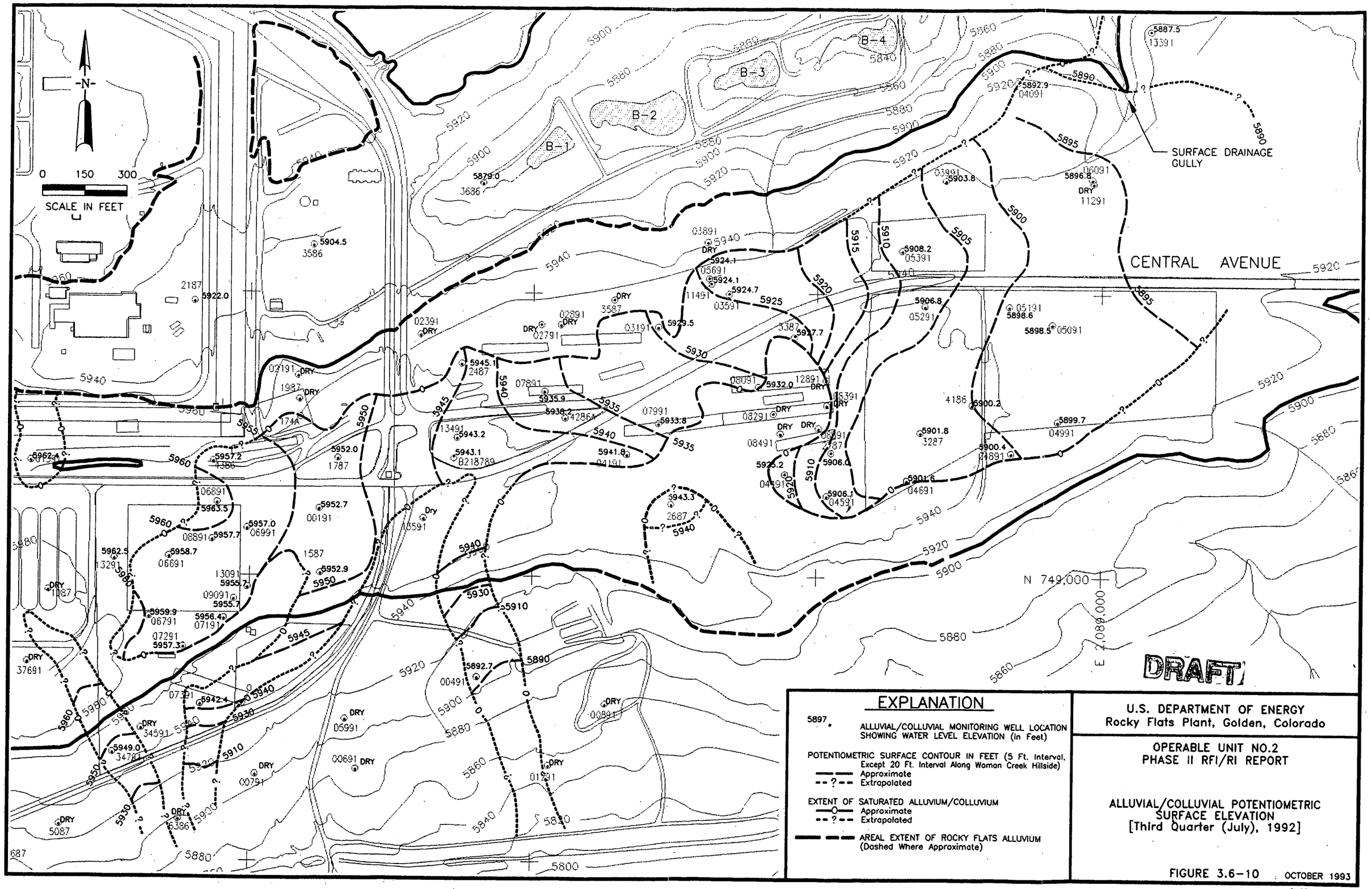
ALLUVIAL/COLLUVIAL POTENTIOMETRIC SURFACE ELEVATION
[Second Quarter (May), 1992]

