

# **NITRATE INVESTIGATION REVISED PHASES 2 THROUGH 5 WORK PLAN REV. 1.0**

**White Mesa Mill Site**

**Blanding, Utah**

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## ABBREVIATIONS AND ACRONYMS

Additional Studies	Additional studies to be performed by DUSA in order to complete the CIR
Agreement States	State agencies authorized to implement the U.S. Nuclear Regulatory Commission's licensing program under the Atomic Energy Act
amsl	above mean sea level
Analysis Monitor	employee or agent of the Analytical Laboratory
Analytical Laboratory	contract analytical laboratory
bgs	below ground surface
CAP	Corrective Action Plan
CCD/SX	Counter Current Decant/Solvent Extraction
CIR	Contamination Investigation Report
cm/s	centimeters per second
COC	chain of custody
Co-Executive Secretary	Co-Executive Secretary of the Utah Water Quality Board of the Utah Department of Environmental Quality
Consent Agreement	Stipulated Consent Agreement Docket No. UGW09-03 dated January 27, 2009
CSM	Conceptual Site Model
$\delta$	delta
Data Users	data requestors/users
DOE	U.S. Department of Energy
DQO	data quality objectives
DRC	Utah Division of Radiation Control
DUSA	Denison Mines (USA) Corp.
EPA	U.S. Environmental Protection Agency
ft/yr	feet per year
GPS	global positioning system
GWDP	Groundwater Discharge Permit
ID	identification
INTERA	INTERA Incorporated
LCS	laboratory control sample
LU/LC	land use/land cover



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MDL	method detection limit
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
Mill	White Mesa Mill
NAVLAP	National Voluntary Laboratory Accreditation Program
NELAP	National Environmental Laboratory Accreditation Program
New Theory	A new theory for a possible source of the nitrate and chloride contamination beneath the Mill, based on DUSA's review of the scientific literature
NOTICE	The October 5, 2010, DRC Notice of Additional Required Action
NRC	U.S. Nuclear Regulatory Commission
PG	Professional Geologist
Plan and Schedule	The plan and schedule for performing Additional Studies and submitting a revised CIR
QA	quality assurance
QA/QC	quality assurance/quality control
QAP	Quality Assurance Plan
QC	quality control
Request	Request for Voluntary Plan and Schedule to Investigate and Remediate Nitrate Contamination at the White Mesa Mill Site
RPD	relative percent difference
SAG	Semi Autogenous Grinding
Sampling and QC Monitor	Sampling and QC data monitor responsible for sample collection, record keeping, and QA/QC activities
SHP	southern high plains
Site	White Mesa Mill
SOP	Standard Operating Procedure
SPLP	Synthetic Precipitate Leaching Procedure
Tolling Agreement	A Tolling Agreement dated December 15, 2010, between DUSA and the Co-Executive Secretary
UAC	Utah Administrative Code
UDEQ	Utah Department of Environmental Quality
USCS	Unified Soil Classification System



## 1.0 INTRODUCTION

Denison Mines (USA) Corp. (“DUSA”) received a Request for Voluntary Plan and Schedule to Investigate and Remediate Nitrate Contamination at the White Mesa Mill (the “Mill”) Site, near Blanding, Utah (the “Request”) from the Co-Executive Secretary (the “Co-Executive Secretary”) of the Utah Water Quality Board, of the Utah Department of Environmental Quality (“UDEQ”) on September 30, 2008. In the Request, the Co-Executive Secretary noted that groundwater nitrate as nitrogen levels have exceeded the State water quality standard of 10 milligrams per liter (“mg/L”) in certain monitoring wells at the Mill Site. For the remainder of this document, any reference to nitrate or ammonium, whether or not the reference specifies “as N,” means the analyte “as nitrogen.”

As a result of the Request, DUSA agreed to submit a plan of action and a schedule for Co-Executive Secretary approval for completion of a Contamination Investigation Report (“CIR”) to determine the physical cause(s), location(s), transfer mechanism(s), and characteristics of all source(s) of the nitrate contamination in order to form a basis for and facilitate later submittal of a groundwater Corrective Action Plan (“CAP”) that meets the requirements of Utah Administrative Code (“UAC”) R317-6-6.15D, or to demonstrate conclusively that DUSA did not cause or contribute to the nitrate contamination in any manner and that, as a result, such a CAP is not necessary. Subsequently, in a letter dated December 1, 2009, UDEQ, noting that elevated chloride concentrations exist, apparently coincident with elevated nitrate concentrations, recommended that DUSA also address and explain the elevated chloride concentrations.

DUSA and the Co-Executive Secretary entered into a Stipulated Consent Agreement Docket No. UGW09-03, dated January 27, 2009 (“Consent Agreement”), related to nitrate contamination at the Mill. Pursuant to Item 6.A of the Consent Agreement, DUSA submitted a Nitrate CIR for the White Mesa Uranium Mill Site, Blanding, Utah, dated December 30, 2009, to the Utah Division of Radiation Control (“DRC”). By a letter dated October 5, 2010, the Co-Executive Secretary notified DUSA of his determination that the CIR is incomplete.

By an email transmitted to the Co-Executive Secretary on October 20, 2010, and pursuant to Item 11 of the Consent Agreement, DUSA requested that the deadline stipulated in item 7.C of the Consent Agreement be amended as follows:

- a. DUSA representatives would meet with the Co-Executive Secretary and his legal counsel within two weeks from the date of the email to discuss the legal responsibilities of DUSA with respect to the nitrate contamination.



- b. Once the legal responsibilities of DUSA with respect to the nitrate contamination have been determined, DUSA would, within 30 days after such a determination was made, submit to the Co-Executive Secretary for approval a plan and schedule to perform any further investigations that may be required in order to remedy any such omissions, content requirements, or failures of performance standards, and to submit a revised CIR.
- c. DUSA would perform such investigations and submit a revised CIR in accordance with the agreed upon plan and schedule.

At an October 26, 2010, meeting with the Co-Executive Secretary, DRC staff, and legal counsel, DUSA reported that it was premature to submit a schedule for submittal of performance standards and a CAP for the nitrate contamination. In turn, DUSA presented a new theory for a possible source of the nitrate and chloride contamination beneath the Mill, based on DUSA's review of the scientific literature ("New Theory"), specifically, that the nitrate contamination source is or could be caused by naturally occurring nitrate and chloride salt deposits located in the vadose zone near or beneath the Mill Site area, which have been mobilized by natural and/or artificial recharge. The parties agreed that this New Theory warranted additional investigation, along with certain of the other additional studies suggested in the October 5, 2010, DRC Notice. DUSA submitted via email on November 15, 2010, a letter setting out the additional studies to be considered that have been identified to date, including the additional studies suggested in the October 5, 2010, DRC Notice, and proposed additional studies relating to the New Theory, and other additional studies that DUSA believes may be relevant. At a November 30, 2010, meeting between DRC Staff and DUSA technical and regulatory staff, DUSA presented a number of additional studies (herein "Additional Studies") to be performed by DUSA in order to complete the CIR. The Co-Executive Secretary and DUSA further agreed that DUSA would prepare a detailed plan and schedule (the "Plan and Schedule") for performing such studies and for submittal of a revised CIR that meets the requirements of all applicable regulations on or before February 15, 2011. During the November 30, 2010, meeting, it was agreed that both the Plan and Schedule and the revised CIR will be subject to Co-Executive Secretary approval. DUSA's commitment to prepare and submit the Plan and Schedule is set out in a Tolling Agreement (the "Tolling Agreement") dated December 15, 2010, between DUSA and the Co-Executive Secretary.

DUSA submitted a draft Work Plan on February 14, 2011. During subsequent discussions with DRC staff, the Co-Executive Secretary and DUSA agreed that the additional studies could require as many as five phases, and the schedule should include points of consultation between phases at which the Co-Executive Secretary and DUSA could evaluate and agree on the redirection, addition, or elimination of subsequent phases.



The Tolling Agreement was revised on April 28, 2011, to allow time for:

- DUSA to prepare and submit a Revised Work Plan for Phase 1 (the final was submitted May 13, 2011).
- DUSA to prepare and submit a revised Work Plan for Revised Phases 2 through 5 (by June 3, 2011), including a Conceptual Site Model (“CSM”) of potential nitrate sources.
- The Co-Executive Secretary to review and approve the revised Work Plans, including modifications.
- The Co-executive Secretary and DUSA to agree on a revised or replacement Consent Agreement that incorporates the deliverables and timelines in the approved Phase 2 through 5 Work Plan.

The tolling agreement was finalized on June 30, 2011.

This document is the revised Work Plan for Phases 2 through 5, which is being submitted in accordance with the Final Tolling Agreement and which contains information for the execution of Phases 2 through 5 as described in the Final Tolling Agreement. The Phases 2 through 5 Work Plan requirements specified in the Final Tolling Agreement Section 6 are shown below.

*6. Phase 2 through 5 Work Plan Rev. 1.0– on or before August 4, 2011, DUSA shall complete and submit for Co-Executive Secretary review and approval a Revised Phase 2 through 5 Work Plan Rev. 1.0, which will include, but is not limited to:*

*a) Detailed description of the activities, equipment, procedures, performance objectives, and decision criteria involved in each Phase, including, but not limited to a description and incorporation by reference of the Phase 2 Detailed Work Plan and Schedule and a description of the agreed details and schedules relating to Phases 4 and 5.*

This revision includes, by reference, the Phase 2 Detailed Work Plan, and provides agreed upon details of Phases 4 and 5.

*b) An initial CSM of the facility (Revision 0), that DUSA will use as a guide to plan/conduct the Nitrate Investigation.*

This is addressed as Section 2.0 of this document.



- c) *A logic diagram for each Phase to identify all studies and decision processes that may be required to meet all applicable regulatory requirements including the performance objectives of the Consent Agreement, Item 6(A)(iv).*

Logic diagrams are attached as figures to this work plan.

- d) *Deadlines for commencement and completion of all field and laboratory work for each Phase, and the final CIR report preparation.*

Deadlines are provided on the schedule included as Table 1 to this document.

- e) *Deadline for submittal of a final revised CIR for Co-Executive Secretary review and approval.*

Deadlines are provided on the schedule included as Table 1 to this document.

## **1.1 Problem Definition**

### **1.1.1 Purpose of the Investigation**

Based on discussions culminating in the Revised Tolling Agreement, DRC and DUSA have agreed to conduct the nitrate investigation in phases. The multi-phased program is designed to evaluate a number of potential sources of nitrate and chloride that may have contributed to the identified plume, including Mill-related sources, non-Mill-related sources, and sources resulting from historical use. The phased approach will include development of a CSM that will be refined as the investigation progresses and will be used by DRC and DUSA at several decision junctures to:

1. Determine which sources should be removed from further consideration.
2. Assist in quantifying the relative contribution of the remaining sources.
3. Determine whether or not to proceed with future phases of the investigation.

The Phase 1 investigation is described in detail in the *Nitrate Investigation Revised Phase 1 Work Plan, White Mesa Mill Site*, dated May 13, 2011 (INTERA, 2011). The Phase 2 investigation is described in detail in the *White Mesa Uranium Mill Phase 2 Nitrate Investigation Detailed Work Plan and Schedule*, dated July 12, 2011.

This work plan describes the remaining phases of the investigation per the Final Tolling Agreement. Each of the phases contemplated by the Final Tolling Agreement is described briefly below. The purpose of Phases 2 through 5 is to collect data to fill the data gaps, test



hypotheses, and update the CSM as described above. Additional plans, as delineated below, will be submitted to address the specific details, activities, equipment, procedures, objectives, and decision criteria for each of the phases specified in the Final Tolling Agreement.

#### **1.1.1.1 Phase 2 – Groundwater Quality Sampling and Analysis**

This phase of the investigation will collect groundwater samples from existing on-site wells. Groundwater will be analyzed for specific compounds associated with military activities at the Site and with agricultural use at the Site. A separate Phase 2 Detailed Work Plan and QAP for conventional groundwater sampling and analysis has been submitted which provides the specific details, activities, equipment, procedures, objectives, and decision criteria for this phase of the investigation. The QAP is based upon the existing DRC-approved QAP for groundwater sampling at the White Mesa Mill.

#### **1.1.1.2 Phase 3 – Deep Bedrock Core Sampling and Analysis**

This phase of the investigation will look at bedrock as a pathway for contaminant migration. Based on the results of Phase 1, locations will be selected for further analysis to trace nitrate and chloride from the base of the alluvium into bedrock. The activities associated with Phase 3 of the nitrate investigation are described herein. Specific location information will be provided at a later date after the receipt of the analytical data from Phase 1.

#### **1.1.1.3 Phase 4 – Stable Isotopic Sampling and Analysis**

Stable isotopes of nitrogen, sulfate, and ammonium will be used to identify and “fingerprint” the contamination in groundwater and compare it to the fingerprint of nitrate and chloride coming from potential sources. A separate Phase 4 Detailed Work Plan and QAP for isotopic groundwater sampling and analysis will be submitted which will provide the specific details, activities, equipment, procedures, objectives, and decision criteria for this phase of the investigation. The Phase 4 QAP will be based upon and utilize the existing DRC-approved QAP for groundwater sampling at the White Mesa Mill. The Phase 4 QAP will follow the same outline as the approved QAP and will supplement the approved QAP to address those activities which are specific to Phase 4 of the nitrate investigation.

#### **1.1.1.4 Phase 5 – Isotopic Soil Sampling and Analysis**

A determination regarding the necessity to complete Phase 5 will be completed after review of the data resulting from the previous phases of the nitrate investigation. If completed, Phase 5 will provide an isotopic “fingerprint” of potential sources of nitrate and chloride in process chemicals, soil, or deep cores. If this phase is required, a separate Work Plan and QAP will be



submitted which will provide the specific details, activities, equipment, procedures, objectives, and decision criteria for this phase of the investigation. A submittal date for the draft QAP for this phase will be established if consultation with DRC determines this phase is needed.

### **1.1.2 Site Description and Background**

The Site is a uranium mill with a vanadium co-product recovery circuit located within the Colorado Plateau physiographic province approximately 5 miles south of the city of Blanding, Utah. Mill construction began in 1979, and conventionally mined uranium ore was first processed in May 1980. Over its 25-year operating history, the Mill has processed over 4 million tons of conventionally mined and alternate feed uranium ores for the recovery of 25 million pounds of  $U_3O_8$  and 34 million pounds of vanadium to date.

Potential on-site sources of nitrate and chloride addressed in the Nitrate CIR (INTERA, 2009) include:

- The septic leach fields at the Site.
- The municipal sewage plant discharge water used historically as Mill water makeup.
- Livestock activities at the wildlife ponds.
- Livestock activities at the Historical Pond.
- Agricultural activities.
- The former Fly Ash Pond.
- Potential historical spills of ammonium-bearing and/or chloride-bearing process chemicals.
- A potential breach in the Mill circuit floor drains or tailings transfer lines.
- A potential leak in the Mill's tailings cells.

#### **1.1.2.1 Site Status**

The Mill was in standby status from November 1999 to April 2002. During the standby period, the Mill received and stockpiled alternate feed materials from the formerly utilized Ashland 1 and Linde remedial action program sites, as well as from other sources of alternate feed materials.

During the period from April 2002 to May 2003, the Mill processed 266,690 tons of alternate feed materials. Subsequently, the Mill entered standby mode but continued to stockpile alternate feed materials.



Uranium mills are licensed to operate either by the U.S. Nuclear Regulatory Commission (“NRC”) or by state agencies authorized to implement the NRC’s licensing program under the Atomic Energy Act (“Agreement States”). The Mill received its initial source material license from the NRC in 1980. The State of Utah became an Agreement State in 2005, at which time regulatory authority for the Mill passed to the Utah DRC. The Mill is regulated under Utah Radioactive Materials License UT 1900479. Groundwater quality is regulated by the Mill’s Utah Groundwater Discharge Permit (“GWDP”) UGW370004.

The Mill is currently operating, having commenced operations in March 2005 with the processing of Cameco alternate feed materials. The Mill has since processed natural ores and alternate feeds. Alternate feeds have been processed both in the main Mill circuit and the alternate feed circuit, which was constructed in 2009.

#### **1.1.2.2 Physical Setting**

The Mill is located near the western edge of the Blanding Basin within the Canyonlands section of the Colorado Plateau physiographic province. Broad, generally horizontal uplift and subsequent erosion have produced topography consisting of high plateaus, mesas, buttes, monuments, and deep canyons incised into the relatively flat-lying Mesozoic and Paleozoic sedimentary rocks.

Northeast of the Mill Site, igneous intrusions forming the core of the Abajo Mountains have disturbed the classic flat-lying Colorado Plateau stratigraphy, resulting in uncharacteristic local folding and faulting of sedimentary rocks. The Abajo Mountains rise to more than 11,000 feet above mean sea level (“amsl”), and have likely provided a source of sediments to the Mill Site (5,600 feet amsl) during intrusion and disturbance of older rocks.

Quaternary deposits overlie the sequence of Mesozoic rocks present in the region. The Cretaceous Mancos Shale and Dakota Sandstone represent the local top of the Mesozoic section in the region and are underlain by the Lower Cretaceous Burro Canyon Formation. This unit is underlain in turn by the Jurassic Morrison Formation (which includes the Brushy Basin, Westwater Canyon, Recapture, and Salt Wash Members), the Summerville Formation, the Entrada Sandstone, and the Navajo Sandstone. The Navajo is underlain by the Jurassic Kayenta Formation, which in turn is underlain by the Triassic Chinle and Moenkopi Formations. Paleozoic sedimentary rocks underlie these Mesozoic units.

Cretaceous geologic units that stratigraphically overlie the Burro Canyon Formation regionally (Mancos Shale and Dakota Sandstone) have been removed by erosion in the vicinity of the Mill. Thus, the lower Cretaceous Burro Canyon Formation (already present during the Mid-Tertiary



Abajo igneous intrusive event) is directly overlain by Quaternary deposits at the Mill Site. The Quaternary colluvial/alluvial sediments are typically coarse-grained deposits that contain little water. The Burro Canyon Formation is described as interbedded conglomerate and grayish-green shale with light-brown sandstone lenses deposited in a fluvial environment (Aubrey, 1989). The average thickness of the unit is approximately 75 feet (U.S. Department of Energy [“DOE”], 2004).

The Burro Canyon Formation hosts the uppermost occurrence of groundwater at the Mill Site. Groundwater in this unit is perched (i.e., isolated from groundwater that occurs in geologic units that underlie the Burro Canyon Formation). Perched water is supported by the relatively impermeable, underlying, fine-grained Brushy Basin Member of the Morrison Formation. The permeability of the Burro Canyon Formation is generally low. Some conglomeratic zones may exist east to northeast of the tailings cells, potentially explaining a relatively continuous zone of higher permeability. The saturated thickness of the perched groundwater zone ranges from approximately 82 feet in the northeast portion of the Mill Site to less than 5 feet in the southwest portion of the Site (DOE, 2004). Groundwater isopleths, based on water level data collected in 2010, indicate that flow in the perched zone is generally from northeast to southwest, although in the eastern portion of the Mill Site, the gradient has a more southerly component.

Groundwater in the regional Entrada/Navajo aquifer is under artesian pressure (upward flow gradient), providing a hydrologic barrier to any potential seepage from overlying geologic units. Perched groundwater within the Burro Canyon Formation is characterized by low yields and is generally of poor quality, containing moderate to high concentrations of chloride, sulfate, and total dissolved solids (Hunt, 1996).

### **1.1.3 Summary of Previous Investigations**

Previous investigations with respect to the presence of nitrate in groundwater under the Mill include a Nitrate and Chloride Source Review Memo (Tischler, 2009), a Nitrate CIR (INTERA, 2009), an Initial Nitrate Monitoring Report (DUSA, 2009), quarterly nitrate and chloride reporting to the DRC (DUSA, 2010-2011), and ongoing investigations into historical land uses, which have not yet been published.

The Nitrate and Chloride Source Review Memo (Tischler, 2009) identifies and discusses potential nitrate sources at the Mill Site, including septic leach fields, municipal sewage plant discharge water used historically as Mill water makeup, livestock activities at the wildlife ponds and the Historical Pond, the former Fly Ash Pond, potential historical spills of ammonium-bearing process chemicals, a potential breach in the Mill circuit floor drains or tailings transfer lines, Mill laboratories, and a potential leak in the Mill’s tailing cells. The Memo also discusses



potential historical sources and offsite sources. The Memo concludes that the most likely sources of nitrate and chloride come from upgradient of the current plume in the municipal sewage plant discharge water used historically as Mill water makeup, from possible livestock activity near the Historical Pond, and possibly from septic leach fields at the Site, in particular, the Semi Autogenous Grinding (“SAG”) leach field and the Main Leach Field. Since the publication of the Nitrate and Chloride Source Review Memo, DUSA’s understanding of historical land uses has continued to be updated through literature, Internet, and other land use studies, which are discussed below.

Land uses proximal to the Mill include farming, ranching, cattle grazing, and feed and grain silos. A further evaluation of historical land use in the vicinity of the Site will be performed to supplement the source evaluation (Source Review Report) (Tischler, 2009) that was included in the Nitrate CIR. This further evaluation is currently under way and will (a) identify areas that have been subject to agricultural activities, and (b) evaluate land-use practices that may have led to elevated levels of nitrate and other contaminants in groundwater. Objective (a) is also required to identify areas for sampling of buildup of atmospheric nitrogen, since the goal is to sample areas that have not been subject to human activities. This analysis includes evaluation of historical aerial photography and historical Landsat satellite imagery, and an Internet-based search of historical military activities in the region.

The Nitrate CIR (INTERA, 2009) also discusses the potential sources identified in the Source Review Memo (Tischler, 2009) and describes the sampling design and installation of 19 new wells used to characterize the nitrate and chloride plumes. The CIR characterizes the nitrate and chloride plumes with the data collected from existing and new monitoring wells at the Mill. The investigation concludes that the nitrate and chloride appear to originate from the same source, which is upgradient of the Mill property more than 1.2 miles from the Mill facilities and was not caused by or contributed to in any manner by Mill activities. In the October 5, 2010 DRC NOTICE of Additional Required Action (“NOTICE”), DRC determined that the 2009 CIR is incomplete, and considered the conclusion regarding the sole source of the nitrogen contamination to be unsubstantiated with direct and reliable evidence. Furthermore, the NOTICE stated that DUSA has additionally identified several on-site sources which have a likelihood of being contributors to the contamination and have yet to be fully examined.

Beginning with the third quarter of 2009, DUSA performed quarterly sampling and analysis of the new nitrate wells.



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## 1.2 Project Description

### 1.2.1 Project Objectives

The purpose of this nitrate investigation is to quantify nitrate and chloride in the alluvial soil column in selected locations at the Site with the following goals:

1. To establish background concentrations of nitrate and chloride in the alluvial soil in the vicinity of the Mill.
2. To use the data generated by this investigation to test the “new theory” hypothesis that the nitrate contamination source is or could be caused by naturally occurring nitrate and chloride salt deposits located in the vadose zone near or beneath the Mill Site, which have been mobilized by natural and/or artificial recharge (Walvoord, et al., 2003; Scanlon, et al., 2005; and others).
3. To use the data to test hypotheses regarding to what extent Mill-related sources contributed, if at all, to the groundwater nitrate plume.
4. To use the data to test hypotheses regarding to what extent present or historic non-Mill-related sources contributed, if at all, to the groundwater nitrate plume.

The nitrate investigation has been divided into five phases which are described in detail in Section 3.0.

### 1.2.2 Project Measurements

Project measurements will include laboratory analysis of groundwater, soil, and rock chemistry, and Unified Soil Classification System (“USCS”) soil type classification made at the time of collection by visual-manual inspection as described in the *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) ASTM D 2488 – 09a* (ASTM, 2009). Note that the classifications presented in *ASTM D 2488 – 09a* are identical to the classifications presented in the *Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) ASTM D 2487 – 10* (ASTM, 2010), but are derived from field observations rather than laboratory analysis. Rock core logging conventions, handling, sample preparation, and curating will be completed using best field judgment of a Utah State Professional Geologist, INTERA’s Standard Operating Procedure (SOP) 11 – Rotary Drilling and Coring, and the U.S. Bureau of Reclamation’s Engineering Geology Field Manual, Chapter 10, pages 276-287, as appropriate (Appendix A). Groundwater, soil, and rock samples will be submitted to the contract analytical laboratory (“Analytical Laboratory”) for analysis of the analytes specified in each of the activity-specific documents. The bedrock core analyses completed in Phase 3 of the investigation will be analyzed using the Synthetic Precipitation



Leaching Procedure (“SPLP”) using U.S. Environmental Protection agency (“EPA”) Method 1312. Method 1312 will produce a leachate which will be analyzed for nitrate, chloride and sulfate, and ammonium using EPA Method 353.2, EPA Method 300.0, and EPA Method 350.1, respectively.

### 1.3 Quality Objectives

Specific quality objectives have been established for each of the data assessment parameters identified. These objectives are expressed as quantitative and qualitative statements concerning the type of data needed to support a decision, based on a specified level of uncertainty. The criteria (predetermined acceptance limits) are expressed as numerical values for laboratory analyses and field tests identified. Further discussion of the deep bedrock core sampling for each parameter and the rationale for its use is presented below.

#### 1.3.1 Precision

Precision is defined as the measure of variability that exists between individual sample measurements of the same property under identical conditions. Precision is measured through the analysis of samples containing identical concentrations of the parameters of concern. For duplicate measurements, precision is expressed as the relative percent difference (“RPD”) of a data pair and will be calculated by the following equation:

$$RPD = [(A-B)/\{(A+B)/2\}] \times 100$$

Where A (original) and B (duplicate) are the reported concentrations for field duplicate sample analyses (or, in the case of analyses performed by the Analytical Laboratory, the percent recoveries for matrix spike and matrix spike duplicate samples) (EPA, 1994a, SW-846, Chapter 1, Section 5.0, page 28).

#### 1.3.2 Accuracy

Accuracy is defined as a measure of bias in a system or as the degree of agreement between a measured value and a known value. The accuracy of laboratory analyses is evaluated based on analyzing standards of known concentration both before and during analysis. Accuracy will be evaluated by the following equation (EPA, 1994a, SW-846, Chapter 1, Section 5.0, page 24):

$$\% \text{ Recovery} = ( | A - B | / C ) \times 100$$

Where:

A = the concentration of analyte in a sample

B = the concentration of analyte in an unspiked sample

C = the concentration of spike added



### **1.3.3 Representativeness**

Representativeness is defined as the degree to which a set of data accurately represents the characteristics of a population, parameter, conditions at a sampling point, or an environmental condition. Representativeness is controlled by performing all sampling in compliance with this work plan.

### **1.3.4 Completeness**

Completeness refers to the amount of valid data obtained from a measurement system in reference to the amount that could be obtained under ideal conditions. Laboratory completeness is a measure of the number of samples submitted for analysis compared to the number of analyses found acceptable after review of the analytical data. Completeness will be calculated by the following equation:

$$\text{Completeness} = (\text{Number of valid data points} / \text{total number of measurements}) \times 100$$

Where the number of valid data points is the total number of valid analytical measurements based on the precision, accuracy, and holding time evaluation.

Completeness is determined at the conclusion of the data validation.

### **1.3.5 Comparability**

Comparability expresses the confidence with which one data set can be compared with another. Comparability of data will be achieved by consistently following standard field and laboratory procedures and by using standard measurement units to report analytical data.

### **1.3.6 Detection and Quantitation Limits**

The method detection limit (“MDL”) is the minimum concentration of an analyte that can be reliably distinguished from background for a specific analytical method. The quantitation limit represents the lowest concentration of an analyte that can be accurately and reproducibly quantified in a sample matrix. Project-required reporting limits are minimum quantitation limits for specific analytical methods and sample matrices that are typically several times the MDL to allow for matrix effects.

## **1.4 Project Organization**

### **1.4.1 Functional Groups**

This work plan specifies roles for a Quality Assurance (“QA”) Manager as well as representatives of three different functional groups: the data requestors/users, the data generators,



and the data reviewers/approvers. The roles and responsibilities of these representatives are described below.

#### **1.4.2 Overall Responsibility for the QA/QC Program**

The overall responsibility for ensuring that the Quality Assurance/Quality Control (“QA/QC”) measures are properly employed is the responsibility of the QA Manager. The QA Manager is typically not directly involved in the data generation (i.e., sampling or analysis) activities. The QA Manager is a qualified person designated by DUSA corporate management.

#### **1.4.3 Data Requestors/Users**

The generation of data that meets the objectives of this work plan is necessary for management to make informed decisions to quantify nitrate and chloride in the bedrock in selected locations at the Site. The data generated by this investigation will be used to test hypotheses regarding potential sources of nitrate and chloride contamination, including naturally occurring sources. Accordingly, the data requestors/users (the “Data Users”) are DUSA’s corporate management and regulatory authorities. The data quality objectives (“DQOs”) required for any sampling event, such as acceptable minimum detection limits, are specified in this work plan.

#### **1.4.4 Data Generators**

The individuals who carry out the sampling and analysis activities at the request of the Data Users are the data generators. Field sampling activities, QA/QC activities, record keeping, and chain-of-custody (“COC”) activities are conducted by one or more sampling and quality control (“QC”)/data monitors (each a “Sampling and QC Monitor”) in accordance with this work plan. Data generation at the Analytical Laboratory utilized by the Mill to analyze the environmental samples is performed by or under an employee or agent (the “Analysis Monitor”) of the Analytical Laboratory, in accordance with the specific requirements of the Analytical Laboratory’s own QA/QC program.

The responsibilities of the data generators are outlined below.

##### **1.4.4.1 Sampling and QC Monitors**

The Sampling and QC Monitors are responsible for field activities. These include:

- a. Ensuring that samples are collected, preserved, and transported as specified in the work plan.
- b. Checking that all sample documentation (labels, field data worksheets, COC records, packing lists) is correct and transmitting that information, along with the samples, to the Analytical Laboratory in accordance with this work plan.



- c. Maintaining records of all samples, tracking those samples through subsequent processing and analysis, and, where applicable, appropriately disposing of those samples at the conclusion of the program.
- d. Preparing QC samples for field sample collection during the sampling event.
- e. Preparing QC and sample data for review by the QA Manager.
- f. Preparing QC and sample data for reporting and entry into a computer data base, where appropriate.

INTERA Incorporated's ("INTERA's") field manager, Rob Sengebush, will serve as Sampling and QC Monitor for Phase 3.

#### **1.4.4.2 Analysis Monitor**

The Analysis Monitor is responsible for QA/QC activities at the Analytical Laboratory. These include:

- a. Training and qualifying personnel in specified Analytical Laboratory QC and analytical procedures prior to receiving samples.
- b. Receiving samples from the field and verifying that incoming samples correspond to the packing list or COC sheet.
- c. Verifying that Analytical Laboratory QC and analytical procedures meet the Analytical Laboratory's QA/QC program, and are in accordance with the requirements for maintaining National Environmental Laboratory Accreditation Program ("NELAP") and/or National Voluntary Laboratory Accreditation Program ("NAVLAP") certification.

#### **1.4.4.3 Data Reviewers/Approvers**

The QA Manager has broad authority to approve or disapprove project plans, specific analyses, and final reports. In general, the QA Manager is responsible for reviewing and advising on all aspects of QA/QC, including:

- a. Ensuring that the data produced by the data generators meet the specifications set out in this work plan.
- b. Making on-site evaluations and submitting audit samples to assist in reviewing QA/QC procedures.
- c. Determining (with the Sampling and QC Monitor and Analysis Monitor) appropriate sampling equipment and sample containers, in accordance with this work plan, to minimize contamination.



- d. Supervising all QA/QC measures to assure proper adherence to this work plan and determining corrective measures to be taken when deviations from this work plan occur.

The QA Manager may delegate certain of these responsibilities to one or more Sampling and QC Monitors or to other qualified personnel.

## **1.5 Special Training and Certification**

All soil and rock core logging will be overseen or conducted by a State of Utah Certified Professional Geologist (“PG”), using the *ASTM D 2488 – 09a Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)* (ASTM, 2009), INTERA’s SOP 11 – Rotary Drilling and Coring, and the U.S. Bureau of Reclamation’s Engineering Geology Field Manual, Chapter 10, pages 276-287, as appropriate (Appendix A).

Site-specific training for all field personnel will be completed as required by Mill procedures and will be conducted by Mill personnel.

## **1.6 Documents and Records**

### **1.6.1 Field Documentation**

Field documentation will consist of, but not be limited to, detailed field note books, COC forms, and digital photographs. In addition, the locations of borings and other field activities will be recorded using a hand-held global positioning system (“GPS”) instrument. Soil and rock core logging and details from the boring such as sampling intervals and sample location will be recorded on a field boring log. Information from the field boring log will be used to create a final boring log. Copies of these forms are included in Appendix B. Completed forms will be included in the report. DRC requested the use of a boring log that matched WMMW-16. The log that will be used is located in Appendix B and contains the same relevant information fields. The boring log form does not include gamma or neutron logging fields or well completion fields, since those elements are not part of this investigation.

### **1.6.2 Reports Generated**

Upon completion of the field work and laboratory analysis, a Report describing the results and the results of the QA/QC checks will be generated and submitted to the DRC.



## 2.0 CONCEPTUAL SITE MODEL

This CSM follows the *ASTM E1689-95(2003)e1 Standard Guide for Developing Conceptual Site Models for Contaminated Sites* (Appendix C).

### 2.1 Site Summary

DUSA's White Mesa property hosts an active uranium mill that is currently processing uranium ore. Concentrations of nitrate as nitrogen have exceeded the State of Utah's water quality standard of 10 mg/L in certain monitoring wells at the Mill Site. Typically, samples from wells that have exceeded the nitrate standard also have higher concentrations of chloride than samples from other wells at the Site.

### 2.2 Site Description

The purpose of this section is to identify the constituents of concern, establish background concentrations of those constituents, discuss potential source locations (including decisions and data needs for determining if a source is viable or can and should be eliminated), and discuss timing and duration of events required to account for the constituent mass observed in groundwater.

#### 2.2.1 Identify Contaminants

DUSA received a *Request for Voluntary Plan and Schedule to Investigate and Remediate Nitrate Contamination at the White Mesa Mill Site*, near Blanding, Utah. The Request was dated September 30, 2008, and was received from the Co-Executive Secretary of the Utah Water Quality Board, of the UDEQ. In the Request, the Co-Executive Secretary noted that groundwater nitrate levels have exceeded the State water quality standard of 10 mg/L in certain monitoring wells at the Mill Site. Figure 1 is a regional map showing the location of the Mill Site. Subsequently, in a letter dated December 1, 2009, UDEQ noted that elevated chloride concentrations exist, apparently coincident with elevated nitrate concentrations. Therefore, nitrate and chloride are considered to be constituents of concern for this investigation. Table 2 presents the first quarter 2011 chloride and nitrate concentrations in groundwater.

#### 2.2.2 Establishing Background Concentrations of Contaminants

Installation of 19 new monitoring wells has allowed the nitrate and chloride plumes to be fully bounded at the Site (Figures 2 and 3). On Figure 2, nitrate iso-contours start at 5 mg/L because that value appears to separate the plume from background. However, as evident from Figure 2, the 10 mg/L contour that defines the groundwater compliance limit for nitrate at a number of wells at the Site as specified in GWDP No. UGW370004 is completely closed and defined at the



Site. Per discussions with UDEQ, the nitrate plume is considered to have been bounded when the concentrations of nitrate in monitoring wells upgradient, downgradient, and in both crossgradient directions are less than 10 mg/L. There is no groundwater standard for chloride, but the iso-contours start at 100 mg/L because that value appears to separate the plume from background.

A feature of the plume maps is that the nitrate (Figure 2) and chloride plumes (Figure 3) are co-located geographically. Almost all locations that have elevated nitrate concentrations also have elevated chloride concentrations, implying that the nitrate and chloride impacts to groundwater had the same source. However, the nitrate plume shows a lobe extending to the southeast coincident with the chloroform plume (Figure 4), but the chloride plume does not. This indicates that elevated nitrate was present in the chloroform plume but chloride was not. The chloride plume demonstrates that there are two distinct plumes, a nitrate-chloride plume and a chloroform plume, which have distinctly different sources.

### **2.2.3 Source Locations, Boundaries, and Volumes**

Potential on-site sources of nitrate and chloride addressed in the CIR (INTERA, 2009) include:

- The septic leach fields at the Mill Site.
- The municipal sewage plant discharge water used historically as Mill water makeup.
- Livestock activities at the wildlife ponds.
- Livestock activities at the Historical Pond.
- Agricultural activities.
- The former Fly Ash Pond.
- Potential historical spills of ammonium-bearing and/or chloride-bearing process chemicals.
- A potential breach in the Mill circuit floor drains or tailings transfer lines.
- A potential leak in the Mill's tailings cells.<sup>1</sup>

Subsequent to publication of the CIR, other potential sources have been identified. One potential source is a natural nitrate reservoir. Such concentrations or “reservoirs” of nitrate and chloride have been identified in the scientific literature (Walvoord, et al., 2003; Scanlon, et al., 2005; and others).

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<sup>1</sup> Based on extensive analysis in the background report, age dating of the groundwater reported in the University of Utah Report (Hurst and Solomon, 2008), mass balance analysis in the original CIR, and the fact that the presence of the nitrate plume is upgradient, the tailings cells are not considered a potential source and will not be studied specifically in Phases 1 through 5.

*Unsaturated-zone chloride and nitrate profiles archive changes in recharge related to recent conversion of rangeland to agricultural ecosystems. Increased recharge associated with dryland as well as irrigated agriculture can lead to degradation of groundwater quality because of leaching of salts that have been accumulating in the unsaturated zone for thousands of years prior to cultivation, because of application of fertilizers, and, in irrigated areas, because of evapo-concentration of applied groundwater. In the SHP (southern high plains), median groundwater nitrate-N concentrations increased by 221% beneath irrigated areas and 163% beneath dryland areas, reflecting LU/LC-induced (land use/land cover) contamination of groundwater. (Scanlon, et al., 2005).*

A second potential source that has been identified is military use of the Mill Site as part of the Blanding Pershing Missile Launch Complex. Pershing missiles were tested by launching them from the Blanding site to a target at the White Sands, New Mexico, Missile Base. The Blanding operation was described as a “shoot and scoot” operation in which mobile launch vehicles would deploy to Black Mesa, adjacent to the White Mesa Bivouac site, fire their missiles and “scoot” back to the bivouac site. One possible scenario that may have resulted in nitrate and chloride contamination at White Mesa is as follows:

- The missile firing at Black Mesa caused clouds of oxidized constituents from burning of rocket motors to “exhaust” on the launch vehicles.
- Launch vehicles “scooted” back to White Mesa where they needed to be cleaned prior to the next launch.
- The military required a water source with which to clean the launch vehicles and several ponds were available at the White Mesa Site (notably, the Historical Pond, which was highly developed at the time – see 1968 aerial photograph with nitrate plume overlain [Figure 5]).
- Cleaning the launch vehicles involved washing them with pond water and letting that water drain directly to the soil near the pond where it infiltrated to groundwater, or returning it to the pond or other containment where it infiltrated to groundwater.

#### **2.2.4 Time of Initiation, Duration, and Rate of Contaminant Release**

Any potential source of nitrate and chloride must meet three necessary conditions to have caused the mass of nitrate and chloride observed in the groundwater plume beneath the Mill Site. First, the potential source must have a means to reach groundwater, such as sufficient water or other fluid to travel through the vadose zone. Second, there must have been sufficient nitrate and chloride in the source to account for the nitrate and chloride mass observed in the groundwater.



Third, there must have been sufficient time to travel from the source through the vadose zone and then downgradient in groundwater to account for the current distribution of the nitrate/chloride plume.

Travel times through the vadose zone depend on the amount of head available to drive them, but have been calculated to be on the order of 18-20 feet per year (“ft/yr”) for a pond-like source that maintains a constant head (HGC, 2009). Thus, it would take approximately two to three years for nitrate and chloride from a pond-like source to reach groundwater, assuming groundwater is 40-60 feet below ground surface (“bgs”).

Perched zone pore velocities beneath and immediately upgradient of the tailings cells were calculated in HGC (2005), based on data from wells MW-23, MW-25, MW-27, MW-28, MW-29, MW-30, MW-31, MW-32, TW4-20, TW4-21, and TW4-22. Estimated hydraulic conductivities range from approximately  $2 \times 10^{-7}$  to  $1 \times 10^{-4}$  centimeters/second (“cm/s”) and yield a geometric average of approximately  $3 \times 10^{-5}$  cm/s or 31 ft/yr. Using hydraulic gradients in the vicinity of each well, the estimated conductivity at each well, and an effective porosity of 0.18, the estimated pore velocities ranged from 49.5 ft/yr at TW4-21, to 0.010 ft/yr at MW-23, and have a geometric average of approximately 4.5 ft/yr. Hydraulic gradients in the vicinity of most of these wells have not changed significantly since 2005, nor have the estimated pore velocities.

The current locus of highest nitrate concentrations in the plume is monitor well TWN-2, approximately 2,850 feet upgradient of monitor well MW-31 where nitrate concentrations have been stable since sampling began at that location in 2005. The average nitrate concentration in samples from MW-31 is 23 mg/L with a standard deviation of 3 mg/L. Assuming that 1) the highest of the estimated range of pore velocities (49.5 ft/yr) is representative, 2) the nitrate between TWN-2 and MW-31 resulted from a single source, and 3) no significant spreading or retardation of seepage occurred in the vadose zone, it would have taken a minimum of 57 years for nitrate to travel from TWN-2 to MW-31 in groundwater. If the Historical Pond had maintained a higher gradient in the vicinity of TWN-2 as was likely (see Figure 5 – current nitrate plume and wells overlain on 1968 aerial photograph), travel times may have been somewhat faster. However, the White Mesa Mill has been present at the Mill Site for only 31 years and there has been no pond at that location since then.

### **2.3 Migration Pathway Descriptions**

A migration pathway is defined as the course through which contaminants in the environment may move away from the source(s) to potential environmental receptors, creating a potential exposure pathway. An exposure pathway is incomplete if any of the following elements are missing: 1) a mechanism of contaminant release from primary or secondary sources, 2) a



transport medium if potential environmental receptors are not located at the source, and 3) a point of potential contact of environmental receptors with the contaminated medium. As discussed in Section 2.4, for the Mill nitrate and chloride, there is no contact with human or ecological receptors.

Thirty-two (32) potential sources were identified in Section 2.3.3.1. Due to the large number of potential sources, similar sources will be grouped together for purposes of discussion. The first group consists of potential process-related sources such as on-site leach fields, Mill circuit sources, and chemical storage facilities. The second group contains ponds and pond-like features including disturbances observed on aerial photographs near far-upgradient and far-downgradient wells that contain elevated nitrate and chloride. This second group of sources also includes the locations of potential impact by military or agricultural uses of the Mill Site, described above. The third group of sources is related to the possibility that a natural nitrate reservoir existed in the vadose zone across the Mill Site prior to modern land use and that the change in land use mobilized that vadose zone reservoir and transported it to groundwater.

Figure 6 is a map showing the location of structural cross sections across the Mill Site. Figures 7 through 9 are structural cross sections with the locations of potential sources plotted on them. Note that the vertical exaggeration of the cross sections ranges from 3:1 to 20:1, which magnifies the apparent slopes of the contacts depicted in the diagrams. Figure 10 is a wire frame diagram of the elevation of the bedrock surface beneath the alluvium, the distribution and thickness of the Mancos Shale at the Site, and the location of structural cross sections. The distribution of the Mancos shown in Figure 10 coincides with the area(s) where the Mancos is estimated to be at least 5 feet thick. Figure 11 is an isopach map showing the thickness of the Mancos Shale with potential nitrate sources overlain. Figures 12 through 15 are schematic diagrams depicting pathways for each group of sources. There are two schematic diagrams for potential process-related sources, one depicting a thick section of Mancos Shale beneath the source and one depicting a thin section, due to the importance of that low permeability unit in the time and or pathway from the surface to groundwater.

Figures 10 and 11 show a paleoridge of Mancos Shale in the vicinity of the Mill Site that would presumably impact seepage from potential sources in two ways: 1) the thicker the Mancos, the slower the expected average rate of downward movement due to the relatively low permeability of the Mancos, and the greater the potential for lateral spreading; and 2) the steeper the slope of the alluvium/Mancos contact, the greater the potential for deflection of seepage downslope. Furthermore, should a mound develop beneath a seepage source, lateral flow from the center of the mound could cause seepage to move laterally in all directions including upslope. With regard to the potential for downslope movement at the margins of the Mancos paleoridge, seepage from



potential process-related sources such as the scale house leach field, may move in an easterly or southerly direction when it encounters the alluvial-Mancos interface, whereas seepage from potential process-related sources such as the SAG leach field on the other side of the paleoridge may be constrained to move in a westerly direction. Note that the thickness of the Mancos Shale beneath the location of the western half of the Historical Pond is less than 5 feet and is not expected to be a significant barrier.

Although the slope of the Mancos surface and the thickness of the Mancos are expected to influence potential seepage as discussed above, the Mancos does not appear to have significantly impacted chloroform seepage from either the abandoned scale house leach field or from the former office leach field. Chloroform migration rates based on hydraulic conductivity measurements in the Burro Canyon Formation south of the abandoned scale house leach field are consistent with relatively minor retardation of seepage in the vadose zone even though the Mancos is relatively thick in this area. Furthermore, the abandoned scale house leach field straddles the bedrock paleoridge suggesting that chloroform should have been diverted to the east or to the southwest away from the axis of the ridge if the ridge had exerted a significant influence. However, chloroform from this former source moved primarily south to MW-4 in the direction of the historic perched groundwater hydraulic gradient. Currently wells TW4-18, TW4-5, TW4-9, and TW4-3, located south of the abandoned scale house leach field, are outside the chloroform plume. Prior to 2002, all of these wells except TW4-9 were within the plume at one time or another. This indicates that prior to 2002, chloroform migration within the Burro Canyon Formation in this area was primarily to the south. In addition, if chloroform seepage had been diverted southwest along the slope of the bedrock surface, it is likely that the plume would have reached TW4-10 sooner than shown by the data. The past and current distributions of chloroform near the abandoned scale house leach field appear to be more a function of changing hydraulic gradients and flow directions due to seepage from the wildlife ponds, the permeability distribution of the Dakota Sandstone/Burro Canyon Formation, and chloroform pumping.

With regard to the former office leach field, chloroform has migrated to the northeast toward TW4-21, which is upslope with respect to the Mancos paleoridge. This behavior is more consistent with the presence of a former perched water mound that caused chloroform to move in all directions away from the leach field source area rather than with diversion along the bedrock slope.

The behavior of chloroform originating from former leach field source areas suggests that Mancos surface topology and/or thickness may or may not exert a significant influence on seepage from potential nitrate sources.



Once seepage migrates into the Dakota Sandstone/Burro Canyon Formation, the relatively thin, sub-horizontal, discontinuous, interbedded shale and conglomeratic zones depicted in the cross sections are expected to exert some influence on the movement of the seepage. The impact of the interbedded shales is expected to be retardation and lateral spreading of seepage because of the relatively low permeability of the shales. The impact of the interbedded conglomeratic zones is expected to be mainly lateral spreading of the seepage. Hydraulic testing at the Mill Site indicates that conglomeratic zones may or may not have higher permeability than surrounding sandstones, and suggests that the degree of cementation is an important control in the permeability of these materials. Overall, the Mancos Shale, where thicker than about 5 feet, is expected to exert more influence on seepage than the sub-horizontal, relatively thin and discontinuous shale and conglomeratic zones present in the Dakota Sandstone and Burro Canyon Formations. However, as discussed above, the Mancos appears to have had minimal impact on chloroform in seepage originating from the abandoned scale house and former office leach fields, suggesting that its impact may be similarly small on seepage from potential nitrate sources.

### **2.3.1 Soil and Bedrock**

Assuming that the nitrate and chloride sources originated at the ground surface or within the alluvial soil (natural nitrate reservoir), alluvial soils and bedrock at the Mill Site would be a potential pathway for contaminant migration. A soil and bedrock investigation is ongoing in Phases 1 and 3 of this investigation and early indications are that there is a nitrate and chloride presence connected with this source.