FIGURE 3.6-9 OCTOBER 1993

OU2RI061 1=300


-N-
0 150 300
SCALE IN FEET
B-1
B-2
B-3
B-4
SURFACE DRAINAGE GULLY
CENTRAL AVENUE
N 749,000
E 2,089,000
DRAFT
EXPLANATION
5897 ALLUVIAL/COLLUVIAL MONITORING WELL LOCATION SHOWING WATER LEVEL ELEVATION (in Feet)
POTENTIOMETRIC SURFACE CONTOUR IN FEET (5 Ft. Interval, Except 20 Ft. Interval Along Woman Creek Hillside)
Approximate
Extrapolated
EXTENT OF SATURATED ALLUVIUM/COLLUVIUM
Approximate
Extrapolated
AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)
U.S. DEPARTMENT OF ENERGY
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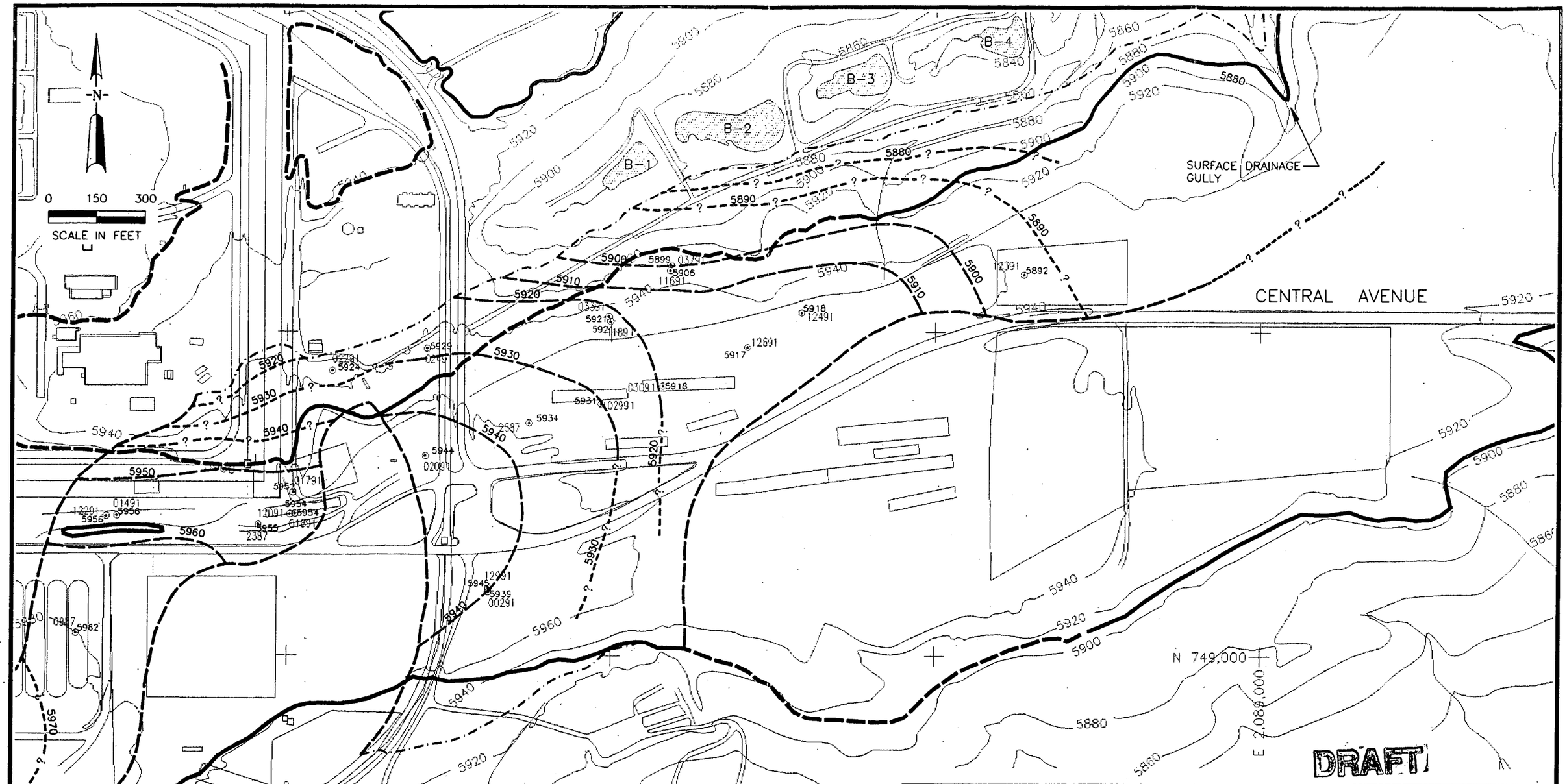
PHASE II RFI/RI REPORT
ALLUVIAL/COLLUVIAL POTENTIOMETRIC SURFACE ELEVATION
[Third Quarter (July), 1992]
FIGURE 3.6-10
OCTOBER 1993
OU2RI112 1=300



EXPLANATION

- 5865 — NO.1 SANDSTONE MONITORING WELL LOCATION SHOWING WATER LEVEL ELEVATION (In Feet)
- 5800 — POTENTIOMETRIC SURFACE ELEVATION CONTOUR (10 Ft. Interval) (—— Approximate) (-- ? -- Extrapolated)
- BOUNDARY OF NO.1 SANDSTONE CHANNEL (—— Approximate) (-- ? -- Extrapolated)
- APPROXIMATE LOCATION OF NO.1 SANDSTONE BASE TRUNCATED BY HILLSIDES
- AREAL EXTENT OF ROCKY FLATS ALLUVIUM (Dashed Where Approximate)

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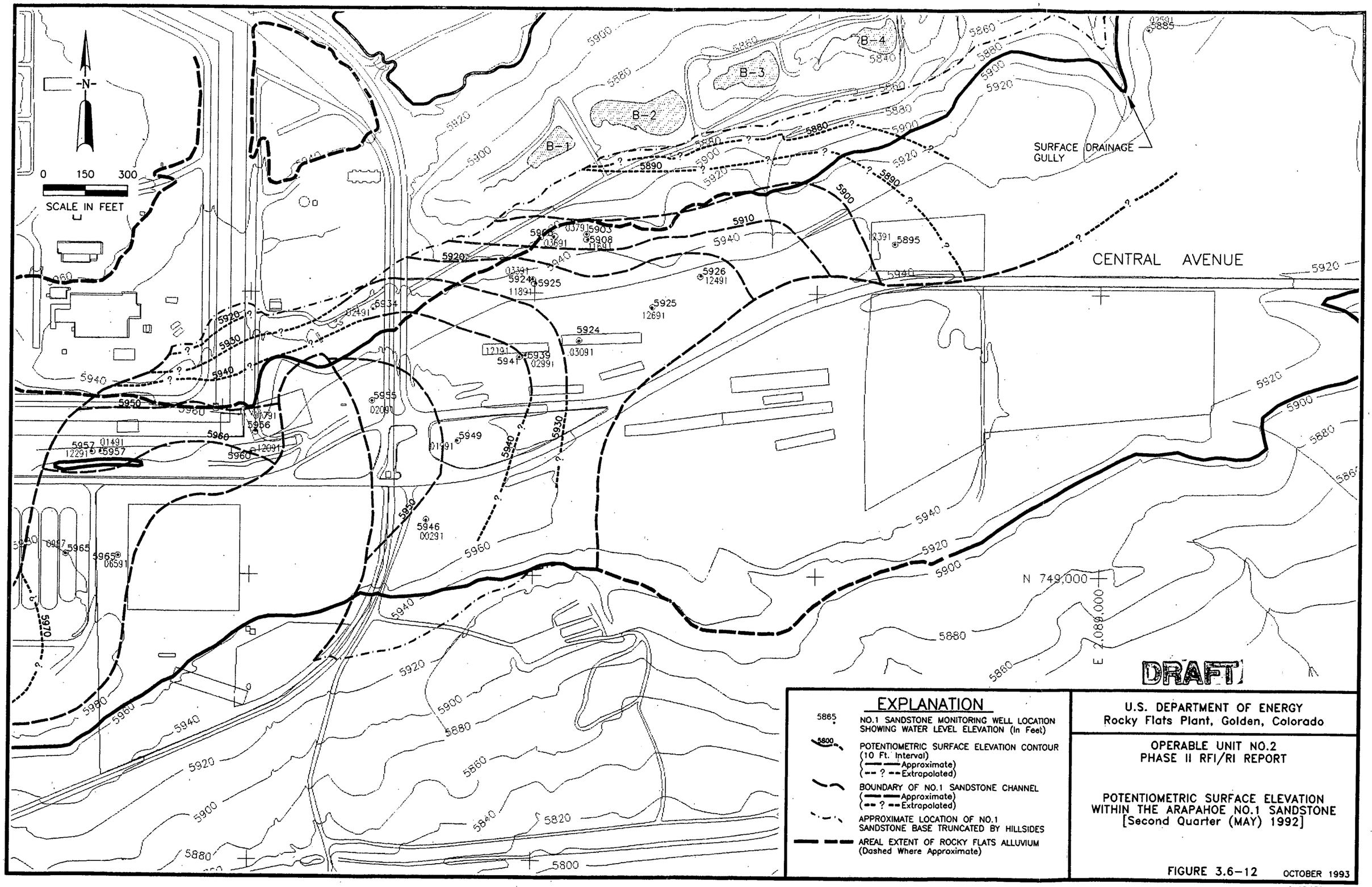
POTENTIOMETRIC SURFACE ELEVATION WITHIN THE ARAPAHOE NO.1 SANDSTONE [First Quarter (March) 1992]

FIGURE 3.6-11 OCTOBER 1993

OU2RI074 1=300



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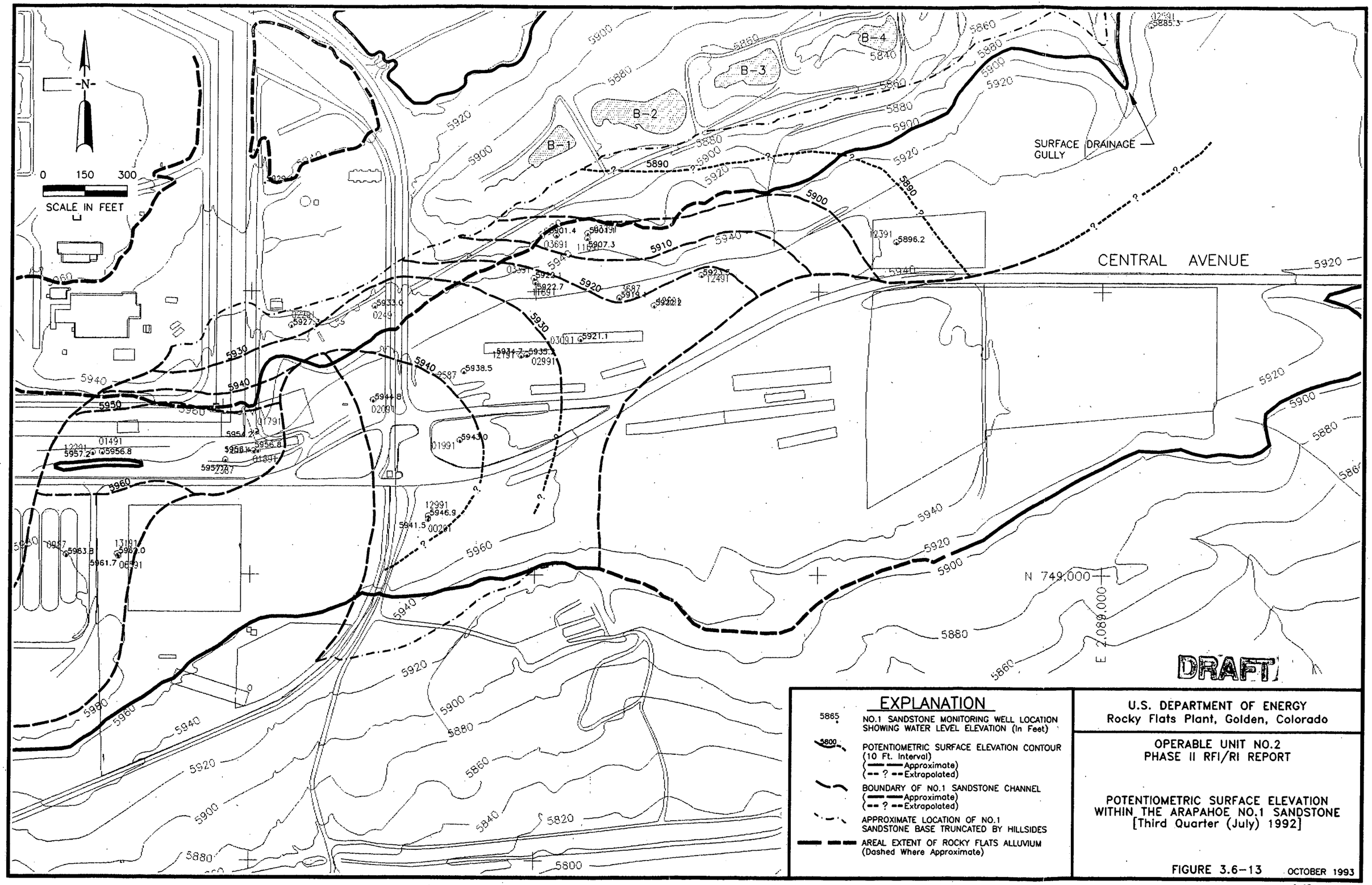
PHASE II RFI/RI REPORT

POTENTIOMETRIC SURFACE ELEVATION WITHIN THE ARAPAHOE NO.1 SANDSTONE
[Second Quarter (MAY) 1992]