### **2.3.2 Groundwater**

Groundwater flow at the Mill Site is generally to the southwest toward discharge points such as Ruin Springs. Groundwater is a potential pathway for contaminant migration. It has been estimated that travel times between the downgradient edge of Tailings Impoundment 3 and Ruin Spring (the nearest location of a potential receptor), a distance of 10,000 feet, would be between 3,300 to 14,000 years.

### **2.3.3 Specific Source Locations and Data Needs**

This section evaluates each potential source location or feature and states the hypothesis that describes the potential pathway to groundwater that might cause observed concentrations of nitrate and chloride in groundwater. The decision that is required to determine whether any hypothesis is correct is stated explicitly. Data needs, data gaps, and data that will be collected for each potential source are also described. For the purpose of developing the logic diagrams (Figures 16-19) and the CSM diagram (Figure 20), potential source locations can be classified by type: potential mill-process-related sources, potential pond-related sources (Fly Ash Pond, Historical Pond, wildlife pond, Lawzy Lake, and other pond-like sources), and the potential



natural nitrate/chloride reservoir source. Please refer to the logic diagrams and the CSM for each group of sources.

The following section will discuss each source and the decision criteria. The terms as defined below are used in the discussions in Section 2.3.3.1.

### **1. Hydrogeologic Study**

DUSA will perform a hydrogeologic evaluation (the “Hydrogeologic Evaluation”) of each potential source to determine if any potential contamination from the potential source could have contributed to the plume. The Hydrogeologic Evaluation will evaluate the vertical permeability of soil and bedrock beneath the surface area from available lithologic logs of soil and bedrock (including logs from Phase 1 and Phase 3 activities). The Hydrogeologic Evaluation will also evaluate the permeabilities within the perched aquifer and rates of groundwater movement in that aquifer between each potential source to the upgradient and downgradient edges of the plume, as appropriate, based on existing permeability information. To the extent data is available, the Hydrogeologic Evaluation will also consider elevations of the alluvial/bedrock interface and other geologic information if appropriate. The Hydrogeologic Evaluation will be submitted to the Executive Secretary for review and comment on or before December 17, 2011.

### **2. Isotopic Analysis**

Phase 4 of the investigation contemplates the performance of a stable isotope analysis of groundwater, with details to be provided later, and Phase 5 contemplates the performance of isotopic soil sampling and analysis, if needed. These Phase 4 and Phase 5 analyses, which may include age dating of water, are referred to in this work plan as the “Isotopic Analysis.” The purpose of the Isotopic Analysis is to determine the isotopic fingerprint (the “Isotopic Fingerprint”) of the plume and of each source, if required. Each Isotopic Fingerprint may be based in part on stable isotope analyses and in part on age dating of water. The details of the Isotopic Analysis and the factors to be considered in developing each Isotopic Fingerprint will be determined, in connection with the review and Executive Secretary approval of more specific plans for Phase 4 and Phase 5, which will be submitted at later dates. The terms “statistically comparable” and “uniquely identifiable” will be defined in the QAPs for these phases.

### **3. Weight of Evidence**

In those circumstances where a potential source cannot be dismissed as not contributing to the plume or included as contributing to the plume based on definitive criteria specified in Section 2.3.3.1, it will be necessary to make a determination whether or not to dismiss or include the potential source based on the existing weight of evidence (the “Weight of Evidence”). For the



purposes of this work plan, a Weight of Evidence analysis means an analysis that weighs the preponderance of all relevant available information to arrive at a decision. It is expected that such an analysis will involve evaluating several different lines of evidence, each of which may not be conclusive by itself in arriving at the decision, but which together can lead to the decision.

#### **4. Potential and Possible Sources**

In the discussion in Section 2.3.3.1 below, all sources to be evaluated under this work plan are referred to as “potential sources.” Potential sources that cannot be definitively rejected or included based on the criteria in Section 2.3.3.1, and which must undergo a Weight of Evidence analysis, are referred to in Section 2.3.3.1 as “possible sources.”

##### ***2.3.3.1 Potential Nitrate/Chloride Source Locations***

Potential Nitrate Source Locations:

1. Main leach field (also known as leach field east of scale house, 1985 to present)
2. Sewage vault/lift station (currently active)
3. Scale house leach field, (also known as leach field south of scale house, 1977-1979)
4. Former office leach field
5. Ammonia tanks
6. SAG leach field (leach field north of Mill building, 1998 to 2009)
7. Cell 1 leach field (leach field east of Cell #1, up to 1985)
8. Fly Ash Pond
9. Sodium chlorate tanks (as a potential chloride source)
10. Ammonium sulfate crystal tanks
11. Lawzy sump
12. Lawzy Lake
13. Former vault/lift station (to former office leach field, 1992 to 2009)
14. Truck shop leach field (1979-1985)
15. New Counter Current Decant/Solvent Extraction (“CCD/SX”) leach field (currently active)
16. Historical Pond (two hypotheses, 16-1 and 16-2)
17. Wildlife pond (two hypotheses, 17-1 and 17-2)



18. CCD (included inadvertently and eliminated as discussed below)
19. YC Precip Mini-Lab
20. V2O5 Mini-Lab & V2O5 Precip (two hypotheses, 20-1 and 20-2)
21. SX Mini-Lab
22. Chem Lab
23. Met Lab
24. V2O5 oxidation tanks (two hypotheses, 24-1 and 24-2)
25. Natural nitrate reservoir
26. – 32. Other ponds or pond-like sources

**1. Main leach field (also known as leach field east of scale house, 1985 to present)**

Hypothesis 1: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The main leach field is on the eastern side of the Mancos paleoridge, while the main nitrate and chloride plume is on the western side, making contributions from this potential source unlikely. Further, this potential source is cross gradient to the plumes.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1985) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).



Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



## 2. Sewage vault/lift station (currently active)

Hypothesis 2: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: This potential source is more than 1,900 feet downgradient of the upgradient boundary of the main plume. Therefore it is unlikely that this source could be a major contributor to the nitrate and chloride plumes.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this



feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

### 3. Scale house leach field, (also known as leach field south of scale house, 1977-1979)

Hypothesis 3: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The scale house leach field is on the eastern side of the Mancos paleoridge, while the main nitrate and chloride plume is on the western side, making contributions from this potential source unlikely. Further, this potential source is cross gradient to the plumes.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1977) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of



the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

#### 4. Former office leach field

Hypothesis 4: Nitrates and chlorides originating from sewage or process chemicals and/or laboratory wastes (prior to 1981) may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: This potential source is more than 2,000 feet downgradient of the upgradient boundary of the main plume. Therefore it is unlikely that this source could be a major contributor to the nitrate and chloride plumes.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1979) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this



feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 5. Ammonia tanks

Hypothesis 5: Ammonium may have leaked from the tanks through the alluvial soil and bedrock to groundwater to the plume and oxidized from ammonia to nitrate. Nitrogen in the ammonia tanks is solely in the ammonium ( $\text{NH}_4^+$ ) form. Ammonium cations are typically strongly retarded in a soil-water system and likely would not travel through the alluvium and bedrock in the ammonia form. It would have to be converted to the nitrate in a process above the alluvium or in the near subsurface. Subsequently, there would have to be a source of water or other fluid (such as a pond) immediately below or adjacent to the ammonium tanks, and it would have to create sufficient head to drive nitrated water all the way to groundwater. If this were the case, nitrogen would be detected as the nitrate (not ammonia) form continuously through the alluvium and the bedrock. The ammonia tanks are not a source of chloride.

Known Conditions: There is no evidence that there has ever been ponded water in the vicinity of the ammonia tanks. Further, this feature is more than 1,500 feet downgradient of the upgradient boundary of the main plume, making it unlikely that this potential source is a major contributor to the nitrate plume.

Necessary Conditions: a) Is there evidence of nitrate concentration in the vadose zone beneath this feature? b) Is nitrate present in the alluvium and bedrock cores below this feature? c) Is there an oxidation source adjacent to or beneath the tanks sufficient to convert ammonia to nitrate? d) Was there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? e) Did this potential source have sufficient mass to have contributed measurably to nitrate observed in the plume? f) Has there been sufficient time since this potential source was put into service (circa 1980) for detectable levels of constituents from this potential source to reach the plume? Note that there would need to be sufficient time for any ammonium to be oxidized to nitrate, for nitrate to be transported to groundwater, and then be transported to the downgradient edge of the plume. And g) Since this potential source is not associated with any chloride, is there a plausible alternate source for chloride? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Data on the concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction



potential in the groundwater beneath this feature. Possible need for Isotopic Analysis Data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Need ammonium and dissolved oxygen from adjacent monitor wells. Possible need for Isotopic Analysis Data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



## 6. SAG leach field (leach field north of mill building, 1998 to 2009)

Hypothesis 6: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The SAG leach field is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,000 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1998) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this



feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



## 7. Cell 1 leach field (leach field east of Cell #1, 1979 to 1985)

Hypothesis 7: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The cell 1 leach field is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,600 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1979) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this



feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 8. Fly Ash Pond

Hypothesis 8: Nitrates and chlorides associated with coal and coal ash, and potential runoff from Site processes, could have ponded and may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. The pond received coal fly ash, containing oxidized nitrogen (the nitrate not ammonium form) sporadically from 1980 to 1989. The pond could have potentially received some washwaters containing ammonium nitrogen from the vanadium circuit from 1980 through the present.

Known Conditions: The Fly Ash Pond is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 2,200 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate, and/or ammonium, and chloride concentrations in the vadose zone beneath this feature? b) If ammonium is present, is there an oxidation source adjacent to or beneath the tanks sufficient to convert ammonium to nitrate? c) Was there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? d) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? And e) Has there been sufficient time since this potential source was put into service (circa 1981) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or



ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



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## 9. Sodium chlorate tanks

Hypothesis 9: Chlorides associated with sodium chlorate storage may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. If this were an appreciable source, it would also be associated with measurably elevated sodium in soil and/or groundwater adjacent to and beneath the tank area. Sodium chlorate is not a source of nitrogen atoms and has been retained for evaluation as a chloride source.

This is a low priority source, and is inaccessible to drilling and coring. Since it is not a source of nitrate, it will not be subject to physical investigation and has only been retained in the list of hypotheses for completeness.

## 10. Ammonium sulfate crystal tanks

Hypothesis 10: Ammonium sulfate crystals may have spilled around the ammonium sulfate crystal tanks. Over time and with rain, the ammonium converts to nitrate and may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. Nitrogen in the ammonium sulfate tanks is solely in the ammonium ( $\text{NH}_4^+$ ) form. Ammonium cations are typically strongly retarded in a soil-water system and likely would not travel through the alluvium and bedrock in the ammonium form. It would have to be converted to the nitrate from a process above the alluvium or in the near subsurface. That is, there would have to be a source of oxygenated water or other oxidizing fluid (such as a pond) immediately below or adjacent to the ammonium sulfate tanks, and it would have to create sufficient head to drive nitrated water all the way to groundwater. If this were the case, nitrogen would be detected as the nitrate (not ammonium) form continuously through the alluvium and the bedrock. The ammonium sulfate tanks are not a source of chloride. A combination of elevated nitrate and sulfate in the soil adjacent to or beneath the tanks or in the groundwater near the tanks would support this as a possible source.

Known Conditions: The ammonium sulfate crystal tanks are on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,200 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate concentration in the vadose zone beneath this feature? b) Are nitrate and sulfate both elevated in the alluvium and bedrock cores below this feature? c) Is there an oxidation source adjacent to or beneath the tanks sufficient to convert ammonium to nitrogen? d) Was there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? e) Did this source have sufficient mass to have contributed measurably to nitrate observed in the plume? f) Has there been sufficient time since this source was put into service (circa 1980) for detectable levels of constituents from this potential source to reach groundwater? Note that there would need to be sufficient time for any ammonium to be oxidized to nitrate, for nitrate to be transported to groundwater, and then be transported to the downgradient edge of the plume. And g) Since this potential source is not associated with any chloride, is there a plausible alternate source for chloride? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Data on the



concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction potential in the groundwater beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Need ammonium and dissolved oxygen from adjacent monitor wells. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 11. Lawzy sump

Hypothesis 11: This unlined sump was used to pump water from Lawzy Lake (which was filled from the frog pond that may have contained water from the municipal water treatment plant located north of the Mill) to Mill processes. Nitrate- and chloride-laden water from the sump may have leached through alluvial soil and bedrock to groundwater and contributed to the plume. While not always present in soils and groundwater associated with cattle wastes and byproducts, cryptosporidium is frequently present in livestock and animal sources, not human or industrial (chemical) sources. If detected along with elevated nitrate, the presence of cryptosporidium would help to earmark the source of nitrate as being of livestock/animal origin.

Known Conditions: Lawzy sump is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,100 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in groundwater? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, ammonium, and cryptosporidium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or



ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 12. Lawzy Lake

Hypothesis 12: Nitrate- and chloride-laden water from Lawzy Lake (which was filled from the frog pond, which may have contained water from the municipal water treatment plant located north of the Mill) may have leached through alluvial soil and bedrock to groundwater and contributed to the plume. While not always present in soils and groundwater associated with cattle wastes and byproducts, cryptosporidium is frequently present in livestock and animal sources, not human or industrial (chemical) sources. If detected along with elevated nitrate, the presence of cryptosporidium would help to earmark the source of nitrate as being of livestock/animal origin.

Known Conditions: Lawzy Lake is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 300 feet upgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to



determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



### **13. Former vault/lift station (to former office leach field, 1992 to 2009)**

Hypothesis 13: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The former vault is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,500 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1992) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this



feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



#### **14. Truck shop leach field (1979-1985)**

Hypothesis 14: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The truck shop leach field is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 2,300 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1979) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this



feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



## 15. New CCD/SX leach field (currently active)

Hypothesis 15: Nitrates and chlorides originating from sewage or process chemicals may have leached through alluvial soil and bedrock to groundwater and contributed to the plume.

Known Conditions: The CCD/SX leach field is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,200 feet downgradient of the upgradient margin of the main plume. This leach field did not yet exist when the nitrate plume was identified.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (2009) for detectable levels of constituents from this potential source to reach groundwater, and if so, to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of



the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 16. Historical Pond

Hypothesis 16-1: The Historical Pond was associated with agriculture and may have been used as a stock pond or a fertilizer mixing pond, or may have collected fertilizer from runoff of nearby agricultural land. Nitrate- and chloride-laden water from the Historical Pond may have leached through the alluvial soil and bedrock to groundwater. While not always present in soils and groundwater associated with cattle wastes and byproducts, cryptosporidium is frequently present in livestock and animal sources, not human or industrial (chemical) sources. If detected along with elevated nitrate, the presence of cryptosporidium would help to earmark the source of nitrate as being of livestock/animal origin. Based on anecdotal information (interviews with landowners), the pond area was one of several areas that may have been used for dumping truckloads of salt for cattle salt licks. If this is correct, elevated levels of sodium chloride may be present in soil and/or groundwater in the areas of the Historical Pond. Historical sheep dipping activities may also have impacted the pond.

Known Conditions: The Historical Pond is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 400 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate, sodium, or chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in groundwater? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach groundwater? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Sufficient (But Not Necessary) Condition: Is cryptosporidium present in the same media (soil or groundwater) with elevated levels of nitrate?

Data Needs for Decision: Data on the concentration of nitrate and/or ammonium, sodium, chloride, and cryptosporidium in the alluvial and bedrock portion of the vadose zone beneath this feature. Data on concentrations of the same constituents in groundwater. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).



Data Gaps: Need nitrate, chloride, ammonium, sodium, and cryptosporidium concentration data from the bedrock portion of the vadose zone. Data on the same constituents in groundwater. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Collect data on concentrations of chemical constituents in groundwater that might be associated with agricultural uses of this feature along with cryptosporidium (Phase 2). If cryptosporidium is present along with elevated nitrate in water or alluvium, support is provided for an agricultural source.

If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

Hypothesis 16-2: Historical pond was filled with water from one or more ponds north of the Mill Site and used by the military during the Pershing Missile Operation at the Blanding Launch Site (1963-1970) as wash water for equipment used to launch missiles. Launch equipment may have become coated with nitrate and chloride as oxidized material from “blow down” rained down on the launch vehicle during missile launch. Aerial photography of the Site shows that the pond was full of water during the period of military use, and was dry in a 1973 photo, after the military left the Site. Nitrate- and chloride-laden water from the Historical Pond may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume.

Per the current owner of Morton-Thiokol, ATK, the Thiokol Pershing Missile rocket motors (models Thiokol TX-174 and TX-175) used aluminum fuel with ammonium perchlorate as an oxygen source. Since ammonium would have been oxidized during the launch combustion process, if ammonium residuals from Pershing equipment decontamination reached the pond, the residuals would already have been oxidized to the nitrate form. Therefore, for this activity to be a nitrate source, an oxidizing environment in groundwater or the alluvium is not required.

Necessary Conditions: a) Is there evidence of nitrate or ammonium, perchlorate, and/or aluminum concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was possibly used by the Pershing Missile Operation (1963 to 1970) for detectable levels of constituents from this activity to reach the plume or for existing constituents in the pond to reach groundwater by hydraulic head generated during this period? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Gaps: Need nitrate, chloride, aluminum, perchlorate, and ammonium concentration data from the bedrock portion of the vadose zone. Data on concentrations of the same constituents in groundwater. Need background concentrations of aluminum in alluvial soils. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Perform a hydrogeologic evaluation to determine if any potential contamination from this potential source could have contributed to the plume. If not, this potential source is ruled out. If the hydrogeologic analysis is not conclusive, proceed as



follows. If the results of Phase 1 or subsequent sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, ammonium, aluminum, or perchlorate) are present above background, conduct a coring study of bedrock to groundwater (Phase 3). If aluminum or perchlorate are elevated in alluvium and/or bedrock, military use is confirmed. Analyze bedrock core samples for concentration data of those constituents. If none of those constituents are present above background, this can be eliminated as a potential source. If any of those constituents are present above background, conduct a mass balance calculation to determine if the concentrations in bedrock are sufficient to have contributed to nitrate and chloride observed in the plume. If the concentrations in bedrock are sufficient to have contributed to nitrate and chloride observed in the plume, conduct an Isotopic Analysis on samples of bedrock core and of groundwater from the plume (Phase 5). If the Isotopic Fingerprint is uniquely identifiable to the potential source, then the source has been identified. If the Isotopic Fingerprint of the core sample is not uniquely identifiable to the potential source but is statistically comparable to the Isotopic Fingerprint of groundwater from the plume, a possible source has been identified. If a possible source has been identified, perform a Weight of Evidence analysis to determine if the possible source has contributed to the plume. If the possible source has been determined to have contributed to the plume, perform a hydrogeologic and mass balance analysis to determine to what extent the source has contributed to the plume.

## 17. Wildlife pond

Hypothesis 17-1: The wildlife pond was historically filled with water from the frog pond, which may have contained water from the municipal wastewater treatment facility located north of the Mill. Nitrate- and chloride-laden water from the wildlife pond may have leached through the alluvial soil and bedrock to groundwater.

Known Conditions: The wildlife pond is on the opposite side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 600 feet upgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach groundwater? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is



not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

Hypothesis 17-2: The wildlife pond was historically associated with agriculture and may have been used as a stock pond or a fertilizer mixing pond, or may have collected fertilizer from runoff of nearby agricultural land, or may have been utilized in connection with historic sheep dipping activities. Nitrate- and chloride-laden water from the wildlife pond may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. It is also possible that military activity could have been associated with the wildlife pond.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, ammonium, and cryptosporidium in the alluvial and bedrock portion of the vadose zone beneath this feature. Data on concentrations of chemical constituents in groundwater that might be associated with agricultural or military uses of this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Data on concentrations of chemical constituents in groundwater that might be associated with agricultural or military uses of this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Collect data on concentrations of chemical constituents in groundwater that might be associated with agricultural uses of this feature along with cryptosporidium (Phase 2). If cryptosporidium is present along with elevated nitrate in water or alluvium, support is provided for an agricultural source.

If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of



the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



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## 18. CCD Circuit

This area was inadvertently added to the Phase 1 Plan. The CCD circuit uses no chlorinated, ammoniated, or nitrated compounds. The CCD area contains no chlorinated, ammoniated, or nitrated process solutions. The former sewage vault and current leach field near the CCD area are addressed as individual sources elsewhere in this section. This area will not be considered further.

## 19. YC Precip Mini-Lab

Hypothesis 19: Ammonium or nitrate-bearing chemicals from the mini-lab may have spilled or leaked. Ammonium-, nitrate-, or chloride-laden water from the mini-lab may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. The mini-lab areas use very small quantities of reagents and process solutions which drain either to an above-the-floor bucket or to an in-floor drain sump, which is pumped back to the process. If this were a source of contamination, there would need to be evidence of a breach or failure of the building floor or the sump. This potential source is inaccessible to geoprobe and core drilling equipment and is a low priority due to generally small amounts of nitrate or chloride that it could possibly have contributed to the plume. Therefore, no sampling will be conducted at this location.

Known Conditions: The YC Precip Mini-Lab is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,400 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Were nitrate-bearing chemicals, ammonium-bearing chemicals or chloride-bearing chemicals used in this mini-lab and at what time periods? b) Is there evidence of a failure of the floor sump and/or floor drains? c) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? d) If only ammonium-bearing compounds were used, is there an oxidation source adjacent to or beneath the mini-lab sufficient to convert ammonium to nitrogen? e) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? And f) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach groundwater? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the use of ammonium-bearing, nitrate-bearing, and chloride-bearing compounds in this mini-lab. Information on the condition and history of the floor, drains, and sumps in the building. Data on the concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction potential in the groundwater adjacent to this building. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).



Data Gaps: Need information on the structure and history of the floors and drains. Need information on chemicals and use rates in the mini-lab. Need nitrate, ammonium, and dissolved oxygen from adjacent monitor wells. Data on concentrations of nitrate, chloride, and ammonium are already available from the groundwater and nitrate monitoring programs. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Determine if there has been a failure or breach of the sink, sump, or collection bucket. If not, this potential source has been eliminated. If not eliminated, perform a hydrogeologic evaluation to determine if any potential contamination from this potential source could have contributed to the plume. If not, this potential source is ruled out. If the hydrogeologic analysis is not conclusive, proceed as follows. If no nitrate-bearing, ammonium-bearing or chloride-bearing compounds were used in this lab, this potential source can be eliminated. Is there any evidence of a failure of the building floor or sumps? If any of these compounds were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen, and is there a hydraulic head sufficient to drive nitrate or chloride from the vadose zone to groundwater? If the answer to any of these is no, this potential source can be eliminated. If a possible source has been identified, perform a Weight of Evidence analysis to determine if the possible source has contributed to the plume. If the possible source has been determined to have contributed to the plume, perform a hydrogeologic and mass balance analysis to determine to what extent the source has contributed to the plume.



## 20. V<sub>2</sub>O<sub>5</sub> Mini-Lab & V<sub>2</sub>O<sub>5</sub> Precip

Hypothesis 20-1: Ammonium or nitrate-bearing chemicals from the mini-lab may have spilled or leaked. Ammonium-, nitrate-, or chloride-laden water from the lab may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. The mini-lab areas use very small quantities of reagents and process solutions which drain either to an above-the-floor bucket or to an in-floor drain sump, which is pumped back to the process. If this were a source of contamination, there would need to be evidence of a breach or failure of the building floor or the sump.

Known Conditions: The V<sub>2</sub>O<sub>5</sub> mini-lab is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,300 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Were nitrate-bearing chemicals, ammonium-bearing chemicals, or chloride-bearing chemicals used in this mini-lab and at what time periods? a) Is there evidence of a failure of the floor sump and/or floor drains? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) If only ammonium-bearing compounds were used, is there an oxidation source adjacent to or beneath the mini-lab sufficient to convert ammonium to nitrogen? d) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? And e) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the use of ammonium-bearing, nitrate-bearing, and chloride-bearing compounds in this mini-lab. Information on the condition and history of the floor, drains, and sumps in the building. Data on the concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction potential in the groundwater adjacent to this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need information on the structure and history of the floors and drains. Need information on chemicals and use rates in the mini-lab. Need nitrate, ammonium, and dissolved oxygen from adjacent monitor wells. Data on concentrations of nitrate, chloride, and ammonium are already available from the groundwater and nitrate monitoring



programs. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Determine if there has been a failure or breach of the sink, sump, or collection bucket. If not, this potential source has been eliminated. If not eliminated, perform a hydrogeologic evaluation to determine if any potential contamination from this potential source could have contributed to the plume. If not, this potential source is ruled out. If the hydrogeologic analysis is not conclusive, proceed as follows. If no nitrate-bearing, ammonium-bearing, or chloride-bearing compounds were used in this mini-lab, this potential source can be eliminated. If any of these compounds were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen, and is there a hydraulic head sufficient to drive nitrate or chloride from the vadose zone to groundwater? If the answer to any of these is no, this potential source can be eliminated. If a possible source has been identified, perform a Weight of Evidence analysis to determine if the possible source has contributed to the plume. If the possible source has been determined to have contributed to the plume, perform a hydrogeologic and mass balance analysis to determine to what extent the source has contributed to the plume.

Hypothesis 20-2: Ammonium sulfate from the mix tanks on the first floor or the precip tanks on the upper floor may have spilled and leached through the alluvial soil and bedrock to groundwater. Nitrogen in the ammonium sulfate mix and precip tanks is solely in the ammonium ( $\text{NH}_4^+$ ) form. Ammonium cations are typically strongly retarded in a soil-water system and likely would not travel through the alluvium and bedrock in the ammonium form. It would have to be converted to the nitrate from a process above the alluvium or in the near subsurface. That is, there would have to be a source of oxygenated water or other oxidizing fluid (such as a pond) immediately below or adjacent to the ammonium tanks, and it would have to create sufficient head to drive nitrated water all the way to groundwater. If this were the case, nitrogen would be detected as the nitrate (not ammonium) form continuously through the alluvium and the bedrock. The ammonium sulfate mix and precip tanks are not a source of chloride.

Necessary Conditions: a) Is there evidence of nitrate concentration in the vadose zone beneath this feature? b) Is nitrate present in the alluvium and bedrock cores below this feature? c) Is there an oxidation source adjacent to or beneath the tanks sufficient to convert ammonium to nitrate? d) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? e) Did this potential source have sufficient mass to have contributed measurably to nitrate observed in the plume? f) Has there been sufficient time since this potential source was put into service (circa 1980) for detectable levels of constituents from this potential source to reach groundwater? Note that there would need to be sufficient time for any ammonium to be oxidized to nitrate, for nitrate to be transported to groundwater, and then be transported to the downgradient edge of the plume. And g) Since this potential source is not associated with any chloride, is there a plausible alternate source for chloride? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Data on the concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction potential in the groundwater beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Need ammonium and dissolved oxygen from adjacent monitor



wells. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Determine if there has been a failure or breach of the floor or floor drain sump. If not, this potential source has been eliminated.

If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



## 21. SX Mini-Lab

Hypothesis 21: Ammonium-, nitrate-, or chloride-bearing chemicals from the mini-lab may have spilled or leaked. Ammonium-, nitrate-, or chloride-laden water from the mini-lab may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. This potential source is inaccessible to geoprobe and core drilling equipment and is a low priority due to generally small amounts of nitrate that it could possibly have contributed to the plume. Therefore, no sampling will be conducted at this location. The mini-lab areas use very small quantities of reagents and process solutions which drain either to an above-the-floor bucket or to an in-floor drain sump, which is pumped back to the process. If this were a source of contamination, there would need to be evidence of a breach or failure of the building floor or the sump.

Known Conditions: The SX Mini-Lab is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,500 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Were nitrate-bearing chemicals, ammonium-bearing chemicals, or chloride-bearing chemicals used in this mini-lab and at what time periods? b) Is there evidence of a failure of the floor sump and/or floor drains? c) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? d) If only ammonium-bearing compounds were used, is there an oxidation source adjacent to or beneath the mini-lab sufficient to convert ammonium to nitrogen? e) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? And f) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the use of ammonium-bearing, nitrate-bearing, and chloride-bearing compounds in this mini-lab. Information on the condition and history of the floor, drains, and sumps in the building. Data on the concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction potential in the groundwater adjacent to this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).



Data Gaps: Need information on the structure and history of the floors and drains. Need information on chemicals and use rates in the mini-lab. Need nitrate, ammonium, and dissolved oxygen from adjacent monitor wells. Data on concentrations of nitrate, chloride, and ammonium are already available from the groundwater and nitrate monitoring programs. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Determine if there has been a failure or breach of the sink, sump, or collection bucket. If not, this potential source has been eliminated. If not eliminated, perform a hydrogeologic evaluation to determine if any potential contamination from this potential source could have contributed to the plume. If not, this potential source is ruled out. If the hydrogeologic analysis is not conclusive, proceed as follows. If no nitrate-bearing, ammonium-bearing, or chloride-bearing compounds were used in this lab, this source can be eliminated. Is there any evidence of a failure of the building floor or sumps? If any of these compounds were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen? Is there a hydraulic head sufficient to drive nitrate or chloride from the vadose zone to groundwater? If the answer to any of these is no, this potential source can be eliminated. If a possible source has been identified, perform a Weight of Evidence analysis to determine if the possible source has contributed to the plume. If the possible source has been determined to have contributed to the plume, perform a hydrogeologic and mass balance analysis to determine to what extent the source has contributed to the plume.

## 22. Chem Lab

Hypothesis 22: Ammonium-, nitrate-, or chloride-bearing chemicals from the Chem Lab may have spilled or leaked, or lab sink drain water may have leaked from the underground piping that conveys lab drain wastes to the tailings cells. Ammonium-, nitrate-, or chloride-laden water from the lab may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. This potential source is inaccessible to geoprobe and core drilling equipment and is low priority due to generally small amounts of nitrate that it could possibly have contributed to groundwater. Therefore, no sampling will be conducted at this location.

Known Conditions: The Chem Lab is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,800 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Were nitrate-bearing chemicals, ammonium-bearing chemicals, or chloride-bearing chemicals used in this lab and at what time periods? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) If only ammonium-bearing compounds were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen? d) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? And e) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the use of ammonium-bearing, nitrate-bearing, and chloride-bearing compounds in this lab. Data on concentrations of the same chemical constituents in groundwater. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need data on the types and amounts of chemicals used at this facility. Data on concentrations of nitrate, chloride, and ammonium are already available from the groundwater and nitrate monitoring programs. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If no nitrate-bearing, ammonium-bearing or chloride-bearing compounds were used in this lab, this potential source can be eliminated. If any of these compounds



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were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen, and is there a hydraulic head sufficient to drive nitrate or chloride from the vadose zone to groundwater? If not, this potential source can be eliminated. Perform a hydrogeologic evaluation to determine if any potential contamination from this potential source could have contributed to the plume. If not, this potential source is ruled out. If the hydrogeologic analysis is not conclusive, proceed as follows. If a possible source has been identified, perform a Weight of Evidence analysis to determine if the possible source has contributed to the plume. If the possible source has been determined to have contributed to the plume, perform a hydrogeologic and mass balance analysis to determine to what extent the source has contributed to the plume.

### 23. Met Lab

Hypothesis 23: Ammonium-, nitrate-, or chloride-bearing chemicals from the Met Lab may have spilled or leaked, or lab sink drain water may have leaked from the underground piping used to convey lab drain wastes to the tailings cells. Ammonium-, nitrate-, or chloride-laden water from the lab may have leached through the alluvial soil and bedrock to groundwater and contributed to the plume. This potential source is inaccessible to geoprobe and core drilling equipment and is a low priority due to generally small amounts of nitrate that it could possibly have contributed to groundwater. Therefore no sampling will be conducted at this location.

Known Conditions: The Met Lab is on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,800 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Were nitrate-bearing chemicals, ammonium-bearing chemicals, or chloride-bearing chemicals used in this lab and at what time periods? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) If only ammonium-bearing compounds were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen? d) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? And e) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the use of ammonium-bearing, nitrate-bearing, and chloride-bearing compounds in this lab. Data on concentrations of the same chemical constituents in groundwater. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need data on the types and amounts of chemicals used at this facility. Data on concentrations of nitrate, chloride, and ammonium are already available from the groundwater and nitrate monitoring programs. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Perform a hydrogeologic evaluation to determine if any potential contamination from this potential source could have contributed to the plume. If not, this



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potential source is ruled out. If the hydrogeologic analysis is not conclusive, proceed as follows. If no nitrate-bearing, ammonium-bearing, or chloride-bearing compounds were used in this lab, this potential source can be eliminated. If any of these compounds were used, is there an oxidation source adjacent to or beneath the lab sufficient to convert ammonium to nitrogen, and is there a hydraulic head sufficient to drive nitrate or chloride from the vadose zone to groundwater? If not, this potential source can be eliminated. If a possible source has been identified, perform a Weight of Evidence analysis to determine if the possible source has contributed to the plume. If the possible source has been determined to have contributed to the plume, perform a hydrogeologic and mass balance analysis to determine to what extent the source has contributed to the plume.



## 24. V<sub>2</sub>O<sub>5</sub> oxidation tanks

Hypothesis 24-1: Ammoniated solutions from the V<sub>2</sub>O<sub>5</sub> oxidation area could have spilled or overflowed, entered the floor drains and/or drain sumps, and leaked out of the drains and through the alluvial soil and bedrock into groundwater before entering the tailings system, contributing to the plume. Anhydrous ammonia is added to raffinate solution from the uranium solvent extraction area in this part of the plant. Nitrogen in this area is solely in the ammonium (NH<sub>4</sub><sup>+</sup>) form. Anything spilled or washed down to floors or sumps is pumped back from the sumps into the process and remains within the building. If this were a source of contamination, there would need to be evidence of a breach or failure of the building floor or the sump. Ammonium cations are typically strongly retarded in a soil-water system and likely would not travel through the alluvium and bedrock in the ammonia form. It would have to be converted to nitrate from a process above the alluvium or in the near subsurface. That is, there would have to be a source of oxygenated water or other oxidizing fluid (such as a pond) immediately below or adjacent to the ammonium tanks, and it would have to create sufficient head to drive nitrated water all the way to groundwater.

Known Conditions: The V<sub>2</sub>O<sub>5</sub> Oxidation Tanks are on the same side of the Mancos paleoridge as the bulk of the main body of the nitrate and chloride plumes and approximately 1,700 feet downgradient of the upgradient margin of the main plume.

Necessary Conditions: a) Is there evidence of a failure of the floor sump and/or floor drains? b) Is there an oxidation source adjacent to or beneath the tanks sufficient to convert ammonium to nitrate? c) Is there a hydraulic head sufficient to drive nitrate from the vadose zone to groundwater? d) Did this potential source have sufficient mass to have contributed measurably to nitrate observed in the plume? e) Has there been sufficient time since this potential source was put into service (circa 1980) for detectable levels of constituents from this potential source to reach the plume? Note that there would need to be sufficient time for any ammonium to be oxidized to nitrate, for nitrate to be transported to groundwater, and then be transported to the downgradient edge of the plume. And f) Since this potential source is not associated with any chloride, is there a plausible alternate source for chloride? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Information on the condition and history of the floor, drains, and sumps in the building. Data on the concentration of nitrate, chloride, ammonium, dissolved



oxygen, and oxidation reduction potential in the groundwater adjacent to this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need information on the structure and history of the floors and drains. Need nitrate, ammonium, and dissolved oxygen from adjacent monitor wells. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



Hypothesis 24-2: Sodium chlorate or chlorinated solutions from the  $V_2O_5$  oxidation area could have spilled or overflowed, entered the floor drains and/or drain sumps, and leaked out of the drains and through the alluvial soil and bedrock into groundwater before entering the tailings system, contributing to the plume. Anything spilled or washed down to floors or sumps is pumped back from the sumps into the process and remains within the building. If this were a source of contamination, there would need to be evidence of a breach or failure of the building floor or the sump. If this were an appreciable source, it would also be associated with measurably elevated sodium in soil and/or groundwater adjacent to and beneath the tank area. Sodium chlorate is not a source of nitrogen atoms, and this hypothesis has been retained for evaluation only as a chloride source.

Necessary Conditions: a) Is there evidence of chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service (1979) for detectable levels of constituents from this potential source to reach groundwater? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Information on the condition and history of the floor, drains, and sumps in the building. Data on the concentration of nitrate, chloride, ammonium, dissolved oxygen, and oxidation reduction potential in the groundwater adjacent to this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need information on the structure and history of the floors and drains. Need nitrate, ammonium, and dissolved oxygen from adjacent monitor wells. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time



frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 25. Natural nitrate reservoir

Hypothesis 25: Increased recharge or irrigation of dry land could have led to leaching of salts that have been accumulating in the unsaturated zone for thousands of years, forming a nitrate reservoir in the subsurface alluvium which is driven through the alluvial soil and bedrock to groundwater by surface water (wildlife or other ponds) percolation.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time for detectable levels of constituents from this potential source to reach the plume? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, and ammonium in the alluvial and bedrock portion of the vadose zone beneath this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater,



alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.

## 26. – 32. Other ponds or pond like sources

Hypothesis 26: These areas were used historically as agriculture-related stock ponds and fertilizer mixing ponds. Anecdotal evidence suggests ponds may have been used for sheep dipping, that occasionally cattle broke through the ice and drowned, and that truckloads of salt crystals were deposited in the vicinity for the cattle. Nitrates and chlorides associated with these agricultural-related activities may have leached through the alluvial soil and bedrock to groundwater. While not always present in soils and groundwater associated with cattle wastes and byproducts, cryptosporidium is frequently present in livestock and animal sources, not human or industrial (chemical) sources. If detected along with elevated nitrate, the presence of cryptosporidium would help to earmark the source of nitrate as being of livestock/animal origin. There is also the potential for military activity in connection with any of the historical ponds near the Site.

Necessary Conditions: a) Is there evidence of nitrate and chloride concentrations in the vadose zone beneath this feature? b) Did this potential source have sufficient mass to have contributed measurably to nitrate and/or chloride observed in the plume? c) Does the hydrogeology support and explain transport to groundwater? And d) Has there been sufficient time since this potential source was put into service for detectable levels of constituents from this potential source to reach groundwater? If this potential source could have contributed to the plume, is the Isotopic Fingerprint statistically comparable to the Isotopic Fingerprint of the plume? If the Isotopic Fingerprint of the potential source is statistically comparable to the Isotopic Fingerprint of the plume, is it uniquely comparable or does the Weight of Evidence indicate that it contributed to the plume?

Data Needs for Decision: Data on the concentration of nitrate, chloride, ammonium, and cryptosporidium in the alluvial and bedrock portion of the vadose zone beneath this feature. Data on concentrations of chemical constituents in groundwater that might be associated with agricultural or military uses of this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Data Gaps: Need nitrate, chloride, and ammonium concentration data from the bedrock portion of the vadose zone. Data on concentrations of chemical constituents in groundwater that might be associated with agricultural or military uses of this feature. Possible need for Isotopic Analysis data. Possible need for Non-Isotopic Groundwater Data (for Weight of Evidence analysis).

Decision Process: Collect data on concentrations of chemical constituents in groundwater that might be associated with agricultural uses of this feature along with cryptosporidium

(Phase 2). If cryptosporidium is present along with elevated nitrate in water or alluvium, support is provided for an agricultural source.

If the results of Phase 1 sampling of the alluvium provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, conduct coring study of bedrock to groundwater (Phase 3). Analyze bedrock core samples for nitrate, chloride, and ammonium concentration data. If the results of Phase 3 sampling of the bedrock provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, perform a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, perform a mass balance to determine source viability. If the source is viable, move to Phases 4 and 5 and send archived core for Isotopic Fingerprint analysis of groundwater, alluvial soil, and bedrock core. If the groundwater and potential source fingerprints match to a reasonable degree, the Weight of Evidence suggests that a source has been identified. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified.

If the results of Phase 1 sampling of the alluvium do not provide evidence that any of the constituents (nitrate, chloride, or ammonium) are present above background, proceed to a hydrogeologic evaluation to determine if this potential source could have generated sufficient mass during the time frame required to produce the plume and if there was a plausible pathway for any potential contamination from this potential source to have contributed to the plume. If the results of the hydrogeologic evaluation are negative, the Weight of Evidence suggests that this feature is not a potential source. If the results of the hydrogeologic evaluation are positive, proceed to a mass balance to determine source viability. If the mass balance determines that the potential source is not viable, the Weight of Evidence suggests that a source has not been identified. If the mass balance determines that the potential source is viable, the Weight of Evidence suggests that a source has been identified.



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## **2.4 Environmental Receptor Identification**

Environmental receptors can include humans or other living organisms (ecological receptors) potentially exposed to and adversely affected by contaminants because they are present at the source(s) or along the contaminant migration pathway.

### **2.4.1 Humans**

Humans are a potential receptor because they may be present at the source; however nitrate and chloride in soil pose no risk to humans. Humans do not come in contact with groundwater at the Site; therefore, the human risk pathway is incomplete. That is, there is no exposed human individual, no human health risk, and no environmental concern associated with humans.

### **2.4.2 Ecological**

Potential ecological receptors are not at risk from nitrates and chlorides in soil. Potential ecological receptors do not come in contact with groundwater at the Mill Site; therefore, the ecological risk pathway is incomplete. That is, there is no exposed ecological receptor, no ecological risk, and no environmental concern associated with ecological receptors.



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## 3.0 DATA GENERATION AND ACQUISITION

### 3.1 Phase 1 Geoprobe Investigation of Background, Natural Nitrate Reservoir, and Potential Site Sources

The purpose of the Phase 1 investigation was to determine background concentrations of nitrate and chloride in the alluvial soil column in undisturbed areas in the vicinity of the Mill, to locate a natural nitrate and chloride reservoir in the alluvial soil, and to compare nitrate and chloride concentrations found in soil near potential Mill sources to background concentrations. The Phase 1 investigation is described in more detail in DUSA's May 13, 2011, submittal to the DRC titled *Nitrate Investigation Revised Phase 1 Work Plan, White Mesa Mill Site, Blanding, Utah* (INTERA, 2011).

### 3.2 Phase 2 Groundwater Quality Sampling and Analysis

The purpose of groundwater sampling for non-isotopic analytes is to test the hypotheses that nitrate and chloride mass observed in groundwater was caused by either military or agricultural uses of the White Mesa Site and to:

1. Establish background for comparison to analytes not already addressed in the Mill's existing background study reports and monitoring programs.
2. Produce valid data for comparison to background.
3. Identify locations of groundwater elevated in the constituents of concern.
4. Provide data for incorporation in the CSM and decision process regarding nitrate sources.

A separate Detailed Work Plan and QAP was submitted to the DRC on July 13, 2011. The Phase 2 Detailed Work Plan and QAP specifies the specific details, activities, equipment, procedures, objectives, and decision criteria for this phase of the investigation. The Phase 2 Detailed Work Plan and QAP is based upon the existing DRC-approved QAP for groundwater sampling at the White Mesa Mill. The Phase 2 Detailed Work Plan and QAP follows the same outline as the approved QAP and: a) supplements the approved QAP to address additional activities which are specific to Phase 2 of the nitrate investigation and are not currently addressed in the QAP, and b) adjusts existing procedures in the approved QAP which need to be modified or omitted to be suitable for the nitrate investigation.

#### 3.2.1 Sampling Design

The following analytes will act as a "fingerprint" of either military or agricultural activities:

- *Cryptosporidium*



- RDX
- HMX
- Perchlorate

It is assumed that any such uses would be associated with ponds or pond-like features to carry constituents to groundwater. Not all locations with elevated nitrate and chloride are associated with an active pond. However, disturbances visible on aerial imagery far upgradient and far downgradient near wells containing elevated concentrations of nitrate and chloride may have been related to historical ponds at those locations. Therefore, the following wells, which are also presented on Figure 21 and Table 3, will be sampled for non-isotopic constituents:

- MW-20
- MW-31
- TWN-19
- TWN-2
- TWN-9
- TWN-17
- MW-19
- MW-27
- MW-30
- TW4-1
- TW4-22
- TW4-24

TWN-2 and TW4-22 will be sampled for cryptosporidium, RDX, and HMX. The other wells will be analyzed for perchlorate only.

### **3.2.2 Field Activities and Sampling Methods**

Field activities are described in detail in the Phase 2 Detailed Work Plan and QAP.

#### **3.2.2.1 Sample Identification**

Each sample collected at the Site during the nitrate investigation will be identified using a unique sample identification number (“ID”). The description of the sample type and the point name will be recorded on the chain-of-custody (“COC”) forms, as well as in the field notes.



Field log books will be used to document field sampling information. Sample IDs will be listed on the sample labels and the COC forms submitted to the laboratory, and will be cross-referenced to the name in permanently bound field log books, on sample data sheets, and on COC forms.

Ground water samples will be named according to the well ID where the sample was collected.

QC samples will be named as follows:

- Duplicate samples will be identified with a fictitious name and time which will be recorded in the field log book.
- Equipment blanks will also have a fictitious name and time which will be recorded in the field log book.

### **3.2.3 Sample Containers and Holding Times**

All sample containers will be supplied by the laboratory and will be certified as new. The type of sample containers to be used for each analysis, the sample volumes required, the preservation requirements, and the holding times for samples prior to extraction and analysis are presented in Table 1 of the Phase 2 QAP (DUSA, 2011).

### **3.2.4 Analytical Methods**

#### **3.2.4.1 Field Analytical Methods**

Field parameters will be collected according to Section 6.2 of the Phase 2 QAP.

#### **3.2.4.2 Laboratory Analytical Methods**

Groundwater samples will be submitted to the analytical laboratory for analysis. A list of analytes and their analytical methods is presented below:

Explosives (RDX and HMX)	EPA Method 8330
Perchlorate	EPA Method 331.0
Cryptosporidium	EPA Method 1623

### **3.3 Phase 3 Deep Bedrock Core Sampling and Analysis**

The objective of deep bedrock core sampling and analysis is to trace nitrate and chloride from the base of the alluvium and into the bedrock column (Dakota Formation and upper Burro Canyon Formation) to the water table. The coring will take place in two separate sub-phases:

1. Phase 3A Deep Bedrock Coring in Undisturbed Locations.



## 2. Phase 3B Deep Bedrock Coring of Potential Nitrate Source Locations.

Analytical results and data collected from Phase 1 of the nitrate investigation will be shared with the DRC. DUSA and the DRC will decide on coring locations based on data and discussion.

### 3.3.1 Sampling Design

Phase 3A: At this time it is anticipated that at least four coring locations associated with locating the natural nitrate reservoir will be chosen based on field test kit and analytical results from the 20 background soil borings advanced during Phase 1A of this investigation. Figure 22 presents the potential locations for coring. Preliminary results from Phase 1A indicate the presence of a nitrate and chloride spike at one of the deeper, undisturbed alluvial locations with nitrate and chloride concentrations rising gradually with depth to a peak and then falling with depth below the peak. This observation is consistent with the findings reported by Walvoord, et al. (2003), in which they described a natural nitrate reservoir beneath desert soils. Some alluvial borings at undisturbed locations saw the highest concentrations of nitrate and chloride at the base of the alluvial material. Still other borings yielded samples in which there was no detected nitrate or chloride in alluvial materials. The alluvium is generally thin at the Mill property, and the presence of a nitrate and chloride spike in the deepest of the alluvial borings suggests that evidence of a natural nitrate reservoir may be found in the upper part of the bedrock at the undisturbed sites. Therefore, the bedrock cores to test the natural nitrate reservoir hypothesis will be advanced through the alluvial soil to approximately 20 feet below the surface of the bedrock, and samples will be taken at 4-foot intervals for shipment to the Analytical Laboratory. Remaining core will be archived. If any nitrate and/or chloride are detected above background in samples sent to the Analytical Laboratory, additional samples from adjacent intervals will be selected from the archived core and sent for Analytical Laboratory analysis. All samples will undergo an SPLP leaching procedure and the leachate will be analyzed for nitrate, chloride, sulfate, and ammonium.