FIGURE 3.6-12 OCTOBER 1993

OU2RI075 1=300

270



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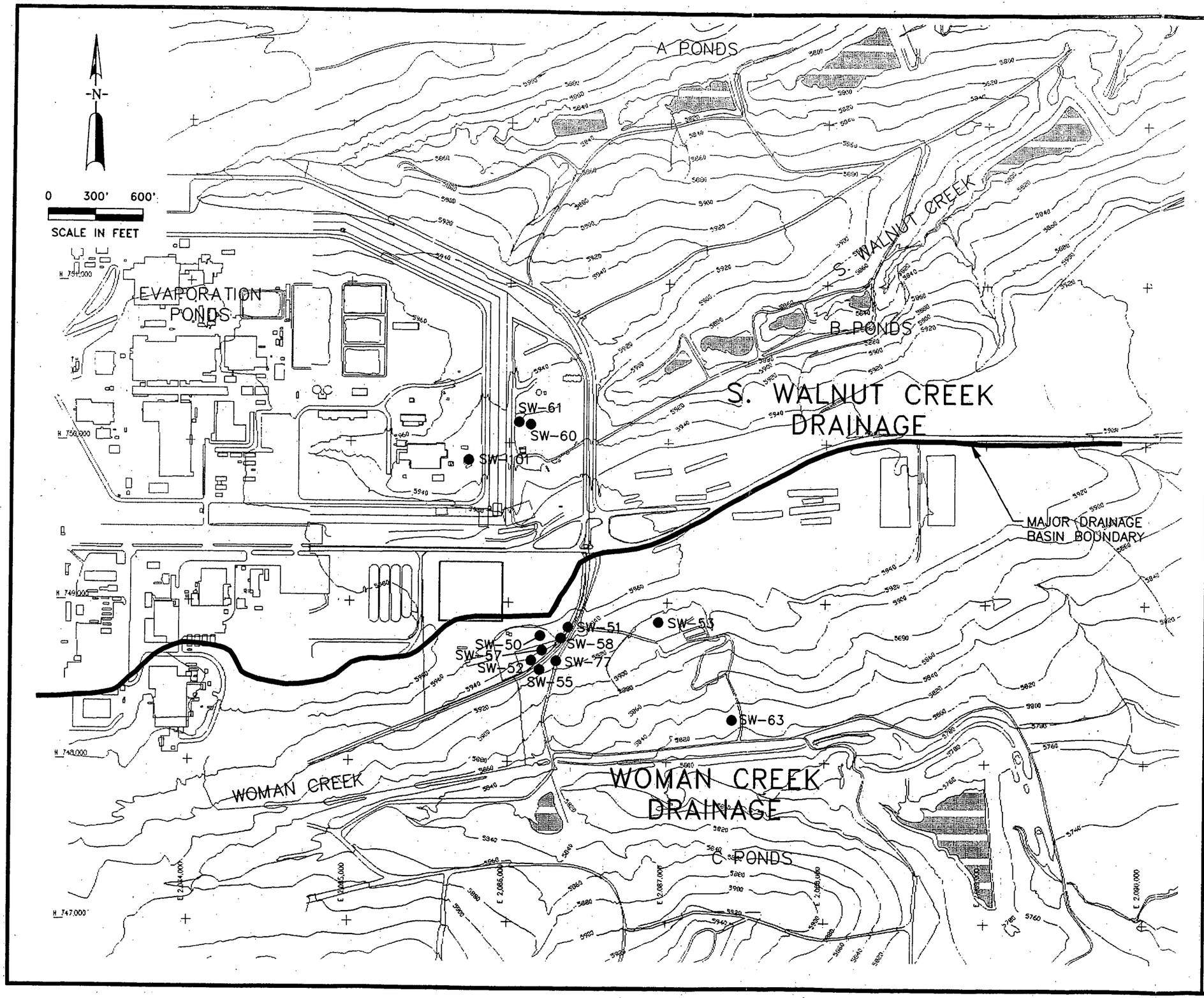
PHASE II RFI/RI REPORT

POTENTIOMETRIC SURFACE ELEVATION WITHIN THE ARAPAHOE NO.1 SANDSTONE [Third Quarter (July) 1992]

FIGURE 3.6-13 OCTOBER 1993

OU2RI114 1=300



EXPLANATION

● SW-60 SURFACE WATER SAMPLING LOCATION

DRAFT

SOURCE:
ROCKY FLATS PLANT DRAINAGE AND FLOOD CONTROL MASTER PLAN DOE APRIL, 1992.

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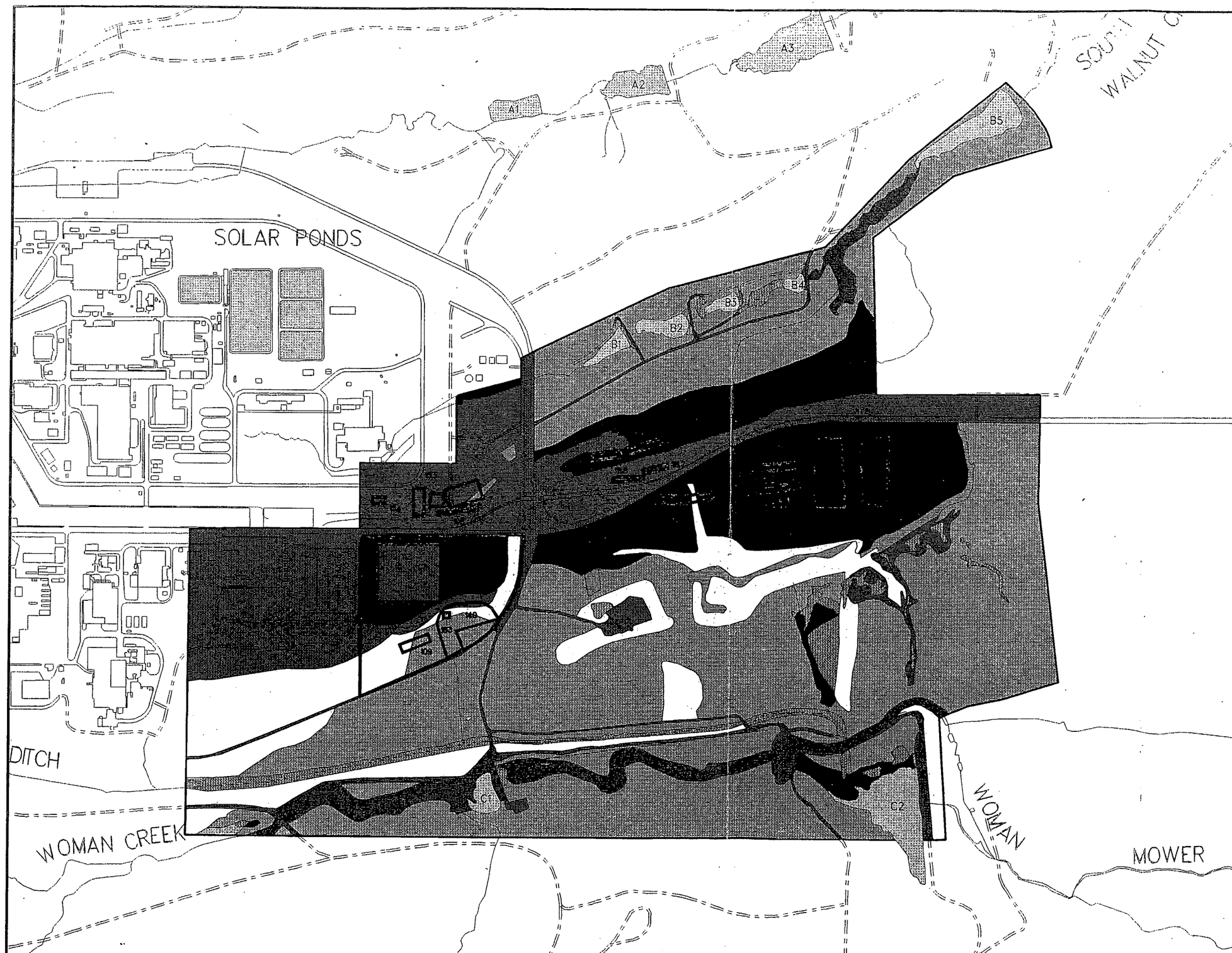
OPERABLE UNIT NO.2
PHASE II RFI/RI REPORT

OU-2 DRAINAGE BASINS

FIGURE 3.7-1 OCTOBER 1993

OU2RI259 1=600



EXPLANATION

Habitat Types

- Short Marsh
- Tall Marsh
- Short Upland Shrubland
- Riparian Shrubland
- Riparian Woodland
- Xeric Grassland
- Mesic Grassland
- Reclaimed Grassland
- Disturbed, Annual Grass/Forb
- Disturbed, Mowed
- Disturbed, Barren Lands
- Structural (Roads, Bldg.)

- OU2 IHSS Boundaries
- Surface Water Impoundments
- Buildings
- Streams and Drainages
- Paved Roads
- Dirt Roads

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Scale 1" = 600'

0 Feet 600 1200

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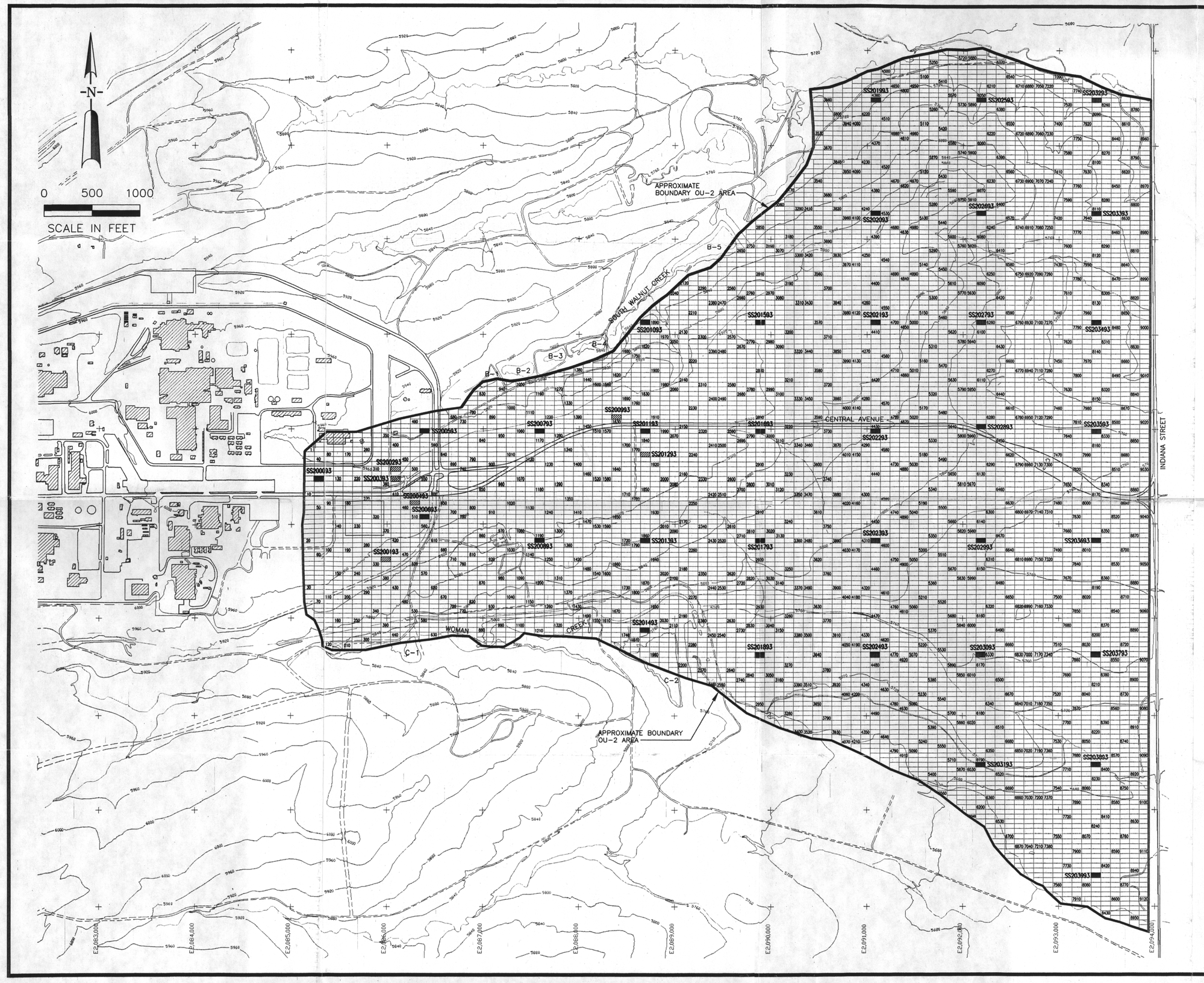
Vegetation Community Types in OU2 and Vicinity

FIGURE 3.8-1 NOVEMBER 1993

10/28/93 OU2VEG.MAP



EXPLANATION

8810	50'x100' PLOT
SS200193	BIASED SURFACE SOIL SAMPLING PLOT LOCATION
SS200093	GRID-BASED SURFACE SOIL SAMPLING PLOT LOCATION