Phase 3B: One coring location associated with each pond or pond-like source and each potential process-related source where nitrate and chloride are detected above twice background in alluvial material (background is defined as the 95% upper confidence interval of data collected in Phase 1A) will be selected based on analytical results from the source borings conducted in Phase 1B of this investigation. The bedrock core will be advanced through the alluvium and bedrock to groundwater. Water levels in the perched aquifer have been relatively stable for the last 20 years. Therefore, the presence of nitrate and chloride above background in the 10-foot interval above the water table would provide strong evidence that a source had indeed contributed those constituents to groundwater. Three (3) samples will be collected from each bedrock core location. Bedrock core samples will be collected randomly from the first  $\frac{1}{3}$ , second  $\frac{1}{3}$ , and



third  $\frac{1}{3}$  interval of the total penetrated depth at each location, but during the evaluation of results, special emphasis will be placed on the sample from the interval above the groundwater table. All samples will undergo an SPLP leaching procedure and the leachate will be analyzed for nitrate, chloride, sulfate, and ammonium. The remaining core will be archived. If nitrate and/or chloride are detected above background in samples sent to the Analytical Laboratory, additional samples from adjacent intervals will be selected from the archived core and sent for Analytical Laboratory analysis.

### **3.3.2 Field Activities and Sampling Methods**

The coring will be conducted with a conventional truck-mounted drill rig using a combination of hollow-stem auger and air-rotary methods, without introducing water or other drilling fluids into the borehole.

Cores will be logged by a Utah-Licensed Professional Geologist. Photographs of cores will be collected and GPS coordinates will be recorded.

No field testing will be conducted on these rock cores. The core intervals for Analytical Laboratory analysis will be packaged and shipped to a State of Utah-certified Analytical Laboratory for analysis for the presence of nitrate, chloride, sulfate, and ammonium in the rock cores following the SPLP leaching method. The Analytical Laboratory will need to crush, pulverize, and blend the rock core material before conducting the analysis. Results will be reported in milligrams per kilogram (“mg/kg”).

The core-hole borings will be backfilled with hydrated bentonite after drilling. The as-built boring locations will be recorded with a hand-held GPS instrument for plotting on the Mill Site map and for future reference in the field.

Equipment decontamination will be implemented for all non-disposable equipment that comes in contact with bedrock before moving equipment to a new location or collecting a new sample. Commercial third-party deionized water will be used for rinsate blank collection.

#### **3.3.2.1 Sample Identification**

Each sample collected at the Site during the nitrate investigation will be identified using a unique sample ID. The description of the sample type and the point name will be recorded on the COC forms, as well as in the field notes.

Field log books will be used to document field sampling information. Sample IDs will be listed on the sample labels and the COC forms submitted to the Analytical Laboratory, and will be



cross-referenced to the name in permanently bound field log books, on sample data sheets, and on COC forms.

Coring samples will be named according to the coring location and top and bottom of the depth interval at which they were collected, following the convention C-††X-tt-dd, where †† X is the core location which will be previously determined based on the soil boring locations given in Phase 1, tt is the top of the depth interval, and dd is the bottom of the depth interval expressed in feet bgs. For example, the sample collected at C-01A in the depth interval between 25 and 26 feet bgs would be named C-01A-25-26.

QC samples will be named as follows:

- Duplicate samples will have the same name as the parent sample with a D added at the end of the sample name.
- Equipment blanks will have the same name as the boring location with a terminal RB added at the end.

### **3.3.3 Sample Containers and Holding Times**

The type of sample containers to be used for each analysis, the sample volumes required, the preservation requirements, and the holding times for samples prior to extraction and analysis are presented in Tables 4 and 5.

### **3.3.4 Analytical Methods**

All rock samples will be submitted to the Analytical Laboratory for SPLP analysis using EPA Method 1312 using Extraction Fluid #3. Method 1312 will produce a leachate of all rock samples which will be analyzed for nitrate, chloride, sulfate, and nitrogen as ammonium using EPA Method 353.2, EPA Method 300.0, and EPA Method 350.1 respectively.

## **3.4 Phase 4 Stable Isotopic Sampling and Analysis of Groundwater in Existing Wells**

The purpose of the Phase 4 isotopic sampling and analysis is to provide additional data, if required, to support or reject hypotheses presented in this Nitrate Investigation Revised Phases 2 through 5 Work Plan, including the hypothesis of a natural nitrate source and hypotheses regarding Mill Site sources.

The stable isotopic composition of nitrogen ( $\text{NO}_3$ ,  $\text{NH}_4$ ), oxygen ( $\text{NO}_3$ ) and sulfur ( $\text{SO}_4$ ) will be measured in well samples from the White Mesa Mill Site to attempt to determine the source and degree of mixing of these compounds in groundwater in light of chemical and hydrologic data



already available. Samples will be collected for nitrate ( $\delta^{15}\text{N}$ ,  $\delta^{18}\text{O}-\text{NO}_3$ ), ammonium ( $\delta^{15}\text{N}$ ), and sulfur ( $\delta^{34}\text{S}$ ,  $\delta^{18}\text{O}-\text{SO}_4$ ) isotopic analysis from selected well locations based on existing conceptual models to attempt to determine the Isotopic Fingerprint or ratios in groundwater in the selected wells. Each well will be purged and monitored until key parameters stabilize. Samples will be collected and analyzed for:

1. Analytical concentration of dissolved nitrate, ammonium, chloride, and sulfate (using EPA Method 300.0).
2. Isotopic composition.

All samples will be preserved, shipped, and analyzed in accordance with a new QAP to be developed for isotopic groundwater sampling and analysis. This new QAP (the "Phase 4 QAP") will specify the specific details, activities, equipment, procedures, objectives, schedules, laboratories, and decision criteria for this phase of the investigation. The Phase 4 QAP will be based upon and utilize the existing DRC-approved QAP for groundwater sampling at the White Mesa Mill. The Phase 4 QAP will follow the same outline as the existing approved QAP for groundwater sampling at the Mill and will supplement the approved QAP to address those activities which are specific to Phase 4 of the nitrate investigation.

The Phase 4 QAP will address the following additional requirements:

- Schedule for sampling
- Sample turnaround
- Selected laboratory(ies)
- Analytical methods
- Sample volumes
- Minimum detection limits for analytes
- Field QA procedures
- Laboratory QC

The Phase 4 QAP will be submitted to DRC on or before September 16, 2011. The schedule assumes DRC will complete review by October 7, 2011, and DUSA will submit a Final Phase 4 QAP by October 28, 2011. Sampling will be completed by January 31, 2012.

Wells will be sampled along a transect essentially north to south through the long axis of the nitrate-chloride plume approximately parallel to the estimated direction of groundwater flow. Wells that will be sampled within the mapped nitrate-chloride plume include TWN-3, TWN-2,



TW4-22, TW4-24, and MW-31. Similarly, wells will be sampled from within the separate nitrate-chloroform plume to characterize the nitrogen accompanying infiltration from the septic leach fields (TW4-18, TW4-11, and TW4-1). Well locations containing elevated tritium indicating the groundwater contained a component of recent recharge (Hurst and Solomon, 2008) will be sampled for the isotopes listed above to expand the application of these results to potential surface sources (MW-30, MW-27, and MW-19, in addition to MW-31 already identified). In addition, water samples will be collected from two (2) distinct occurrences of elevated nitrate in groundwater upgradient and northeast of the Mill Site plumes, and from one downgradient location southwest of the Mill Site, to determine if the nitrate sources are similar or if there is continuity of transport processes across the Site (TWN-19, TWN-17, TWN-9, and MW-20) (Figure 23 and Table 6).

Two specific technical concepts are incorporated in this isotopic Phase to improve the probability of interpreting what is often an inconclusive overlap of signature for nitrogen isotopic data in discriminating among multiple sources. First the  $\delta^{18}\text{O}$  of both sulfate and nitrate molecules will be analyzed because the exchange of oxygen isotopes in these molecules occurs in both atmospheric and aqueous environments. The consequence of this analysis is that different  $^{18}\text{O}/^{16}\text{O}$  ratios are indicative of the antecedent environment, which further contributes to interpretation of solute source and evolutionary pathway.

Secondly, nitrogen may be present as ammonium in the groundwater in wells affected by septic leach field drainage or infiltration from the Historical Pond or natural wildlife ponds. If nitrate and/or ammonium are detected in the groundwater chemical analysis, then the sample will be tested for  $\delta^{15}\text{N}$  of ammonium as well as nitrate.

### **3.4.1 Field Activities and Sampling Methods**

Field activities will be described in detail in the Phase 4 Detailed Work Plan and QAP.

#### **3.4.1.1 Sample Identification**

Each sample collected at the Site during the nitrate investigation will be identified using a unique sample ID. The description of the sample type and the point name will be recorded on the COC forms, as well as in the field notes.

Field log books will be used to document field sampling information. Sample IDs will be listed on the sample labels and the COC forms submitted to the laboratory, and will be cross-referenced to the name in permanently bound field log books, on sample data sheets, and on COC forms.



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Groundwater samples will be named according to the well ID where the sample was collected.

QC samples will be named as follows:

- Duplicate samples will be identified with a fictitious name and time which will be recorded in the field log book.
- Equipment blanks will also have a fictitious name and time which will be recorded in the field log book.

### **3.4.2 Sample Containers and Holding Times**

All sample containers will be supplied by the laboratory and will be certified as new. The type of sample containers to be used for each analysis, the sample volumes required, the preservation requirements, and the holding times for samples prior to extraction and analysis will be presented in Table 1 of the Phase 4 QAP.

### **3.4.3 Analytical Methods**

#### ***3.4.3.1 Field Analytical Methods***

Field parameters will be collected according to Section 6.2 of the Phase 4 QAP.

#### ***3.4.3.2 Laboratory Analytical Methods***

Groundwater and wastewater samples will be submitted to the analytical laboratory for isotopic analysis. SOPs from the analytical laboratory are included as Appendix D.

## **3.5 Phase 5 Isotopic Soil Sampling and Analysis**

A determination regarding the necessity to complete Phase 5 will be made after review of the data obtained from the previous phases of the nitrate investigation. For example, if the isotopic values of nitrogen and sulfur in groundwater samples analyzed in Phase 4 indicate that a distinction can be made among potential sources, then Phase 5 will be pursued. The objective of this phase is to identify potential and possible endmember source candidates and characterize the nitrogen and sulfur isotopic composition according to the criteria described in Section 2.3.3.1 of this Nitrate Investigation Revised Phases 2 through 5 Work Plan. This sampling will include:

- (a) Any soils and/or bedrock that DUSA determines could represent a natural nitrate reservoir.
- (b) Any soils and/or bedrock representative of any of the Phase 1 or 3 Mill Site sources that DUSA and the executive Secretary agree, based on the results from Phase 1 or Phase 3, could have contributed to the plume.



- (c) Influent to any sewage vault or leach field identified in paragraph B as requiring isotopic analysis.

Each sample will be collected and analyzed for:

1. Analytical concentration of dissolved nitrate, ammonium, chloride, and sulfate (using EPA Methods to be identified in the QAP and Sulfate Method 300.0).
2. Isotopic composition.

Samples will be collected for nitrogen, oxygen ( $\delta^{15}\text{N}$ ,  $\delta^{18}\text{O-NO}_3$ ), and sulfur ( $\delta^{34}\text{S}$ ,  $\delta^{18}\text{O-SO}_4$ ) isotopic analysis according to the criteria in Section 2.3.3.1 of this Nitrate Investigation Revised Phases 2 through 5 Work Plan to evaluate the possibility of each being a source.

Representative leach samples will be collected from background alluvial boring sediments from three (3) natural nitrate reservoirs and three (3) gypsum lithologies for nitrogen and sulfur isotopic composition respectively. Samples from each boring or medium will be collected at approximately the same intervals as specified in Phases 1 and 3 for non-isotopic characterization in this Nitrate Investigation Revised Phases 2 through 5 Work Plan. Since isotopic results from these potential samples will be compared directly to Isotopic Fingerprints of groundwater, background samples are not required.

All samples will be collected, preserved, shipped, and analyzed following a separate QAP to be developed for isotopic sampling and analysis of soil, extracts, and manufactured products. The QAP will be submitted specifying the specific details, activities, equipment, procedures, laboratories, procedures, schedules, and decision criteria for this phase of the investigation. The QAP will be based upon and utilize the existing DRC-approved QAP for groundwater sampling at the White Mesa Mill. The QAP will follow the same outline as the approved QAP and will supplement the approved QAP to address those activities which are specific to Phase 5 of the nitrate investigation.

The QAP will address the following additional requirements:

- Schedule for sampling
- Sample turnaround
- Selected laboratory(ies)
- Analytical methods
- Sample volumes



- Minimum detection limits for analytes
- Field QA procedures
- Laboratory QC

The Phase 5 QAP will be submitted to DRC on or before June 4, 2012. The schedule assumes DRC will complete review by June 18, 2012, and DUSA will submit a Final QAP by June 29, 2012. Sampling will be completed by July 31, 2012.

### **3.6 Sample Handling and Custody**

#### **3.6.1 Sample Labeling**

Alluvial material will be collected in glass jars. Deep bedrock core samples will be collected in resealable plastic bags due to the inflexible nature of the samples and the inability to “fit” rock cores into a traditional sample jar.

Resealable plastic bags which are archived will be labeled with an indelible marker with the following information:

- Sample identification
- Date

Alluvium and deep bedrock cores provided to the Analytical Laboratory for analysis will be labeled with an adhesive label showing the following information:

- Sample identification
- Date
- Time of collection
- Project name
- Sampler’s initials
- Analysis required

Glass jars and resealable bags will be sealed and placed on ice in a cooler.

#### **3.6.2 Sample Documentation**

Documentation during sampling is essential to proper sample identification. All personnel will adhere to the following general guidelines for maintaining field documentation:

- Documentation will be completed in permanent black or blue ink.



- All entries will be legible.
- Errors will be corrected by crossing out the entry with a single line and then dating and initialing the lineout.
- Any serialized documents will be maintained by INTERA and referenced in the field log book.
- Unused portions of pages will be crossed out, and each page will be signed and dated.

The field team leader and sampling personnel are responsible for proper documentation of activities.

### **3.6.3 Chain of Custody**

Standard sample custody procedures will be used to maintain and document sample integrity during collection, transportation, storage, and analysis. A sample will be considered to be in custody if one of the following statements applies:

- It is in a person's physical possession or view.
- It is in a secure area with restricted access.
- It is placed in a container and secured with an official seal in such a way that the sample cannot be reached without breaking the seal.

COC procedures provide an accurate written record that traces the possession of individual samples from the time of collection in the field to the time of acceptance at the Analytical Laboratory. The COC form will also be used to document all samples collected and the analyses requested. Information that the field personnel will record on the COC form includes the following:

- Project name and number
- Sampling location
- Name and signature of sampler
- Destination of sample (Analytical Laboratory name)
- Sample ID
- Date and time of collection
- Number and type of containers filled
- Analyses requested
- Preservatives used (if applicable)



- Filtering (if applicable)
- Signatures of individuals involved in custody transfer, including the date and time of transfer
- Air bill number (if applicable) or courier information
- Project contact and phone number

Unused lines on the COC form will be crossed out. Field personnel will sign COC forms. The COC form will be placed in a waterproof plastic bag and taped to the inside of the shipping container used to transport the samples. Signed air bills will serve as evidence of custody transfer between field personnel and the courier, and between the courier and the Analytical Laboratory. Copies of the COC form and the air bill will be retained and filed by field personnel before the containers are shipped.

The Analytical Laboratory sample custodian will receive all incoming samples, sign the accompanying COC forms, and retain copies of the forms as permanent records. The Analytical Laboratory sample custodian will record all pertinent information concerning the samples, including the persons delivering the samples, the date and time received, sample condition at the time of receipt (e.g., sealed, unsealed, or broken container; temperature; or other relevant remarks), the sample IDs, and any unique Analytical Laboratory IDs for the samples. When the sample transfer process is complete, the custodian is responsible for maintaining internal log books, tracking reports, and other records necessary to maintain custody throughout sample preparation and analysis.

The Analytical Laboratory will provide a secure storage area for all samples. Access to this area will be restricted to authorized personnel. The custodian will ensure that samples requiring special handling, including samples that are heat- or light-sensitive or radioactive, or that have other unusual physical characteristics, are properly stored and maintained pending analysis.

#### **3.6.4 Sample Shipment**

The following procedures will be implemented when samples collected during the remediation activities are shipped:

- The cooler will be filled with bubble wrap, sample containers, and packing material. Sufficient packing material will be used to minimize sample container breakage during shipment.
- The COC forms will be placed inside a plastic bag. The bag will be sealed and taped to the inside of the cooler lid. The air bill, if required, will be filled out before the samples



are handed over to the carrier. The Analytical Laboratory will be notified if the sampler suspects that the sample contains any substance that would require Analytical Laboratory personnel to take safety precautions.

- The cooler will be closed and taped shut with packing tape around both ends. If the cooler has a drain, it will be taped shut both inside and outside of the cooler.
- Signed and dated custody seals will be placed on the front and side of each cooler. Wide clear tape will be placed over the seals.
- The COC form will be transported within the taped, sealed cooler. When the cooler is received at the Analytical Laboratory, Analytical Laboratory personnel will open the cooler and sign the COC form to document transfer of samples.
- Multiple coolers may be sent in one shipment to the Analytical Laboratory. The outsides of the coolers will be marked to indicate the number of coolers in the shipment.

## **3.7 Quality Control**

### **3.7.1 Field Quality Control Methods**

Field QC measures include complete documentation of all field activities on the appropriate forms. Field QC samples include the collection of field duplicates for analysis by the Analytical Laboratory. Field duplicates will be collected at a frequency of 1 duplicate per 10 field samples. Duplicates will be collected by mixing the field sample and splitting the sample into 2 containers. The samples will be labeled as separate samples and submitted blind to the Analytical Laboratory. Duplicate assessment will be completed as described in Section 3.7.3.4, below.

### **3.7.2 Analytical Laboratory Quality Control Methods**

Analytical QA/QC will be governed by the QA/QC program of the Analytical Laboratory. Every effort will be made to use Analytical Laboratories that are certified by the State of Utah and by NELAP and/or NAVLAP, and are capable of performing the analytical procedures specified in the Phase 2 Work Plan and QAP, and have a QA/QC program that includes the spikes, blanks, and duplicates described below.

#### **3.7.2.1 Spikes, Blanks, and Check Samples**

Analytical Laboratory QC samples will assess the accuracy and precision of the analyses. Following are descriptions of the types of QC samples that may be used by the Analytical Laboratory to assess the quality of the data. Analytical QC will be completed as required by the specific method used for analysis. Assessment of Analytical Laboratory QC samples will be as specified in the method.



a. Matrix Spike/Matrix Spike Duplicate

A spiked field sample analyzed in duplicate may be analyzed with every analytical batch. Analytes stipulated by the analytical method, by applicable regulations, or by other specific requirements may be spiked into the samples. Selection of the sample to be spiked depends on the information required and the variety of conditions within a typical matrix. The matrix spike sample serves as a check evaluating the effect of the sample matrix on the accuracy of analysis. The matrix spike duplicate serves as a check of the analytical precision. Assessment of the matrix spike/matrix spike duplicate will be completed using the method- and Analytical Laboratory-established limits.

b. Method Blanks

Each analytical batch shall be accompanied by a method blank. The method blank shall be carried through the entire analytical procedure. Contamination detected in analysis of method blanks will be used to evaluate any Analytical Laboratory contamination of environmental samples which may have occurred. Method blank detections will be assessed to determine if there is any effect on the sample data usability. Method blank effects will be discussed and a determination made on a case-by-case basis.

c. Check Samples

Each analytical batch shall contain a number of check samples. For each method, the Analytical Laboratory will analyze the check samples or their equivalents specified in the analytical method. Check samples may include a laboratory control sample (“LCS”), calibration checks, laboratory fortified blanks, or sample duplicates. Check samples will be reviewed for compliance with the Analytical Laboratory and method-specified acceptance limits.

### **3.7.3 Internal Quality Control Checks**

#### **3.7.3.1 Field Quality Control Check Procedures**

The QA Manager will perform the QA/QC analysis of field procedures as described below.

#### **3.7.3.2 Review of Compliance with Procedures in this Work Plan**

Observation of technician performance is monitored by the QA Manager on a periodic basis to ensure compliance with this work plan.



### **3.7.3.3 Completeness Review**

The QA Manager will review all analytical results to confirm that the analytical results are complete (i.e., there is an analytical result for each required constituent). The completeness goal for this project is 95%.

### **3.7.3.4 Duplicates**

The following analysis will be performed on duplicate field samples:

- Relative percent difference.

RPDs will be calculated in comparisons of duplicate and original field sample results. Non-conformance will exist when the RPD is greater than 35, unless the measured concentrations are less than 5 times the required detection limit (EPA, 1994b).

### **3.7.3.5 Use of QC Samples to Assess Conformance with this Work Plan**

QC samples generated during field activities and in the Analytical Laboratory will be used to assess the usability of the data for meeting project objectives. QC data which do not meet the requirements specified herein may require that the associated sample data be flagged for limited use or be removed from the overall data pool. Data flagging will follow standard EPA guidelines specified in Functional Guidelines as applicable to the analytical method. QC samples will be used to determine if the data meet the project objectives.

## **3.7.4 Instrument Equipment Testing, Inspection, and Maintenance**

The Analytical Laboratory is responsible for the maintenance of its instruments in accordance with Analytical Laboratory procedures and as required in order to maintain its NELAP and/or NAVLAP certifications. Preventive maintenance will be performed on a scheduled basis to minimize downtime and the potential interruption of analytical work.

Sampling and field equipment shall be tested, inspected, and maintained in accordance with manufacturers' recommendations.

## **3.7.5 Instrument Calibration**

A fundamental requirement for collection of valid data is the proper calibration of all sample collection and analytical instruments. Analytical Laboratory equipment shall be calibrated in accordance with Analytical Laboratory procedures and as described in the analytical methods.



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## 4.0 DATA EVALUATION

Data evaluation will be completed as described throughout this work plan. Analytical data will be evaluated as described using Analytical Laboratory generated QC samples as specified in the analytical methods. Field data will be evaluated against the specific QC samples generated in the field and documentation will be reviewed for completeness and accuracy.

For the SPLP, Extraction Fluid #3 will be used. Standard extraction requires the addition of nitric acid and sulfuric acid during the leaching process. Since the leachates will be analyzed for nitrate+nitrite and sulfate, the deionized leaching process contemplated by the method (for cyanide-containing samples) will be used in lieu of the standard leaching procedure.

As previously described, the soil samples are being leached and analyzed using water methodologies, which will yield concentrations in liquid units (such as mg/L). During the data interpretation and preparation of a revised CSM, the calculations and/or the relationship for converting the results to soil mass units will be provided.

Data usability will be assessed based on compliance with the QC standards specified in the analytical method.

Separate detailed work plans and QAPs will be provided for Phases 2, 4, and 5 which will describe the data evaluation process to be used for each of those phases.



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## 5.0 AUDITS

DUSA may perform system and performance audits in order to ensure that data of known and defensible quality are produced during a sampling program. The frequency and timing of system and performance audits shall be as determined by DUSA.

### 5.1 System Audits

System audits are qualitative evaluations of all components of field and Analytical Laboratory QC measurement systems. They determine if the measurement systems are being used appropriately. System audits will review field and Analytical Laboratory operations, including sampling equipment, Analytical Laboratory equipment, sampling procedures, and equipment calibrations, to evaluate the effectiveness of the QA program and to identify any weakness that may exist. The audits may be carried out before all systems are operational, during the program, or after the completion of the program. Such audits typically involve a comparison of the activities required under this work plan with those actually scheduled or performed. A special type of systems audit is the data management audit. This audit addresses only data collection and management activities.

### 5.2 Performance Audits

The performance audit is a quantitative evaluation of the measurement systems of a program. It requires testing the measurement systems with samples of known composition or behavior to evaluate precision and accuracy. With respect to performance audits of the analytical process, either blind performance evaluation samples may be submitted to the Analytical Laboratory for analysis, or the auditor may request that it provide results of the blind studies that the Analytical Laboratory must provide to its NELAP and/or NAVLAP accreditation agency on an annual basis. The performance audit is carried out without the knowledge of the analysts, to the extent practicable.

### 5.3 Follow-Up Actions

Response to the system audits and performance audits is required when deviations are found.

### 5.4 Audit Records

Audit records for all audits conducted will be retained in DUSA Central Files. These records will contain audit reports, written records of completion for corrective actions, and any other documents associated with the audits supporting audit findings or corrective actions.



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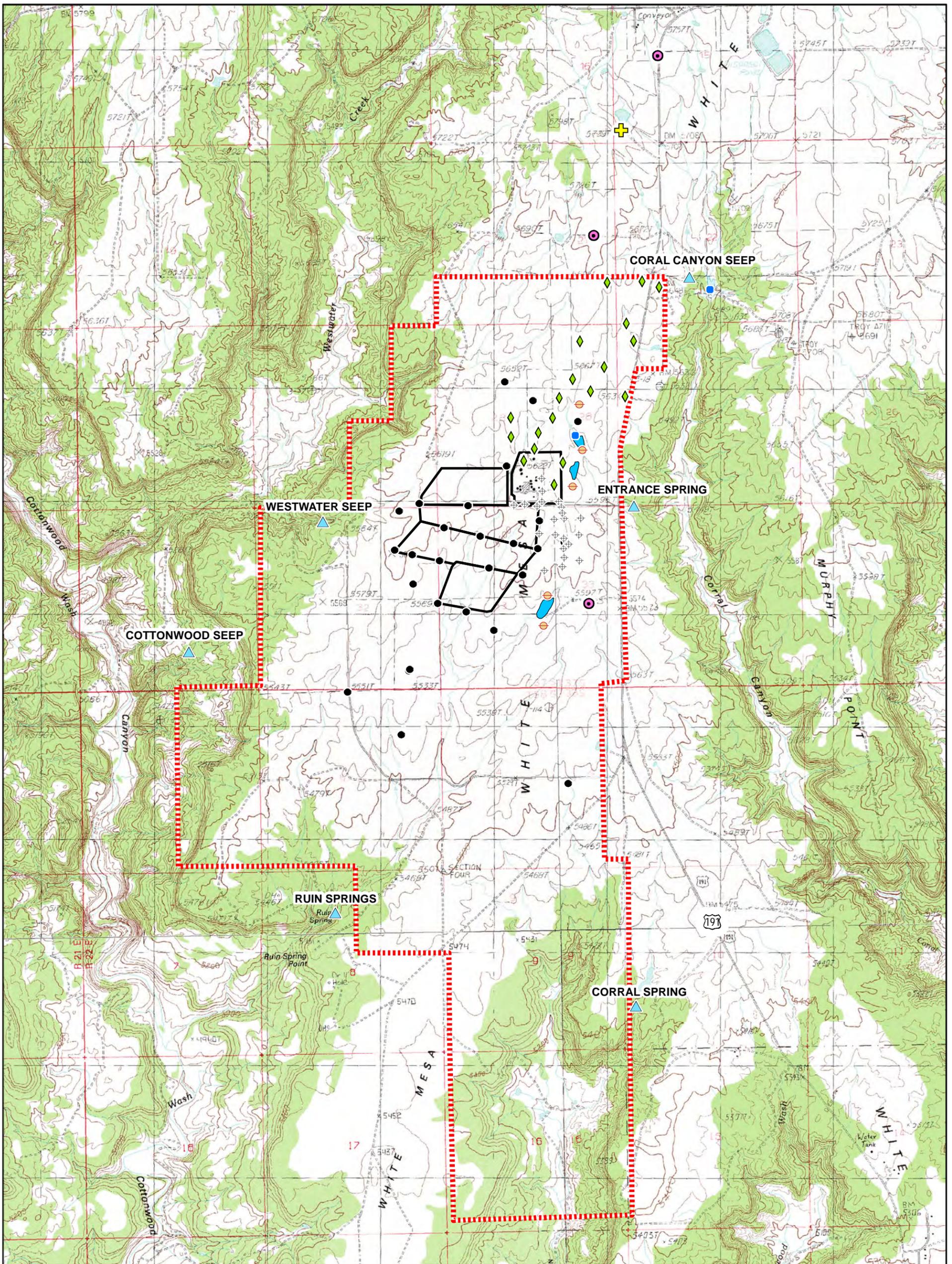
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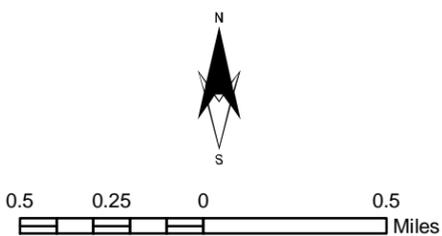


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## FIGURES

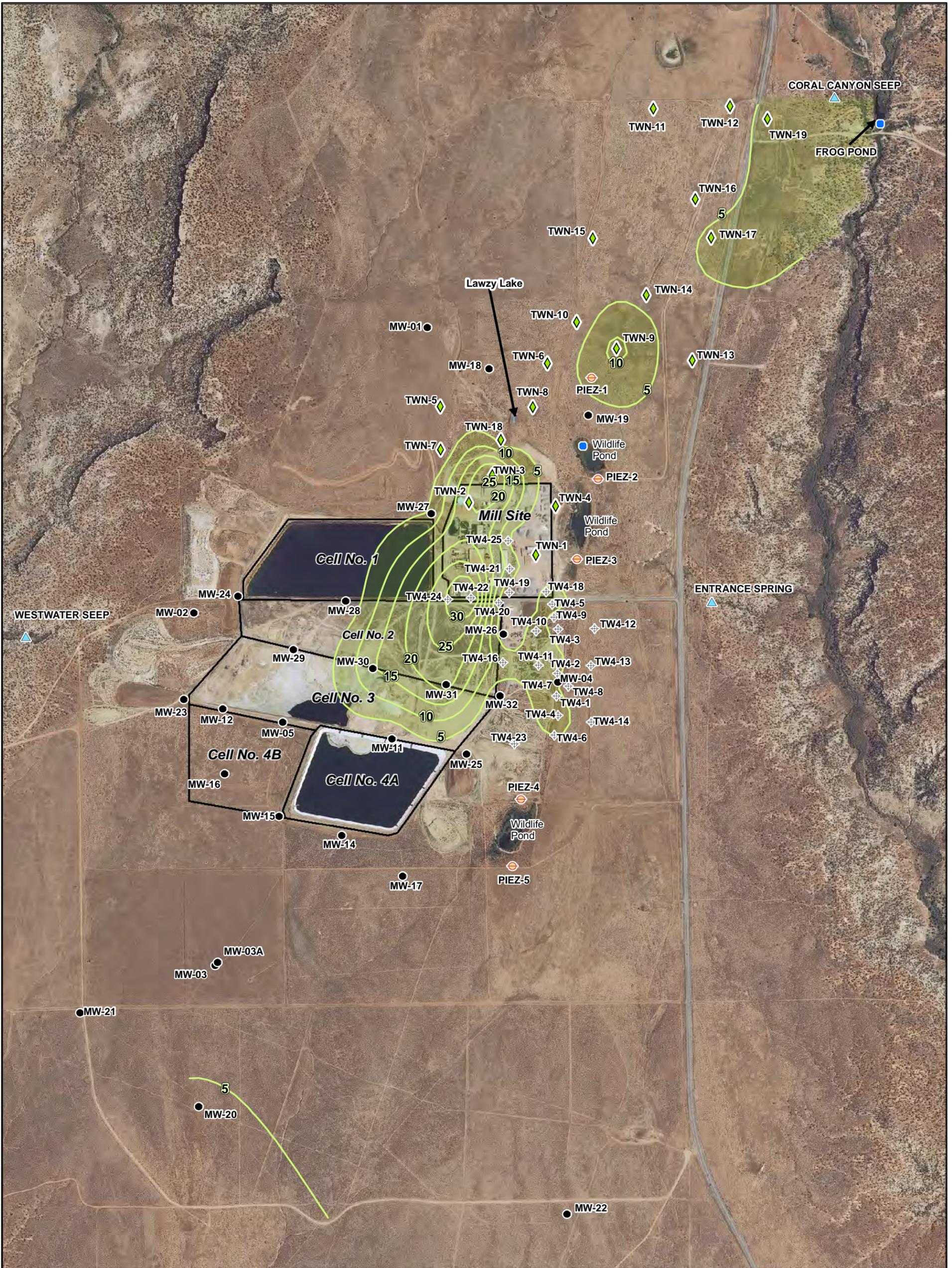


Source(s): Utah GIS Portal website



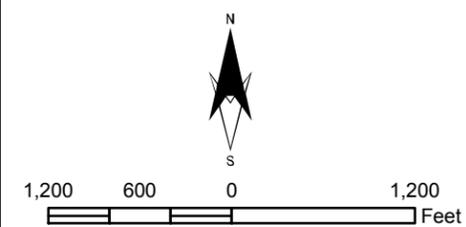
Legend	
	DUSA Property Boundary
	Monitoring Well
	Piezometer
	Regional Well
	Spring/Seep
	Surface Water
	Chloroform Monitoring Well
	Nitrate Monitoring Well
	Windmill

**Figure 1**  
**Map Showing Location of White Mesa Mill Site Nitrate Investigation Revised Phase 2-5 Work Plan**



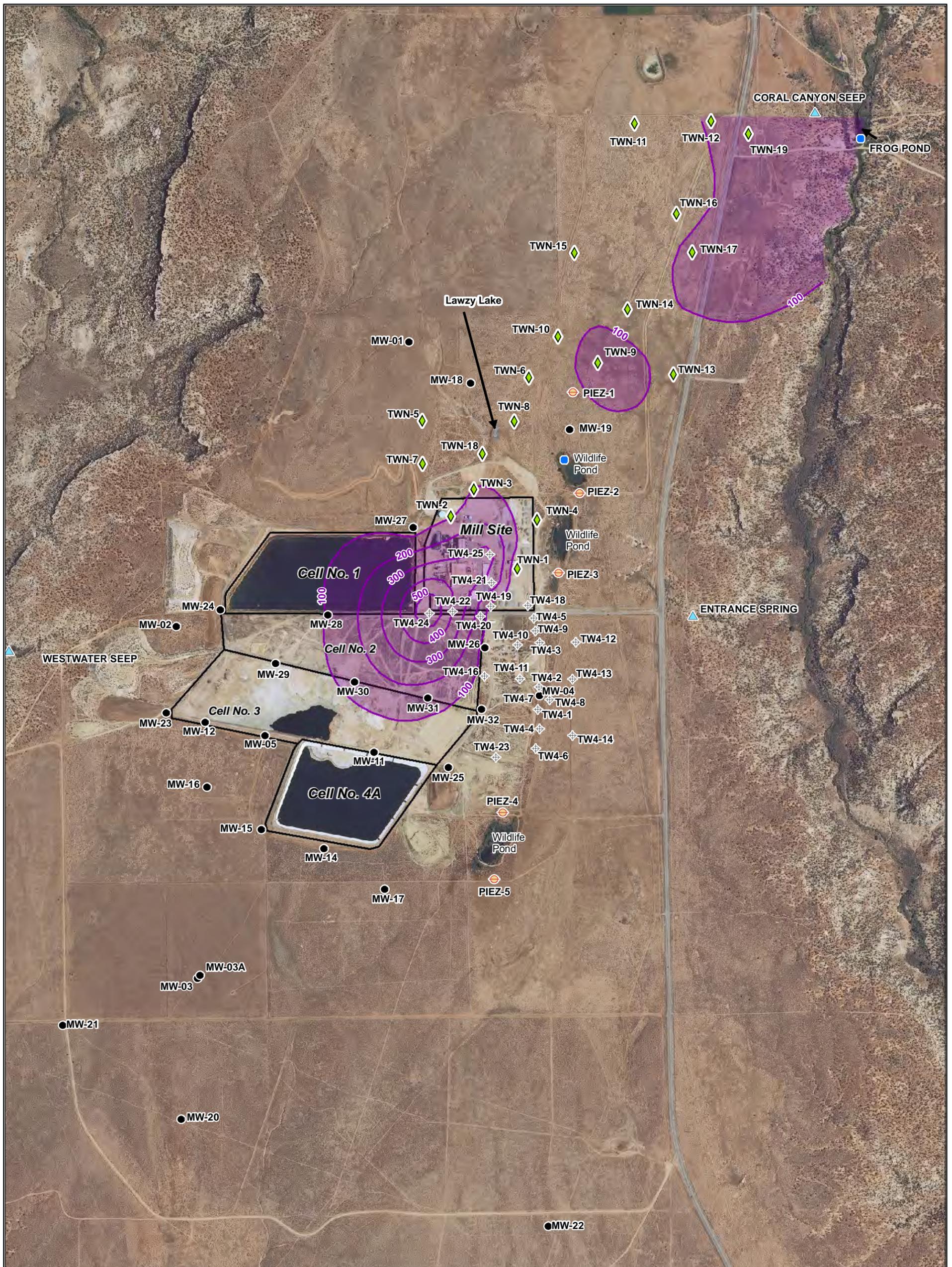
Nitrate data from Contamination Investigation Report (INTERA, 2009). Boundary of plume has not changed significantly since 2009.

Source(s): Aerial – Utah GIS Portal website; Wells – HGC, Inc., May 2008 report.



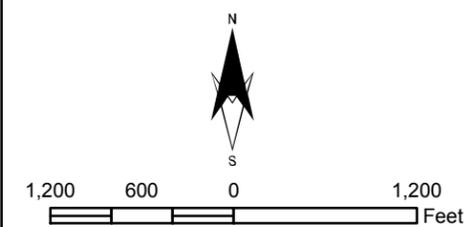
Legend	
●	Monitoring Well
○	Piezometer
▲	Spring/Seep
●	Surface Water
⊕	Chloroform Monitoring Well
◆	Nitrate Monitoring Well
—	Nitrate Concentration (mg/L)

Figure 2  
Map Showing Nitrate Plume  
Nitrate Investigation Revised  
Phase 2-5 Work Plan



Chloride data from Contamination Investigation Report (INTERA, 2009). Boundary of plume has not changed significantly since 2009.

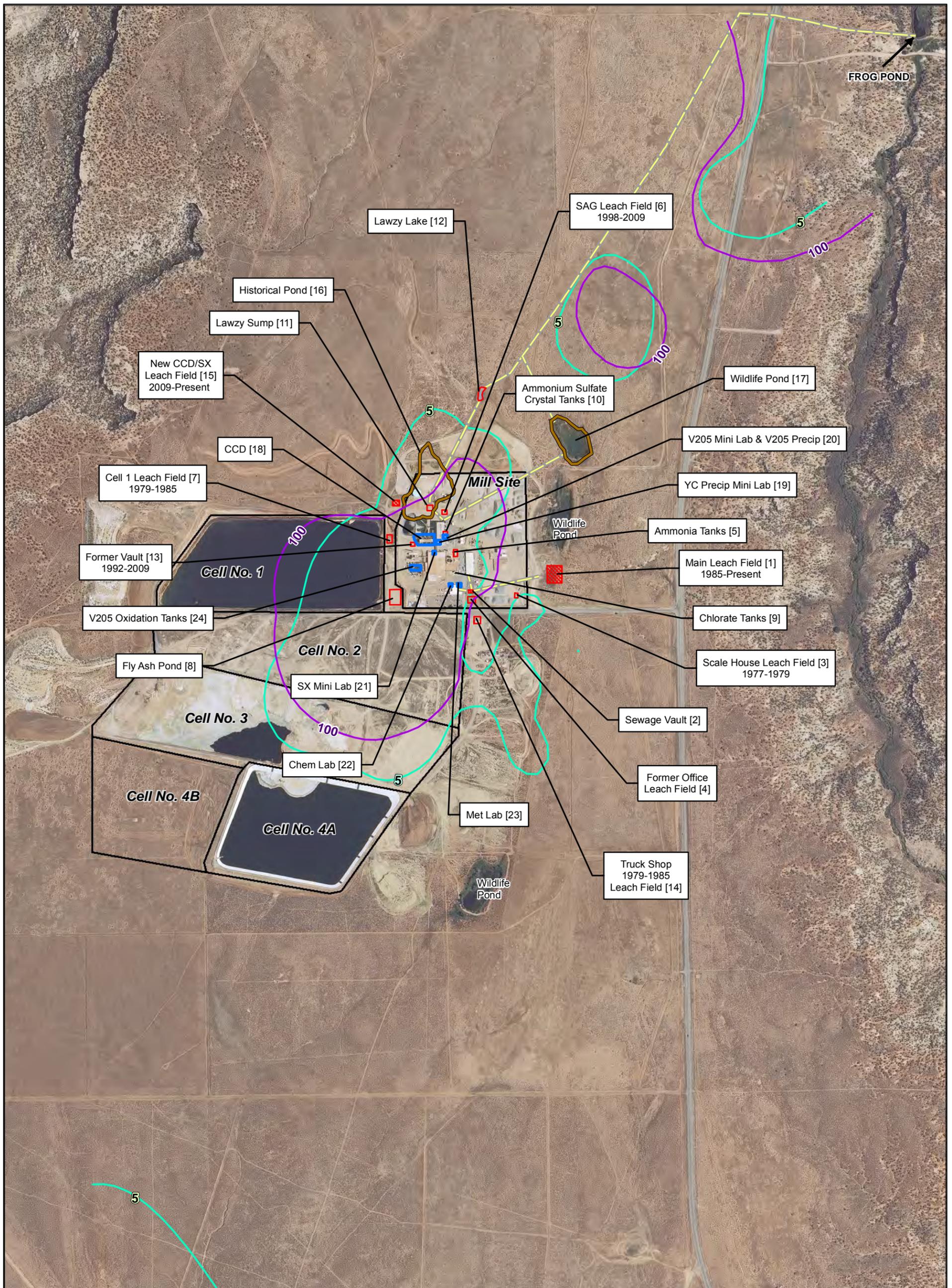
Source(s): Aerial – Utah GIS Portal website; Wells – HGC, Inc., May 2008 report.



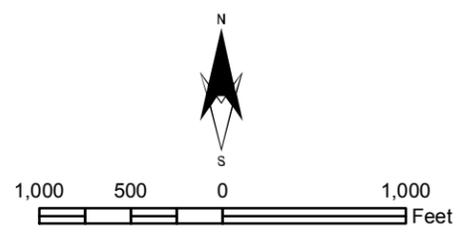
Legend	
● Monitoring Well	● Surface Water
○ Piezometer	⊕ Chloroform Monitoring Well
▲ Spring/Seep	◆ Nitrate Monitoring Well
	— Chloride Concentration (mg/L)

Figure 3  
Map Showing Chloride Plume  
Nitrate Investigation Revised  
Phase 2-5 Work Plan





Source(s): Aerial – Utah GIS Portal website

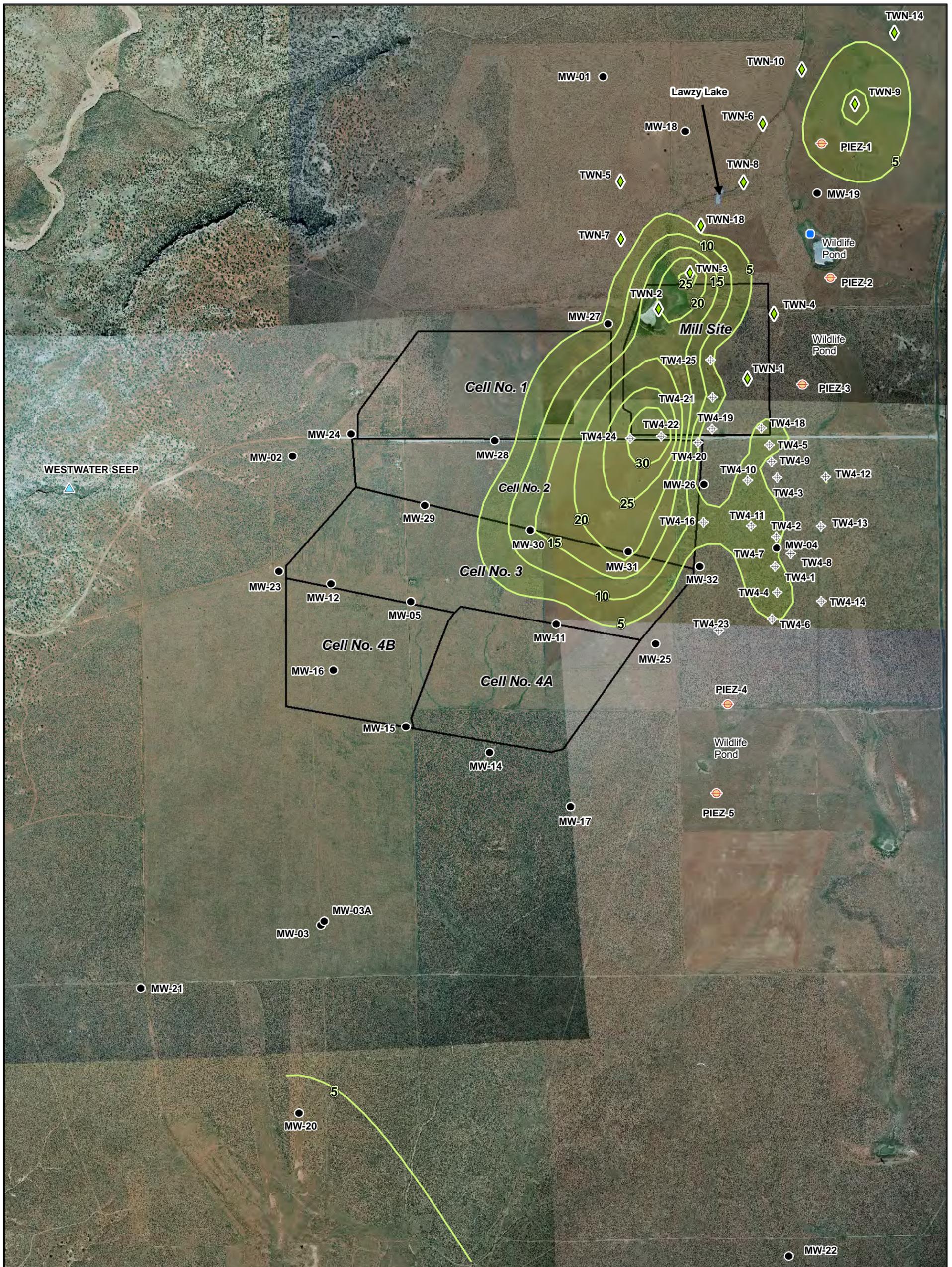


Legend	
<span style="color: purple;">—</span>	Chloride Concentration (mg/L)
<span style="color: cyan;">—</span>	Nitrate Concentration (mg/L)
<span style="border: 1px solid blue; display: inline-block; width: 10px; height: 10px;"></span>	Inaccessible Potential Mill Site Source – No Geoprobe Boring
<span style="border: 1px solid red; display: inline-block; width: 10px; height: 10px;"></span>	Potential Mill Site Source – Geoprobe Boring
<span style="border: 1px solid brown; display: inline-block; width: 10px; height: 10px;"></span>	Other Potential Nitrate and Chloride Source – Geoprobe Boring
<span style="border: 1px dashed yellow; display: inline-block; width: 10px; height: 10px;"></span>	Pipeline
<span style="background-color: red; border: 1px solid black; display: inline-block; width: 10px; height: 10px;"></span>	Leach Field (currently in operation) Sampling Method to be Determined

**Figure 4**  
**Map Showing Nitrate and Chloride Plumes Together**  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan

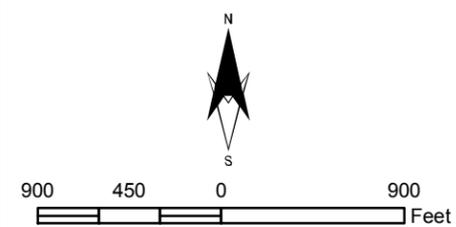


Data from Contamination Investigation Report (INTERA, 2009).  
 Boundary of plume has not changed significantly since 2009.



Nitrate data from Contamination Investigation Report (INTERA, 2009). Boundary of plume has not changed significantly since 2009.