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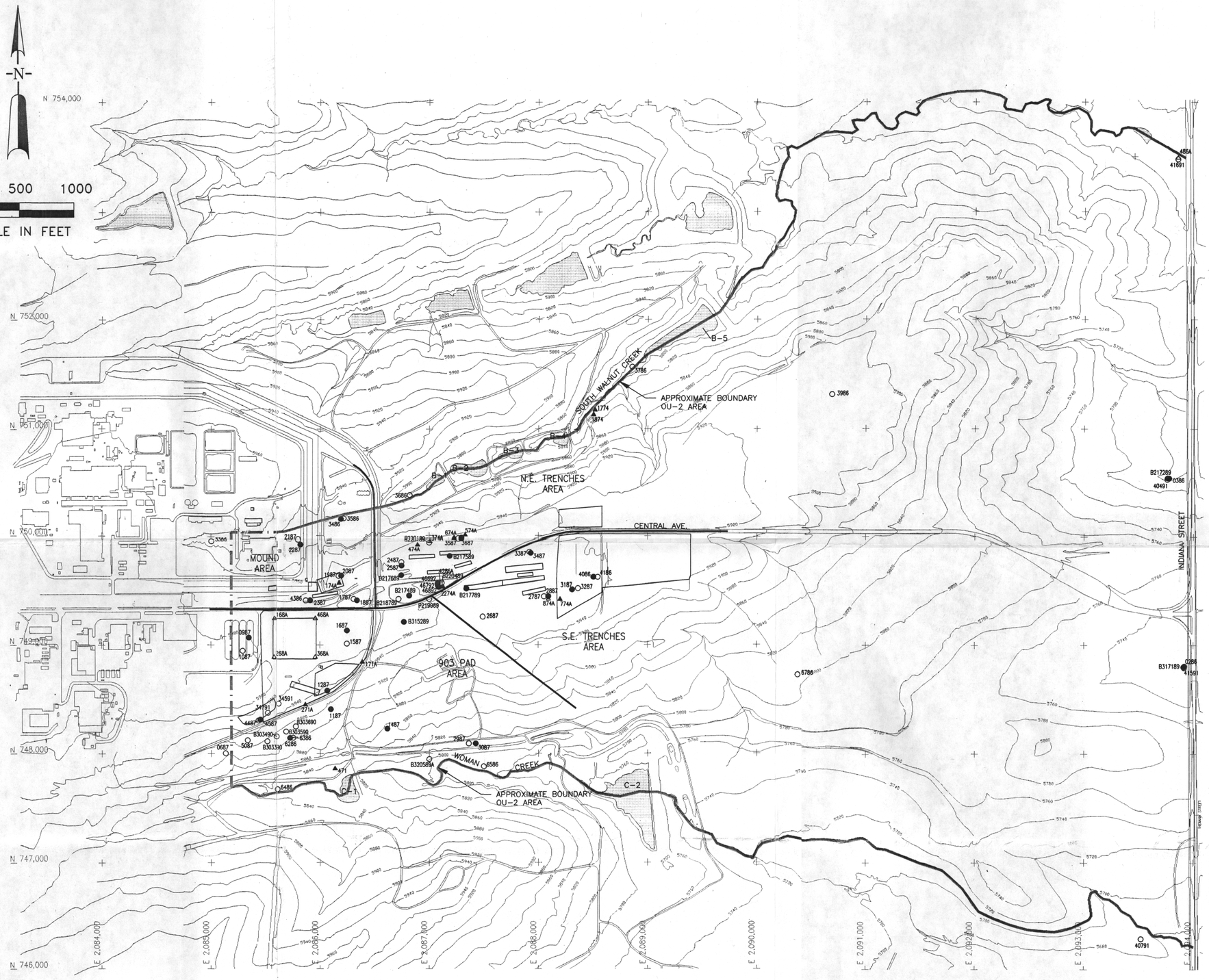
1993 SURFACE SOIL SAMPLING
PLOT LOCATIONS

PLATE 2.5-1 OCTOBER 1993

OU2RI011 1=500
OU02-A-001577
1 of 5



EXPLANATION

3786 ○	1986–1990 ALLUVIAL MONITORING WELL
3087 ●	1986–1990 BEDROCK MONITORING WELL
4286A ○	ABANDONED MONITORING WELL
174A ▲	1968–1974 MONITORING WELL
⬠	INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
▬	APPROXIMATE BOUNDARY OF OU–2 STUDY AREA