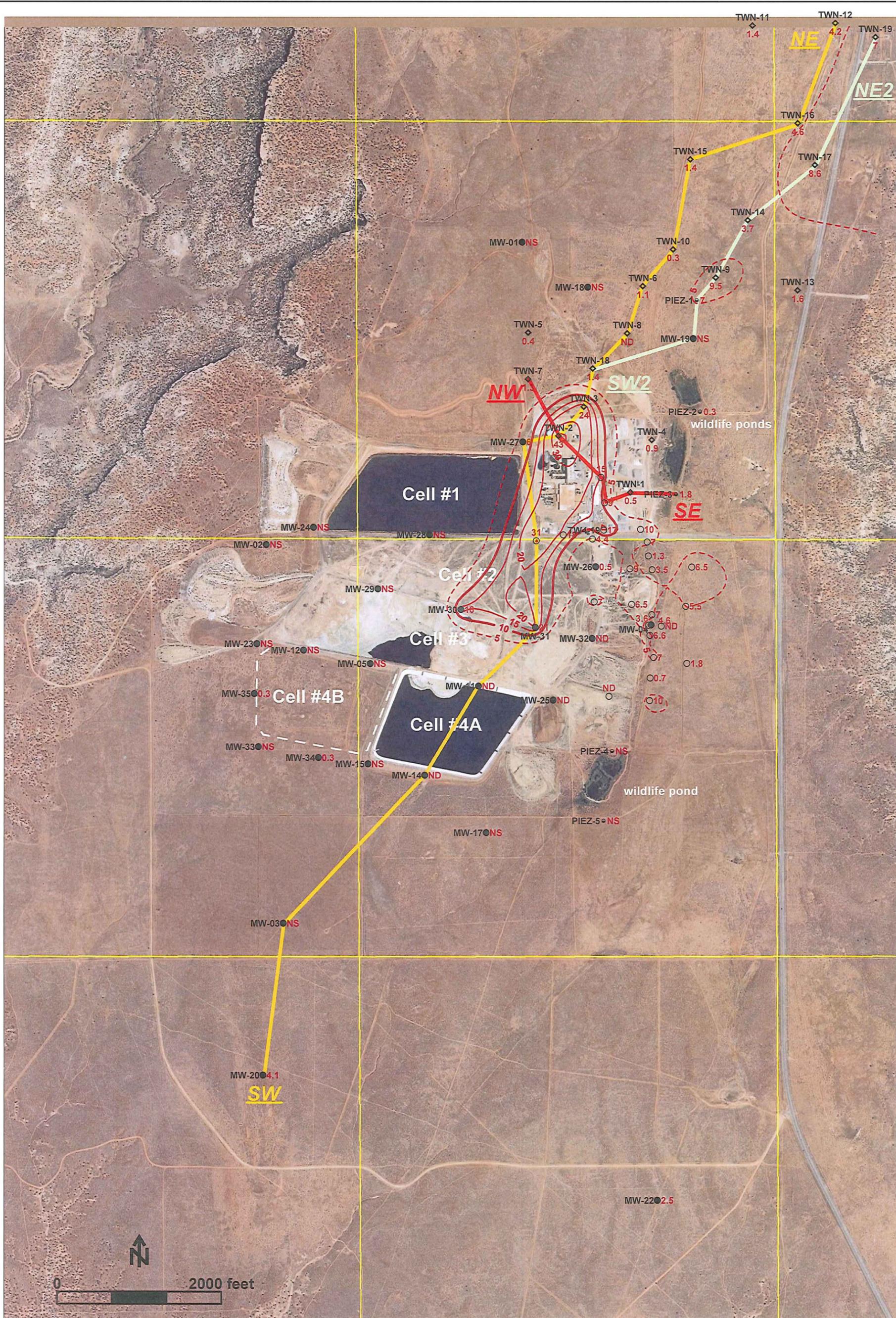
Source(s): Aerial – EDAC, dated 1968; Wells – HGC, Inc., May 2008 report.



Legend	
●	Monitoring Well
○	Piezometer
▲	Spring/Seep
●	Surface Water
⊕	Chloroform Monitoring Well
◆	Nitrate Monitoring Well
—	Nitrate Concentration (mg/L)



**Figure 5**  
Nitrate Plume Overlay on  
1968 Aerial Photograph  
Nitrate Investigation Revised  
Phase 2-5 Work Plan



**EXPLANATION**

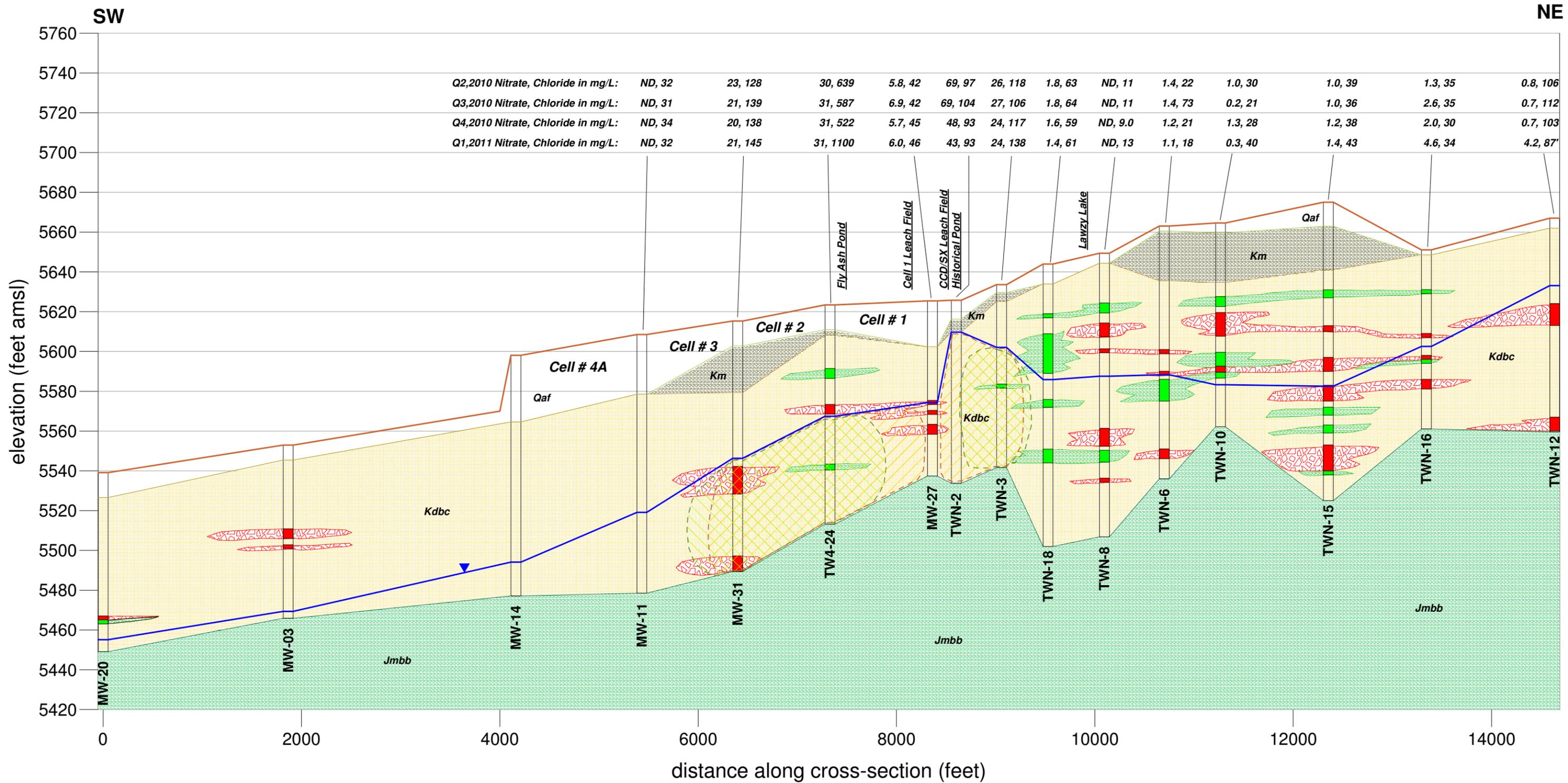
- MW-4 ● 4.6 perched monitoring well showing concentration in mg/L
- 6.6 temporary perched monitoring well showing concentration in mg/L
- PIEZ-1 ⊖ 7 perched piezometer showing concentration in mg/L
- TWN-1 ◆ 0.5 temporary perched nitrate monitoring well showing concentration in mg/L



**HYDRO  
GEO  
CHEM, INC.**

**KRIGED 1st QUARTER, 2011 NITRATE (mg/L)  
(NITRATE + NITRITE AS N)  
AND LOCATIONS OF CROSS-SECTIONS  
SW-NE, NW-SE, AND SW2-NE2**

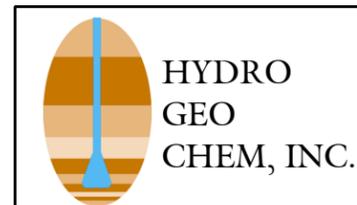
APPROVED	DATE	REFERENCE	FIGURE
SJS		H:/718000/may11/photobase/phntq1xsf6.srf	6



vertical exaggeration = 20 : 1

**EXPLANATION**

- Qaf Alluvium/Fill
- Km Mancos Shale
- Kdbc Dakota Sandstone/ Burro Canyon Formation
- Jmbb Brushy Basin Member of Morrison Formation
- Shale in Dakota / Burro Canyon Formation
- Conglomerate in Dakota / Burro Canyon Formation
- ▼ Piezometric Surface
- Approximate Area >10 mg/L Nitrate
- Approximate Area >100 mg/L Chloride

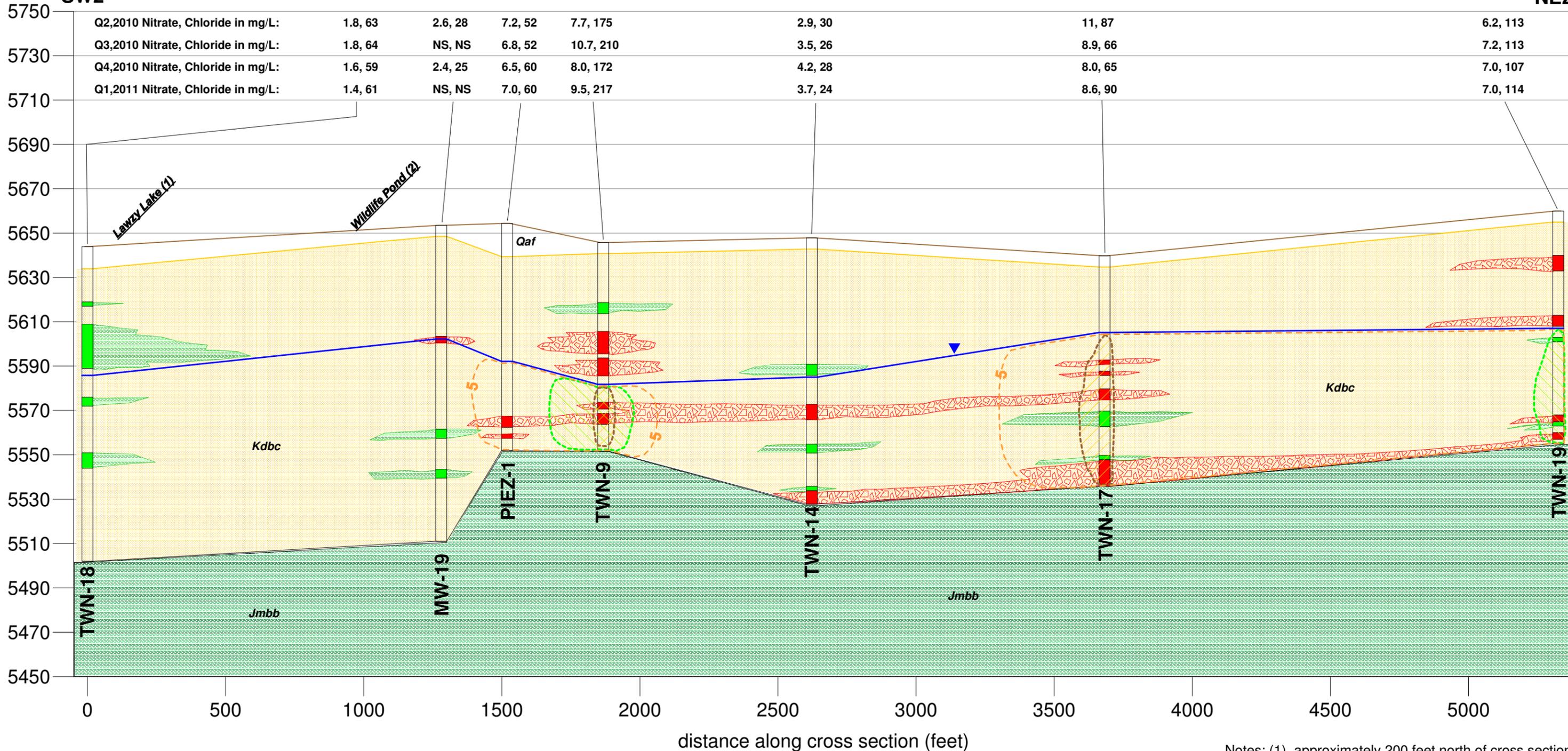


**INTERPRETIVE NORTHEAST-SOUTHWEST  
CROSS SECTION (NE-SW)  
WHITE MESA SITE**

APPROVED SJS	DATE 5/24/11	REFERENCE H:/718000/dakota/xsection/nsxsectb_rev2.srf	FIGURE 7
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SW2

NE2

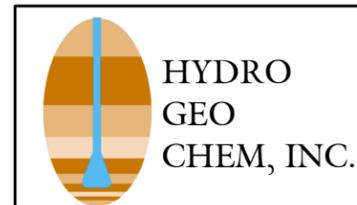


Notes: (1) approximately 200 feet north of cross section  
 (2) approximately 200 feet south of cross section

**EXPLANATION**

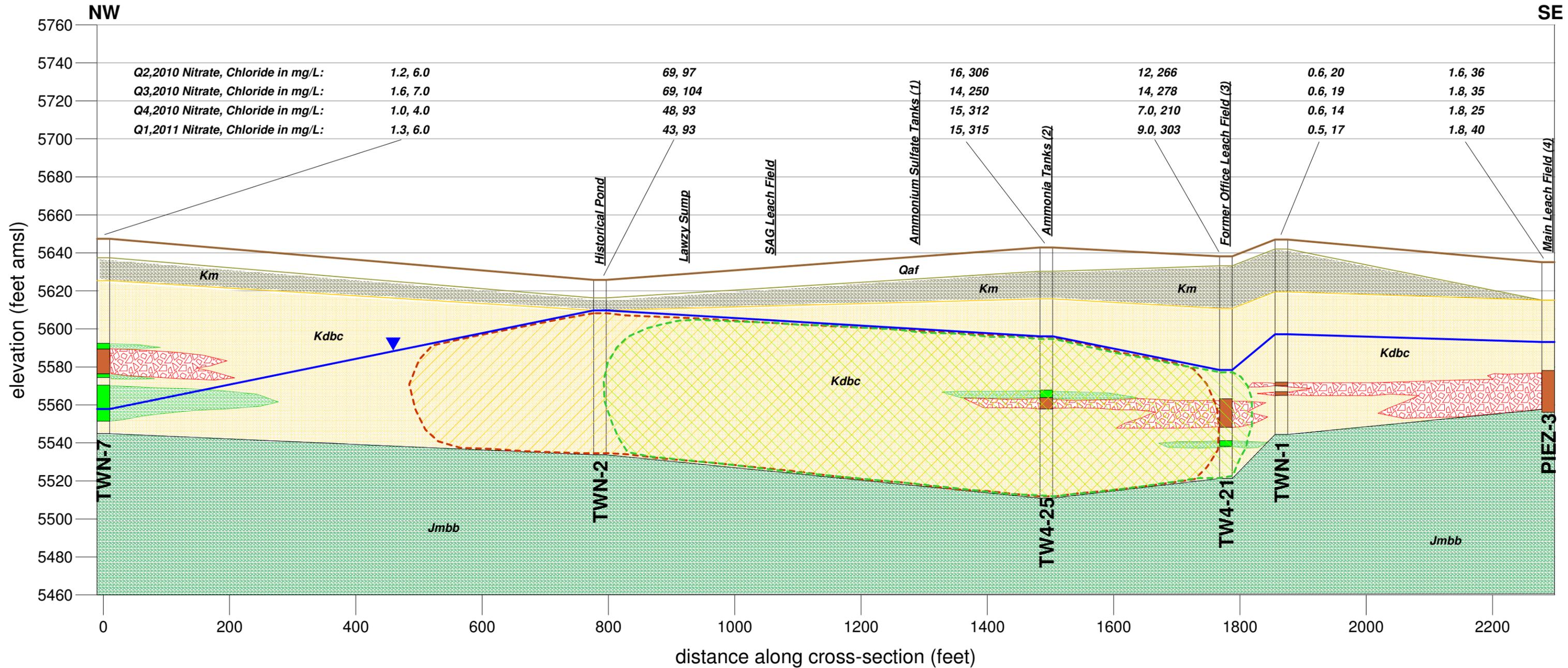
- Qaf Alluvium/Fill
- Kdbc Dakota Sandstone/ Burro Canyon Formation
- Jmbb Brushy Basin Member of Morrison Formation
- Piezometric Surface
- Shale in Dakota / Burro Canyon Formation
- Conglomerate or Conglomeratic Sandstone in Dakota / Burro Canyon Formation
- Approximate 5 mg/L Nitrate Isocon
- Approximate Area > 10 mg/L Nitrate
- Approximate Area >100 mg/L Chloride

vertical exaggeration = 8 : 1



**INTERPRETIVE NORTHEAST-SOUTHWEST  
 CROSS SECTION (NE2-SW2)  
 WHITE MESA SITE**

APPROVED SJS	DATE 5/24/11	REFERENCE H:/718000/dakota/ xsection/ns2xsect/ns2xsectb_rev2.srf	FIGURE 8
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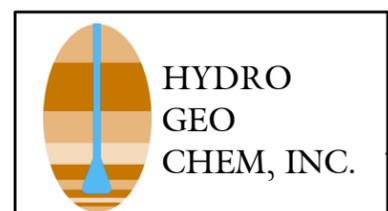


Notes: (1) approximately 115 feet southwest of cross-section  
 (2) approximately 150 feet southwest of cross-section  
 (3) approximately 300 feet south of cross-section  
 (4) immediately south of cross-section

vertical exaggeration = 3 : 1

**EXPLANATION**

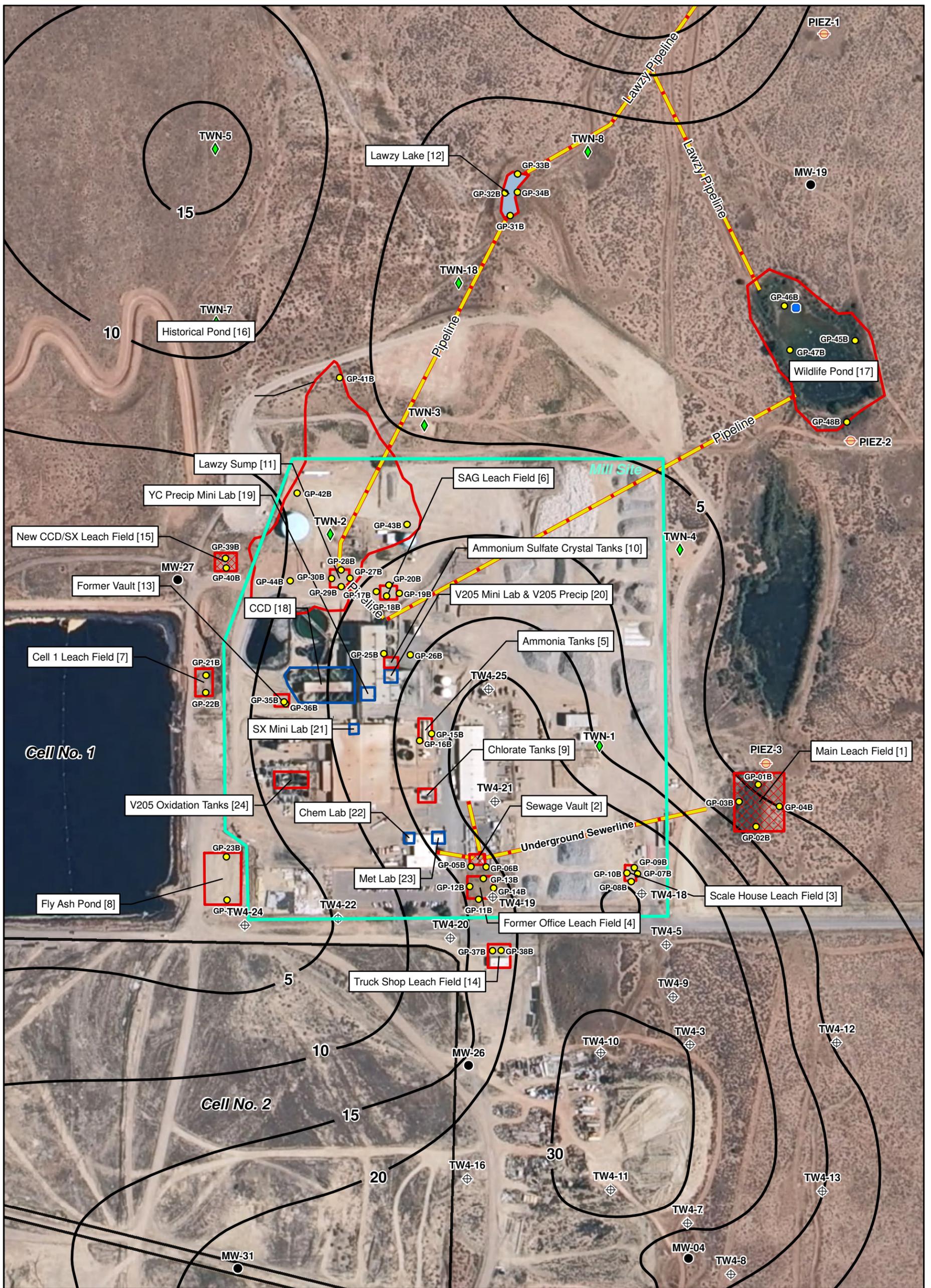
- Qaf Alluvium/Fill
- Km Mancos Shale
- Kdbc Dakota Sandstone/ Burro Canyon Formation
- Jmbb Brushy Basin Member of Morrison Formation
- Shale in Dakota / Burro Canyon Formation
- Conglomerate or Conglomeratic Sandstone in Dakota / Burro Canyon Formation
- Piezometric Surface
- Approximate Area >10 mg/L Nitrate
- Approximate Area > 100 mg/L Chloride



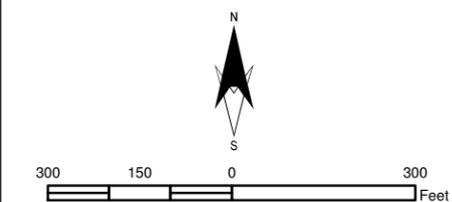
**INTERPRETIVE NORTHWEST-SOUTHEAST  
 CROSS SECTION (NW-SE)  
 WHITE MESA SITE**

APPROVED SJS	DATE 5/24/11	REFERENCE H:/718000/dakota/ xsection/ewxsect/ewxsectb_rev2.srf	FIGURE 9
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Sources: Aerial - Utah GIS Portal website, dated 2009;  
Wells - HGC, May 2008 Report



Legend	
	Pipeline
	Potential Nitrate and Chloride Sources
	Leach Field (currently in operation)
	Leach Field - Geoprobe Boring and Core Drilling Location
	Potential Source Location - No Geoprobe Boring or Core Boring
	Monitoring Well
	Piezometer
	Surface Water
	Chloroform Monitoring Well
	Nitrate Monitoring Well
	Geoprobe Boring



Figure 11  
Nitrate Source Areas: Geoprobe Boring and Core Drilling Locations Showing the Thickness of the Mancos Shale  
Nitrate and Chloride Source Investigation

Nitrate at Potential Site Source  
Where Mancos is Thin  
(i.e., leach field, ammonia tanks,  
ammonium sulfate crystal tanks, etc.)

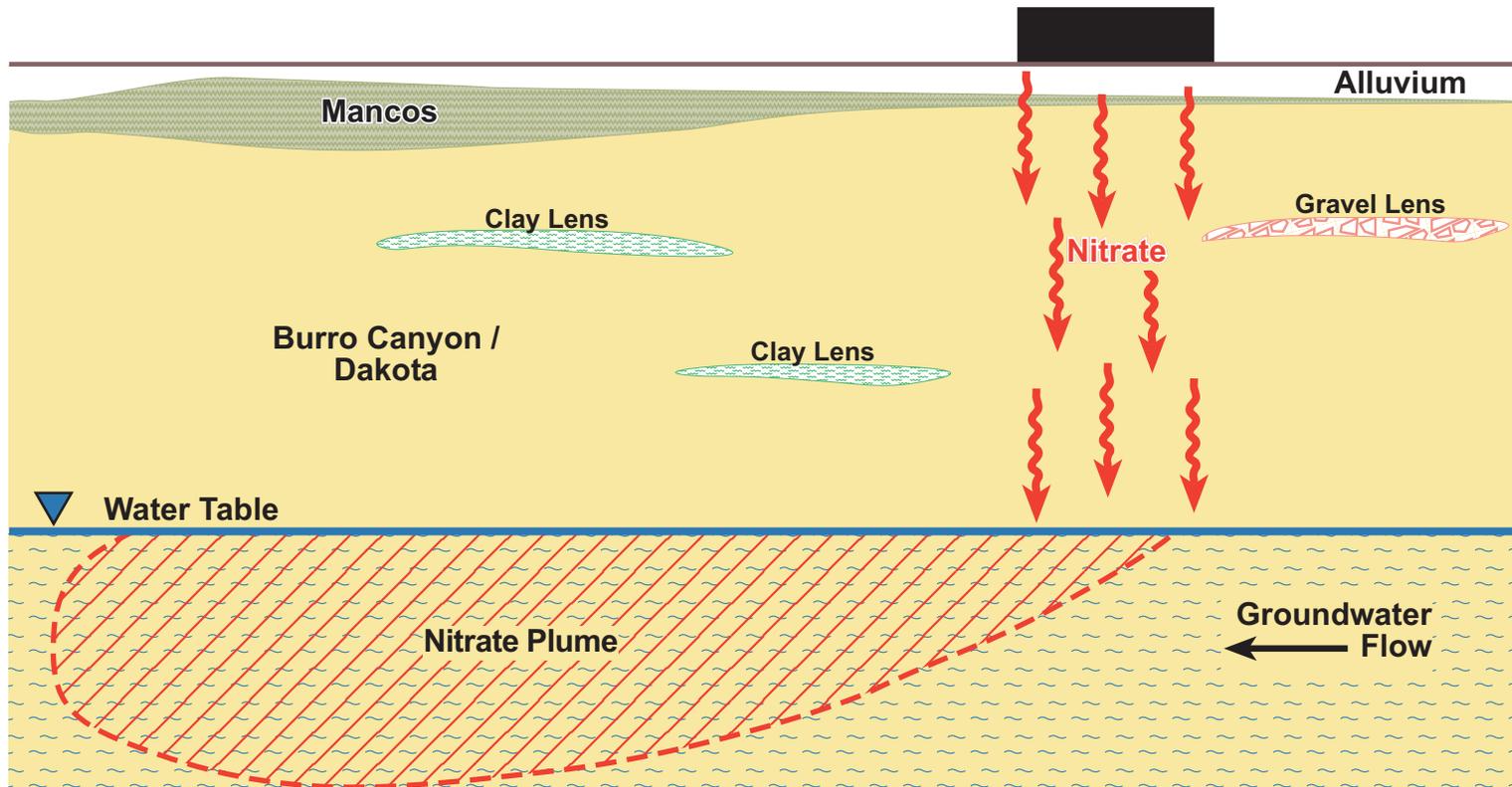


Figure 12  
Potential Natural  
Nitrate Reservoir Source  
Nitrate Investigation Revised  
Phase 2-5 Work Plan



Nitrate at Potential Site Source  
Where Mancos is Thick  
(i.e., leach field, ammonia tanks,  
ammonium sulfate crystal tanks, etc.)

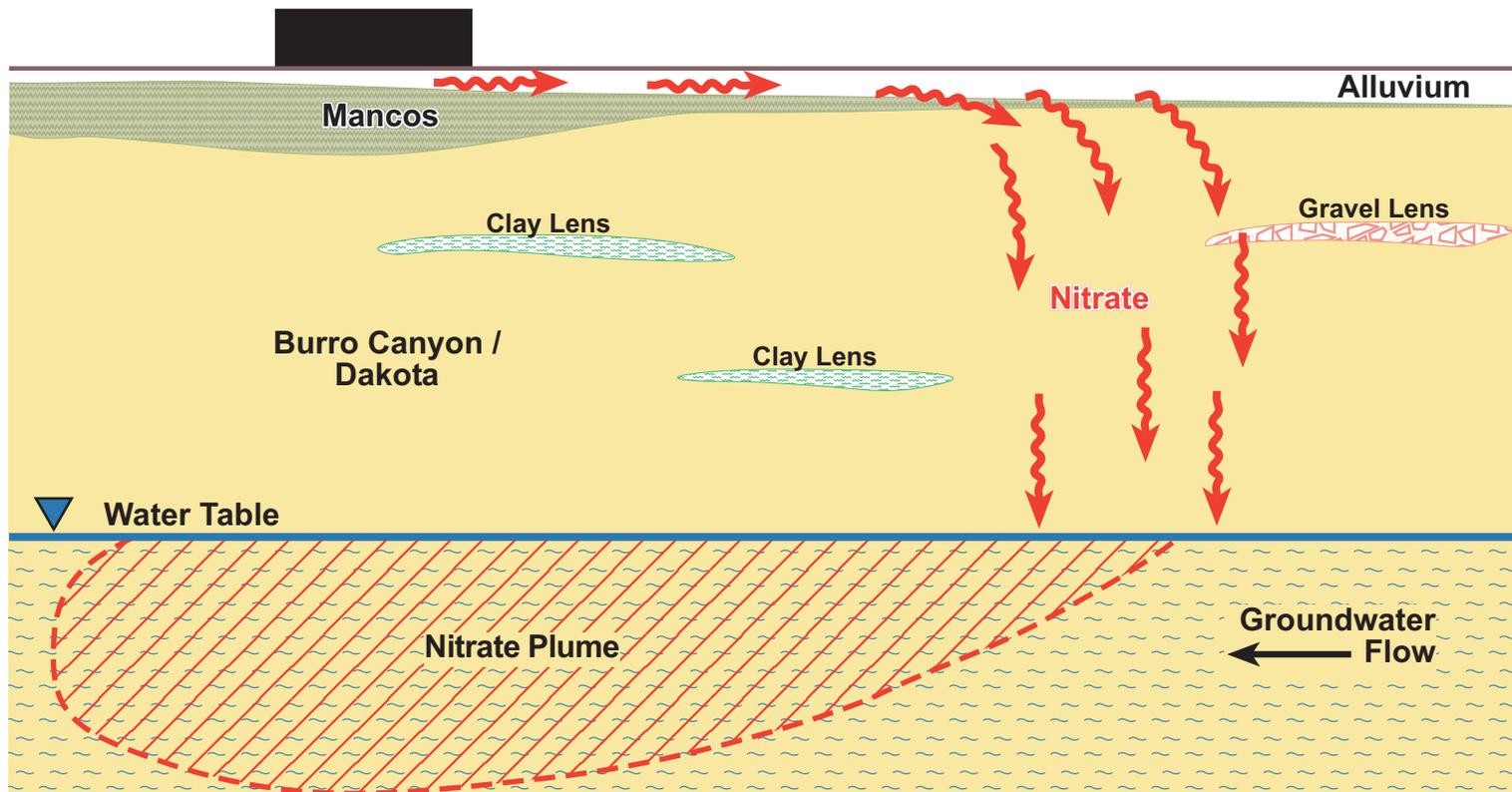


Figure 13  
Potential Process-Related Source  
Where Mancos is Thin  
Nitrate Investigation Revised  
Phase 2-5 Work Plan



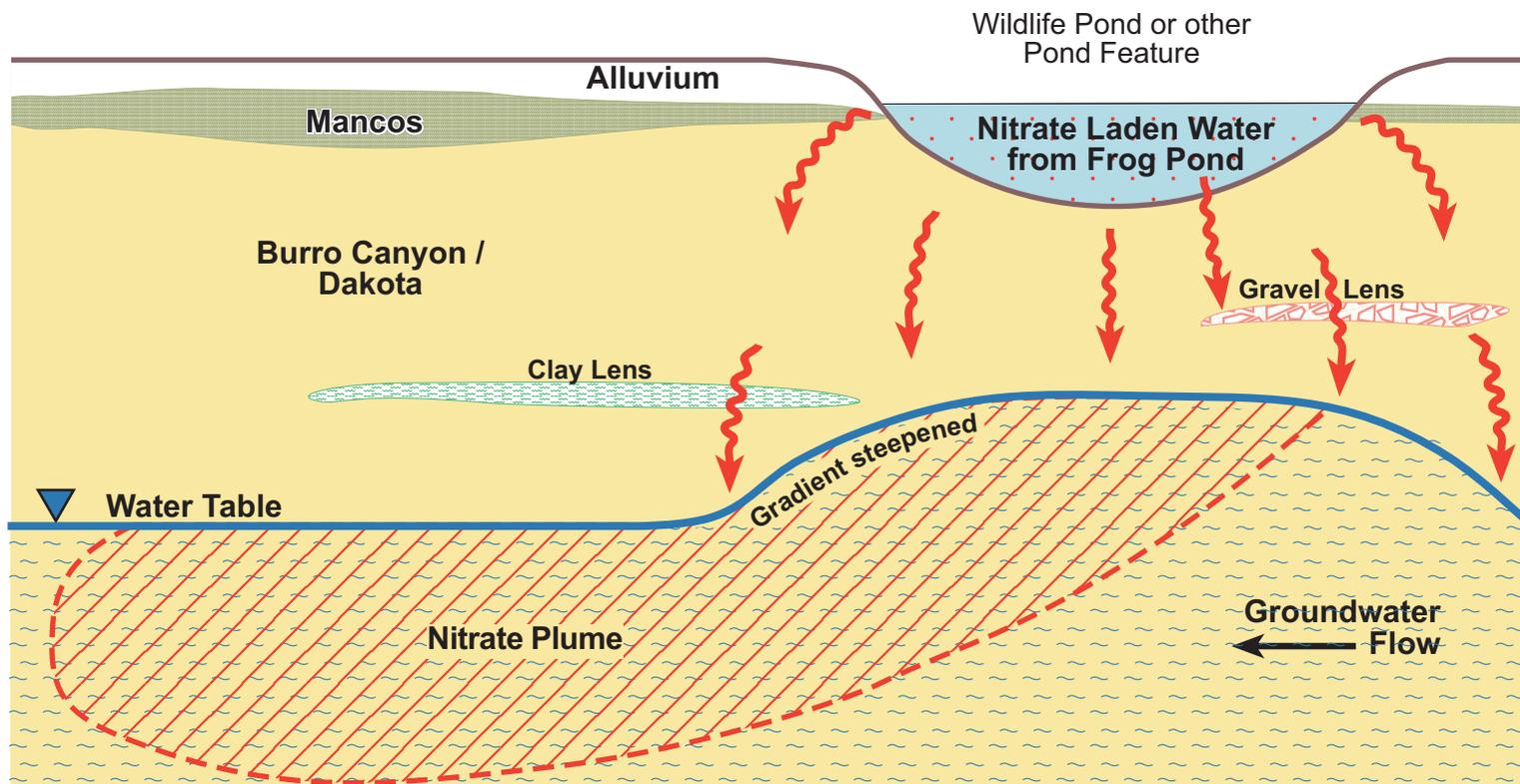


Figure 14  
 Potential Process-Related Source  
 Where Mancos is Thick  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan



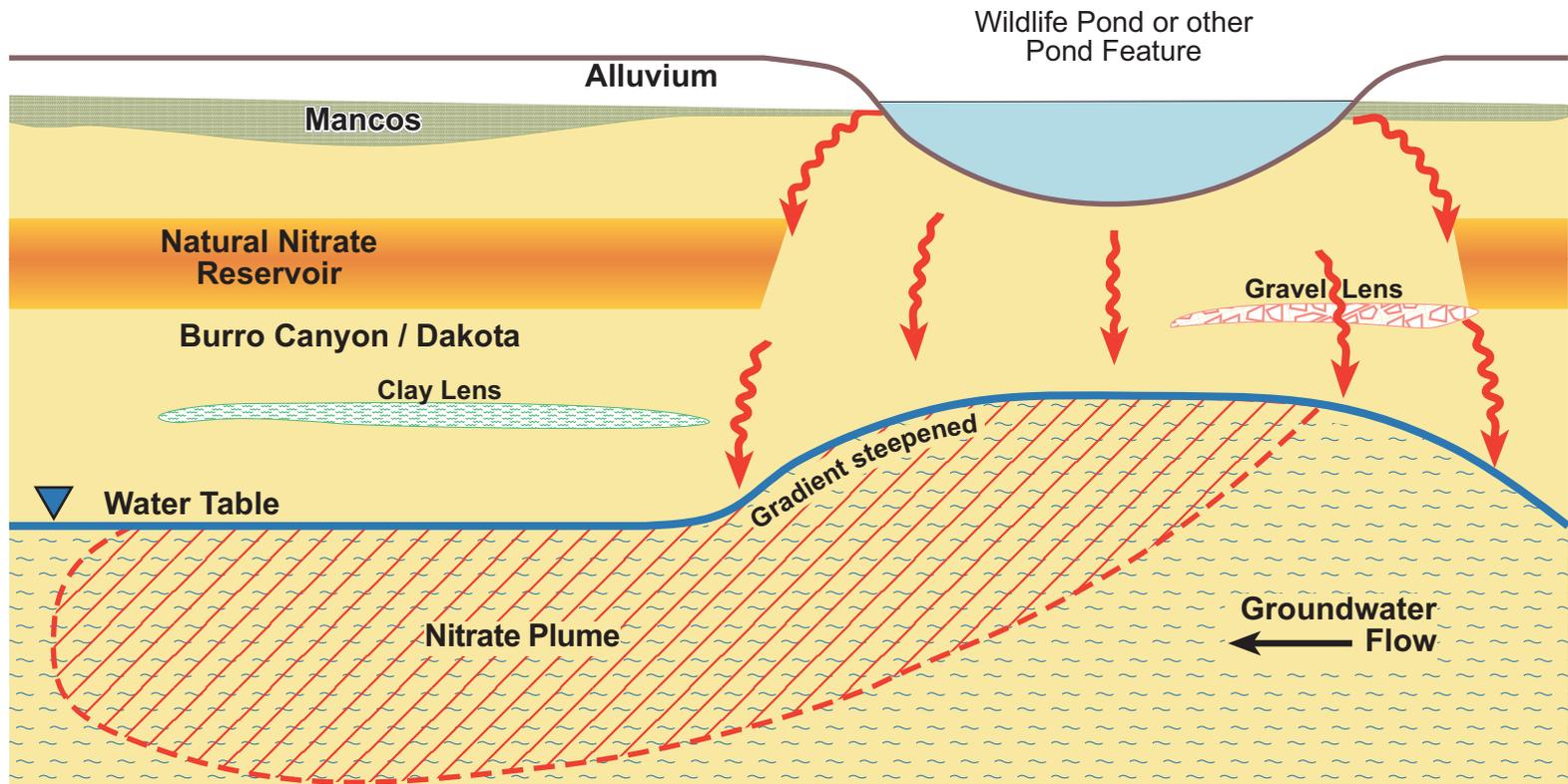


Figure 15  
 Potential Pond or Pond-Like Source  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan



# Natural Nitrate Reservoir Investigation

**Phase 1**

**Phase 5**

**Phase 3**

**Phase 5**

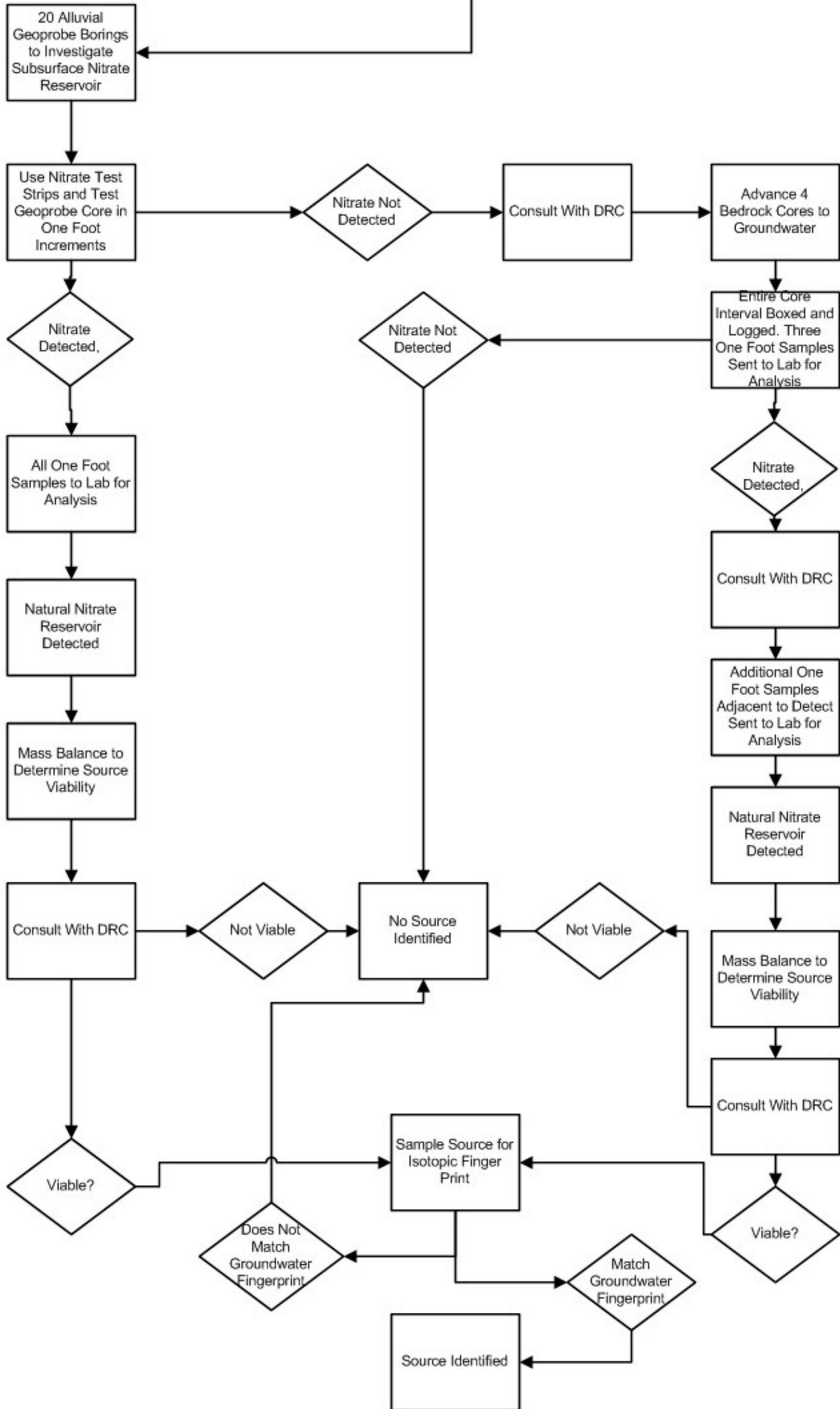


Figure 16  
Logic Diagram for Potential Natural Nitrate Reservoir Source Investigation  
Nitrate Investigation Revised  
Phase 2-5 Work Plan



# Potential Process Related Source Investigation

Phase 1

Phase 5

Phase 3

Phase 5

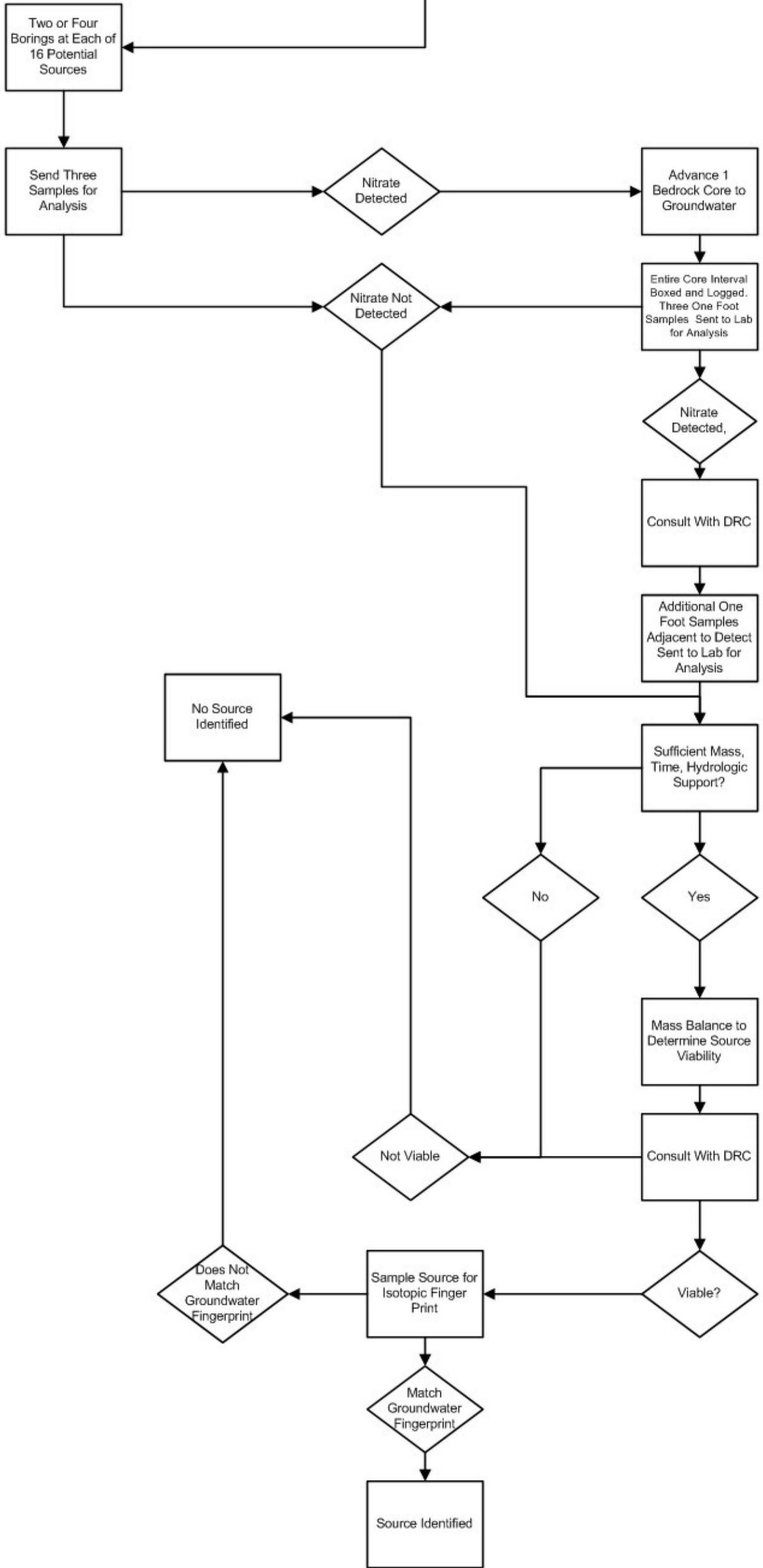


Figure 17  
 Logic Diagram for Potential Process Related Source Investigation  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan



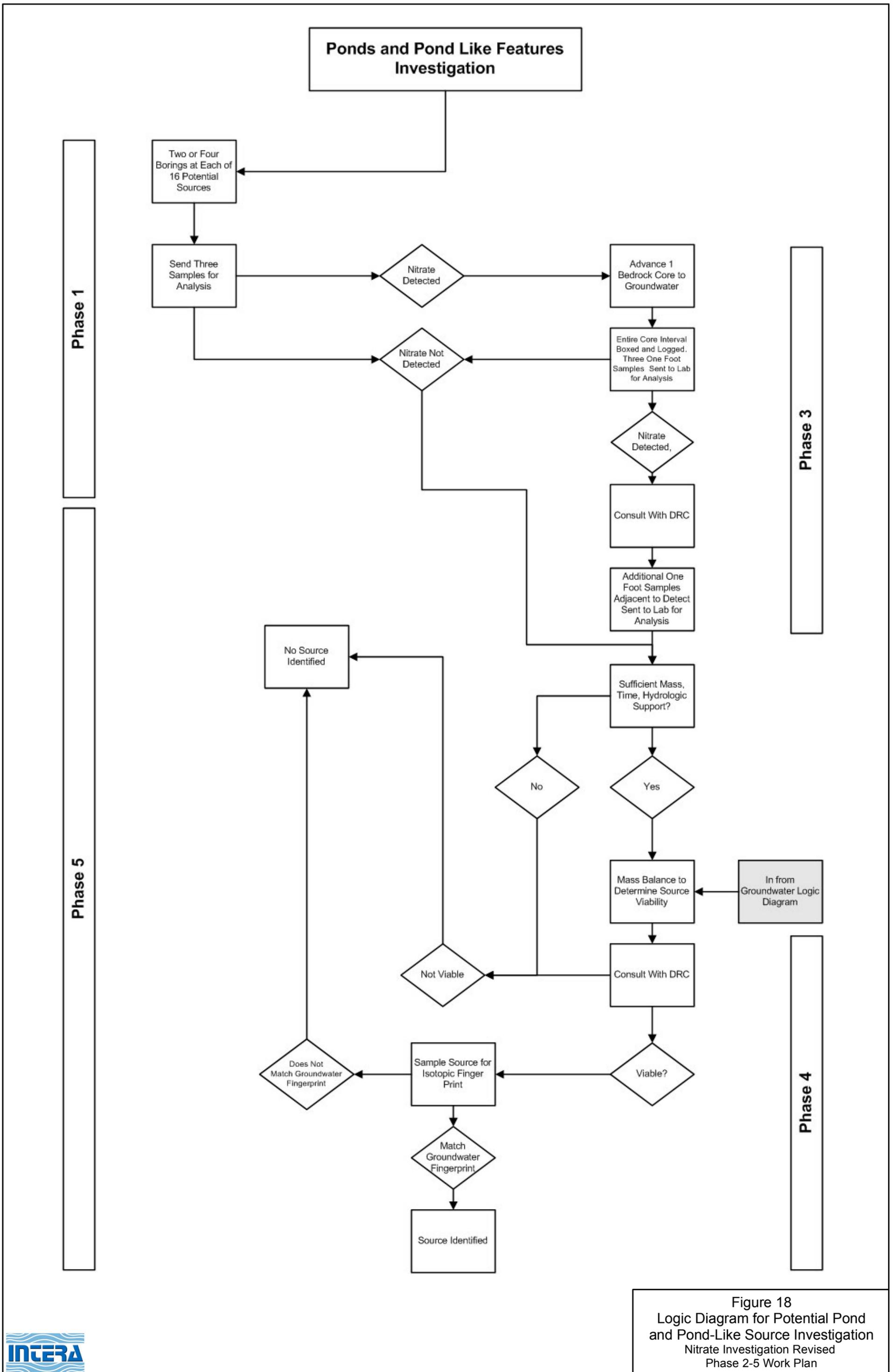


Figure 18  
 Logic Diagram for Potential Pond  
 and Pond-Like Source Investigation  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan



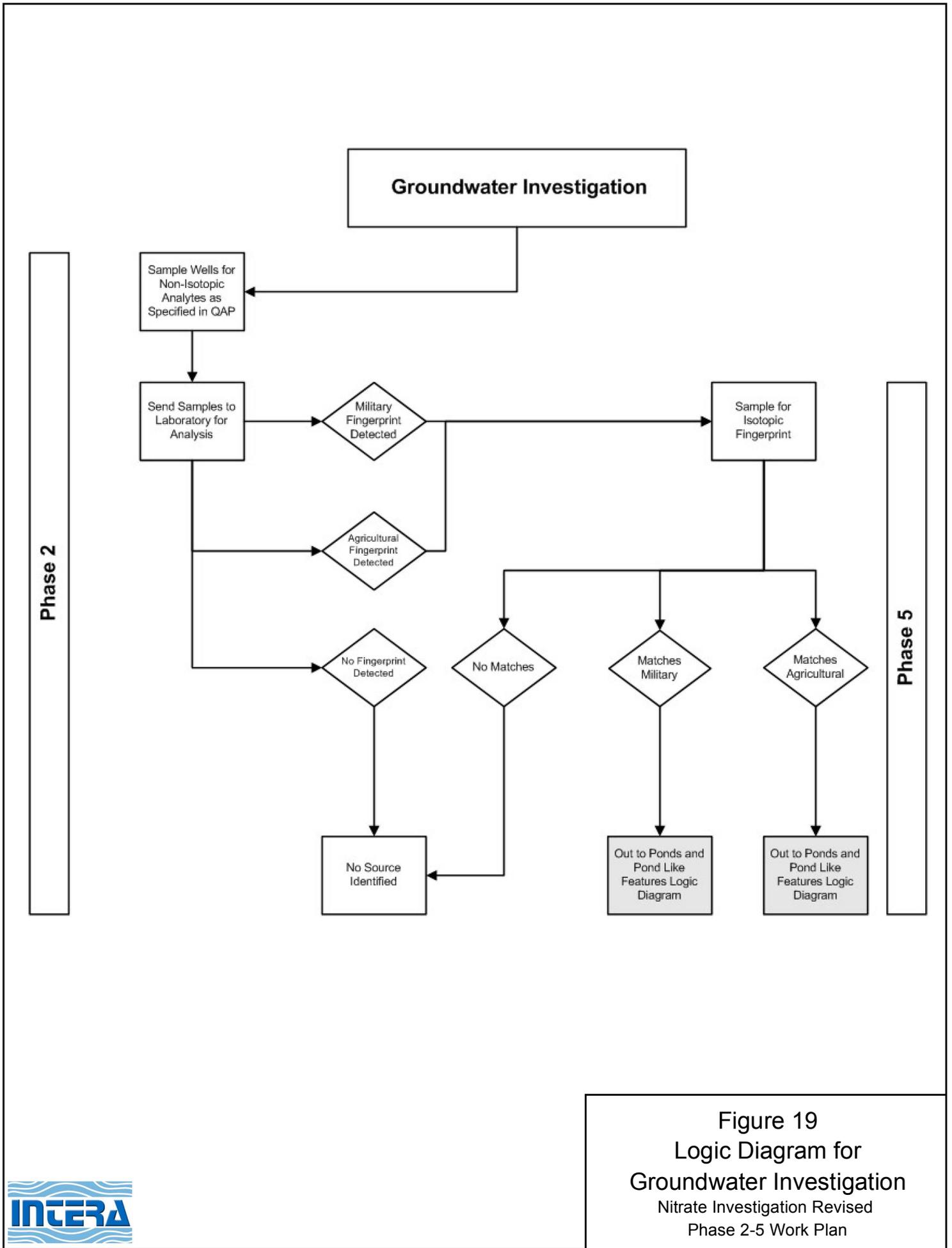
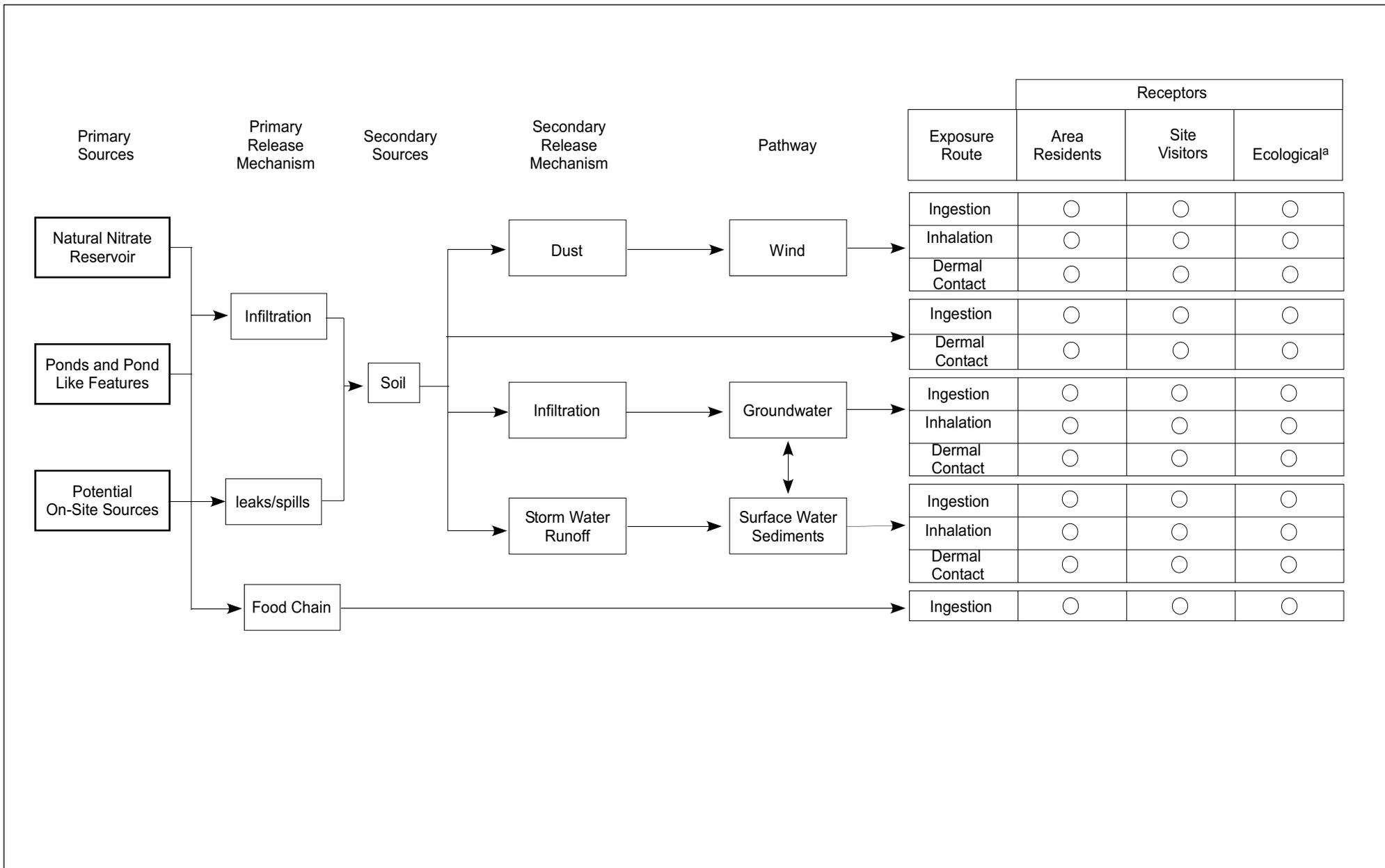


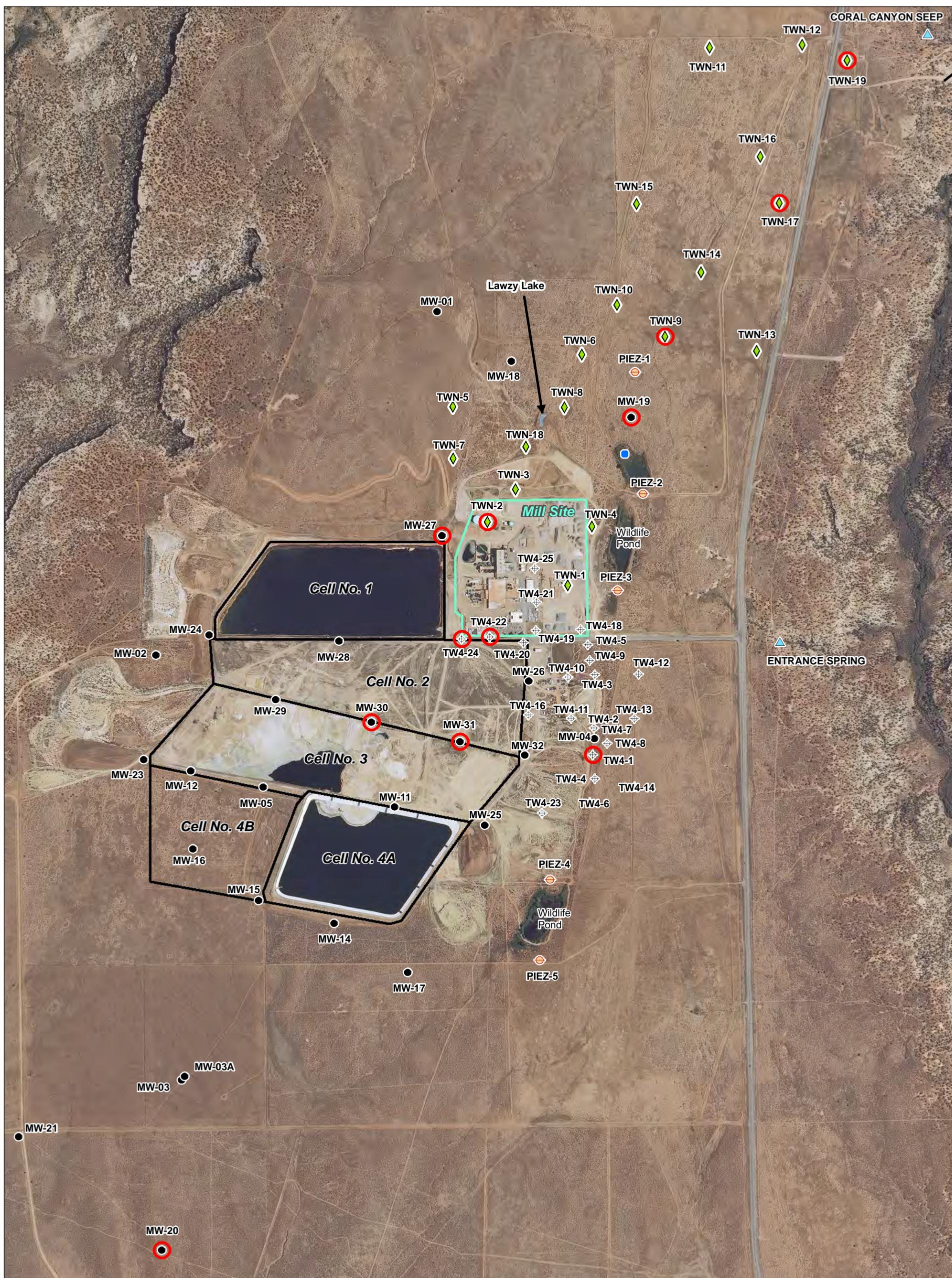
Figure 19  
 Logic Diagram for  
 Groundwater Investigation  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan



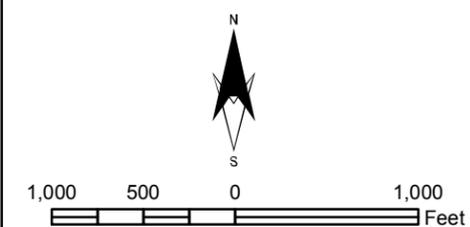


This diagram is based on Figure 2-2 of Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA and ASTM E1689-95.

	●	Pathway Complete, further evaluation recommended		<p align="center"><b>Figure 20</b>  <b>Diagram for Conceptual Model at White Mesa Mill Nitrate Investigation Phase 2-5 Revised Work Plan</b></p>
	○	Pathway evaluated and found incomplete, no further evaluation recommended		
	a	Ecological receptors may include plants, insects, worms, mammals, and birds		

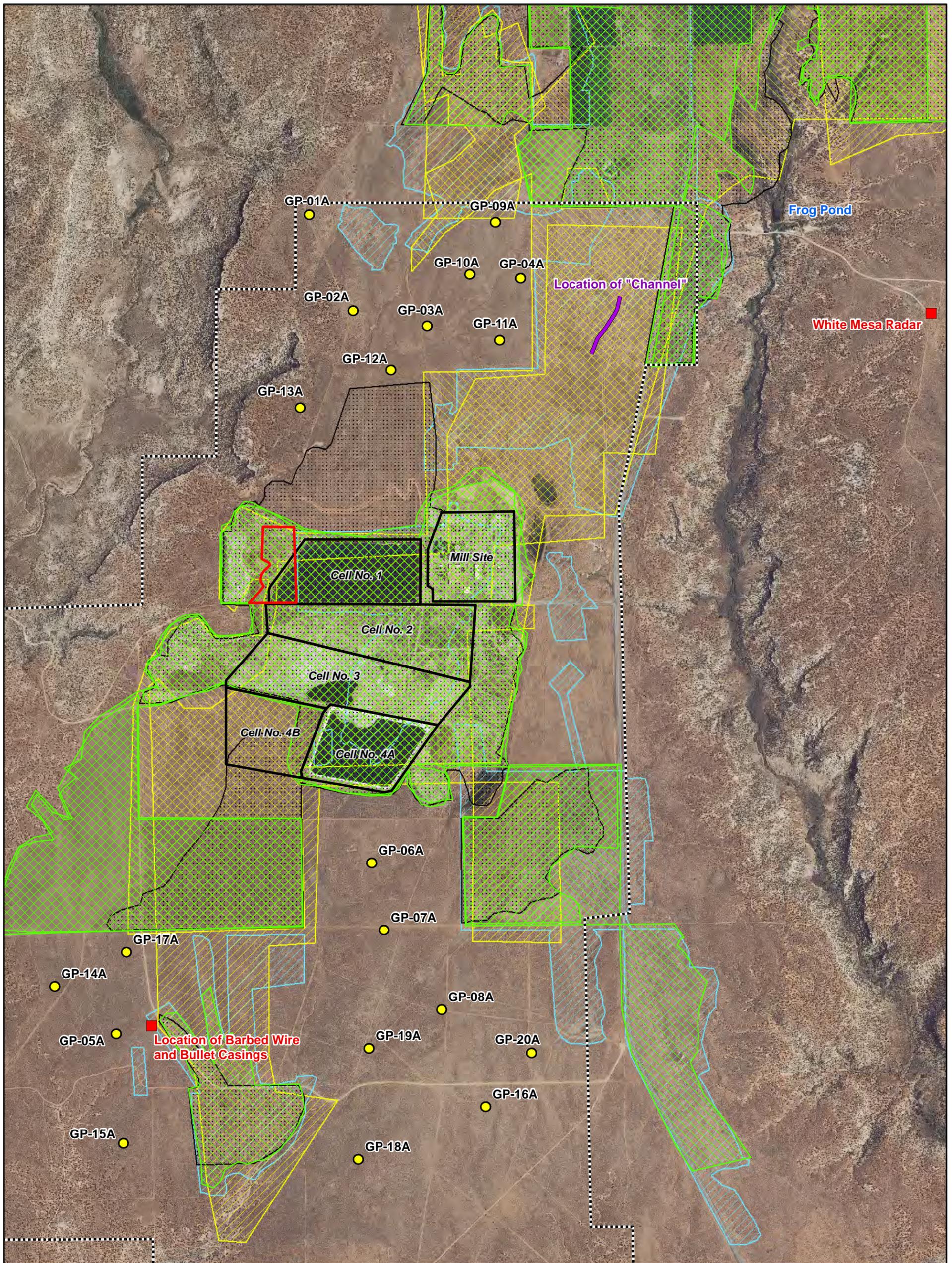


Source(s): Aerial – Utah GIS Portal website, dated 2009;  
 Wells – HGC, Inc., May 2008 report.

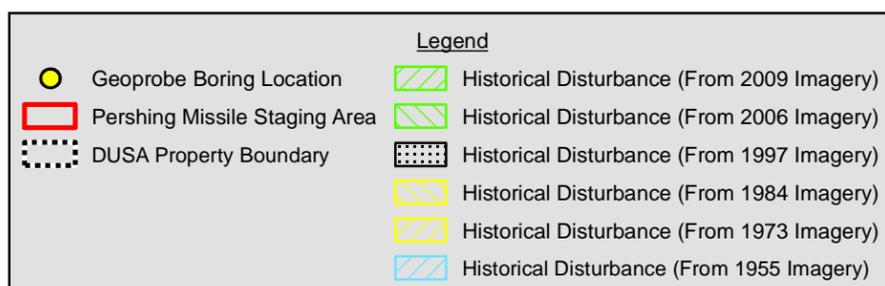


Legend	
<span style="color: red;">○</span>	Wells used in Phase 2 Groundwater Sampling
<span style="color: black;">●</span>	Monitoring Well
<span style="color: orange;">○</span>	Piezometer
<span style="color: blue;">▲</span>	Spring/Seep
<span style="color: blue;">■</span>	Surface Water
<span style="color: grey;">⊕</span>	Chloroform Monitoring Well
<span style="color: green;">◆</span>	Nitrate Monitoring Well

**Figure 21**  
 Phase 2 Groundwater  
 Sampling Locations  
 Nitrate Investigation Revised  
 Phase 2-5 Work Plan

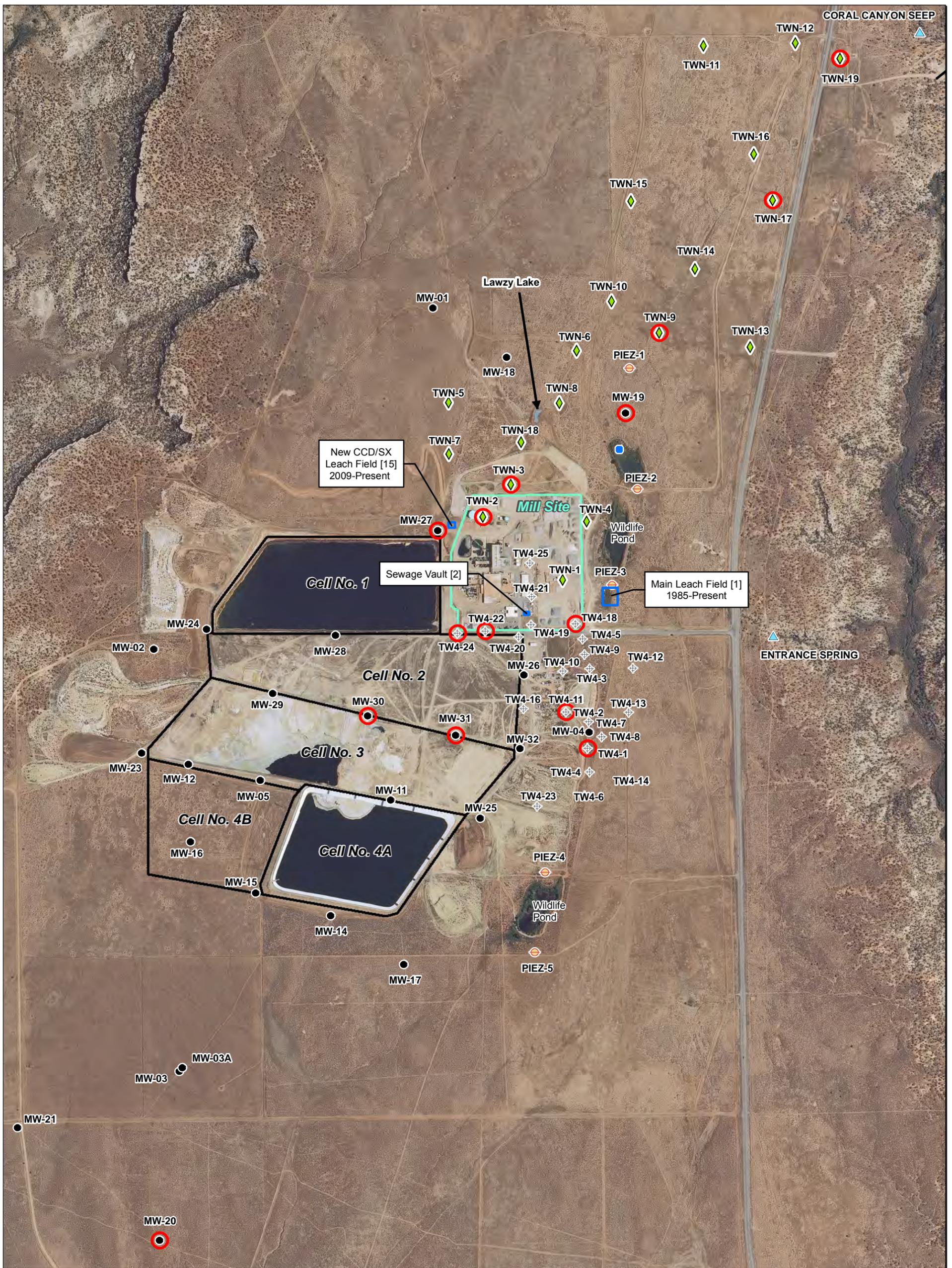


Source(s): Utah GIS Portal website, dated 2009;  
U.S. Geological Survey



**Figure 22**  
Phase 3 Potential  
Coring Locations  
Nitrate Investigation Revised  
Phase 2-5 Work Plan

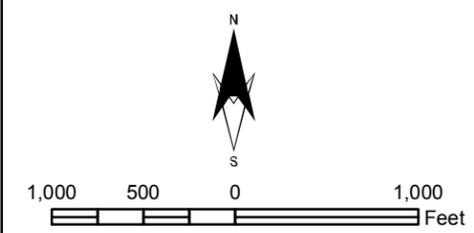




Source(s): Aerial – Utah GIS Portal website, dated 2009; Wells – HGC, Inc., May 2008 report.

**Legend**

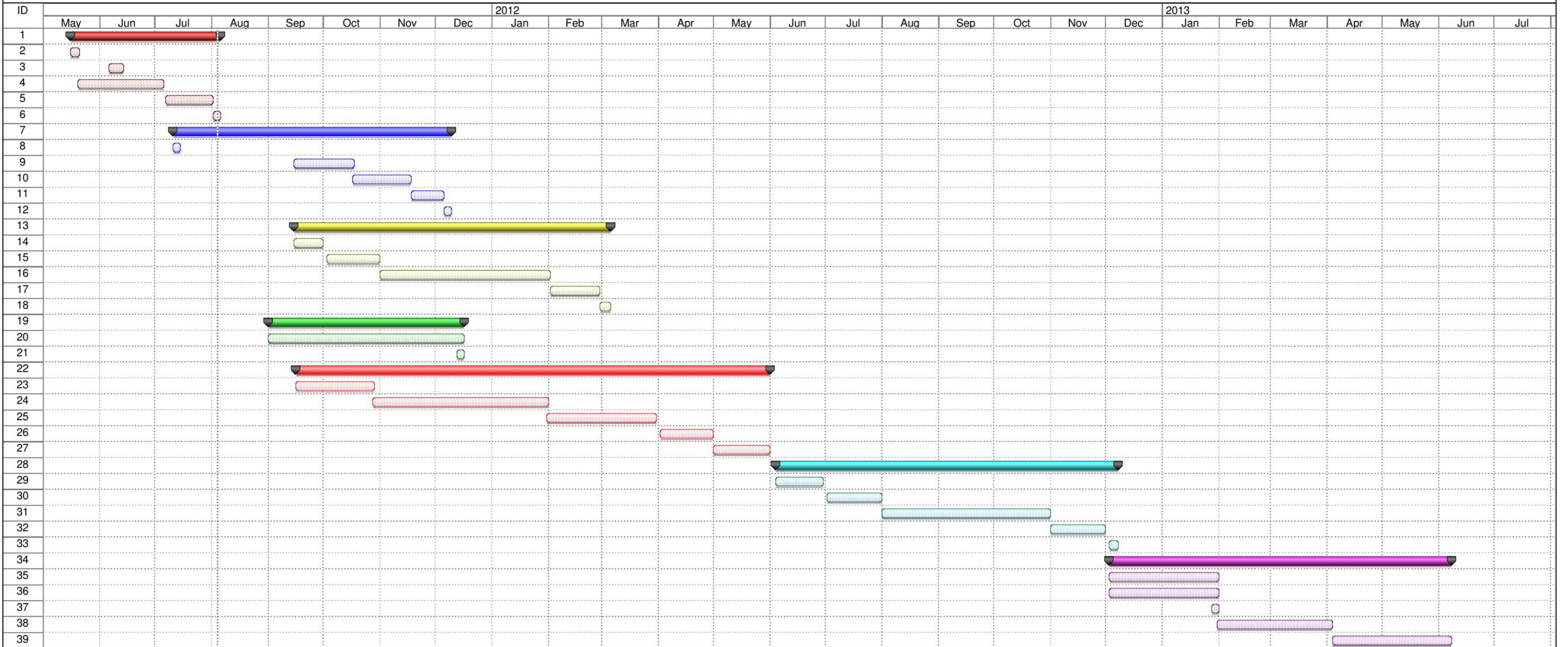
	Wells used in Phase 4 Groundwater Sampling		Spring/Seep
	Waste Water Sample - Only for Phase 4		Surface Water
	Monitoring Well		Chloroform Monitoring Well
	Piezometer		Nitrate Monitoring Well



**Figure 23**  
Phase 4 Groundwater Sampling Locations  
Nitrate Investigation Revised  
Phase 2-5 Work Plan

## **TABLES**

**Table 1. Work Plan Schedule**  
**Denison White Mesa Mill Nitrate and Chloride Investigation**



Project: Table 1\_Work Plan Schedule  
 Date: Thu 8/4/11

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			



**Table 2: Summary of Most Recent  
Chloride and Nitrate Concentrations in Groundwater**

Well	Date	Chloride (mg/L)	Data Qualifier	Nitrate (mg/L)	Data Qualifier
MW-1	4/11/2011	18		0.1	U
MW-2	4/12/2011	7		0.1	U
MW-3	4/13/2011	64		0.3	
MW-3A	4/13/2011	65		1.2	
MW-4	6/1/2011	35		4.9	D
MW-5	4/12/2011	54		0.2	
MW-11	4/4/2011	31		0.1	U
MW-12	4/5/2011	64		0.1	U
MW-14	4/4/2011	20		0.1	U
MW-15	4/12/2011	43		0.2	
MW-17	5/25/2011	36		1.1	
MW-18	4/6/2011	46		0.1	U
MW-19	4/6/2011	26		2.6	D
MW-20	4/11/2011	64		2.9	D
MW-22	4/6/2011	55		2.3	D
MW-23	4/11/2011	8		0.3	
MW-24	4/5/2011	45		0.2	
MW-25	4/4/2011	31		0.1	U
MW-26	6/20/2011	39		0.3	
MW-27	4/5/2011	43		6.4	D
MW-28	4/11/2011	109		0.2	
MW-29	4/5/2011	38		0.1	U
MW-30	6/20/2011	127		17	D
MW-31	6/20/2011	145		22	D
MW-32	5/25/2011	31		0.1	U
MW-34	4/13/2011	69		0.3	
MW-35	4/12/2011	64		0.1	U
Piez-1	4/25/2011	58		6.8	D
Piez-2	4/25/2011	8		0.3	
Piez-3	4/25/2011	35		1.7	
TW4-1	6/1/2011	35		7	D
TW4-10	6/1/2011	42		3.3	D
TW4-11	6/1/2011	49		7.3	D
TW4-12	5/25/2011	32		7	D
TW4-13	5/25/2011	56		5.4	D
TW4-14	5/26/2011	24		1.4	
TW4-15	5/31/2011	88		0.4	
TW4-16	5/26/2011	81		5	D
TW4-17	2/23/2011	40		0.1	U
TW4-18	5/26/2011	36		9	D



**Table 2: Summary of Most Recent  
Chloride and Nitrate Concentrations in Groundwater**

Well	Date	Chloride (mg/L)	Data Qualifier	Nitrate (mg/L)	Data Qualifier
TW4-19	6/7/2011	148		12	D
TW4-2	6/2/2011	42		6.8	D
TW4-20	6/1/2011	177		4.8	D
TW4-21	6/1/2011	297		13	D
TW4-22	6/1/2011	138		17	D
TW4-23	5/25/2011	44		0.1	U
TW4-24	5/26/2011	1110		35	D
TW4-25	5/25/2011	321		16	D
TW4-26	5/26/2011	15		10	D
TW4-3	5/25/2011	23		3.7	D
TW4-4	6/1/2011	35		7	D
TW4-5	5/26/2011	35		7.2	D
TW4-6	5/26/2011	42		0.3	
TW4-7	6/1/2011	35		4	D
TW4-8	5/25/2011	45		0.1	
TW4-9	5/25/2011	38		3.4	D
TWN-1	4/20/2011	19		0.5	
TWN-10	4/21/2011	28		1.2	
TWN-11	4/26/2011	76		1.4	
TWN-12	4/26/2011	109		1	
TWN-13	4/26/2011	49		0.1	U
TWN-14	4/27/2011	30		3.5	D
TWN-15	4/27/2011	49		1.6	
TWN-16	4/27/2011	39		1.6	D
TWN-17	4/28/2011	81		9	D
TWN-18	4/26/2011	67		1.8	
TWN-19	4/28/2011	120		6.9	D
TWN-2	4/28/2011	85		40	D
TWN-3	4/28/2011	128		26	D
TWN-4	4/20/2011	21		0.9	
TWN-5	4/20/2011	44		0.3	
TWN-6	4/20/2011	22		1.5	
TWN-7	4/21/2011	6		1.7	
TWN-8	4/19/2011	10		0.1	U
TWN-9	4/28/2011	192		10	D
UWLP	4/25/2011	1	U	0.1	U

Notes

U= Not detected at minimum detectable concentration

D= Reporting limit was raised due to sample matrix



Table 3: Phase 2 Groundwater Sampling Locations

Monitoring Well Location	Sample ID <sup>a</sup>	Duplicate/MS/MSD Location ID	Date & Time Sampled	Number of Samples	Duplicate Location ID <sup>a</sup>	Matrix	Analyte (Method) <sup>2</sup>	Sample Containers *	Preservative	Reporting Limit <sup>1</sup>	Holding Time	Sample Temperature Requirements	Comments
<b>Campaign 1</b>													
MW-20	MW-20			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-31	MW-31			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-19	TWN-19			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-2	TWN-2	X		1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
							Cryptosporidium 1623	1 – 10 liter cubitainer	None	0.1 µg/L	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 ug/L	7 days to extraction/40 days for extract	≤ 6°C	
TWN-9	TWN-9			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-17	TWN-17			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-19	MW-19			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-27	MW-27			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-30	MW-30			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TW4-1	TW4-1			2	TW4-1D	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TW4-22	TW4-22			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
							Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TW4-24	TW4-24			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TW4-24	TW4-24-RB			1	NA	Aqueous	Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	

Table 3: Phase 2 Groundwater Sampling Locations

Monitoring Well Location	Sample ID <sup>a</sup>	Duplicate/MS/MSD Location ID	Date & Time Sampled	Number of Samples	Duplicate Location ID <sup>a</sup>	Matrix	Analyte (Method) <sup>2</sup>	Sample Containers *	Preservative	Reporting Limit <sup>1</sup>	Holding Time	Sample Temperature Requirements	Comments
<b>Campaign 2 (if needed)</b>													
MW-19	MW-19			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
MW-20	MW-20			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
MW-27	MW-27			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
MW-30	MW-30			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
MW-31	MW-31			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TWN-2	TWN-2			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TWN-9	TWN-9			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TWN-17	TWN-17			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TWN-19	TWN-19			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TW4-1	TW4-1			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
TW4-24	TW4-24	X		1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
DIFB	DIFB			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	

Table 3: Phase 2 Groundwater Sampling Locations

Monitoring Well Location	Sample ID <sup>a</sup>	Duplicate/MS/MSD Location ID	Date & Time Sampled	Number of Samples	Duplicate Location ID <sup>a</sup>	Matrix	Analyte (Method) <sup>2</sup>	Sample Containers *	Preservative	Reporting Limit <sup>1</sup>	Holding Time	Sample Temperature Requirements	Comments
<b>Background Wells- Campaign 2</b>													
TWN-8	TWN-8			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-11	TWN-11			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-13	TWN-13			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-15	TWN-15			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
TWN-16	TWN-16			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-1	MW-1			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-2	MW-2			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-3	MW-3			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-12	MW-12			1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	
MW-18	MW-18	X		1	NA	Aqueous	Cryptosporidium 1623	1 – 10 liter cubitainer	None	NA	96 hours until filtration	≤ 20°C	
							Explosives (RDX and HMX) EPA 8330	3 – 1 liter amber glass bottles	None	0.1 µg/L	7 days to extraction/40 days for extract	≤ 6°C	
							Perchlorate EPA 6850	1 – 250 ml. polyethylene	None	0.5 µg/L	28 days	≤ 10°C	

<sup>a</sup> Duplicate sample locations and equipment blank sample locations subject to change due to field conditions at discretion of field team leader

Table 4: Phase 3 Coring Sample Locations

Boring Location <sup>a</sup>	Sample Location ID <sup>b,c</sup>	Date & Time Sampled	Number of Samples	DTW (ft bgs)	TD (ft bgs)	Sample Interval (ft bgs)	Duplicate Collected	Duplicate Location ID <sup>c</sup>	Matrix	Minimum Sample Mass/Volume	Sample Containers <sup>d</sup>	Analyte (Method)	Comments				
<b>Phase 3A - Deep Bedrock Coring in Undisturbed Locations</b>																	
TBD	C-++A-tt-dd											C-++A-tt-ddD	Rock	200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)	
TBD	C-++A-tt-dd										Rock		200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)		
TBD	C-++A-tt-dd										Rock		200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)		
TBD	C-++A-tt-dd										Rock		200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)		
TBD	C-++A-RB		1									NA	Aqueous	250 mL 250 mL	Two (2) 4-oz, Plastic or Glass	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)	
<b>Phase 3B - Deep Bedrock Coring of Potential Nitrate Source Locations</b>																	
TBD	C-++B-tt-dd											C-++B-tt-ddD	Rock	200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)	
TBD	C-++B-tt-dd										Rock		200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)		
TBD	C-++B-tt-dd										Rock		200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)		
TBD	C-++B-tt-dd										Rock		200 g	Ziploc Bag	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)		
TBD	C-++B-RB		1									NA	Aqueous	250 mL 250 mL	Two (2) 250-mL, Plastic	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1)	

a Locations to be determined upon receiving Phase 1 laboratory analytical results

b ++# is the location ID from Phase 1 and tt-dd is the sample depth interval

c Duplicate sample location and equipment blank sample location subject to change due to field conditions at discretion of field team leader

d Sample preservation methods and holding times shown in Table 5

**Table 5: Phase 3 Coring Laboratory Analytical Parameters**

Analyte	Analytical Method	Reporting Limit	Holding Time	Preservation	Temperature Requirement
SPLP Leachate	EPA 1312*	NA	28 days	None	Cool to $\leq 4^{\circ}\text{C}$
Nitrate+Nitrite	EPA 353.2	0.01 mg/L	28 days	H <sub>2</sub> SO <sub>4</sub> to a pH <2**	Cool to $\leq 4^{\circ}\text{C}$ **
Chloride and Sulfate	EPA 300.0	Chloride – 0.1 mg/L Sulfate – 0.75 mg/L	28 days	None**	Cool to $\leq 4^{\circ}\text{C}$ **
Ammonia as N	EPA 350.1	0.05 mg/L	28 days	H <sub>2</sub> SO <sub>4</sub> to a pH <2**	Cool to $\leq 4^{\circ}\text{C}$ **

\* Extraction Fluid 3 will be used. Standard extraction requires the addition of nitric acid and sulfuric acid during the leaching process. Since the leachates will be analyzed for nitrate+nitrite and sulfate, the DI leaching process contemplated by the method (for cyanide containing samples) will be used in lieu of the standard leaching procedure.

\*\*Preservation and temperature requirements listed are for the leachates generated from the SPLP leaching procedure 1312 and for the equipment rinse samples collected during drilling activities.



**Table 6: Phase 4 Groundwater Isotopic Fingerprinting Sample Locations**

Sample Location	Sample ID <sup>a</sup>	Date & Time Sampled	Number of Samples	Duplicate Collected	Duplicate Location ID <sup>a</sup>	Analyte (Method)	Comments
TWN-3	TWN-3		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TWN-2	TWN-2		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TW4-22	TW4-22		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TW4-24	TW4-24		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
MW-31	MW-31		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TW4-18	TW4-18		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TW4-18	TW4-18		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TW4-11	TW4-11		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TW4-1	TW4-1		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
MW-30	MW-30		2		MW-30D	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
MW-27	MW-27		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
MW-19	MW-19		2		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TWN-19	TWN-19		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TWN-17	TWN-17		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	
TWN-9	TWN-9		1		NA	Nitrate+Nitrite (EPA 353.2) Chloride and Sulfate (EPA 300.0) Ammonia (EPA 350.1) Nitrate Isotope Analysis Ammonia Nitrogen Isotope Analysis Sulfate Isotope Analysis	

<sup>a</sup> Duplicate sample location and equipment sample location subject to change due to field conditions at discretion of field team leader

## **APPENDIX A**

**U.S. Bureau of Reclamation's Engineering Geology Field Manual**

## **11.0 GENERAL**

When installing monitoring wells in consolidated formations, the reliability and overall sample quality of the drilled samples from either direct–fluid rotary or air, water, and foam systems is very similar to that of the samples obtained in unconsolidated formations. Where reliable samples are needed to fully characterize the monitored zone, it is suggested that cores be taken. Coring can be conducted by either wireline or conventional methods. N-series split inner tube core barrels are usually used. Air is the preferred drilling fluid. Dust control for air–rotary methods is achieved through the use of a plastic diaper that fits around the back of the rig and prevents dust migration. Techniques for obtaining and handling the cores are described below. Both single– and double–tube core barrels may be utilized.

These guidelines are of necessity general in nature, as differing site conditions and project goals may require adjustments and/or modifications to the procedures.

## **11.1 EQUIPMENT LIST**

### **11.1.1 Core recovery and photography**

- V trough to hold retrieved core
- camera
- Photographic bar scale
- index cards for photograph data (boring #, core run #, etc.).

### **11.1.2 Logging**

- Measuring tape at least 10 feet long, graduated to at least 0.1 feet
- Hand lens
- Boring logs
- Geologist's hammer
- Knife
- Hydrochloric acid (5%)
- Protractor
- Small plastic ruler
- Pencils
- Munsell color chart
- Calculator

### **11.1.3 Handling and Sample Preparation**

- Permanent markers (red, blue, and black or alternate colors)
- Core bags
- Chisel for breaking core
- Heavy aluminum foil
- Hand saw
- Masking tape
- Duct tape
- Core boxes

## **11.2 RECOVERING AND PHOTOGRAPHING**

Once the core barrel has been retrieved from the borehole, it is essential that the procedures used to handle and document the core be both efficient and complete. To minimize moisture loss and other environmental effects, the core should be kept out of direct sunlight when possible and samples should be sealed as soon as possible. The return from each core run should be transferred to the V block so that the top (higher elevation) is always to the logger's and photographer's left. The core should then be photographed promptly. Each photo should include clear and visible markers (e.g., index cards) with the boring number, core run number depths at the top and bottom of the run, date, and time. A bar scale should also be included in each photo. For uniformity, the core should be photographed in lengths not exceeding about four feet.

## **11.3 MARKING THE CORE**

After photographing, the core may be marked with two vertical marker stripes down its entire length to establish an orientation benchmark or scribe line and to allow for the reassembly of the core if the core pieces are somehow mixed up or dropped. A red stripe may be drawn on the right side of the core (Red on Right) and a blue stripe may be drawn on the left side of the core (the side closest to the logger with the bottom of the run on the logger's right). To ensure consistency and efficiency, tape the red and blue markers together so that the core can be marked simultaneously. Care should be taken to mark the scribe lines as straight as possible. Sections chosen for laboratory analyses should not be marked. Depths should then be marked on the core in black marker where possible. Intervals of core loss, when identifiable, can be replaced with a core loss block (e.g., wood or Styrofoam) with the depths marked on the block. Some types of Styrofoam may not accept marking and will require a label, such as masking tape. Otherwise, an interval of appropriate length is left open at the end of each run and labeled as C-UN (core loss – unknown depth).

## **11.4 TOTAL RECOVERY AND RQD**

The total core recovery for that core run should be measured. The total recovery is defined as:

$$\text{Total core recovery} = (\text{length of all core pieces recovered} / \text{total length drilled})$$

The total recovery should be noted in the proper field log column as a fraction, and if time permits, a percentage. The field log also contains a column for noting the number and size of core pieces. The Rock Quality Designation (RQD) of the core should then be determined.

The RQD is defined as:

$$\text{RQD} = (\text{length of intact core pieces 4" in length}) / \text{total length drilled}$$

Pieces shorter than 4 inches (10 cm) in length resulting from close fractures or weathering should not be summed. Pieces broken during the drilling process or during handling ("mechanical breaks") should be fitted together and considered as one piece. These features are usually identifiable fresh breaks with a different character than natural discontinuities. The RQD values of individual beds, structural domains, weakness zones, and etc. should be logged separately.

## **11.5 LOGGING CONVENTIONS**

### **11.5.1 Lithologic Log Conventions**

Mark each core run in the "run number" column on the log as a rectangular box the length of the run. A vertical line should be drawn through the middle of the box. Intervals prepared for laboratory analysis (see sample preparation below) should be marked as solid segments in the core run symbol.

A standard macroscopic petrologic description (use Figure 11–2 as a guide) should be entered for each rock type encountered. Descriptions should include the following information:

- Rock type – the predominant type should be written in upper case, adjectives in lower case (see example log)
- Color – use of the Munsell color chart is recommended where pertinent
- Composition – identify important components and approximate percentages
- Texture – grain/crystal size, roundness, sphericity, voids, inclusions, etc.
- Weathering – include degree (fresh, slightly, moderately, highly, completely)

- Hardness – soft, moderately, medium, and extremely hard, based on scratch test with pocket knife
- Fossils – occurrence (type) and abundance
- Any pertinent or unusual aspects.

Any variation within a rock type should be noted at the appropriate depth. The proper symbol for the rock type should be drawn on the log in the "Lithologic Symbol". Abbreviations should be used in written descriptions to increase efficiency, but must be defined in a key that can be deciphered in the office. It is imperative that field logs be legible – write neatly! Use a scale of 1" = 5' or smaller (1" = 1').

### **11.5.2 Fracture Log**

The generic term for discontinuities without reference to genesis or mode of origin is "fracture." A "joint" is defined as a fracture that has experienced dominantly opening movement normal to the fracture plane. A "fault" is defined as a fracture for which movement parallel to the fracture plane can be demonstrated. The term "fracture" should be used in the log description unless sufficient evidence exists for a term describing its origin. Fractures should be recorded graphically on the field log in the "Lithologic Symbol" column at the depths and orientations at which they occur. Mechanical breaks should be shown as a jagged line and labeled "MB." Fractures should be described in the lithology column at the depths at which they occur. This description should include:

- Wall roughness – smooth or tough
- Fracture fillings – terms used to describe fracture fillings include
  - clean – no fracture filling material
  - stained – coloration of rock only, no recognizable filling material
  - filled – recognizable filling material

The percentage of the filling material present and its composition should be noted in the description. If possible, the separation distance between fracture walls should be recorded as well (in mm).

- Slickensides – the occurrence of slickensides and their relative orientation should also be noted.
- Fracture orientation – the orientation of fractures should be measured with a protractor relative to the red core scribe line.

## **11.6 OPERATIONAL NOTES**

For all sampling and coring operations, the log should be a complete chronology of drilling and sampling operations within the hole, including delays. The log should contain equipment data, including the type of core barrel and bit, and its length and diameter. In addition, the average rotational speed, downward hydraulic pressure, and average rate of penetration should be noted. Keep track of time (military or 24-hour clock) on the left-hand margin of the log at regular intervals.