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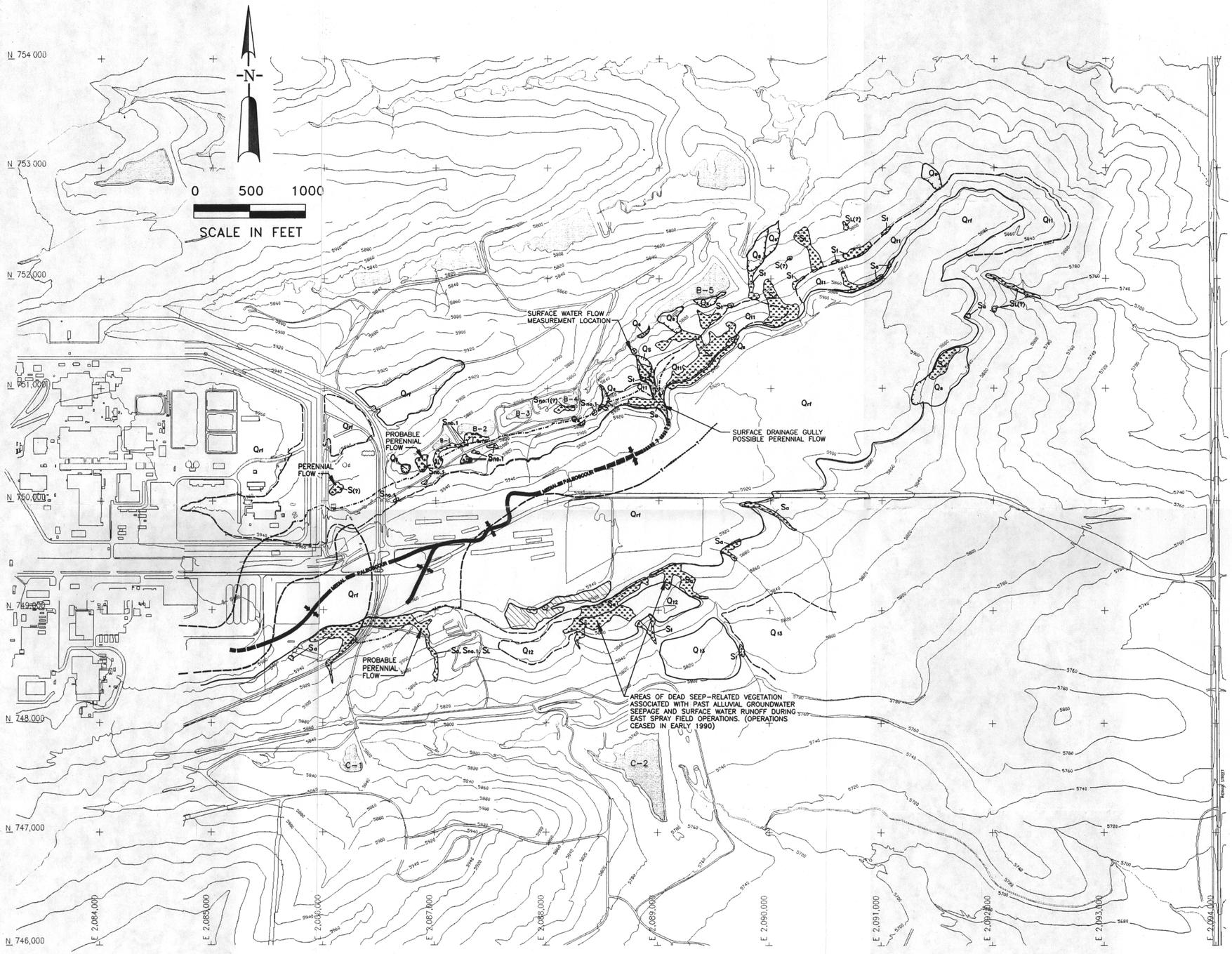
OU–2 MONITORING WELL LOCATIONS
(HISTORICAL AND OTHER INVESTIGATIONS)

PLATE 1.3–2 OCTOBER 1993

OU2RI002 1=500



EXPLANATION

Vegetated Area Associated With Groundwater Seepage (Vegetation consists of cattails, baltic rushes, and some woody bushes). Seepage Face Along Uphill Boundary of Vegetated Area.

Tree

S_a Rocky Flats Alluvium Groundwater Seepage

S_t High Terrace Alluvium Groundwater Seepage

$S_{no.1}$ Arapahoe No.1 Sandstone Groundwater Seepage

S_L Laramie Sandstone Groundwater Seepage

GEOLOGIC CONTACTS

Dashed Where Approximate

Extrapolated

Erosional Limit of Sandstone (i.e. Intersection of Sandstone Bottom and Topography of Hillside)

Gravel Quarry

QUATERNARY DEPOSITS

Q_s Slumps (Hatched Where Head Scarps Are Developed)

Q_{t3} Terrace Alluvium No.3

Q_{t2} Terrace Alluvium No.2

Q_{t1} Terrace Alluvium No.1

Q_{rf} Rocky Flats Alluvium

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OU-2 SEEP LOCATIONS AND GEOLOGIC FEATURES

PLATE 3.6-1 OCTOBER 1993

OU2RI149 1=500
0482-A-001577 3 of 5

EXPLANATION

GEOLOGIC CONTACTS

Dashed Where Approximate

Inferred

AF ARTIFICIAL FILL

GRAVEL QUARRY

QUATERNARY DEPOSITS

- Qe Slumps (Hatched Where Head Scarps Are Developed)
- Qd Debris Fans
- Qc Colluvium
- Qal Valley Fill Alluvium
- Qhu Undifferentiated Terrace Alluvium
- Q13 Terrace Alluvium No.3
- Q12 Terrace Alluvium No.2
- Q11 Terrace Alluvium No.1
- Qrf Rocky Flats Alluvium