## **11.7 HANDLING AND SAMPLE PREPARATION**

Once the core has been logged, intervals to be sampled should be selected and prepared. Once the core piece to be sampled is identified, place it on a large sheet(s) of aluminum foil and wrap it tightly. Be consistent with the position of the core each time you prepare a sample (e.g., always keep the lower depth or bottom to your right). Place the core in the plastic core bag in such a way that the core is resting on one side seam of the bag and you are holding the bag by the opposite side seam. There should be at least 3 inches of empty bag above the core. After tilting the bag until the core slides all the way to the bottom of the bag, lay the bag down on a flat surface with the seam you are holding away from you. Roll the core so that the empty side of the bag is tightly wrapped around the core and air space is minimized. Double tape the core close to the bottom with a continuous strip of masking tape. Then, grasp the top portion of the bag above the core and, holding it upright; spin it until the bag top is tightly wound. Fold the twisted top down and tuck it under the extra bag wrap, and then tape the core close to the top tightly so that the twist doesn't come undone.

The end product should be airtight and relatively wrinkle-free to minimize entrapped air. With the bottom to your right, label the sample with the job number, borehole, core run number, depth interval, date, and your initials. Store the samples in a protected dark and, if possible, cool place.

## **11.8 CURATING CORE**

After the samples have been prepared, the core should be boxed. If the core is to be bagged, follow the same procedure as outlined above without using aluminum foil. For large core pieces, use two bags placed on opposite ends. Mark bags appropriately. Core pieces that are too long to fit into the core box should be broken carefully. If the core cannot be broken by hand, a well-placed rap with a rock hammer or similar instrument should be used to break the core at the desired location. The core should be placed in the box, starting in the upper left-hand corner (long side of the box toward you) and with the bottom of the core in the lower right corner (just as in reading a printed page). One box per core run should be used unless the top and bottom of

**Standard Operating Procedures**  
**SOP 11 – ROTARY DRILLING AND CORING**

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each run are clearly marked with blocks. Missing intervals and sampled intervals should be replaced with appropriately marked blocks. The job number, borehole, core run number, depth interval, date, your initials, and the depths at the beginning and end of each partition of the box should be labeled on the underside of the lid. Once the core has been placed in the box, it is helpful to take a picture of the box, including the inside of the lid, to provide a record of its contents. Use duct tape to hinge the lid along the top long side of the box. The box itself should be marked in case lids are accidentally switched or lost. One end of the box should be marked with the job number, borehole, core run number, depth interval, date, and your initials. The other end should be marked with the borehole number, core run number and depth interval to aid in identification when stacked with other core boxes.

## **Chapter 10**

# **GUIDELINES FOR CORE LOGGING**

These guidelines incorporate procedures and methods used by many field offices and are appropriate for "standard" engineering geology/geotechnical log forms, computerized log forms, and many of the modified log forms used by various Bureau of Reclamation (Reclamation) offices.

### **General**

#### **Introduction**

This chapter describes the basic methods for engineering geology core logging and provides examples and instructions pertaining to format, descriptive data, and techniques; procedures for working with drillers to obtain the best data; caring for recovered core; and water testing in drill holes. The chapter also provides a reference for experienced loggers to improve their techniques and train others. Most of the discussions and examples shown pertain to logging rock core, but many discussions apply to soil core logging, standard penetration resistance logs, and drive tube sample logging.

#### **Purpose, Use, and Importance of Quality Core Logging**

The ability of a foundation to accommodate structure loads depends primarily on the deformability, strength, and groundwater conditions of the foundation materials. The remediation of a hazardous waste site can be formulated only by proper characterization of the site. Clear and accurate portrayal of geologic design and evaluation data and analytical procedures is paramount. Data reported in geologic logs not only must be accurate,

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consistently recorded, and concise, but also must provide quantitative and qualitative descriptions.

Logs provide fundamental data on which conclusions regarding a site are based. Additional exploration or testing, final design criteria, treatment design, methods of construction, and eventually the evaluation of structure performance may depend on core logs. A log may present important data for immediate interpretations or use, or may provide data that are used over a period of years. The log may be used to delineate existing foundation conditions, changes over time to the foundation or structure, serve as part of contract documents, and may be used as evidence in negotiations and/or in court to resolve contract or possible responsible party (PRP) disputes.

For engineering geology purposes, the basic objectives of logging core are to provide a factual, accurate, and concise record of the important geological and physical characteristics of engineering significance. Characteristics which influence deformability, strength, and water conditions must be recorded appropriately for future interpretations and analyses. Reclamation has adopted recognized indexes, nomenclature, standard descriptors and descriptive criteria, and alphanumeric descriptors for physical properties to ensure that these data are recorded uniformly, consistently, and accurately. Use of alphanumeric descriptors and indexes permits analysis of data by computer. These descriptors, descriptive criteria, examples, and supporting discussions are provided in chapters 3, 4, and 5.

Exploration should be logged or, as a minimum, reviewed by an experienced engineering geologist. The logger should be aware of the multiple uses of the log and the needs and interests of technically diverse users. The

## CORE LOGGING

experienced logger concentrates on the primary purposes of the individual drill hole as well as any subordinate purposes, keeping in mind the interests of others with varied geological backgrounds including geotechnical engineers, contract drillers, construction personnel, and contract lawyers. An experienced logger tailors the log to meet these needs, describing some seemingly minor features or conditions which have engineering significance, and excluding petrologic features or geologic conditions having only minor or academic interest. Less experienced loggers may have a tendency to concentrate on unnecessary garnishment, use irrelevant technical terms, or produce an enormously detailed log which ignores the engineering geology considerations and perhaps the purpose for completing the drill hole. Adequate descriptions of recovered cores and samples can be prepared solely through visual or hand specimen examination of the core with the aid of simple field tests. Detailed microscopic or laboratory testing to define rock type or mineralogy generally are necessary only in special cases.

Empirical design methods, such as the Rock Mass Rating System Geomechanics Classification (RMR) and Q-system Classification (Q), are commonly used for design of underground structures and are coming into common use for other structures as well. If these methods are used, the necessary data must be collected during core logging.

If hazardous waste site characterization is the primary purpose of the drilling, the log should concentrate on providing data for that type of investigation.

Drilling and logging are to determine the in-place condition of the soil or rock mass. Any core condition, core loss, or damage due to the type of bit, barrel, or other equipment used, or due to improper techniques used in

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the drilling and handling processes should be described. Such factors may have a marked effect on the amount and condition of the core recovered, particularly in soft, friable, weathered, intensely fractured materials or zones of shearing. Geologic logs require the adequate description of materials; a detailed summary of drilling equipment, methods, samplers, and significant engineering conditions; and geologic interpretations. Complete geologic logs of drill holes require adequate descriptions of recovered surficial deposits and bedrock, a detailed summary of drilling methods and conditions, and appropriate physical characteristics and indexes to ensure that adequate engineering data are available for geologic interpretation and analysis.

### **Format and Required Data for the Final Geologic Log**

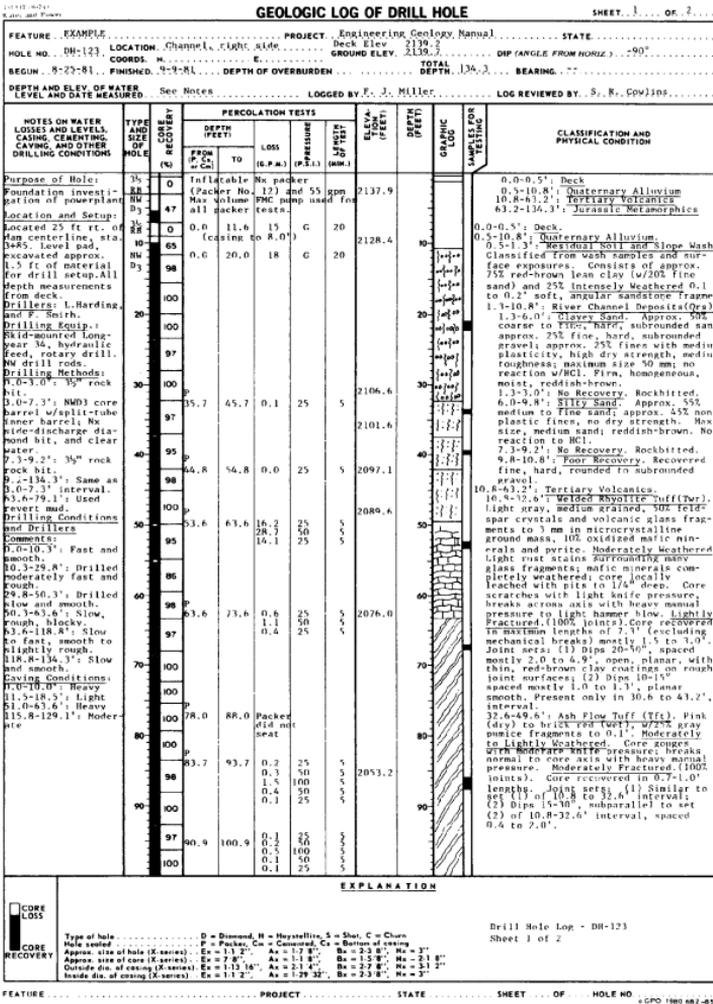
#### **Organization of the Log**

The log forms are divided into five basic sections: a heading block; a left-hand column for notes; a center column for indexes, additional notes, water tests and graphics; a right-hand column for classification and physical conditions; and a comments/explanation block at the bottom. Data required for each column are described in the following discussion and the referenced example logs. Log DH-123, figure 10-1, and log B-102, figure 10-2, are the most complete and preferred examples; other variations are presented but in some cases are not complete.

#### **Heading**

The heading block at the top of the form provides spaces for supplying project identifying information, feature,

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GEOLOGIC LOG OF DRILL HOLE										SHEET 2 OF 2
FEATURE	LOCATION	PROJECT	STATE							
HOLE NO.	COORDS. N	E.	GROUND ELEV.	DIP (ANGLE FROM HORIZ.)						
BEGIN	FINISHED	DEPTH OF OVERBURDEN	TOTAL DEPTH	REBARING						
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED.			LOGGED BY			LOG REWIND BY				
NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS  Casing and Cementing Record Size Casing Interval Depth Drilled 4" 0.0' 0.0-3.2' 6" 2.2' 3.2-5.2' 8" 5.2' 5.2-10.0' 10" 10.0' 10.0-15.0' 12" 15.0' 15.0-23.0' 14" 23.0' 23.0-33.0' 16" 33.0' 33.0-48.0' 20" cemented 80.0-134.0'	TYPE AND SIZE OF HOLE  98 100 110 95 98 89 100 130 100 40 50 60 70 80 90	PERCOLATION TESTS			LOSS (G.P.M.) PRESSURE (P.S.I.) HEAD (FEET) TIME (MIN.) GRAVIM. LOG SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION  37.6-42.1': Altered Ash Flow Buff. Reddish-brown. Fragments can be broken from core with light to moderate manual pressure, pumice fragments powder w/light finger pressure. Very Intensely Fractured. Core recovered in lengths to 0.5', mostly fragments to 0.2' core segments. This discontinuous brown clay films on all joint surfaces. 49.5-63.2': Basalt (TB). Gray to black. Moderately to tightly vesicular, vesicles 1/16 to 1/2". Largest 5/16" across; coated or rimmed with fine clay. Lightly Weathered. Core scratches with moderate knife pressure, and breaks 60 to 90° to core axis with moderate hammer blow. Moderately Fractured. Recovered mostly as 0.5' to 1.3" lengths maximum 2.3'. Joint sets: (1) Dips 85° to 90°, 2 fractures cross core axis at 53.4 and 61.2'. Irregular surfaces with oxide stains; (2) Dips 0 to 30° spaced 0.5-2.9', irregular rough surfaces, with thin, discontinuous clay coatings. 50.35-61.4': Intensely Fractured. 59.2-63.2' (100% joints). Core recovered as 0.2 to 0.3' lengths maximum length 0.5'; joints dip 10 to 35°; spaced 0.2 to 0.4' irregular, rough surfaces, joints open and filled with up to 1/4" of buff colored clay. 63.2-134.3': Jurassic Metamorphic Rock 63.2-134.3': Amphibolite Schist (Jm) Dark green to greenish gray, fine-grained, schistose to subschistose, composed chiefly of hornblende and quartz with calcite veinlets to 3/4" along schistosity and epidote stringers throughout. 63.2-122.3': Lightly Weathered. Red-brown oxidation. Tests on rock discontinuities. Core breaks along schistosity with moderate to heavy hammer blow, scratches w/heavy knife pressure. Moderately Fractured. (60% joints, 40% cleavage) except as noted below. Core recovered in lengths to 1/8", mostly 0.6 to 1.3'. Cleavage dips: 65° spaced 0.8 to 1.9'. Two joint sets noted: (1) Dip 15-30°, spaced 0.7 to 2.0', smooth, coated with oxides of Fe and Mn; (2) Dips 5-20°, normal to set (1), spaced 0.4 to 2.5', most surfaces smooth, locally minor slickensides. 67.2-101.2': Lightly Fracture. (50% joints, 50% cleavage). Core recovered in lengths to 2.9', mostly 1.6 to 2.1'. 113.2-117.2': Intensely Fractured. (80% joint, 20% cleavage) Core recovered in lengths to 0.7', mostly 0.3 to 0.6'. CONTINUED IN CENTER COLUMN.				
		CLASSIFICATION AND PHYSICAL CONDITION CONT'D								
117.2-120.8': Dike. Light gray, fine-grained. Upper contact welded, dips 28°. Lower contact broken, dips 35°. Lightly weathered. Solution pitting to 1/8". Core breaks with moderate hammer blow. Intensely to Moderately Fractured. (100% joints). Joints are randomly oriented and spaced; surfaces are irregular and rough; no sets discernible. Recovered mostly as 0.3 to 0.7' core lengths. 122.3-134.3': Fresh. No oxidation on discontinuities. Core breaks along schistosity or across axis with heavy hammer blow; scratches with heavy knife pressure. Lightly Fractured, except as noted below (50% joints, 50% cleavage). Recovered in lengths to 4.2', mostly 1.6 to 2.7'. Cleavage dips 85° to 70°, spaced 1.5 to 4.5'. Joint sets noted: (1) Dips 15-55°, spaced 1.5 to 5.3', most surfaces smooth, planar; (2) Dips 10-25° normal to set (1), spaced 2.0 to 6.5', most surfaces planar and smooth, about 5% with minor slickensides, 10% healed by Qtz. Calc. 122.4-127.7': Intensely Fractured. (50% joints, 50% cleavage). Recovered in lengths to 0.6', mostly 0.3 to 0.6'. 125.1-125.8': Shear Zone. 0.5' thick. No Recovery (72.1-125.3'). Upper contact (71), lower contact dips 62-67° (subparallel to schistosity). Consists of 70% greenish, moist, soft clay gouge and 30% 1/6 to 1/4" platy, slickensided, amphibolite fragments. Lower 1/2' of shear is healed by quartz calcite. Fragments break with heavy finger pressure.										



Figure 10-2

Drill Hole Log - DH-123  
Sheet 2 of 2

Figure 10-1.—Drill hole log, DH-123, sheet 2 of 2.

# CORE LOGGING

STANDARD PENETRATION TEST HOLE NO. **B-102**

SHEET 1 OF 3

PROJECT		FEATURE		AREA		1963 SEED INVESTIGATION		STATE			
STATION/OFFSET STA. 10+00.0 P. 8.11. 015		DEPTH TO BEDROCK 133.5		GROUND ELEV. 4396.3		ANGLE FROM HORIZ. 90.0		DIP			
BEGUN 9-19-63		FINISHED 9-29-63		TOTAL DEPTH 133.5		BEARING					
DEPTH TO WATER 75.11-10-63		LOGGED BY		REVIEWED BY							
NOTES	STANDARD PENETRATION TEST				CORRECTED PENETRATION RESISTANCE (BLows PER FOOT)	CORRECTED PENETRATION RESISTANCE (BLows PER FOOT)	CORRECTED PENETRATION RESISTANCE (BLows PER FOOT)	CLASSIFICATION AND PHYSICAL CONDITION			
	NUMBER OF BLOWS	SOUNDING	BLOWS PER FOOT					GRAVIMETRIC WET WEIGHT	GRAVIMETRIC MOISTURE	CLASSIFICATION	PHYSICAL CONDITION
			1 TO 10	10 TO 30							
<p>DRILL EQUIPMENT: HOLE RIG - POWER DRIVEN; DRILL - BEAN 80 WATER PUMP.</p> <p>DRILLER: ALBERT COLETER</p> <p>DRILL SETUP: SET UP ON LHS SIDE OF CRUST OF CAR NEAR STA. 10+00.</p> <p>DRILLING METHOD: 6" DIA. 3" BORED WITH 6" HOLLOW STEEL FLIGHT AUGERS (N. 1.0" AND 1.5" DIA. 1.00" IN. TORQ. PR. TESTS ON APPROX. 2-300' INTERVALS, EXCEPT 100' INTERVALS WHERE 1.5" DIA. 1.00" IN. TORQ. PR. TESTS WERE MADE. CRITERIA OF CORRECT DRILLING: 1.5" DIA. 1.00" IN. TORQ. PR. TESTS WERE MADE. CRITERIA OF CORRECT DRILLING: 1.5" DIA. 1.00" IN. TORQ. PR. TESTS WERE MADE. CRITERIA OF CORRECT DRILLING: 1.5" DIA. 1.00" IN. TORQ. PR. TESTS WERE MADE.</p>											
18	17.7			83		4396.3		0-2 in. 0.1" SAND ENHANCEMENT			
32	11.4		*	97		4391.5		0.1-1 in. 0.1" SAND. LIGHT GRAY SAND TO BROWN AND RED. LARGE ANGRULAR GRAVELS AND BLOBS OF VESICULAR SANDS AND SCORPUS BASAL. MAXIMUM SIZE: 3". INCLUDES SILTY SAND WITH GRAVEL. FINE TO MEDIUM SANDS BLOBS AND OCCURRING AS HOOD BASE ON WEST OF CAR. ANGLES INTERNAL. OCCASIONALLY RETURN EXCEPT FOR SANDS DESCRIBED BELOW.			
40	13.3		*	102				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
20	16.6		*	100				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
37	25.0		*	93				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
30	19.9		*	100				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
31	16.7		*	100				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
12	24.0		*	97				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
30	22.8		*	93				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
30	15.6		*	97				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
30	16.8		*	97				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
16			*	90				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
26	16.2		*	90				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
36	27.4		*	83				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
36	21.2		*	90				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
50	16.7		*	83	100		60	0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
50	20.5		*	71	100		70	0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
50	18.9		*	83	100		70	0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
50	17.5		*	100	100			0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
50	17.1		*	83	91		80	0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
50	24.0		*	71	83			0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
48	19.0		*	6	73		90	0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
48	50.1		*	6	100			0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			
				87				0.1-1 in. 0.1" SAND. APPROX. USE COURSE TO FINE. HARD. SUBANGULAR TO ROUNDED SANDS. USE FINE WITH LOW PLASTICITY AND SLIGHTLY TO MODERATE. PRESENTS WITH MODERATE FRAGILITY. NO REACTION TO ACID (90').			

FEATURE: \_\_\_\_\_ AREA: 1963 SEED INVESTIGATION SHEET 1 OF 3 HOLE NO. B-102

**Figure 10-2.—Drill hole log, B-102, for Standard Penetration Test, sheet 1 of 3.**

# FIELD MANUAL

## STANDARD PENETRATION TEST HOLE NO. B-102

SHEET 2 OF 3

PROJECT		FEATURE		AREA		1983 SEED INVESTIGATION		STATE					
STATION/OFFSET		STA. 10+02.7, 8.1' U/S		GROUND ELEV.		3796.3		ANGLE FROM HORIZ.		W. 0.8 DOWN			
BEGIN		9-19-83		FINISHED		9-29-83		DEPTH TO BEDROCK		103.5			
DEPTH TO WATER		70.4		11-10-83		LOGGED BY				TOTAL DEPTH		114.0	
NOTES		STANDARD PENETRATION TEST (DESIGNATION E-2; EARTH MANUAL)				RECEIVED TIME		CLASSIFICATION		PHYSICAL CONDITION			
NUMBER OF BLOW	PENETRATION	BLOWS PER FOOT				DEPTH SCALE FEET	DEPTH SCALE METERS	ELEVATION FEET	ELEVATION METERS	SAMPLES FOR TESTING			
		140 LB. HAMMER-30 IN. DROP	10	20	30							40	
<p>AND FAST, ALTERNATING SOIL</p> <p>CASING RECORD</p> <p>DATE SZ HOLE CS</p> <p>8-18 AP 15.0 15.0</p> <p>8-20 AP 45.5 44.0</p> <p>8-21 AP 45.5 44.0</p> <p>8-22 AP 45.5 44.0</p> <p>8-23 AP 45.5 44.0</p> <p>8-24 AP 45.5 44.0</p> <p>8-25 AP 45.5 44.0</p> <p>8-26 AP 45.5 44.0</p> <p>8-27 AP 45.5 44.0</p> <p>8-28 AP 45.5 44.0</p> <p>8-29 AP 45.5 44.0</p> <p>8-30 AP 45.5 44.0</p> <p>8-31 AP 45.5 44.0</p> <p>8-32 AP 45.5 44.0</p> <p>8-33 AP 45.5 44.0</p> <p>8-34 AP 45.5 44.0</p> <p>8-35 AP 45.5 44.0</p> <p>8-36 AP 45.5 44.0</p> <p>8-37 AP 45.5 44.0</p> <p>8-38 AP 45.5 44.0</p> <p>8-39 AP 45.5 44.0</p> <p>8-40 AP 45.5 44.0</p> <p>8-41 AP 45.5 44.0</p> <p>8-42 AP 45.5 44.0</p> <p>8-43 AP 45.5 44.0</p> <p>8-44 AP 45.5 44.0</p> <p>8-45 AP 45.5 44.0</p> <p>8-46 AP 45.5 44.0</p> <p>8-47 AP 45.5 44.0</p> <p>8-48 AP 45.5 44.0</p> <p>8-49 AP 45.5 44.0</p> <p>8-50 AP 45.5 44.0</p> <p>8-51 AP 45.5 44.0</p> <p>8-52 AP 45.5 44.0</p> <p>8-53 AP 45.5 44.0</p> <p>8-54 AP 45.5 44.0</p> <p>8-55 AP 45.5 44.0</p> <p>8-56 AP 45.5 44.0</p> <p>8-57 AP 45.5 44.0</p> <p>8-58 AP 45.5 44.0</p> <p>8-59 AP 45.5 44.0</p> <p>8-60 AP 45.5 44.0</p> <p>8-61 AP 45.5 44.0</p> <p>8-62 AP 45.5 44.0</p> <p>8-63 AP 45.5 44.0</p> <p>8-64 AP 45.5 44.0</p> <p>8-65 AP 45.5 44.0</p> <p>8-66 AP 45.5 44.0</p> <p>8-67 AP 45.5 44.0</p> <p>8-68 AP 45.5 44.0</p> <p>8-69 AP 45.5 44.0</p> <p>8-70 AP 45.5 44.0</p> <p>8-71 AP 45.5 44.0</p> <p>8-72 AP 45.5 44.0</p> <p>8-73 AP 45.5 44.0</p> <p>8-74 AP 45.5 44.0</p> <p>8-75 AP 45.5 44.0</p> <p>8-76 AP 45.5 44.0</p> <p>8-77 AP 45.5 44.0</p> <p>8-78 AP 45.5 44.0</p> <p>8-79 AP 45.5 44.0</p> <p>8-80 AP 45.5 44.0</p> <p>8-81 AP 45.5 44.0</p> <p>8-82 AP 45.5 44.0</p> <p>8-83 AP 45.5 44.0</p> <p>8-84 AP 45.5 44.0</p> <p>8-85 AP 45.5 44.0</p> <p>8-86 AP 45.5 44.0</p> <p>8-87 AP 45.5 44.0</p> <p>8-88 AP 45.5 44.0</p> <p>8-89 AP 45.5 44.0</p> <p>8-90 AP 45.5 44.0</p> <p>8-91 AP 45.5 44.0</p> <p>8-92 AP 45.5 44.0</p> <p>8-93 AP 45.5 44.0</p> <p>8-94 AP 45.5 44.0</p> <p>8-95 AP 45.5 44.0</p> <p>8-96 AP 45.5 44.0</p> <p>8-97 AP 45.5 44.0</p> <p>8-98 AP 45.5 44.0</p> <p>8-99 AP 45.5 44.0</p> <p>9-00 AP 45.5 44.0</p> <p>9-01 AP 45.5 44.0</p> <p>9-02 AP 45.5 44.0</p> <p>9-03 AP 45.5 44.0</p> <p>9-04 AP 45.5 44.0</p> <p>9-05 AP 45.5 44.0</p> <p>9-06 AP 45.5 44.0</p> <p>9-07 AP 45.5 44.0</p> <p>9-08 AP 45.5 44.0</p> <p>9-09 AP 45.5 44.0</p> <p>9-10 AP 45.5 44.0</p> <p>9-11 AP 45.5 44.0</p> <p>9-12 AP 45.5 44.0</p> <p>9-13 AP 45.5 44.0</p> <p>9-14 AP 45.5 44.0</p> <p>9-15 AP 45.5 44.0</p> <p>9-16 AP 45.5 44.0</p> <p>9-17 AP 45.5 44.0</p> <p>9-18 AP 45.5 44.0</p> <p>9-19 AP 45.5 44.0</p> <p>9-20 AP 45.5 44.0</p> <p>9-21 AP 45.5 44.0</p> <p>9-22 AP 45.5 44.0</p> <p>9-23 AP 45.5 44.0</p> <p>9-24 AP 45.5 44.0</p> <p>9-25 AP 45.5 44.0</p> <p>9-26 AP 45.5 44.0</p> <p>9-27 AP 45.5 44.0</p> <p>9-28 AP 45.5 44.0</p> <p>9-29 AP 45.5 44.0</p> <p>9-30 AP 45.5 44.0</p> <p>9-31 AP 45.5 44.0</p> <p>9-32 AP 45.5 44.0</p> <p>9-33 AP 45.5 44.0</p> <p>9-34 AP 45.5 44.0</p> <p>9-35 AP 45.5 44.0</p> <p>9-36 AP 45.5 44.0</p> <p>9-37 AP 45.5 44.0</p> <p>9-38 AP 45.5 44.0</p> <p>9-39 AP 45.5 44.0</p> <p>9-40 AP 45.5 44.0</p> <p>9-41 AP 45.5 44.0</p> <p>9-42 AP 45.5 44.0</p> <p>9-43 AP 45.5 44.0</p> <p>9-44 AP 45.5 44.0</p> <p>9-45 AP 45.5 44.0</p> <p>9-46 AP 45.5 44.0</p> <p>9-47 AP 45.5 44.0</p> <p>9-48 AP 45.5 44.0</p> <p>9-49 AP 45.5 44.0</p> <p>9-50 AP 45.5 44.0</p> <p>9-51 AP 45.5 44.0</p> <p>9-52 AP 45.5 44.0</p> <p>9-53 AP 45.5 44.0</p> <p>9-54 AP 45.5 44.0</p> <p>9-55 AP 45.5 44.0</p> <p>9-56 AP 45.5 44.0</p> <p>9-57 AP 45.5 44.0</p> <p>9-58 AP 45.5 44.0</p> <p>9-59 AP 45.5 44.0</p> <p>9-60 AP 45.5 44.0</p> <p>9-61 AP 45.5 44.0</p> <p>9-62 AP 45.5 44.0</p> <p>9-63 AP 45.5 44.0</p> <p>9-64 AP 45.5 44.0</p> <p>9-65 AP 45.5 44.0</p> <p>9-66 AP 45.5 44.0</p> <p>9-67 AP 45.5 44.0</p> <p>9-68 AP 45.5 44.0</p> <p>9-69 AP 45.5 44.0</p> <p>9-70 AP 45.5 44.0</p> <p>9-71 AP 45.5 44.0</p> <p>9-72 AP 45.5 44.0</p> <p>9-73 AP 45.5 44.0</p> <p>9-74 AP 45.5 44.0</p> <p>9-75 AP 45.5 44.0</p> <p>9-76 AP 45.5 44.0</p> <p>9-77 AP 45.5 44.0</p> <p>9-78 AP 45.5 44.0</p> <p>9-79 AP 45.5 44.0</p> <p>9-80 AP 45.5 44.0</p> <p>9-81 AP 45.5 44.0</p> <p>9-82 AP 45.5 44.0</p> <p>9-83 AP 45.5 44.0</p> <p>9-84 AP 45.5 44.0</p> <p>9-85 AP 45.5 44.0</p> <p>9-86 AP 45.5 44.0</p> <p>9-87 AP 45.5 44.0</p> <p>9-88 AP 45.5 44.0</p> <p>9-89 AP 45.5 44.0</p> <p>9-90 AP 45.5 44.0</p> <p>9-91 AP 45.5 44.0</p> <p>9-92 AP 45.5 44.0</p> <p>9-93 AP 45.5 44.0</p> <p>9-94 AP 45.5 44.0</p> <p>9-95 AP 45.5 44.0</p> <p>9-96 AP 45.5 44.0</p> <p>9-97 AP 45.5 44.0</p> <p>9-98 AP 45.5 44.0</p> <p>9-99 AP 45.5 44.0</p> <p>10-00 AP 45.5 44.0</p>													
<p>MECH. CRUMBLES WITH LIGHT MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>81-82-83 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>84-85 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>86-87 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>88-89 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>90-91 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>92-93 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>94-95 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>96-97 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>98-99 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p> <p>100-101 SILTY SAND APPROX. 95% COARSE TO FINE SAND; SUBANGULAR TO SUB-ROUNDED SAND; FINE FINES WITH LOW PLASTICITY AND QUICK DILATANCY; SOIL COARSE TO FINE; LOW MANUAL PRESSURE; MODERATE MANUAL PRESSURE; NO REACTION TO ACID (SPH)</p>													

FEATURE: \_\_\_\_\_ AREA: 1983 SEED INVESTIGATION SHEET 2 OF 3 HOLE NO. B-102

**Figure 10-2.—Drill hole log, B-102, for Standard Penetration Test, sheet 2 of 3.**

# CORE LOGGING

## STANDARD PENETRATION TEST HOLE NO. B-102

SHEET 3 OF 3

PROJECT..... FEATURE.....		AREA: 1963 SEED INVESTIGATION.....		STATE.....	
STATION/OFFSET STA. 17-02.2, 8.17 U/S.....		GROUND ELEV. 434.3 ANGLE FROM HORIZ. 90.0 DOWN.....			
BEGIN 8-18-83..... FINISHED 8-28-83.....		DEPTH TO BEDROCK 103.5.....		TOTAL DEPTH..... 171.0 BEARING.....	
DEPTH TO WATER TO N) 11-12-83.....		LOGGED BY.....		REVIEWED BY.....	
NOTES	STANDARD PENETRATION TEST (DESTINATION C-01, EARTH MANUAL)		CLASSIFICATION (DESTINATION)		CLASSIFICATION AND PHYSICAL CONDITION
	NUMBER OF BLOWS IN FOOT	BLOWS PER FOOT	DEPTH IN FEET	TEST NO.	
	1 TO 10	10 TO 20	0 TO 10	1 TO 10	
	10 TO 20	20 TO 30	10 TO 20	11 TO 20	
	20 TO 30	30 TO 40	20 TO 30	21 TO 30	
	30 TO 40	40 TO 50	30 TO 40	31 TO 40	
	40 TO 50	50 TO 60	40 TO 50	41 TO 50	
	50 TO 60	60 TO 70	50 TO 60	51 TO 60	
	60 TO 70	70 TO 80	60 TO 70	61 TO 70	
	70 TO 80	80 TO 90	70 TO 80	71 TO 80	
	80 TO 90	90 TO 100	80 TO 90	81 TO 90	
	90 TO 100	100 TO 110	90 TO 100	91 TO 100	
	100 TO 110	110 TO 120	100 TO 110	101 TO 110	
	110 TO 120	120 TO 130	110 TO 120	111 TO 120	
	120 TO 130	130 TO 140	120 TO 130	121 TO 130	
	130 TO 140	140 TO 150	130 TO 140	131 TO 140	
	140 TO 150	150 TO 160	140 TO 150	141 TO 150	
	150 TO 160	160 TO 170	150 TO 160	151 TO 160	
	160 TO 170	170 TO 180	160 TO 170	161 TO 170	
	170 TO 180	180 TO 190	170 TO 180	171 TO 180	
	180 TO 190	190 TO 200	180 TO 190	181 TO 190	
	190 TO 200	200 TO 210	190 TO 200	191 TO 200	
	200 TO 210	210 TO 220	200 TO 210	201 TO 210	
	210 TO 220	220 TO 230	210 TO 220	211 TO 220	
	220 TO 230	230 TO 240	220 TO 230	221 TO 230	
	230 TO 240	240 TO 250	230 TO 240	231 TO 240	
	240 TO 250	250 TO 260	240 TO 250	241 TO 250	
	250 TO 260	260 TO 270	250 TO 260	251 TO 260	
	260 TO 270	270 TO 280	260 TO 270	261 TO 270	
	270 TO 280	280 TO 290	270 TO 280	271 TO 280	
	280 TO 290	290 TO 300	280 TO 290	281 TO 290	
	290 TO 300	300 TO 310	290 TO 300	291 TO 300	
	300 TO 310	310 TO 320	300 TO 310	301 TO 310	
	310 TO 320	320 TO 330	310 TO 320	311 TO 320	
	320 TO 330	330 TO 340	320 TO 330	321 TO 330	
	330 TO 340	340 TO 350	330 TO 340	331 TO 340	
	340 TO 350	350 TO 360	340 TO 350	341 TO 350	
	350 TO 360	360 TO 370	350 TO 360	351 TO 360	
	360 TO 370	370 TO 380	360 TO 370	361 TO 370	
	370 TO 380	380 TO 390	370 TO 380	371 TO 380	
	380 TO 390	390 TO 400	380 TO 390	381 TO 390	
	390 TO 400	400 TO 410	390 TO 400	391 TO 400	
	400 TO 410	410 TO 420	400 TO 410	401 TO 410	
	410 TO 420	420 TO 430	410 TO 420	411 TO 420	
	420 TO 430	430 TO 440	420 TO 430	421 TO 430	
	430 TO 440	440 TO 450	430 TO 440	431 TO 440	
	440 TO 450	450 TO 460	440 TO 450	441 TO 450	
	450 TO 460	460 TO 470	450 TO 460	451 TO 460	
	460 TO 470	470 TO 480	460 TO 470	461 TO 470	
	470 TO 480	480 TO 490	470 TO 480	471 TO 480	
	480 TO 490	490 TO 500	480 TO 490	481 TO 490	
	490 TO 500	500 TO 510	490 TO 500	491 TO 500	
	500 TO 510	510 TO 520	500 TO 510	501 TO 510	
	510 TO 520	520 TO 530	510 TO 520	511 TO 520	
	520 TO 530	530 TO 540	520 TO 530	521 TO 530	
	530 TO 540	540 TO 550	530 TO 540	531 TO 540	
	540 TO 550	550 TO 560	540 TO 550	541 TO 550	
	550 TO 560	560 TO 570	550 TO 560	551 TO 560	
	560 TO 570	570 TO 580	560 TO 570	561 TO 570	
	570 TO 580	580 TO 590	570 TO 580	571 TO 580	
	580 TO 590	590 TO 600	580 TO 590	581 TO 590	
	590 TO 600	600 TO 610	590 TO 600	591 TO 600	
	600 TO 610	610 TO 620	600 TO 610	601 TO 610	
	610 TO 620	620 TO 630	610 TO 620	611 TO 620	
	620 TO 630	630 TO 640	620 TO 630	621 TO 630	
	630 TO 640	640 TO 650	630 TO 640	631 TO 640	
	640 TO 650	650 TO 660	640 TO 650	641 TO 650	
	650 TO 660	660 TO 670	650 TO 660	651 TO 660	
	660 TO 670	670 TO 680	660 TO 670	661 TO 670	
	670 TO 680	680 TO 690	670 TO 680	671 TO 680	
	680 TO 690	690 TO 700	680 TO 690	681 TO 690	
	690 TO 700	700 TO 710	690 TO 700	691 TO 700	
	700 TO 710	710 TO 720	700 TO 710	701 TO 710	
	710 TO 720	720 TO 730	710 TO 720	711 TO 720	
	720 TO 730	730 TO 740	720 TO 730	721 TO 730	
	730 TO 740	740 TO 750	730 TO 740	731 TO 740	
	740 TO 750	750 TO 760	740 TO 750	741 TO 750	
	750 TO 760	760 TO 770	750 TO 760	751 TO 760	
	760 TO 770	770 TO 780	760 TO 770	761 TO 770	
	770 TO 780	780 TO 790	770 TO 780	771 TO 780	
	780 TO 790	790 TO 800	780 TO 790	781 TO 790	
	790 TO 800	800 TO 810	790 TO 800	791 TO 800	
	800 TO 810	810 TO 820	800 TO 810	801 TO 810	
	810 TO 820	820 TO 830	810 TO 820	811 TO 820	
	820 TO 830	830 TO 840	820 TO 830	821 TO 830	
	830 TO 840	840 TO 850	830 TO 840	831 TO 840	
	840 TO 850	850 TO 860	840 TO 850	841 TO 850	
	850 TO 860	860 TO 870	850 TO 860	851 TO 860	
	860 TO 870	870 TO 880	860 TO 870	861 TO 870	
	870 TO 880	880 TO 890	870 TO 880	871 TO 880	
	880 TO 890	890 TO 900	880 TO 890	881 TO 890	
	890 TO 900	900 TO 910	890 TO 900	891 TO 900	
	900 TO 910	910 TO 920	900 TO 910	901 TO 910	
	910 TO 920	920 TO 930	910 TO 920	911 TO 920	
	920 TO 930	930 TO 940	920 TO 930	921 TO 930	
	930 TO 940	940 TO 950	930 TO 940	931 TO 940	
	940 TO 950	950 TO 960	940 TO 950	941 TO 950	
	950 TO 960	960 TO 970	950 TO 960	951 TO 960	
	960 TO 970	970 TO 980	960 TO 970	961 TO 970	
	970 TO 980	980 TO 990	970 TO 980	971 TO 980	
	980 TO 990	990 TO 1000	980 TO 990	981 TO 990	
	990 TO 1000	1000 TO 1010	990 TO 999	991 TO 999	
	1000 TO 1010	1010 TO 1020	1000 TO 1009	1001 TO 1009	
	1010 TO 1020	1020 TO 1030	1010 TO 1019	1011 TO 1019	
	1020 TO 1030	1030 TO 1040	1020 TO 1029	1021 TO 1029	
	1030 TO 1040	1040 TO 1050	1030 TO 1039	1031 TO 1039	
	1040 TO 1050	1050 TO 1060	1040 TO 1049	1041 TO 1049	
	1050 TO 1060	1060 TO 1070	1050 TO 1059	1051 TO 1059	
	1060 TO 1070	1070 TO 1080	1060 TO 1069	1061 TO 1069	
	1070 TO 1080	1080 TO 1090	1070 TO 1079	1071 TO 1079	
	1080 TO 1090	1090 TO 1100	1080 TO 1089	1081 TO 1089	
	1090 TO 1100	1100 TO 1110	1090 TO 1099	1091 TO 1099	
	1100 TO 1110	1110 TO 1120	1100 TO 1109	1101 TO 1109	
	1110 TO 1120	1120 TO 1130	1110 TO 1119	1111 TO 1119	
	1120 TO 1130	1130 TO 1140	1120 TO 1129	1121 TO 1129	
	1130 TO 1140	1140 TO 1150	1130 TO 1139	1131 TO 1139	
	1140 TO 1150	1150 TO 1160	1140 TO 1149	1141 TO 1149	
	1150 TO 1160	1160 TO 1170	1150 TO 1159	1151 TO 1159	
	1160 TO 1170	1170 TO 1180	1160 TO 1169	1161 TO 1169	
	1170 TO 1180	1180 TO 1190	1170 TO 1179	1171 TO 1179	
	1180 TO 1190	1190 TO 1200	1180 TO 1189	1181 TO 1189	
	1190 TO 1200	1200 TO 1210	1190 TO 1199	1191 TO 1199	
	1200 TO 1210	1210 TO 1220	1200 TO 1209	1201 TO 1209	
	1210 TO 1220	1220 TO 1230	1210 TO 1219	1211 TO 1219	
	1220 TO 1230	1230 TO 1240	1220 TO 1229	1221 TO 1229	
	1230 TO 1240	1240 TO 1250	1230 TO 1239	1231 TO 1239	
	1240 TO 1250	1250 TO 1260	1240 TO 1249	1241 TO 1249	
	1250 TO 1260	1260 TO 1270	1250 TO 1259	1251 TO 1259	
	1260 TO 1270	1270 TO 1280	1260 TO 1269	1261 TO 1269	
	1270 TO 1280	1280 TO 1290	1270 TO 1279	1271 TO 1279	
	1280 TO 1290	1290 TO 1300	1280 TO 1289	1281 TO 1289	
	1290 TO 1300	1300 TO 1310	1290 TO 1299	1291 TO 1299	
	1300 TO 1310	1310 TO 1320	1300 TO 1309	1301 TO 1309	
	1310 TO 1320	1320 TO 1330	1310 TO 1319	1311 TO 1319	
	1320 TO 1330	1330 TO 1340	1320 TO 1329	1321 TO 1329	
	1330 TO 1340	1340 TO 1350	1330 TO 1339	1331 TO 1339	
	1340 TO 1350	1350 TO 1360	1340 TO 1349	1341 TO 1349	
	1350 TO 1360	1360 TO 1370	1350 TO 1359	1351 TO 1359	
	1360 TO 1370	1370 TO 1380	1360 TO 1369	1361 TO 1369	
	1370 TO 1380	1380 TO 1390	1370 TO 1379	1371 TO 1379	
	1380 TO 1390	1390 TO 1400	1380 TO 1389	1381 TO 1389	
	1390 TO 1400	1400 TO 1410	1390 TO 1399	1391 TO 1399	
	1400 TO 1410	1410 TO 1420	1400 TO 1409	1401 TO 1409	
	1410 TO 1420	1420 TO 1430	1410 TO 1419	1411 TO 1419	
	1420 TO 1430	1430 TO 1440	1420 TO 1429	1421 TO 1429	
	1430 TO 1440	1440 TO 1450	1430 TO 1439	1431 TO 1439	
	1440 TO 1450	1450 TO 1460	1440 TO 1449	1441 TO 1449	
	1450 TO 1460	1460 TO 1470	1450 TO 1459	1451 TO 1459	
	1460 TO 1470	1470 TO 1480	1460 TO 1469	1461 TO 1469	
	1470 TO 1480	1480 TO 1490	1470 TO 1479	1471 TO 1479	
	1480 TO 1490	1490 TO 1500	1480 TO 1489	1481 TO 1489	
	1490 TO 1500	1500 TO 1510	1490 TO 1499	1491 TO 1499	
	1500 TO 1510	1510 TO 1520	1500 TO 1509	1501 TO 1509	
	1510 TO 1520	1520 TO 1530	1510 TO 1519	1511 TO 1519	
	1520 TO 1530	1530 TO 1540	1520 TO 1529	1521 TO 1529	
	1530 TO 1540	1540 TO 1550	1530 TO 1539	1531 TO 1539	
	1540 TO 1550	1550 TO 1560	1540 TO 1549	1541 TO 1549	
	1550 TO 1560	1560 TO 1570	1550 TO 1559	1551 TO 1559	

## FIELD MANUAL

hole number, location, coordinates, elevation, bearing and plunge of hole, dates started and completed, and the name(s) of the person(s) responsible for logging and review. Locations should preferably be in coordinates unless station and offset are all that is available.

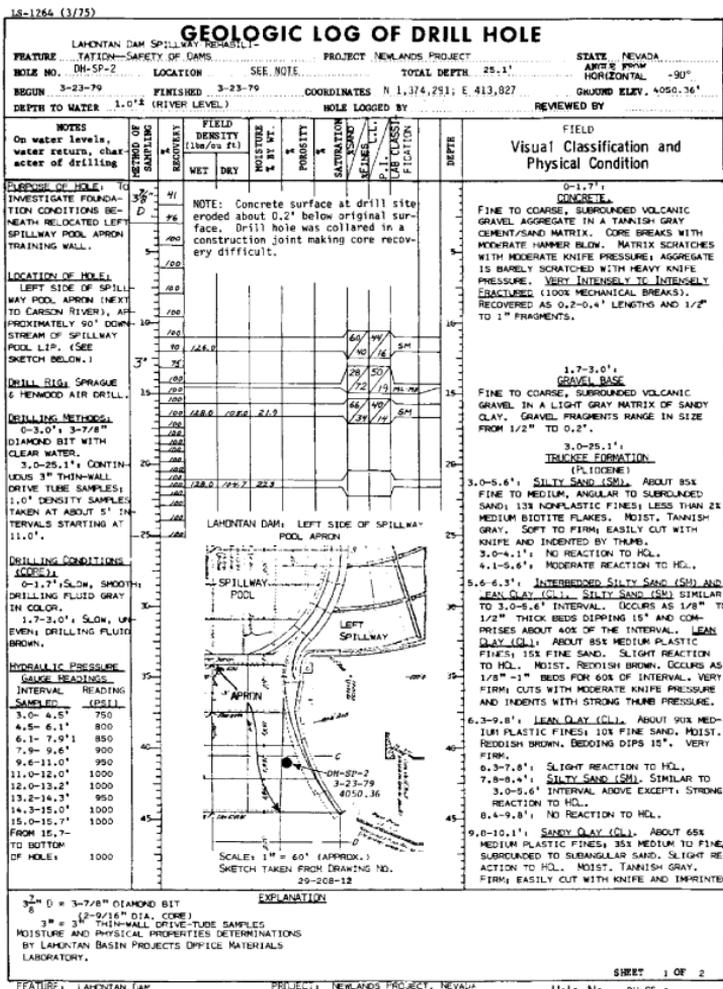
Provide both coordinates and station and offset if available. The dip or plunge of the hole can be the angle from horizontal or from vertical, but the reference point should be noted on the log. Spaces for depth to bedrock and water levels are also provided. All this information is important and should not be omitted. Below the heading, the body of the log form is divided into a series of columns covering the various kinds of information required according to the type of exploratory hole.

### **Data Required for the "Drilling Notes" Column**

Data for the left-hand column of all drill hole logs are similar whether for large-diameter sampling, Standard Penetration Tests, rock core, or push-tube sampling logs. These data are field observations and information provided by the driller on the Daily Drill Reports. Examples are provided for some of these data headings; a suggested guideline and preferred order is presented in the following paragraphs but may differ depending on the purpose and type of exploration. Headers for data can indicate whether depths are in feet (ft) or meters (m), eliminating the need to repeat "ft" or "m" for each interval entry. An example of the Drilling Notes column is provided on figures 10-1 through 10-4.

**General Information.**—This includes headers and data for the hole purpose, the setup or site conditions, drillers, and drilling and testing equipment used.

# CORE LOGGING



**Figure 10-3.—Drill hole log, DH-SP-2, sheet 1 of 2.**

# FIELD MANUAL

GEOLOGIC LOG OF DRILL HOLE—CONTINUATION SHEET							
FEATURE: LAHONTAN DAM SPILLWAY REPAIR/RECON. PROJECT, NEVADA PROJECT, NEVADA							
HOLE NO.: DH-SP-2	TATION - SAFETY OF DAMS						
SHEET 2 OF 2							
NOTES (CONTINUED)	FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION (CONTINUED)						
<p><b>CASING RECORD:</b> Size: 4"</p> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%; border-bottom: 1px solid black;">INTERVAL DRILLED OR SHAFTED:</td> <td style="width: 50%; border-bottom: 1px solid black;">CASING DEPTH:</td> </tr> <tr> <td style="border-bottom: 1px solid black;">0.0-3.0'</td> <td style="border-bottom: 1px solid black;">0.0'</td> </tr> <tr> <td style="border-bottom: 1px solid black;">3.0-25.1'</td> <td style="border-bottom: 1px solid black;">3.0'</td> </tr> </table> <p><b>HOLE CONDITION:</b> LEFT HOLE OPEN. COULD NOT BACKFILL DUE TO RISING RIVER LEVEL.</p>	INTERVAL DRILLED OR SHAFTED:	CASING DEPTH:	0.0-3.0'	0.0'	3.0-25.1'	3.0'	<p>9.8-10.1' (CONTINUED); WITH MODERATE THUMB PRESSURE.</p> <p>10.1-10.4': <u>CLAYEY SAND (SC)</u>. ABOUT 75% FINE TO MEDIUM, SUBANGULAR TO SUBROUNDED SAND; 25% MEDIUM PLASTIC FINES. MODERATE TO STRONG REACTION TO HCL. MOIST. TANNISH GRAY. FIRM; CUTS EASILY WITH KNIFE.</p> <p>10.4-10.6': <u>SANDY CLAY (CL)</u>. SIMILAR TO 9.8-10.1' INTERVAL.</p> <p>10.6-11.0': <u>LEAN CLAY (CL)</u>. SIMILAR TO 6.3-9.8' INTERVAL.</p> <p>11.0-25.1': <u>CLAYEY SAND (SC-SM)</u>. ABOUT 70% MEDIUM TO FINE, SUBANGULAR TO SUBROUNDED SAND; 30% LOW TO MEDIUM PLASTIC FINES. SCATTERED AREAS GIVE MODERATE REACTION TO HCL. MOIST. TAN. FIRM; CUTS EASILY WITH KNIFE AND INDENTS WITH MODERATE THUMB PRESSURE. WITH CONTINUED WORKING, PERCENTAGE OF FINES INCREASES TO APPROXIMATELY 40% APPARENTLY DUE TO BREAKDOWN OF CLAYSTONE GRAINS OR WEATHERED VOLCANIC MATERIAL.</p> <p>13.7-15.0': <u>SANDY CLAY (CL-M)</u>. ABOUT 65% LOW TO MEDIUM PLASTIC FINES; 35% FINE TO MEDIUM, SUBANGULAR TO SUBROUNDED SAND. NO REACTION TO HCL. MOIST. BROWN. VERY FIRM; CUTS WITH MODERATE KNIFE PRESSURE, INDENTS WITH HEAVY THUMB PRESSURE.</p> <p>17.1-18.6': <u>CLAYEY SAND—POORLY GRADED SAND (SC-SP)</u>. ABOUT 90% MEDIUM TO COARSE, SUBANGULAR TO SUBROUNDED SAND; 10% MEDIUM PLASTIC FINES. OCCASIONAL MODERATE REACTION TO HCL. MOIST, GREENISH TAN. FIRM; CUTS EASILY WITH KNIFE, IMPRINTED WITH MODERATE THUMB PRESSURE.</p> <p>18.6-18.8': <u>SANDY CLAY (CL)</u>. ABOUT 75% MEDIUM PLASTIC FINES; 25% MEDIUM TO FINE, SUBANGULAR TO SUBROUNDED SAND. NO REACTION TO HCL. MOIST. BROWN. VERY FIRM; CUTS WITH MODERATE KNIFE PRESSURE, IMPRINTED WITH MODERATE TO STRONG THUMB PRESSURE.</p> <p>21.1-21.6': <u>CLAYEY SAND (SC)</u>. ABOUT 85% MEDIUM, SUBANGULAR TO SUBROUNDED SAND; 15% MEDIUM PLASTIC FINES. NO REACTION TO HCL. MOIST. TAN. SOFT; CRUMBLES WITH LIGHT MANUAL PRESSURE, INDENTS WITH LIGHT THUMB PRESSURE.</p> <p>24.6-24.7': <u>SANDY CLAY (CL)</u>. SIMILAR TO 18.6-18.8' INTERVAL.</p>
INTERVAL DRILLED OR SHAFTED:	CASING DEPTH:						
0.0-3.0'	0.0'						
3.0-25.1'	3.0'						
	SHEET 2 OF 2						
FEATURE: LAHONTAN DAM	PROJECT: NEVADA PROJECT, NEVADA						
	HOLE NUMBER: SP-2						

**Figure 10-3.—Drill hole log, DH-SP-2, sheet 2 of 2.**



# FIELD MANUAL

GEOLOGIC LOG OF DRILL HOLE—CONTINUATION SHEET			
FEATURE	PROJECT		SHEET 2 OF 3
HOLE NO.	SPT-107-2		
NOTES (Continued)	VISUAL CLASSIFICATION AND PHYSICAL CONDITION (Continued)		
<b>Estimated Drilling Fluid Return and color:</b> 0-48.5', 90% to 100% reddish brown	11.0-12.2' (Continued): mottled with red oxide and gray-green reduced material. No reaction with HCl.		
<b>Caving Conditions</b> None.	12.2-12.5': No Recovery.		
<b>Casing and cementing Record</b>	12.5-14.0': Rockbit.		
<b>size Depth Casing Interval Drilled</b>	14.0-15.1': Silty Sand (SM). Similar to 11.0-12.2' except: 60% sand and 40% fines with no to low plasticity; coarse sand size increased.		
7" 5.0' 5.0-48.5'	15.1-15.5': No Recovery.		
	15.5-17.0': Rockbit.		
	17.0-17.7': Clayey Gravel (GC-SC). Approx. 40% fine, hard, subrounded gravel; approx. 40% fine to coarse sand; approx. 20% fines with low plasticity; maximum size 10 mm. Soft; wet (due to mud contamination); brown to gray.		
	17.7-18.0': Sandy Clay (CL). Approx. 70% fines with low plasticity; approx. 25% size to medium with traces of coarse sand; approx. 5% fine, hard, subrounded gravel; maximum size 10 mm. Very soft; moist; gray with red oxide mottling. No reaction with HCl.		
ement only used in piezometer installation from 21.0' to surface.	18.0-18.5': No Recovery.		
	18.5-20.0': Rockbit.		
<b>Completion</b>	20.0-21.3': Silty Sand (SM). Approx. 65% predominantly fine to traces of coarse sand; approx. 35% fines with no to low plasticity; trace fine, hard, angular to subangular gravel, partially white quartz; maximum size 10 mm. Very soft; wet (due to mud contamination); blue-gray. No to weak reaction with HCl.		
Pulled flights. Installed one porous tube piezometer with a tip elevation of 210.0' (see diagram on Sheet 3). Finished hole with 4" standpipe and screw cap with 2.5' stickup for piezometer access. Set a 4x4' subwood post for future hole identification. Hole was not surveyed.	21.3-21.5': No Recovery.		
	21.5-23.0': Rockbit.		
	23.0-23.7': Silty Sand (SM). Approx. 50% fine to coarse sand; approx. 25% nonplastic fines; approx. 25% fine to coarse, hard, subangular gravel; traces of white quartz; maximum size 10 mm. Soft; moist; blue-green. Weak reaction with HCl.		
	23.7-24.3': Lean Clay (CL). Approx. 80% fines with medium plasticity; approx. 20% fine sand; maximum size fine sand. Soft; moist; blue with white calcium carbonate stains. Moderate to strong (in white areas) reaction with HCl.		
	24.3-24.5': No Recovery.		
	24.5-26.0': Rockbit.		
	26.0-27.3': Lean Clay (CL). Approx. 60% fines with medium plasticity; approx. 40% fine sand; maximum size fine sand. Firm; moist; blue with extensive white cementation due to calcium carbonate. Strong hydrogen sulfide odor. Strong reaction with HCl.		
	27.3-27.5': No Recovery.		
	27.5-29.0': Rockbit.		
<b>Time Required to Complete Hole:</b>	29.0-29.3': Lean Clay (CL). Similar to 23.7-24.3' interval except: Firm, with extensive white cementation due to calcium carbonate. Strong hydrogen sulfide odor. Strong reaction with HCl.		
Hole set up: 5 hours	29.3-33.2': Lean Clay (CL). Approx. 35% fines with medium plasticity; approx. 25% fine sand; maximum size fine sand. Soft; moist; blue with white calcium carbonate stains and occasional carbonate-cemented, firm to hard areas. Strong hydrogen sulfide odor. No to strong (in white cementation) reaction with HCl.		
Drilling: 11 hours	30.2-30.5': No Recovery.		
Downtime: 8 hours	30.5-32.3': Rockbit.		
	32.3-33.5': Sandy Clay (CL). Approx. 63% fines with medium plasticity; approx. 35% predominantly fine sand; maximum size fine sand. Soft to very firm with depth in tube; moist to dry with depth. Dark blue with white and gray, calcium carbonate cement; trace calcareous concretionary material. Very strong reaction with HCl.		
	33.5-33.8': No Recovery.		
	33.8-35.0': Rockbit.		
	35.0-36.0': Sandy Clay (CL). Approx. 70% fines with medium plasticity; approx. 30% fine sand; maximum size fine sand. Firm; dry to moist; blue with extensive gray calcium carbonate mottling. Very strong reaction with HCl.		
	36.0-36.5': No Recovery.		
	36.5' - 48.5': PANGLOSS GNEISS (Cretaceous Marine Sedimentary Rocks)		
	36.5-38.0': Rockbit.		
	38.0-39.0': Sandy Claystone (ST). Recovered as Sandy to Silty Clay (CL-ML), with approx. 20% fines with no to low plasticity; and very firm with some cemented sandy claystone (?) fragments easily broken with fingers. Dry to moist; blue with gray calcium carbonate mottling. Very strong reaction with HCl. Hydrogen sulfide odor. May include some in-place, altered rock.		

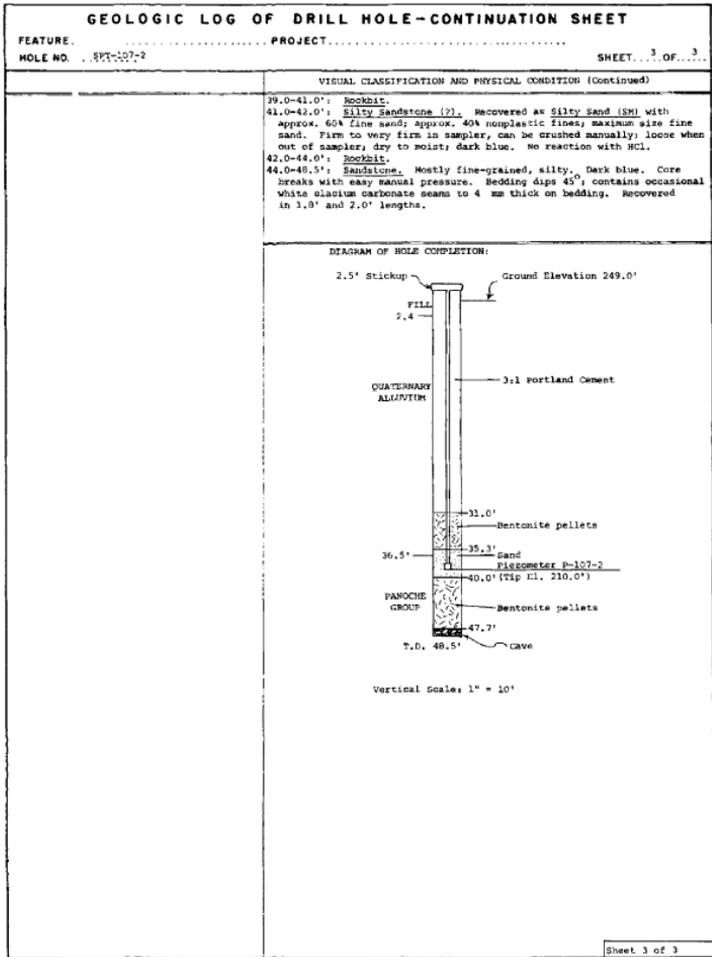
FEATURE: Figure 11-10-12, Sheet 2 of 3

PROJECT:

HOLE NO. SPT-107-2

**Figure 10-4.—Drill hole log, SPT-107-2, sheet 2 of 3.**

# CORE LOGGING



**Figure 10-4.—Drill hole log, SPT-107-2, sheet 3 of 3.**

## FIELD MANUAL

**1. Purpose of hole** — Includes reason for drilling the hole, such as foundation investigation, materials investigation, instrumentation, sampling, or testing.

**2. Drill site or setup** — Includes general physical description of the location of the drill hole. Information on unusual setups, such as adjacent to a stream, or drilled from a barge, gallery, or adit, may help understand the unusual conditions.

**3. Drillers** — Names of drillers may be significant for reference or for evaluating or interpreting core losses, drilling rates, and other drilling conditions.

### **4. Drilling equipment** —

- Drill rig (make and model)
- Core barrel(s), tube(s), special samplers (type and size)
- Bits (type and size)
- Drill rods (type and size)
- Collar (type)
- Water test equipment (rod or pipe size, hose size, pump type and capacity, and relative position and elevation of pressure gauges or transducers), packers (type—mechanical or pneumatic)

Example: Skid-mounted Sprague and Henwood Model 250. NWD3 bottom discharge bit with a 5-ft (1.5-m), split-tube inner barrel. 5-ft (1.5-m) NW rods. Water tested with NX pneumatic

## CORE LOGGING

packer No. 12 with 1-1/4-inch (in) (32-millimeter [mm]) pipe, Bean pump with 35-gallons per minute (gal/min) (159 liters per minute) maximum volume, and 1-in (25-mm) water meter. (Water testing equipment can be a separate heading if desired.)

**Drilling Procedures and Conditions.**—These headers and data should include methods, conditions, driller's comments, and records for water losses, caving, or casing.

**1. Drilling methods** — Synopsis of drilling, sampling, and testing procedures, including procedures and pressures for drive or push tubes used through the various intervals of the hole.

**2. Drilling conditions and driller's comments** —

Note by interval the relative penetration rate and the action of the drill during this process (i.e., 105.6-107.9: drilled slowly, moderate blocking off, hole advancing 15 minutes per foot [.3 meter]). Unusual drilling conditions should be summarized. Changes in drilling conditions may indicate differences in lithology, weathering, or fracture density. The geologist needs to account for variations in driller's descriptions; each driller may describe similar conditions with different adjectives or percentage estimates. Any other comments relative to ease or difficulty of advancing or maintaining the hole should be noted by depth intervals. Drillers' comments need to adequately describe conditions encountered while advancing the hole. Statements such as "normal drilling" or "no problems encountered" are not useful.

Differences in drilling speeds, pressures, and penetration rates may be related to the relative

## FIELD MANUAL

hardness and density of materials. Abrupt changes in drilling time may identify lithologic changes or breaks and also may pinpoint soft or hard interbeds within larger units. Often, these may be correlated with geophysical logs. If the driller provides useful and accurate records of drilling conditions and procedures, an accurate determination of the top and bottom of key marker horizons can be made even without core.

Drilling progress should be recorded while drilling; recovery can be improved by relating recovery to optimum pressures and speeds, as well as providing data for interpretation. For each run, the driller should record the time when starting to drill and when stopping to come out of the hole. Most of these drilling progress data are qualitative rather than quantitative values. Controlling factors are not only the type of materials encountered but also may be mechanical or driller variables. These variables may include type and condition of the bit, rotation speed, drilling fluid pressure, etc. THE PURPOSE OF THE BORING IS TO OBTAIN THE HIGHEST QUALITY CORE AND MOST COMPLETE RECOVERY AND INFORMATION, NOT JUST FEET PER HOUR OR SHIFT.

**3. Drilling fluid** — Type and where used (including drilling fluid additives). This may be combined with or discussed under the heading, drilling methods.

**4. Drilling fluid return** — Include interval/percent return. Drilling fluid return may be combined with color.

**5. Drill fluid color** — Include interval/color.

## CORE LOGGING

**6. Caving conditions** — Intervals of cave with appropriate remarks about the relative amount of caving are to be noted. When possible, report the actual caving interval rather than the depth of the hole.

**7. Casing record** — Casing depth is the depth of casing at the start of the drilled interval (see the example below).

**8. Advancement (push-tube or Standard Penetration Test (SPT) applications)** — Include depth/ interval sampled.

**9. Cementing record** — Note all intervals cemented and if intervals were cemented more than once. This information may be combined with the casing record, as shown below:

Example of casing and cementing record:

Interval drilled (feet)	Size (inch)	Casing depth (feet)
0.0-2.3	6 Cs	0.0
2.3-4.5	6 Cs	2.0
4.5-9.2	6 Cs	4.0
9.2-15.3	NxCs	8.0
15.3-18.7	NxCs	15.0
18.7-33.2	Cmt	12.1-18.7 Cmt

**Hole Completion and Monitoring Data.**—Data shown in this section of the left-hand column include hole completion, surveys, water levels, drilling rates or time, and reason for hole termination.

## FIELD MANUAL

### **1. Borehole survey data** — Include if obtained.

Example of survey data:

Depth	Bearing	Plunge
59		90° <sup>1</sup>
79	S 72°W	90°
99	S 75° W	89°
119	S 72° W	89°
Average	S 72° W	89°

<sup>1</sup> ° = degrees.

**2. Water level data** — Note depths and/or elevations, water quantities, and pressures from artesian flows. Water levels or flows should be recorded during hole advancement, between shifts, or at the beginning or end of a shift, but definitely should be recorded at completion of the hole and periodically thereafter. It may be advantageous to leave space or provide a note to refer the user to additional readings provided elsewhere on the log for subsequent measurements. Computer generated logs allow convenient updating of water levels long after the hole is completed.

Examples of drill hole logs illustrate optional format and subsequent readings. Examples of how to record data are:

## CORE LOGGING

Date 1981	Hole depth (feet)	Depth to water (feet)
11-02	25.0	6.0
Bailed 100 gal:		
Level before		6.0
Level after		21.0

or:

Date	Hole depth (feet)	Depth to water (feet)
11-03-81	25.0	15.0
11-04-81	40.0	29.0
01-05-82	95.2	7.0
01-15-82	95.2	Flowing 25 gal/min
02-03-82	95.2	Flowing 5 gal/min at 5 pounds per square inch (lb/in <sup>2</sup> )

**3. Hole completion** — Indicate how hole was completed or backfilled; if jetting, washing, or bailing was employed; depth of casing left in hole or that casing was pulled; location and type of piezometers; location, sizes, and types of slotted pipes (including size and spacing of slots) or piezometer risers; type and depth of backfill or depths of concrete and/or bentonite plugs; location of isolated intervals; and elevation at top of riser(s). Hole completion can be shown graphically (see figure 10-5).

# FIELD MANUAL

IS-1264-A (4/75)

GEOLOGIC LOG OF DRILL HOLE											
FEATURE San Luis Dam-SEED		PROJECT Central Valley Project, California		STATE California		HOLE NO. DH-DN/P-60-1		GROUND ELEVATION 381.5'		ARTICLE FROM	
LOC. 217-02		COORDINATES FINISHED 2-23-82		TOTAL DEPTH 50.0'		VERTICAL Vertical					
BEGUN 2-17-82		See Note		HOLE LOGGED BY J. Darling		DRILLER H. Ferrell					
NOTES	Type and Size of Hole	Recovery	WET DEPTH (lb/ft <sup>3</sup> )		Dry	Wet Density	DEPTH	FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION			
			Wet	Dry							
Purpose of Hole: Under the Safety Examination of Existing Dams (SEED) program, to obtain undisturbed PHTMEX soil samples and to install piezometers.	RB	0					0.0-22.0';	ZONE 3 EMBANKMENT			
Location of Hole: Station 60+21.8; offset 542.3' left of dam centerline.	RB	0					0.0-5.0';	Rockbit - No Recovery			
Drill Log: Falling 1500	P	100	181.5	118.8	15.6		5.0-5.10';	Sandy clay (CL). Approx. 70% medium plastic fines; 30% fine to coarse sand; trace of lime, hard, subangular to angular gravel, max. size 20 mm. Soft to firm; moist; brown with bluffs of blue clay to 20 mm. Strong reaction with HCl.			
Drilling Methods: Drilled with 4 1/2" "Reverable mud".	P	75	***		12.7		5.10-6.65';	Pitcher Sample.			
G.O.-5.0'; 6 1/2" rockbit	P	95	182.0	124.6	12.4		6.65-7.0';	Sandy clay (ML). Approx. 60% medium to low plastic fines; 40% fine to coarse sand; 10% fine and coarse, hard, subrounded gravel, max. size 40 mm. Soft; moist to dry; blue-green. Weak reaction with HCl.			
5.0-7.0'; Pitcher sampler.	P	100	182.2	121.4	28.4		7.0-10.0';	Rockbit - No Recovery.			
7.0-10.0'; 8 1/2" rockbit	P	85	181.8	91.6	25.2		10.0-12.0';	Contaminated Sample - Sand/Clay (CL). Similar to 6.67-7.0' interval except: Firm.			
10.0-14.0'; Pitcher sampler.	P	100	182.2	101.9	28.2		12.0-12.36';	Sandy clay (CL-CH). Approx. 60% medium to highly plastic fines; 40% fine to coarse sand; 10% fine and coarse, hard, subrounded gravel, max. size 60 mm. Firm; moist to dry; blue-green. Weak reaction with HCl.			
14.0-15.0'; 8 1/2" rockbit.	P	100	182.2	101.9	28.2		12.36-13.74';	Pitcher Sample.			
15.0-50.0'; Pitcher sampler.	P	80	182.2	107.7	19.4		13.74-14.0';	Sandy Clay (CL-CH). Similar to 12.0-12.36' interval except: max. size 40 mm; traces of brown spots.			
33.0-35.0'; Clean 45.0' out with 8 1/2" rockbit.							14.0-15.0';	Rockbit - No Recovery.			
Drilling Conditions: 0.0-33.0'; Medium fast, smooth.							15.0-15.35';	Clayey sand with gravel (SC). Approx. 50% fine to coarse sand; 50% low plastic fines; 20% fine and coarse, subrounded to subangular gravel, max. size 60 mm. Soft; moist to wet; gray-black to green. Weak reaction with HCl.			
33.0-49.0'; Medium slow, smooth.							15.35-16.79';	Pitcher Sample.			
Estimated Drilling Fluid Returns: 0.0-25.0'; 85% 25.0-35.0'; 75% 35.0-45.0'; 80% 45.0-50.0'; 95-98%							16.79-19.0';	Lean to Fat Clay (CL-CH). Approx. 95% medium to highly plastic fines; 5% fine sand. Firm; dry to moist; blue-green. Weak reaction with HCl.			
Casing Record: Drilled Depth Type Interval Casing Case							17.0-19.0';	Scattered claystone fragments and brown clay lumps.			
0.0-14.0' 0.0 14.0-25.0' 8.5" 10" 25.0-50.0' 20.0" 10"							19.0-19.30';	Lean to Fat Clay (CL-CH). Approx. 80% medium to highly plastic fines; 20% fine to coarse sand; 10% fine, hard, subrounded gravel, max. size 15 mm. Firm; dry to moist; blue-green, with traces of brown spots. Weak reaction with HCl.			
Hole Completion: Flushed hole with fresh mud and Petro Breaker 4 & B. Installed two vibrating							19.30-20.73';	Pitcher Sample.			
							20.73-21.57';	Clayey Sand with Gravel (SC). Approx. 60% fine to coarse sand; 40% low plastic fines; 30% fine and coarse, hard, subrounded gravel, max. size 40 mm. Soft to firm; moist to wet; brown with blue-green mottling. No reaction with HCl.			

### EXPLANATION

Sheet 1 of 3

FEATURE: San Luis Dam-SEED      FEATURE: Central Valley Project, California      HOLE NO. DH-DN/P-60-1

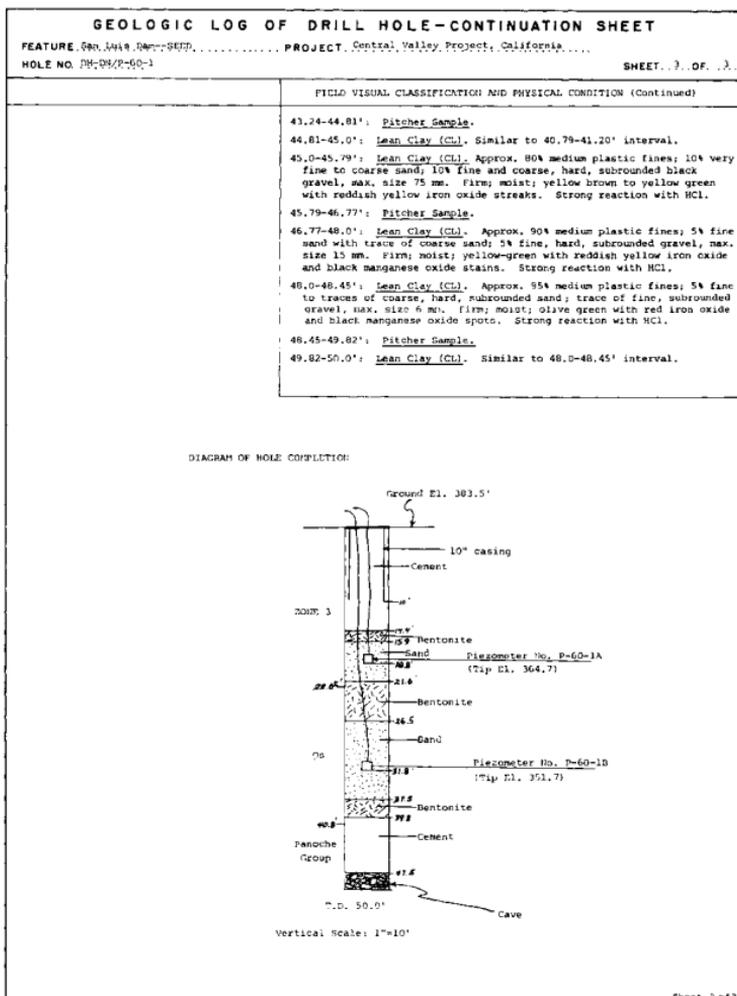
**Figure 10-5.—Drill hole log, DH-DN/P-60-1, sheet 1 of 3.**

# CORE LOGGING

GEOLOGIC LOG OF DRILL HOLE—CONTINUATION SHEET																	
FEATURE: San Luis Dam—SEED	PROJECT: Central Valley Project, California	SHEET: 2 OF 3															
HOLE NO. DH-DN/P-60-1																	
NOTES (Continued)	FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION (Continued)																
<p>Hole Completion (Continued): wire piezometers; tips at 38.8' (E1, 304.7) and 31.8' (E1, 351.7). Backfilled hole to surface as shown on diagram, sheet 3. Left 20' of 10" casing in hole.</p> <p>Drilling Mud Level</p> <table style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 10%;">Date</th> <th style="width: 10%;">Depth Mud</th> <th style="width: 10%;">Depth Hole</th> </tr> </thead> <tbody> <tr> <td>2-17-62</td> <td>7.0'</td> <td>25.0'</td> </tr> <tr> <td>2-18</td> <td>2.0'</td> <td>25.0'</td> </tr> <tr> <td>2-22</td> <td>7.5'</td> <td>45.0'</td> </tr> <tr> <td>2-23</td> <td>6.4'</td> <td>45.0'</td> </tr> </tbody> </table>	Date	Depth Mud	Depth Hole	2-17-62	7.0'	25.0'	2-18	2.0'	25.0'	2-22	7.5'	45.0'	2-23	6.4'	45.0'	<p>21.57-22.01': Pitcher Sample.</p> <p>NOTE: The top of the Quaternary Slopewash is assumed to lie within the sample taken from the 21.57-22.81' interval.</p> <p style="text-align: center;">*22.0- 240.79': <u>QUATERNARY SLOPEWASH AND RESIDUAL SOIL.</u></p> <p>22.81- 233.4': <u>Fat Clay (CH)</u>. Approx. 90% highly plastic fines; 10% fine to coarse, hard, subrounded sand. Firm; moist; brown, light brown, dark brown with scattered white grains of calcium carbonate. No reaction with HCl except for violent reaction on carbonate grains.</p> <p>At 23.0': One hard, subrounded, 90 mm dia. cobble.</p> <p>23.4- 224.7': <u>Pitcher Sample</u>. (Contaminated by Drilling Mud.)</p> <p>24.7-25.0': <u>Fat Clay (CH)</u>. Approx. 95% highly plastic fines; 5% fine to coarse sand; 5% fine and coarse, hard, subrounded gravel, max. size 30 mm. Firm; moist; dark brown. No reaction with HCl.</p> <p>25.0- 226.3': <u>Fat Clay with Gravel (CH)</u>. Approx. 80% highly plastic fines; 15% fine and coarse, hard, rounded gravel, max. size 50 mm; 5% fine to coarse sand. Firm; moist; dark brown. No reaction with HCl.</p> <p>226.3- 226.7': <u>Pitcher Sample</u>.</p> <p>226.7-27.0': <u>Fat Clay with Gravel (CH)</u>. Similar to 25.0- 226.3' interval except: Red-brown to brown; one 80 mm rounded cobble.</p> <p>27.0-27.58': <u>Fat Clay (CH)</u>. Approx. 95% highly plastic fines; 5% fine to trace of coarse, hard, subrounded sand, max. size 4 mm. Firm; moist; red-brown. Weak reaction with HCl.</p> <p>27.58-28.81': <u>Pitcher Sample</u>.</p> <p>28.81-29.43': <u>Fat Clay (CH)</u>. Similar to 27.0-27.58' interval.</p> <p>29.0-29.43': No reaction with HCl.</p> <p>29.43-30.81': <u>Pitcher Sample</u>.</p> <p>30.81-31.81': <u>Sandy Clay (CL)</u>. Approx. 75% low to medium plastic fines; 25% fine to medium sand. Soft; moist; yellow-brown with red-brown streaks. No reaction with HCl.</p> <p>31.0-31.81': Very soft; moist to wet. Possibly cave.</p> <p>31.81-32.82': <u>Pitcher Sample</u>.</p> <p>32.82-33.0': <u>Sandy Clay (CL)</u>. Similar to 30.81-31.81' interval.</p> <p>33.0-35.0': <u>No Recovery - Sample lost in hole</u>.</p> <p>35.0-35.36': <u>Sandy Clay (CL)</u>. Similar to 30.81-31.81' interval except: Trace of coarse, hard, subrounded sand, max. size 4 mm. Weak reaction with HCl.</p> <p>35.36-36.78': <u>Pitcher Sample</u>.</p> <p>36.78-37.0': <u>Sandy Clay (CL)</u>. Similar to 30.81-31.81' interval except: trace of coarse, hard, subrounded sand; trace of fine, subrounded gravel, max. size 10 mm.</p> <p>37.0-37.17': <u>Sandy Clay (CL)</u>. Approx. 75% medium plastic fines; 25% fine to traces of coarse, hard, subrounded sand, max. size 4 mm. Firm; moist; brown. Weak reaction with HCl.</p> <p>37.17-38.80': <u>Pitcher Sample</u>.</p> <p>38.80-39.0': <u>Sandy Clay (CL)</u>. Similar to 37.0-37.17' interval.</p> <p>39.0-39.22': <u>Lean Clay (CL)</u>. Approx. 90% low plastic fines; 10% fine to traces of coarse sand, max. size 4 mm; trace of soft, light brown claystone fragments to 20 mm max. size, easily broken with fingers. Firm; moist to wet; brown with dark brown streaks. No reaction with HCl.</p> <p>39.22-40.75': <u>Pitcher Sample</u>.</p> <p style="text-align: center;">*40.79-50.0': <u>PANOCHE FORMATION</u> (Cretaceous)</p> <p>40.79-41.20': <u>Lean Clay (CL)</u>. Similar to 39.0-39.22' interval except: Very firm; trace to 10% claystone fragments; many calcium carbonate streaks. Strong reaction with HCl. Light brown to light yellow brown.</p> <p>41.20-42.81': <u>Pitcher Sample</u>.</p> <p>42.81-43.24': <u>Lean Clay (CL)</u>. Similar to 40.79-41.20' interval.</p>	
Date	Depth Mud	Depth Hole															
2-17-62	7.0'	25.0'															
2-18	2.0'	25.0'															
2-22	7.5'	45.0'															
2-23	6.4'	45.0'															
FEATURE: San Luis Dam—SEED	PROJECT: Central Valley Project, California	SHEET: 2 OF 3 HOLE NO. DH-DN/P-60-1															

Figure 10-5.—Drill hole log, DH-DN/P-60-1, sheet 2 of 3.

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Sheet 3 of 3  
HOLE NO. DH-DN/P-60-1  
60-1

**Figure 10-5.—Drill hole log, DH-DN/P-60-1, sheet 3 of 3.**

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**4. Reason for hole termination** — State whether the hole reached the planned depth or reason why the hole was stopped short.

**5. Drilling time** — Total time, setup time, drilling time, and downtime should be recorded on drillers' daily sheets and should also be recorded on the drill log. These records are essential for determining exploration program costs.

### Center Columns of the Drill Log

**Computer Logs.**—Computer-generated logs offer several options for the content and format of the log such as permeability, penetration resistance, or rock properties which have some differences in format. Examples of each are shown in figures 10-2 through 10-5.

**Standard Geologic Log Form.**—The following discussion pertains to the center columns for the standard Reclamation log (form 7-1337). The columns shown on all figures are self-explanatory. The columns can be modified or new columns added to the existing log form for recording appropriate indexes or special conditions.

The percolation tests (water-pressure tests) column should record the general information of the tests. Additional data may be recorded on "water testing" log forms or drillers' reports.

Type and size of hole, elevation, and depth columns are self-explanatory.

Core recovery should be recorded in percent of recovery by run. Although desirable, core recovery does not necessarily require a visual graph. Core recovery should be noted carefully by the driller for each run on the daily

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drill reports; however, this column should be the record of those measurements determined by the geologist during logging. Measuring the core while in the split tube or sampler, if possible, will produce the most accurate recovery records.

A hole completion column may be added which graphically portrays how the hole was completed. If used, an explanation of the graphic symbols should be provided on the log form.

Rock quality designation (RQD) should be reported by core run. RQD should be included on the log in graph or tabular form regardless of the type project. RQD is used in almost any engineering application of the hole data. Most contractors are interested in RQD as an index of blasting performance, rippability, and stability. RQD is described and explained in chapter 5.

A lithologic log or graphic column is helpful to quickly visualize the geologic conditions. Appropriate symbols may be used for correlation of units, shear zones, water levels, weathering, and fracturing (see figure 10-1).

The samples and testing column should include locations of samples obtained for testing and can later have actual sample results inserted in the column, if the column is enlarged.

**Modifications to Standard Log Form.**—Modifications or adaptations of the center columns are permissible and, in some instances, encouraged. Examples are:

1. The use of a continuation sheet for longer drill logs saves time and is easier to type. The sheets may have only one column to continue the right-hand narrative, or may be divided into two or more

## CORE LOGGING

columns. See sheets 2 and 3 for drill hole SPT-107-2, figure 10-4, for an example; also see sheet 3 of 3 for drill hole DH-DN/P-60-1, figure 10-5.

2. The center column may be modified to portray additional data such as hole completion, various indexes, alphanumeric descriptors, or laboratory test data.

Standard penetration test hole SPT-107-2, figure 10-4, is a modified penetration resistance log which shows laboratory test results; a percent gravel/percent sand/ percent fines column; liquid limit/plasticity index (LL/PI) column, a field moisture column, and other modifications. Drill hole DH-SP-2, figure 10-3, has columns for reporting field density test results, moisture, porosity, percent saturation, percent fines/percent sand, LL/PI, and laboratory classification.

3. Another modification, shown on DH-SP-2, figure 10-3, is a drawing showing the location of the hole in relation to the structure being explored. Diagrams or graphs, such as water levels, may illustrate data better than a column of figures.

### **Required Data and Descriptions for the Right-Hand "Classification and Physical Condition" Column**

**General.**—An accurate description of recovered core and a technically sound interpretation of nonrecovered core are the primary reasons for core logging. The logger needs to remember that any interpretation, such as a shear, must be based on observed factual data. The interpreted reason for the core loss is given, but usually

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it is best to define the area of core loss as the interval heading. For example:

99.4. to 101.6: No Recovery. Interpreted to be intensely fractured zone. Drillers reported blocking off, core probably ground up during drilling.

103.4 to 103.7: Open Joint?. Drillers reported 0.3-ft drop of drill rods during drilling and loss of all water. Joint surfaces in core do not match.

0.7 to 11.6: Silty Sand. Poor recovery, only 6.2 ft recovered from interval. Classification based on recovered material and wash samples.

0.9 to 3.2: Rockbitted. No samples recovered. (Usually this would be subheaded under a previous description, inferring the materials are the same as the last recovered).

**Descriptions of Surficial Deposits.**—Surficial deposits such as slope wash, alluvium, colluvium, and residual soil that are recovered from drill holes are described using USBR 5000 and 5005. If samples cannot be obtained, then description of the cuttings, percent return and color of drilling fluid, drilling characteristics, and correlation to surface exposures is employed. Always indicate what is being described—undisturbed samples, SPT or wash samples, cuttings, or cores. Descriptors and descriptive criteria for the physical characteristics of soils must conform to the established standards. Chapter 11 provides guidelines for soil and surficial deposit descriptions.

Extensive surficial deposits usually are described using geologic and soil classifications. Where surficial deposits are very shallow and not pertinent to engineering applications for design or remediation or where geologic

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classification such as landslides or talus is preferable, units may be given genetic or stratigraphic terms only. For example, Quaternary basin fill, recent stream channel deposit, Quaternary colluvium, zone 3 embankment, and random fill may be described generally; or these may be unit headings with group name subheadings. The format is:

**Geologic and group name.** i.e., Alluvium, (sandy silt). Field classification in parentheses if classified, refer to chapters 3 and 11 for exceptions.

**Classification descriptions.** Additional descriptors (particle sizes, strength, consistency, compactness, etc., from the USBR 5000 and 5005 standards descriptive criteria).

**Moisture.** (dry to wet).

**Color.**

If cores or disturbed samples are not available, describe as many of the above items as can be determined from cuttings, drill water color, drilling characteristics, correlation to surface exposures, etc. Remember that for rockbitted, no recovery, or poor recovery intervals, a classification and group name should be assigned as a primary identification.

**Description of Rock.**—Description of rock includes a rock unit name based on general lithologic characteristics followed by data on structural features and physical conditions. Bedrock or lithologic units are to be delineated and identified, not only by general rock types but by any special geological, mineralogical features with engineering significance, or those pertinent to interpretation of the subsurface conditions.

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Any information which is characteristic of all of the rock units encountered normally is included under the main heading, producing more concise logs. Differences can be described in various subheadings. Rock core is to be described in accordance with descriptors and descriptive criteria presented in chapters 4 and 5. A suggested format is:

**1. Rock name** — A simple descriptive name, sufficient to provide others with possible engineering properties of the rock type; may include geological age and/or stratigraphic unit name.

**2. Lithology (composition/grain sizes/texture/color)** — Give a brief mineralogical description. Describe grain shape and size or sizes and texture using textural adjectives such as vesicular, porphyritic, schistose. (Do not use petrographic terms such as hypidiomorphic, subidioblastic). Other pertinent descriptions could include porosity, absorption, physical characteristics that assist in correlation studies, and other typical and/or unusual properties. Provide the wet color of fresh and weathered surfaces.

Contacts should be described here also. If the contacts are fractured, sheared, open, or have other significant properties, the contacts should be identified and described under separate subheadings.

**3. Bedding/foliation/flow texture** — Provide a description of thickness of bedding, banding, or foliation including the dip or inclination of these features.

**4. Weathering/alteration** — Use established descriptors which apply to most of the core or use individual subheadings. For alteration other than

## CORE LOGGING

weathering, use appropriate descriptors. These may or may not be separate from weathering depending upon rock type and type of alteration. Also, include slaking properties if the material air or water slakes. (Weathering may be used as first or second order headings for some logs.)

**5. *Hardness*** — Use established descriptors.

**6. *Discontinuities*** — These include shears, joints, fractures, and contacts. Discontinuities control or significantly influence the behavior of rock masses and must be described in detail. Detailed discussions of indexes and of descriptive criteria, descriptors, and terminology for describing fractures and shears are provided in chapter 5 and 7.

Fractures or joints should be categorized into sets if possible, based on similar orientations, and each set should be described. When possible, each set should be assigned letter and/or number designations and variations in their physical properties noted by depth intervals. Significant individual joints also may be identified and described. Physical measurements such as spacing and orientation (dip or inclination from core axis), information such as composition, thickness, and hardness of fillings or coatings; character of surfaces (smooth or rough); and, when possible, fracture openness should be recorded. In drill core, the average length between fractures is measured along the centerline of the core for reporting any of the fracture indexes. However, when a set can be distinguished (parallel or subparallel joints), true spacing is measured normal to the fracture surfaces.

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**Description of Shears and Shear Zones.**—Shears and shear zones should be described in detail, including data such as the percentage of the various components (gouge, rock fragments, and associated features such as dikes and veins) and the relationship of these components to each other. Gouge color, moisture, consistency and composition, and fragment or breccia sizes, shape, surface features, lithology, and strengths are recorded. The depths, dip or inclination, and true thickness, measured normal to the shear or fault contacts, also must be determined, if possible, along with healing, strength, and other associated features. A thorough discussion of shears and shear zones is contained in chapter 5.

**Description of Core Loss.**—The significance of core loss is often more important than recovered core. Lost core may represent the worst conditions for design concepts, or it may be insignificant, resulting from improper drilling techniques or equipment. Core losses, their intervals, and the interpreted reason for the loss should be recorded on the log.

**Written Description Form.**—The written description for physical conditions consists of main headings, indented subheadings, and text which describes the important features of the core. Headings and indented subheadings divide the core into readily distinguishable intervals which are pertinent to an engineering geology study. Assigned unit names should correlate with those unit names used for surface mapping. These headings may describe portions of the core or the entire core, depending on how well the headings encompass overall characteristics. Items characteristic of the entire core in one hole may be stated under the major heading; however, in other holes, this same information may have to be broken out into various subheadings because it is not applicable to the entire core. In this discussion,

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several logs are referenced as examples. These logs do not necessarily reflect the established standards, and each may be deficient in some format or context; they are existing logs which are included as examples of different situations which may be encountered. A discussion of headings follows:

**1. Main headings** — The main heading usually divides surficial deposits from bedrock. However, other methods are also acceptable, for example, the summary log in figure 10-5.

**2. First order heading** — The first order headings may be based on weathering or lithology. When the initial rock type exhibits more than one weathering break or the lithologic properties are most significant, lithology would be the first order heading. Weathering may be used as first order headings where significant. If a weathering break coincides with a lithologic break, or only one weathering break is present, they may both be included in the main heading. Depending on lithologies present, for example, if there is only one rock type, the first order headings may be based on fracturing. Lithology, weathering, or fracturing can also be the subject of the first order heading. In certain circumstances, a shear or shear zone or other feature could be given a first order or any lower order heading in order to emphasize a feature's presence or importance. The arrangement which will result in the simplest log is usually the best and should be used. The following examples illustrate the use of first, second, and third order headings. These examples are not intended to represent examples of complete logs.

An example in which weathering is preferred as the first order heading is:

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0.0-5.0: SLOPE WASH (main heading).—General description could include the total description of the unit.

5.0-200.0: PALEOZOIC CALAVERAS GROUP (main heading).

5.0-100.3: Moderately Weathered (first order heading based on weathering; descriptions of weathering applicable to all lithologies could be presented here).

5.0-10.9:	Basalt
10.9-20.1:	Limestone
20.1-50.3:	Shale
50.3-100.3:	Sandstone

100.3-150.0:	<u>Slightly Weathered</u>
100.3-120.2:	Sandstone
120.2-150.0:	Shale

150.0-200.6:	<u>Fresh Shale</u>
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An example in which lithology is preferred as the first-order subheading is:

0.0-5.0: SLOPE WASH (main heading).—General description, could include the total description of the unit.

5.0-200.6: PALEOZOIC CALAVERAS GROUP (main heading).—General description applicable to all lithologies.

5.0-100.3: Sandstone (first order heading based on lithology)

5.0-10.2: Intensely weathered

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10.2-40.1: Moderately weathered

40.1-80.2: Slightly weathered

80.2-100.3: Fresh

100.3-150.1: Fresh Shale (first order heading which combines weathering and lithology)

150.1-200.6: Fresh Diabase

**3. Second order heading** — The second order heading and the associated description contain the characteristics of the rock that are unique to an interval that is not described in the main and first order headings. The second order heading usually is based on weathering if the first order heading is based on lithology. If the first order heading is based on weathering, the second order heading would usually be based on lithology. Fracture data can be described here if similar throughout the interval; if not, divide fracture data into third order headings.

**4. Third order heading** — The third order heading is usually based on fracture data, subordinate features, variations in lithology, etc. This includes variations of rock quality within a certain lithology due to shears, joints, bedding or foliation joints, or other discontinuities. Core recovery lengths are an indicator of fracturing and should be described under this heading, as in the interval from 87.2 to 101.2 in DH-123 figure 10-1. If the fractures are mainly prominent joint sets or other discontinuities, the spacing and orientation of individual sets, along with the overall fracture characteristics, should be noted.

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**5. Additional indentations** — Additional indentations usually are used to describe important additional subordinate features, such as veins or veinlets, variations in lithology, shears, and zones of non- or poor recovery.

In summary, any information consistent throughout a higher order heading, but usually included in a lower one, should be described in the higher order heading to prevent repetition.

### **Data Required for the Comments/Explanation Block**

The comments/explanation block at the bottom of the log form is used for additional information. This may include abbreviations used, gauge height for packer tests, and notes. The hole start and completion date should be in the heading, as well as the date logged. Revision dates of the log should be noted to ensure that the most recent version of the log can be identified. (Date logged and any subsequent revision dates should be entered in this block). The computer log file name can be recorded in this block.

### **Method of Reporting Orientation of Planar Discontinuities and Structural Features**

True dips can be measured directly in vertical holes. The dips of planar features in vertical holes are recorded as "dips 60°" or "60° dip" (see drawing 40-D-6499, figure 5-9). True dip usually is not known in angle holes; and, orientation is measured from the core axis and called inclination, i.e., "Joints are inclined 45° from the core axis" (figure 5-9). If dips are known from oriented core or other surveys, dips may be recorded instead of inclination

## CORE LOGGING

in angle holes. Figure 5-9 demonstrates how misinterpretations can occur; the inclination of a joint in the core from a 45° inclined angle hole can be interpreted as a horizontal joint or as a vertical joint by rotating the core.

### **Core Recovery and Core Losses**

Descriptions of core in the Classification and Physical Condition column should describe the recovered core, not only by physical measurements (maximum, minimum, and mostly range or average), but should identify and include the interpretation for any core losses, especially if the losses are thought to represent conditions different from the core recovered. Designers and other users of the completed log can incorporate into their design all the factual data that are seen and recorded. What is not seen or reported (core losses) is more difficult to incorporate into the design and may well be the most significant information. Also, core losses and interpretations of the reasons for their loss are significant engineering data that may correlate open joints, soft zones, or shears from boring to boring or from surface features to the subsurface explorations.

Core losses can result from three generalized conditions: inaccurate measurements by the drillers; poor drilling techniques, equipment, and handling; or geologic conditions. The geologist, using the depth of hole, recovered core, observations of the core, and drillers observations, is the individual to make interpretations of the core loss. All core should be measured by the logger. If using a split-tube barrel, the core should be measured while in the barrel and always after core segments are fitted together (using the midpoint of core ends). Unaccountable losses should be reconciled, and the location of the loss determined.

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Tape checks or rod checks are the most reliable and preferred methods for knowing the exact location of geologic conditions (top of each run is known with certainty) and where losses occur. All core runs should be measured and recorded; gains and losses can be transferred to adjacent runs and cancel out each other during the process of determining where the core loss is located. Inaccurate drillers' measurements, or locations where portions of the previously drilled interval was left in the hole (pulled off, or fell back in and redrilled), can be determined by examining and matching the end and beginning of each core run to see if they fit together or show signs of being redrilled. Gains may be attributed to pulling out the bottom of the hole, mismeasurement, recovering core left in the hole from the previous run, or recovery of expansive, slaking, or stress relieving materials.