BEDROCK OUTCROPS

- Qcs Claystone
- Qss Sandstone

ADDITIONAL DATA SOURCE: – Malde, 1955
– Rockwell, 1987

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DRAFT

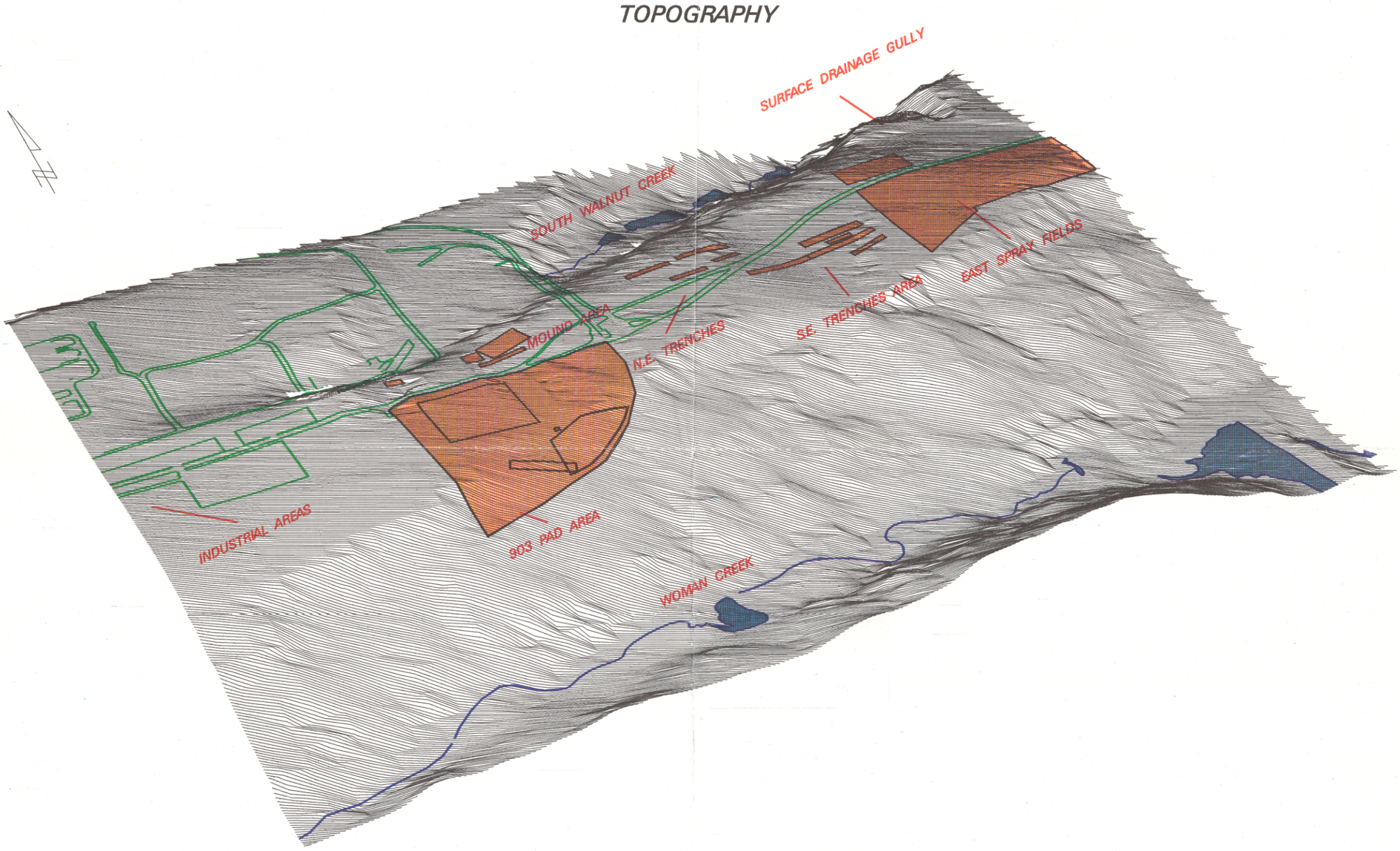
OU–2 SURFICIAL GEOLOGY

PLATE 3.5–2 OCTOBER 1993

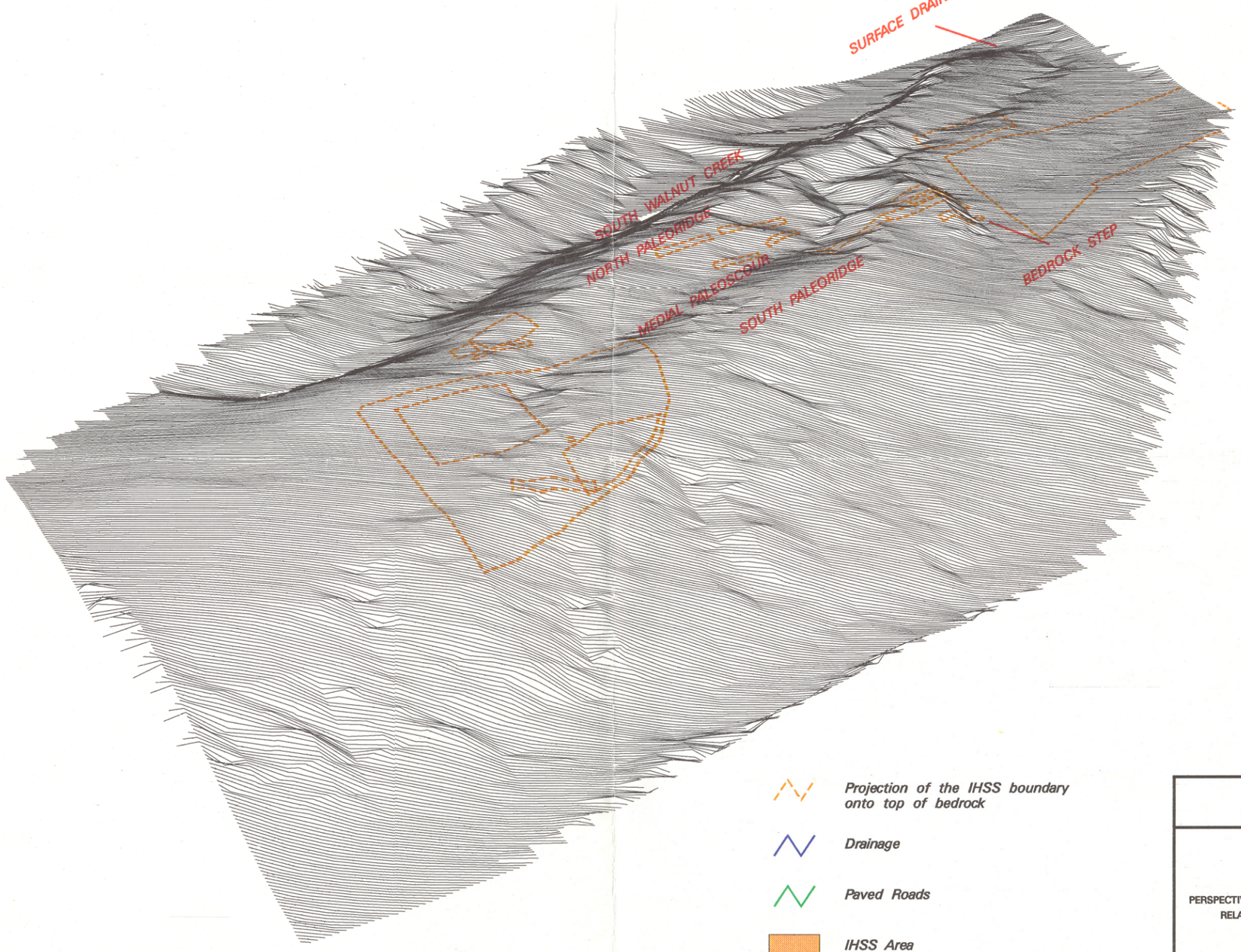
0422-A-001577

OU2RI122 1=500 4 of 5

TOPOGRAPHY



TOP OF BEDROCK SURFACE



DRAFT

Projection of the IHSS boundary onto top of bedrock

Drainage

Paved Roads

IHSS Area

Vertical exaggeration = 3X

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PERSPECTIVE VIEW OF OU-2 TOPOGRAPHIC FEATURES RELATIVE TO TOP OF BEDROCK SURFACE (LOOKING NORTHEAST)

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PLATE 3.5-1 October 1993