Where unaccountable losses occur, the examination of core to determine the reason for that loss is critical. Poor drilling methods (excessive pressure, speed, excessive water discharge from the drill bit, not stopping when fluid return plugs), inaccurate measurements, or geologic conditions responsible for core losses should be determined. Core may have spun in the barrel after blocking; an intensely fractured zone may have been ground up; or a shear zone, open joint(s), solution cavity, or joint fillings may have been washed away. Geologic interpretation of the core loss is based on examining recovered core and the fractures present in the core. Drill water losses and color or changes in the drilling conditions noted by the driller may suggest an interpretation of the core loss. Where losses occur near a recovered clay "seam," clay coats fracture surfaces, slickensides and/or breccia and gouge are present, the core loss may be interpreted as a shear or shear zone. The description should include all the factual information—discontinuity surface orientations, slickensides, coatings, gouge and/or fractures; and the

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interpretation that the loss occurred in a shear. Depending on the confidence in the interpretation based on the observed conditions, the description can be given as "shear," or "shear?," or "probable shear zone." When a portion of a shear zone has been lost during drilling, the no recovery zone should be described as part of the shear and the loss or part of the loss included in the shear's thickness.

### **Samples**

If the geologist selects representative or special samples for laboratory testing, an appropriate space should be left in the core box to ensure that when logs are reviewed or photographs are taken, core recovery is not misleading. Either filler blocks or a spacer which indicates the top and bottom depths of the sample and a sample number can be used to fill the sample space. For N-size cores, a length of 2- by 2-inch (50- by 50-mm) block or other spacers that fill the tray work well. These blocks also should be used to separate core runs. The lettering on the blocks should be easily readable at a distance. Spray painting the blocks white or yellow and lettering them with black waterproof pens enhances visibility and legibility. The sample interval, and sample number if desired, must be recorded in the Samples for Testing column on the log. Portions of the core may be preserved as representative samples or to protect samples from slaking or other deterioration.

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### Core Photography

#### General Photographic Methods

Transmittal of core photographs with the final logs is recommended. The photos may be included in the data package or as an appendix to the data report. Cores should be photographed while fresh. Before and after photographs of materials that slake or stress-relieve are recommended. The importance of photographing the core before it has been disturbed in transit and before its moisture content has changed cannot be overemphasized. If proper precautions during transport are followed, and the core is logged in a timely manner, reasonably good photographs can be obtained away from the drilling site. This permits the labeling of core features, if desired.

If possible, cores should be photographed in both color and black and white at 8- by 10-inch (200- by 250-mm) size. Black and white photographs do not degrade over time like color photographs. Core photographs should be submitted with the final logs in the geology data report; color photographs are best for data analysis.

Many methods are employed for photographing core. Each box of core can be photographed separately as the box is first filled or three or more boxes can be photographed at a time. There are advantages to both procedures:

- Greater detail and photographs depicting fresher conditions are the major advantages of photographing each box individually.
- When photographing several boxes at a time, transitional features, changes in weathering or fracturing, or large shear zones can be seen in one photograph.

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The best method is a combination of the two. Pictures of individual boxes at the drill site and later pictures of the entire hole are the best of two worlds.

### **Individual Box Photography**

Any portion of core that is in danger of altering or disaggregating because of slaking or "discing" due to stress relief, expansion, or shrinkage due to changes in moisture or confinement because of down time, ends of shifts, or weekends must be boxed and photographed. Under these circumstances, the core should be photographed while at or near the material natural condition (even if a box is only partially filled).

Each photograph should be taken from approximately the same distance so that the scale of each photograph is identical. The box should fill the frame of the camera, thereby obtaining the highest quality resolution or core detail, and the camera should be held as close to normal to the core as possible. A tripod should be used if possible. Tilting the core box and, if necessary, standing in a pickup bed or other vantage point may be helpful. Most core boxes can be tilted about 70 to 80° before any core is in danger of spilling out, so very little additional height is required. A simple 2- by 4-foot (0.6- by 1.2-m) wood frame may be constructed, or the core box may be leaned against a tool box, pickup tailgate, or other stable object. A Brunton compass can be used to ensure that the box and the camera are placed at a consistent, uniform angle. Shadows should be eliminated as much as possible.

All core should be photographed both wet and dry. In hot or dry weather, the unphotographed boxed core should be covered by moist cloth. When ready to photograph, any dry zones should be touched up using a wet cloth or

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paintbrush. In extremely hot weather, the boxed core can be sprayed or sprinkled with water. A water hose, garden sprayer, or spray bottle works well for this operation. Wait for the water to be absorbed so that there is no objectionable sheen or glare-producing film of water on the core at the instant of film exposure.

A labeled lid, letter board, or another frame which shows feature, drill hole number, photograph, or core box number, and depths of the top and bottom of the cored interval should be included in the photograph. A scale in feet and/or tenths of a foot or meters is helpful.

### **Photographing Multiple Boxes**

As soon as possible after the core is removed from the barrel and boxed, the core should be photographed. To facilitate the photography, construct a frame capable of supporting three or more boxes at a time for use at the drill yard or core storage yard. Photograph the core dry then spray with water to bring back the natural moisture color. The same precautions about glare referred to previously should be followed.

A frame which shows the project, feature, hole number, box \_\_ of \_\_ boxes, and from—to, as a minimum, should be used for the photograph. Other optional but recommended entries may include date photographed, and a scale.

### **Special Circumstances**

Special photography such as closeups of shear zones or other special features may be worthwhile. When these photographs are taken, a common object or scale should be included to provide the viewer with relative or actual dimensions.

## CORE LOGGING

When cores are coated with drill mud, a brush, wet rag, or pocket knife should be used to wash or scrape off the mud so that materials are their natural color and features of the core are not obscured. This step obviously must be taken prior to logging the material.

### **Photograph Overlays**

Acetate or mylar overlays on photographs of core can help interpretation of exposed features. Details shown may include labels for shears, weathering, lithologies, or items of special interest. Other items that may be shown on overlays are joint sets, and they may be coded by an alpha or numeric character or by colored ink.

### **Equipment Necessary for Preparing Field Logs**

The following equipment or supplies are necessary for adequately preparing geologic logs:

Core recovery sheets and rough log forms or computer data sheets.—For recording core recovery and maintaining accurate depth measurements for determining core loss intervals.

Drillers' reports.—Daily drill reports (figure 10-6) to check measurements for core recovery, identifying changes in condition or contacts in intervals of poor recovery, determining reasons for core loss, and evaluating openness of fractures.

Knife.—Core hardness/strength characteristics; cleaning or scraping drill mud from core to allow logging and measurement of core recovery.

Hammer.—Core hardness/strength characteristics.



## CORE LOGGING

Tape measure or folding ruler (engineering scale with hundredths of feet or metric as appropriate).—Recovery measurements, thickness of units, shears and fillings, and spacing of fractures.

Protractor.—Measuring orientation of contacts, bedding and foliation, and fracture orientation.

Hydrochloric acid.—Mineral or cementing agent identification (3:1 distilled water to acid).

Hand lens.—Mineral or rock identification, minimum 10X.

Marking pen.—Waterproof ink for marking core for mechanical breaks, depth marks on core, sample marking.

Paintbrush and/or scrub brush, and water.—For cleaning core and for identifying wet color and incipient fractures.

Color identification charts (Munsel Color System or American Geological Institute Rock Color Chart).

Filler block (spacer) material.—For identifying non-recovery intervals and location of samples and for recording drill depths.

Sample preparation materials.—Wax, heater, container, brush, cheese cloth, etc.

Rock testing equipment.—Schmidt hammer, point load apparatus, pocket penetrometer or torvane.

## FIELD MANUAL

### **Instruction to Drillers, Daily Drill Reports, and General Drilling Procedures**

Communication between the geologist and driller is extremely important. Establishment of lines of communication, both orally and in writing, is key to a successful exploration program.

The role of the geologist in the drilling program is as an equal partner with the driller at the drill site. Establishment of this partnership at the beginning of the drilling program will result in better data. Failure to establish a good working relationship with the drill crew often results in unanswered questions and a poor quality end product. One way to establish good working rapport is to keep the drillers informed and to plan with them.

#### **Drill Hole Plan**

A suggested method for ensuring that a clear understanding of what the drilling requirements and expectations are from the drill hole is the preparation of a drill hole plan. The plan is prepared prior to starting the hole and after the geologist has used available interpretive data and has determined whether special testing and procedures or deviations in standard practice are required. This document provides the driller with information about safety, special site conditions, purpose of the hole, procedures to be followed, water testing requirements, materials expected to be recovered, any special sampling or geophysical testing required, and hole completion requirements.

#### **Guidelines for Drillers**

The following guidelines provide a framework for preparing written instructions for drill crews or for

## CORE LOGGING

contract drill specifications. Also, the guidelines serve to help geologists correct poor drilling procedures, collect additional data, or improve core handling and logging.

**Drill Setup.**—To ensure that drill holes are completed at the desired location and along the correct bearing and plunge, the use of aiming stakes and a suitable device for measuring angles should be provided by the geologist and used by the drill crews. Drillers should use aiming stakes set by the geologist or survey crew for the specified bearing of the drill hole. The rig must be anchored properly so that it will not shift. If stakes have been removed or knocked over, they should be replaced by the geologist. Also, drillers must ensure the hole is drilled at the designated angle. The geologist should check the plunge angle with Brunton compass, and/or the drillers should use an appropriate measuring device.

**Daily Drill Reports Preparation.**—The drillers should prepare duplicate daily drill reports using carbon paper (additional copies of each report may be required on contract rigs). All copies must be legible and preferably printed. One copy should be provided to the geologist for monitoring progress and for preparation of the geologic log. The drill report has a space opposite each run for each item of information required; each of these spaces need to be filled out completely. Data should be added to the report or recorded in a notebook after each run. Drillers should record data as it occurs. See drawing 40-D-6484 (figure 10-6) as an example for reporting daily drill activities. Many field offices have local forms on which these data can be recorded. Comments regarding specific items to be recorded on the daily reports are contained in the following paragraphs.

**1. Recording depths and core loss** — Check for agreement on depths for intervals drilled by

## FIELD MANUAL

consecutive shifts. Depths should be recorded in feet and tenths of feet or to the nearest centimeter, as appropriate. Tape checks or rod checks may be required at change of shift or more frequently when requested by the geologist. The section entitled "Core Recovery and Core Losses" contains instructions for proper use of core measurements, filler blocks (spacers), and tape checks. The driller is responsible for knowing the depth of the barrel and the hole at all times. Discrepancies between intervals drilled and recovery need to be resolved. Only standard length drill rods should be used. Core should be measured while it is still in the inner barrel and after it is placed in the core box. Record the most correct measurement of the two in the report. In the event core is left in the hole, the next run should be shortened accordingly; the left amount and proper hole entry and startup procedures should be followed to facilitate recovery.

**2. Recording drilling conditions** — Make sure drilling conditions, such as fast or slow, hard or soft, rough or smooth, even or erratic, moderately fast or very slow, bit blocks off, etc., are indicated for each run. Record time in minutes per foot (meter) of penetration. Any changes in the drilling rate within a run also should be noted along with intervals of caving or raveling. If the bit becomes plugged or blocking off is suspected, the driller should stop drilling and pull the core barrel. Also, when drill circulation is lost, the driller should pull and examine the core.

**3. Drilling fluid return and color** — The type, color, and estimated percent of drilling fluids returned should be recorded for each core run. The depth of changes in fluid loss or color is particularly

## CORE LOGGING

important. If drilling mud is used, indicate number of sacks used per shift. In case of total loss of drilling fluid, it may be necessary to pressure test the interval.

**4. Description of core** — Drillers need to describe the core in general terms; i.e., moderately hard, very hard, soft, clay seams, broken, color, etc. If familiar with the rock types, drillers may report more than just general terminology.

**5. Water-pressure testing** — Holes in rock are typically water tested in 10-foot (3-m) intervals at pressures of approximately  $\frac{1}{2}$  lb/in<sup>2</sup> (3.5 kilopascals [kPa]) to 1 lb/in<sup>2</sup> (6.90 kPa) per foot (1/3 m) of cover up to 100 lb/in<sup>2</sup> (690 kPa). NOTE: Pressures may be modified for each site. Factors such as density of materials, "overburden pressure" or "cover," bedding, purpose of testing, distances from free faces, water levels, and artesian pressures all must be taken into account so that pressure testing does not unintentionally hydrofracture the foundation or jack foundation materials. Pressures should be determined by the geologist. If a range of pressures is used, and disproportionately high water losses are obtained at the higher pressures, the pressures should be stepped down and water losses at the lower pressures recorded. Water test pressures should be stepped up 3 to 5 times and then stepped down. Flow versus pressure should be plotted; and if the relationship is not linear or smoothly curved, hydrofracturing or jacking may be occurring. If the decreasing pressure curve does not follow the increasing pressure curve, washing, plugging, or hydrofracturing or jacking may be occurring without the foundation materials returning to the prewater test state. Intentionally increasing the pressure until the foundation is fractured or jacked is a good

## FIELD MANUAL

way to determine appropriate grout pressures. Gravity tests, overlapping pressure tests, and variations in the length of the interval tested may be used to ensure complete test data. For example, a packer interval of 8 feet (2.4 m) may be used if the hole is caving too badly to get 10 feet (3 m) of open hole. Also, if a packer will not seat at 10 feet (3 m) above the bottom of the hole and there is good rock at 12 feet (3.66 m), a 12-foot test interval may be used. If losses are above 15 gal/min (1.146 liters per second [L/sec]), exceed pump or system capacity, or water is known to be bypassing the packer, reduce the length of the packer interval and retest.

Losses should be recorded in gallons and tenths of gal/min (L/sec). The driller should record the water meter reading at 1-minute intervals, and the test should be run for a full 5 minutes at each pressure increment after the flow has stabilized. The driller should report the average flow in gal/min (L/sec) for the 5-minute test. Each driller should keep his own record of the packer data in case questions arise concerning the testing. A suggested form for recording data is shown in figure 10-7.

**6. Casing or cementing depths** — The depth of the casing or the cemented interval should be shown for each core run. Do not cement any more of the hole than is necessary to repair a caving or raveling interval. The use of additives such as calcium chloride or aluminum powder, if permitted, will reduce the set time. These materials should be added to the water and not to the cement.

**7. Recording unusual conditions** — All unusual conditions or events should be noted in the "Notes"



## FIELD MANUAL

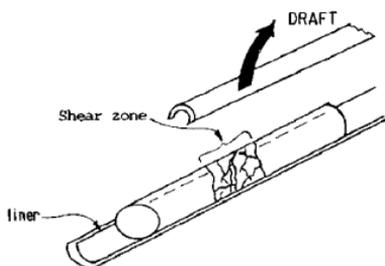
column of the report. This includes such items as sudden changes in drilling speed, loss of circulation, drop of drill string (open joints or cavities), casing and cementing procedures, caving, squeezing, packer failures, and gas.

**8. Recording setups, drilling, and downtime** — Time must be noted on reverse side of report. Type, number, and size of bit is indicated here also.

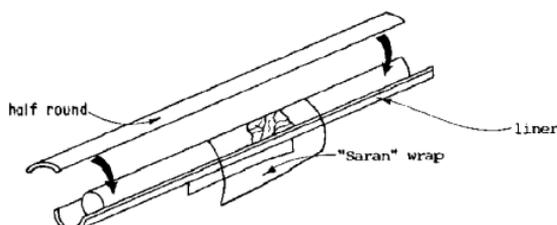
**9. Recording water level measurements** — Measurement should be recorded at the start of each day shift and shown on the day shift report. Holes should be jetted or bailed prior to completion of the hole to obtain reliable water level data. Immediately after jetting or bailing, the depth to water should be recorded.

**10. Care of core and core boxes** — Split-tube (triple tube) core barrels should be used. If not used, the core should not be damaged when extracted from the core barrel. Do not beat on the barrel with a metal hammer; use a rubber mallet/hammer or a piece of wood. The best way to remove core from a solid barrel is by using a pump to pressurize the inside of the barrel and extrude the core (stand back!). The mud pump will work satisfactorily for this. Core should be extracted from the inner tube and carefully placed into core boxes by hand. The use of cardboard or plastic halfrounds is recommended (see figure 10-8. Core pieces should be fitted into the core box and fragments should be arranged to save space. Long pieces may be broken for better fit in the core box, but a line should be drawn across the core to denote mechanical breaks. If 5-foot (1.5-m) core

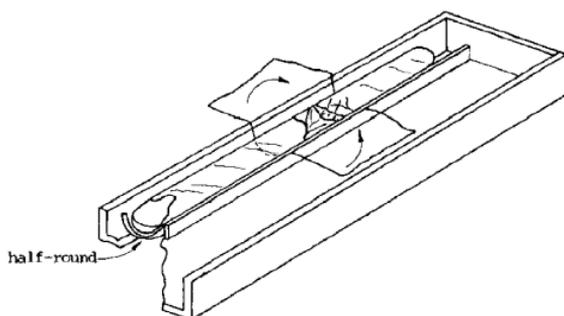
## CORE LOGGING



1. Remove upper split liner to expose fractured rock or shear zone.



2. Place "Saran" wrap over shear zone; then place half-round over top of core and wrap.



3. Take to core box, rotate liner, half-round and core 180° and place in core box; then wrap "Saran" wrap over top of core. An additional half-round may then be placed over the zone to protect it, or to write on. Shear zone may be lifted out of box as a unit if waxing of sample is desired.

**Figure 10-8.—Use of half-round to protect core.**

## FIELD MANUAL

boxes are used, mechanical breaks to fit 5-foot runs in boxes are reduced. Figure 10-9 shows a typical core box for N-size core.

Core should be placed in the core box from left to right, with the top to the left, bottom to the right, starting at the top of the box so the core reads like a book. The ends and top of the box should be marked with black enamel paint or indelible felt pen. Core blocks, which mark the depths, are placed between each run and the depth marked. Data on the outside of the left end of the box should include the project, feature, drill hole number, box number, and depth interval in the box.

Filler blocks (spacers) are necessary to properly record information and minimize disturbance to the core during handling. Blocks should be placed with a planed side marked with either black enamel paint or indelible felt-tip pen; 2- by 2-inch (50- by 50-mm) blocks work well for N-size core. All core runs must be separated with blocks properly labeled at the top and bottom of the run. Sample intervals should be marked in the boxes using wooden blocks of lengths equal to the missing core so that the sample may be returned to the box. Gaps for core losses should not be left in the core box. Core left in the hole and recovered on the next run may be added to the previous run. Filler blocks inserted where unaccountable core losses occur should show the length of loss in tenths of feet, as follows: LC (lost core) 0.3 foot, or NR (no recovery) 0.3 foot. The core loss block indicates that a certain length of core was unaccountably lost within a run, and the block should be placed at the depth of the core loss. If the point of core loss cannot be determined, the block can be placed in the core box at the bottom of

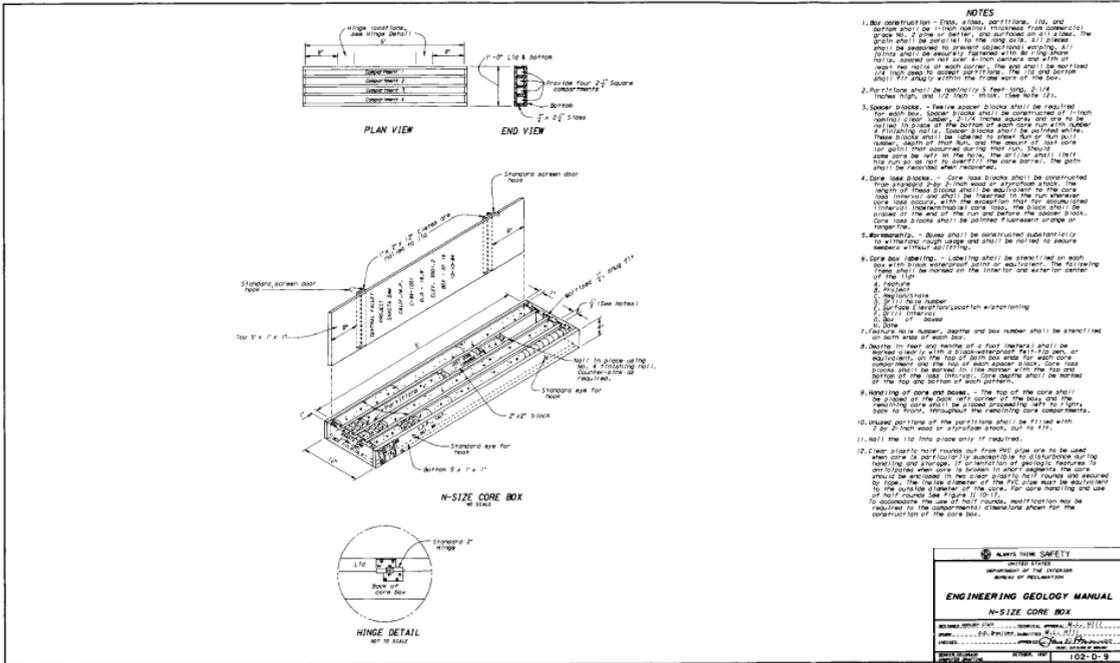


Figure 10-9.—Standard N-size core

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## CORE LOGGING

the run, preceding the bottom of run block. Cavities may be marked on the block. All spacer, sample, and core loss blocks should be nailed to the bottom or sides of the box to prevent movement of the core.

At the drill site, core boxes should be lined up, preferably on boards or planks, in order from top to bottom, with labels and up side to left, in a safe area and kept covered with lids. While in the field, do not place boxes where sliding or caving of slopes is likely to occur and keep out of the way of vehicles and equipment. Core boxes, especially those containing soft, slaking, or intensely fractured core material, should be covered immediately to prevent damage by rain or drying. Tray partitions in boxes should be nailed so that nails do not protrude from bottom of boxes.

When the core is moved, be careful to prevent disturbance, breakage, or spilling. Damage to the core during transportation can be minimized by using nailed-down spacers and a 3/4- to 1-inch thick (19-25-mm) foam-rubber pad placed between the top of the core and the secured core box lid.

**Hole Completion.**—Completion of the drill hole should meet the requirements established by the exploration program and at the direction of the field geologist. Drill holes usually will be completed either with sufficient casing or plastic pipe to assure that the hole will stay open for later water level observations. In areas where vandalism may occur or when long-term monitoring is contemplated, a standpipe and suitable cap with lock should be installed. Completion information should be indicated on the driller's report. The drill hole number should be stamped or welded into the casing. If groundwater observation riser pipes have been installed,

## FIELD MANUAL

install a minimum 3-foot (1-m) length of surface casing with a locking cap as a standpipe to mark the drill hole and protect the riser pipe. Grouted in place, this standpipe can also serve to protect the observation well from infiltration by surface runoff.

### **Concrete Core Logging**

Concrete structures are commonly cored to assess the quality of concrete or as part of foundation investigations on existing features. An early macroscopic assessment of concrete core is warranted for the following reasons:

- Concrete physical condition may suggest changes in the drilling program or sampling techniques that would be difficult to modify after drilling is complete. A different approach in drilling or sampling techniques may be necessary to determine the cause of distress or failure.
- Shipping, handling, and sample preparation may modify the concrete core by inducing, modifying, or masking fractures or causing core disintegration.
- Core could be lost or destroyed before reaching the laboratory.
- Macroscopic examination may provide the required information eliminating the need for a petrographic examination.

This section is based on American Society for Testing Materials Designations (ASTM) C 823-83 and C 856-83.

**Purposes of Examination.**—Investigations of in-service concrete conditions are usually done to: (a) determine the ability of the concrete to perform

## CORE LOGGING

satisfactorily under anticipated conditions for future service; (b) identify the processes or materials causing distress or failure; (c) discover conditions in the concrete that caused or contributed to satisfactory performance or failure; (d) establish methods for repair or replacement without recurrence of the problem; (e) determine conformance to construction specification requirements; (f) evaluate the performance of the components in the concrete; and (g) develop data for fixing financial and legal responsibility.

In addition to the usual drill log information, the following should be provided, if available:

- Reason for and objectives of the coring program.
- Location and original orientation of each core.
- Conditions of operation and service exposure.
- Age of the structure.
- Results of field tests, such as velocity and rebound or Schmidt hammer data.

Figure 10-10 is an example of a drill hole log showing the types of information that can be shown and a format for a log showing both rock and concrete core.

**Examination.**—Concrete core is commonly marked in the field showing the top and bottom depths at the appropriate ends and at any of the following features. Below are listed the major items to examine and record:

**Fractures** — Cracks or fractures in core are best seen on smooth surfaces and can be accented by wetting and partial drying of the surface. Old crack surfaces are often different colors than fresh fracture

# CORE LOGGING

GEOLOGIC LOG OF DRILL HOLE NO. DH-101		SHEET 1 OF 2																																																																																																																																																																																
<p>FEATURE: EAST PARK DAM - SEED                      LOCATION: SEE NOTES                      BEGIN: 03-17-68 FINISHED: 03-22-68                      DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED: 0.3 (1199.20)</p>	<p>PROJECT: ORLAND PROJECT                      COORDINATES: N 819981 E 1695161                      TOTAL DEPTH: 36.1 ft                      DEPTH TO BEDROCK: 16.6 ft</p>	<p>STATE: CALIFORNIA                      GROUND ELEVATION: 1199.5                      ANGLE FROM HORIZON: 90 BEARING:                      HOLE LOGGED BY: STEVEN SHERER                      REVIEWED BY:</p>																																																																																																																																																																																
NOTES	PERMEABILITY TESTS	FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION	DEPTH																																																																																																																																																																															
<p>ALL MEASUREMENTS ARE IN FEET FROM GROUND SURFACE.</p> <p><b>DRILLED BY:</b> Regional Drill Crew, H. Jack Fry, Driller.</p> <p><b>PURPOSE OF HOLE:</b>                      To determine condition of sea concrete, lift line bonding and foundation/concrete contact, permeability and rock properties of bedrock.</p> <p><b>LOCATION OF HOLE:</b> 2.0 ft from southwest edge of sea crest; 50.5 ft from right abutment.</p> <p><b>DRILL RIG:</b> Soregus &amp; Herwood.</p> <p><b>DRILLING METHODS:</b>                      Drilled with clean water.                      0.0 to 21.6 ft: Continuous coring with 6-inch dia. by 3 ft long core barrel and diamond bit, except:                      21.1 to 21.8 ft: NQD-3 core barrel with diamond bit; refusal at 21.2 ft.                      Hole dia. 7 inches; core dia. 5.78 to 6.0 inches.                      21.6 to 21.7 ft: NQD-3 core barrel with diamond bit; refusal at 21.7 ft.                      21.7 to 22.8 ft: 3-inch casing.                      22.8 to 35.1 ft: Continuous coring with NQD-3 core barrel with diamond bit and split inner barrel; hole dia. 2.98 inches; core dia. 1.76 inches.</p> <p><b>DRILLING CONDITIONS:</b>                      0.0 to 21.1 ft: Slow and smooth with some roughness.                      21.1 to 22.8 ft: Very rough with chatter; would not advance.                      22.8 to 35.1 ft: Moderate speed and smooth.</p> <p><b>ESTIMATED DRILLING FLUID RETURN:</b>                      0.0 to 16.6 ft: 100% gray.                      16.6 to 35.1 ft: 100% dark gray.</p> <p><b>CASING RECORD:</b>                      Type: HQ Casing.                      Casing                      Depth Interval Drilled (feet)                      -- 0.0 to 21.7 ft                      22.8 22.8 to 35.1 ft</p> <p><b>DEPTH TO WATER DURING DRILLING (at start of</b></p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th style="text-align: center;">DEPTH (ft VALUE)</th> <th style="text-align: center;">PERMEABILITY (K VALUE)</th> <th style="text-align: center;">PRESSURE (PSI) TOP (DOWN)</th> <th style="text-align: center;">HELE TYPE/SIZE</th> <th style="text-align: center;">% RECOVERY</th> <th style="text-align: center;">CLASSIFICATION</th> <th style="text-align: center;">DEPTH</th> </tr> <tr> <td style="text-align: center;">0</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td style="text-align: center;">0</td> </tr> <tr> <td style="text-align: center;">5</td> <td style="text-align: center;">2.29 x 10<sup>-5</sup> ft/s</td> <td style="text-align: center;">0</td> <td style="text-align: center;">6" D</td> <td 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<td style="text-align: center;">21.6</td> <td style="text-align: center;">6.12 x 10<sup>-5</sup> ft/s</td> <td style="text-align: center;">0</td> <td style="text-align: center;">NQD-3</td> <td style="text-align: center;">.2</td> <td></td> <td style="text-align: center;">21.6</td> </tr> <tr> <td style="text-align: center;">22.8</td> <td></td> <td></td> <td style="text-align: center;">NQD-3</td> <td></td> <td></td> <td style="text-align: center;">22.8</td> </tr> <tr> <td style="text-align: center;">35.1</td> <td></td> <td></td> <td style="text-align: center;">NQD-3</td> <td></td> <td></td> <td style="text-align: center;">35.1</td> </tr> <tr> <td style="text-align: center;">40</td> <td></td> <td></td> <td style="text-align: center;">NQD-3</td> <td></td> <td></td> <td style="text-align: center;">40</td> </tr> <tr> <td style="text-align: center;">45</td> <td></td> <td></td> <td style="text-align: center;">NQD-3</td> <td></td> <td></td> <td style="text-align: center;">45</td> </tr> <tr> <td 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</table>	DEPTH (ft VALUE)	PERMEABILITY (K VALUE)	PRESSURE (PSI) TOP (DOWN)	HELE TYPE/SIZE	% RECOVERY	CLASSIFICATION	DEPTH	0						0	5	2.29 x 10 <sup>-5</sup> ft/s	0	6" D	.1		5	10			6" D			10	15		0		.0		15	20			6" D			20	21.1			NQD-3			21.1	21.2			3" CS			21.2	21.6	6.12 x 10 <sup>-5</sup> ft/s	0	NQD-3	.2		21.6	22.8			NQD-3			22.8	35.1			NQD-3			35.1	40			NQD-3			40	45			NQD-3			45	50			NQD-3			50	55			NQD-3			55	60			NQD-3			60	65			NQD-3			65	70			NQD-3			70	75			NQD-3			75	80			NQD-3			80	85			NQD-3			85	90			NQD-3			90	95			NQD-3			95	100			NQD-3			100	BOTTOM OF HOLE							<p style="text-align: center;">0.0 to 16.6 ft: CONCRETE.</p> <p><b>About 65% BY VOLUME</b> inorganic, metamorphic and sedimentary aggregate. About 6% of aggregate is subangular to well rounded, spherical and tabular, fine and coarse gravel; about 80% angular to subrounded, medium to coarse sand; about 8% subrounded to well rounded, spherical to tabular cobbles. Some amorphous gravel and cobble pieces are oxidized around outer 1/4 inch. Some secondary silica oxidized to intensely weathered. Occasional small 1/8 to 1/2 inch diameter tree branch fragments throughout and small bits of plant material are common. About 35% BY VOLUME fine-grained, gray-colored sand/cement matrix with few to many scattered air vesicles ranging from 1/8 to 1 inch, mostly 1/8 to 1/4 inch, maximum aggregate size 6 inches. Moderately soft to moderately hard, easy to moderately easy to groove matrix with knife; poorly to well bonded and unstrained except as noted. See "COMMENTS" below for explanation of abbreviation.</p> <p><b>DEPTH</b>  <b>0.25 ft:</b> LL 2; not bonded, water flowing into hole, and out downhole face of case.                      2.6 ft: AA, Bte.                      4.4 ft: AA, MB.                      6.2 ft: AA, MB.                      7.8 ft: LL 2, MB; soft and broken into pieces, water seeping on downhole face.                      8.6 ft: AA, Bte.                      8.9 to 10.7 ft: Many small air vesicles.                      10.7 ft: AA, Bte. 0.4 ft (10.8) in conglomerate piece in concrete.  <b>12.5 ft:</b> LL 2 measured on face of core, but not seen in core.                      12.6 ft: AA, MB; 1/4 to 1 inch piece of wood at 12.6 ft.                      12.6 to 14.4 ft: Many small air vesicles.                      14.4 ft: AA, MB.                      14.7 to 16.6 ft: Many small air vesicles.                      16.6 ft: Contact of concrete with conglomerate bedrock is well-bonded, irregular surface.</p> <p style="text-align: center;">16.6 to 35.1 ft: <u>UPPER JURASSIC/LOWER CRETACEOUS</u> <u>STONY CREEK FORMATION</u></p> <p>Conglomerate. Light gray-brown to dark gray and green. Composed chiefly of well-rounded to subrounded, spherical to tabular, coarse sand- to cobble-size rock fragments of chert, quartzite, quartz and serpenine in dark gray ferruginous and argillaceous cementation. Texture is about 80% rock fragments and about 10% cementing matrix. Rock fragments composed of approximately 80% predominantly fine and coarse gravel and about 20% coarse sand. Thickly bedded with 1- to 2-1/2 ft thick fining upward sequence to massive. Intensely to moderately weathered. Dark gray to dark brown with moderate to heavy oxide staining throughout cementation. <u>Moderately hard to moderately soft.</u> Core</p>	<p style="text-align: center;">6" D: 6-inch dia. by 3ft long core barrel and diamond bit.                      NQD-3: NQD-3 core barrel with diamond bit.                      3" CS: 3-inch casing.</p> <p><b>Definition of Bonding:</b>                      Well bonded: No to few small air vesicles; no separation of concrete along lift line; well consolidated.                      Moderately well bonded: No to a few small air vesicles; separates along lift line; well consolidated.                      Poor bonding: Large and/or numerous air vesicles at contact; easy to separate along lift line; soft concrete mortar or absence of concrete mortar.</p>
DEPTH (ft VALUE)	PERMEABILITY (K VALUE)	PRESSURE (PSI) TOP (DOWN)	HELE TYPE/SIZE	% RECOVERY	CLASSIFICATION	DEPTH																																																																																																																																																																												
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BOTTOM OF HOLE																																																																																																																																																																																		
<p><b>PERCOLATION TESTS:</b> Gravity water loss tests were conducted using an inflatable packer. No packer used during 0.0- to 10.7-foot test interval.</p> <p><b>EXPLANATION OF SYMBOLS USED IN DESCRIPTION OF CONCRETE:</b>                      AA: Breaks around aggregate.                      T&amp;A: Breaks through and around aggregate.                      LL: Lift line.                      MB: Mechanical break, not at bottom of core run.                      Btm: Break at bottom of core run.                      AG: Breaks around gravel in conglomerate.</p>		<p>SHEET 1 OF 2 DRILL HOLE DH-101</p>																																																																																																																																																																																

**Figure 10-10.—Log of concrete and rock core.**

## CORE LOGGING

surfaces. Old fracture surfaces often have reaction products or alteration of the surfaces. Fractures often follow structural weaknesses.

**Reacted particles** — Rims on gravel or sand are often caused by weathering processes unless other factors indicate chemical reactions with the cement paste. Crushed aggregate with rims probably is due to chemical reaction with the cement paste.

**Reaction products** — Crushed aggregate with rims usually indicates alteration in the concrete, such as alkali-silica reaction or alkali-carbonate reaction. Rims in paste bordering coarse aggregate and light colored areas in the paste may be gel-soaked or highly carbonated paste adjoining carbonate aggregate that has undergone an alkali-carbonate reaction. White areas of fairly hard, dry material or soft, wet material that has fractured and penetrated the concrete and aggregate or fills air voids should be recorded. Alkali aggregate reaction products can be differentiated from calcium carbonate deposits by using hydrochloric acid. The reaction products do not fizz.

**Changes in size or type of fine and coarse aggregate** — Sizes, shapes, and types of aggregate can vary in a structure due to changes in mixes, placement procedure, or sources and should be logged.

**Voids** — Voids (honeycomb, popcorn) are indicators of trapped air, inadequate vibration, or insufficient mortar to effectively fill the spaces among coarse aggregate particles. Voids should be described and the volume percent estimated.

## FIELD MANUAL

**Segregation of components** — Concrete components can become segregated or concentrated during placement. Large aggregate sizes can separate from fine aggregate, and paste can separate from the aggregate, especially near forms or finished surfaces.

**Cold joints or lift lines** — Weak joints or zones can form in concrete due to long periods between buckets or mixer loads. Poor vibration or poor or improper preparation of previous lift surfaces can form zones of weakness or actual planes similar to joints in rock. These surfaces, called lift lines, should be described and any material on the surfaces described. Lift lines can be very subtle and difficult to locate. Design or construction data often provide clues as to where to look for lift lines and construction joints. The core should be examined wet. Clues to lift line locations are: (1) aligned aggregate along the surfaces each side of a line, (2) coarser aggregate above the lift line than is below the line, (3) different shape, gradation, or composition of aggregate above and below the lift line, (4) a thin line of paste on the lift line, and (5) no aggregate crosses the lift line.

**Steel or other imbedded items** — Reinforcing steel and orientations should be described as well as other materials encountered such as timber, steel lagging, dirt, or cooling pipes.

**Changes in color of the cement** — Changes in paste color can indicate reaction products or changes in cement type or cement sources and should be logged.

**Aggregate-paste bond** — The bond between the aggregate and cement should be described. A good bond is characterized by concrete breaking through

## CORE LOGGING

the aggregate and not around the particles. A fair bond is characterized by concrete breaking through and around the aggregate. A poor bond has concrete breaking around the aggregate.

**Aggregate rock type** — The aggregate rock type can be important in determining the causes of concrete problems. For example, limestone often has chert inclusions suggesting an aggregate reaction, whereas an igneous rock such as granite probably will not react with cement. Both the coarse and fine aggregate should be examined.

**Aggregate shape** — Aggregate shape is usually unique to each source. Rounded or subrounded aggregate is probably natural. Angular (sharp) aggregate is probably crushed.

**Mechanical breaks** — Mechanical breaks in the core and whether the break is around or through the aggregate should be noted.

## **APPENDIX B**

### **Field Forms**



# LOG OF BORING

(Page of )

Project Name:

Date Started : Driller :  
 Date Completed : Depth to Water :  
 Drilling Method : Logged By :  
 Sampling Method : Northing :  
 Drilling Company : Easting :

Project #:

Depth in Feet	Sample Interval	Pen./Rec.	Nitrogen (ppm)	Chloride (ppm)	DESCRIPTION	USCS
0						
5						
10						
15						
20						
25						
30						
35						
40						

Notes:

Coordinate System –

Site Location: \_\_\_\_\_ Drilling Co: \_\_\_\_\_

## Soil Boring Log (Field)

Depth to Water (ft): \_\_\_\_\_

Boring No.: \_\_\_\_\_

Drilling Method: \_\_\_\_\_ Driller: \_\_\_\_\_

Total Depth (ft): \_\_\_\_\_

Date: \_\_\_\_\_

Drilling Start: \_\_\_\_\_

Drilling Equipment: \_\_\_\_\_ Northing: \_\_\_\_\_ Easting: \_\_\_\_\_

Borehole Diameter: \_\_\_\_\_

Date: \_\_\_\_\_

Drilling Finish: \_\_\_\_\_

Sample Method: \_\_\_\_\_ Logger: \_\_\_\_\_

Split Spoon Length: \_\_\_\_\_

Coord. System \_\_\_\_\_

Depth in Feet (BLS)	USCS	Descriptor	Soil Type	Color	Partical Size	Grading	Angularity/shape	Density	Plasticity	Moisture	Odor	PID/FID	% Rec.	Sample No./Int.	Comments
		Sandy	SAND		very fine	poor	angular	(sand or gravel) very loose	non-plastic	dry	none				
		Clayey	CLAY		fine	well	subangular	loose dense	slightly plastic	moist	organic				
		Silty	SILT		medium		subrounded	very dense	plastic	wet	hydrocarbon				
		Gravelly	GRAVEL		coarse		rounded	(silt or clay) very soft soft hard very hard	very plasitc						
Depth in Feet (BLS)	USCS	Descriptor	Soil Type	Color	Partical Size	Grading	Angularity/shape	Density	Plasticity	Moisture	Odor	PID/FID	% Rec.	Sample No./Int.	Comments
		Sandy	SAND		very fine	poor	angular	(sand or gravel) very loose	non-plastic	dry	none				
		Clayey	CLAY		fine	well	subangular	loose dense	slightly plastic	moist	organic				
		Silty	SILT		medium		subrounded	very dense	plastic	wet	hydrocarbon				
		Gravelly	GRAVEL		coarse		rounded	(silt or clay) very soft soft hard very hard	very plasitc						
Depth in Feet (BLS)	USCS	Descriptor	Soil Type	Color	Partical Size	Grading	Angularity/shape	Density	Plasticity	Moisture	Odor	PID/FID	% Rec.	Sample No./Int.	Comments
		Sandy	SAND		very fine	poor	angular	(sand or gravel) very loose	non-plastic	dry	none				
		Clayey	CLAY		fine	well	subangular	loose dense	slightly plastic	moist	organic				
		Silty	SILT		medium		subrounded	very dense	plastic	wet	hydrocarbon				
		Gravelly	GRAVEL		coarse		rounded	(silt or clay) very soft soft hard very hard	very plasitc						
Depth in Feet (BLS)	USCS	Descriptor	Soil Type	Color	Partical Size	Grading	Angularity/shape	Density	Plasticity	Moisture	Odor	PID/FID	% Rec.	Sample No./Int.	Comments
		Sandy	SAND		very fine	poor	angular	(sand or gravel) very loose	non-plastic	dry	none				
		Clayey	CLAY		fine	well	subangular	loose dense	slightly plastic	moist	organic				
		Silty	SILT		medium		subrounded	very dense	plastic	wet	hydrocarbon				
		Gravelly	GRAVEL		coarse		rounded	(silt or clay) very soft soft hard very hard	very plasitc						



# LOG OF SOIL BORING: SB-03

(Page 1 of 1)

Project Name: Santa Fe River Assessment	Date Started : 10/23/09	Driller : J. Aguire
Project #: NME-VR2-SR	Date Completed : 10/23/09	Depth to Water : NA
	Drilling Method : HSA (7-3/4 OD)	Logged By : E. Romesser
	Sampling Method : continuous (5' interval)	X Coordinate : 1731486.02990
	Drilling Company : Rodgers & Co., Inc.	Y Coordinate : 1705469.01180

Depth in Feet	Sample Interval	Pen./Rec.	PID (ppm)	DESCRIPTION	USCS	GRAPHIC
0		NA	NA	SILTY SAND trace Cobbles, brown (5YR 4/6)		
5		60/24	<1	Fill: SILTY SAND little Gravel (up to 2"), dark brown (7.5YR 3/2), fine to medium gravel, coal & brick pieces	SM	
10				SAND some Gravel & Cobbles, reddish (2.5YR 7/6), fine- to medium-grained sand, fine to coarse gravel & cobbles	SW	
				Not Sampled: boulder, augered down to 11.5' bgs		
15		30/30	<1	Tesuque formation contact SAND, reddish (2.5YR 7/6), fine-grained sand (little medium grained), subangular, moist SAND, reddish (2.5YR 5/8), fine-grained sand, subangular, dry	SP	
20		60/43	<1	SAND trace Gravel, reddish (2.5YR 4/8), fine- to coarse-grained sand, subangular, fine gravel, subangular SAND little Gravel, reddish (2.5YR 4/8), fine- to coarse-grained sand, fine gravel, strongly cemented, laminar layers at ~12" from bottom		
25		60/48	<1	SAND, reddish (2.5YR 4/8), fine- to coarse-grained sand, subangular to subrounded, 2" cobble, dry		
30		60/44	<1	SAND little Gravel, reddish (2.5YR 4/8), fine- to coarse-grained sand, subanglar to subrounded, fine to coarse gravel, subangular to subrounded, strongly cemented, dry	SW	
35		60/29	<1	SAND little Gravel, reddish (2.5YR 4/8), fine- to coarse-grained sand, subanglar to subrounded, fine to coarse gravel, subangular to subrounded, strongly cemented, 2" cobbles, dry		
		18/24	<1	SAND, reddish (2.5YR 4/8), fine-grained sand, very thin laminar	SP	
				SAND, reddish (2.5YR 4/8), fine- to coarse-grained sand, subangular, strongly cemented (sample taken w/ 2' split spoon)	SW	
40				Bottom of Boring at 35.5' bgs		

Notes:

1. Post hole 0-4' bgs.
2. NA = Not Applicable.
3. Refusal at 35.5' bgs, Split Spoon: blow counts 15-69-175.
4. X = Sample interval sent for laboratory analysis.

5. Groundwater not encountered - monitoring well not installed. Soil boring abandoned with bentonite/cement slurry on 10/23/09.



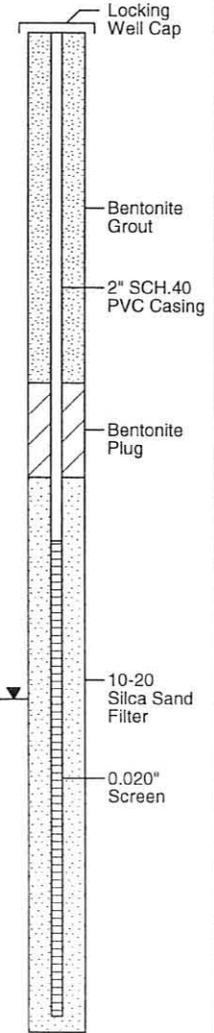
# LOG OF SFRMW-01

(Page 1 of 1)

Project Name: Santa Fe River Assessment	Date Started : 10/20/09 Date Completed : 10/20/09 Drilling Method : HSA (7-3/4 OD) Sampling Method : continuous (5' interval) Drilling Company : Rodgers & Co., Inc.	Driller : J. Aguire Depth to Water : 21' bgs Logged By : E. Romesser X Coordinate : 1731606.54850 Y Coordinate : 1705086.39280
Project #: NME-VR2-SR		

Depth in Feet	Sample Interval	Pen./Rec. (inches)	PID (ppm)	DESCRIPTION	USCS	GRAPHIC
0		NA	NA	Cuttings: SAND w/ Gravel, trace cobbles, dark brown (7.5YR 3/2), fine-grained sand, fine to coarse gravel, road-base engineered fill, dry		
5		60/10	<1	SAND trace Gravel, brown (5YR 4/2), fine- to medium-grained sand, fine to coarse gravel, subangular, dry	SW	
10		60/18	<1	SAND trace Gravel, brown (5YR 4/2), fine- to medium-grained sand, fine to coarse gravel, subangular, subangular cobbles, dry		
15		60/32	-	Tesuque formation contact SAND, whitish brown (10YR 8/3), fine-grained sand, subangular, dry		
20		60/19	-	SAND, same as previous; reddish brown (5YR 7/8), fine-grained sand, subangular, moist		
25		60/36	3.0	SAND, reddish brown (5YR 6/8), fine-grained sand, subangular, wet	SP	
30		30/18	1.1	SAND, reddish-brown (5YR 5/8), medium- to coarse-grained sand, subangular, saturated		
				Bottom of Boring at 31.5' bgs		

SFRMW-01:  
Flush Grade,  
24" Dia. Flush  
Concrete Pad



Notes:

1. Post hole 0-4' bgs.
2. NA = Not Applicable.
3. X = Sample interval sent for laboratory analysis.
4. - = PID malfunction.



# FIELD GUIDE FOR SOIL AND STRATIGRAPHIC ANALYSIS V.2

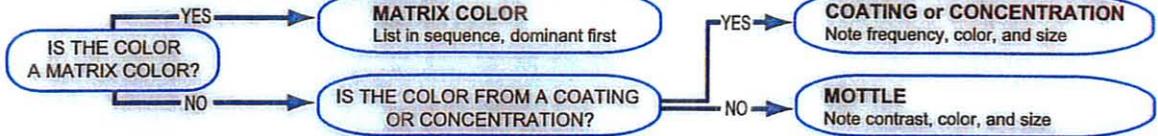
**START HERE**

## DENSITY OR CONSISTENCY

	N-VALUE		N-VALUE	q <sub>u</sub> (tsf)	
COARSE GRAINED DEPOSITS	0-4	▶ VERY LOOSE	FINE GRAINED DEPOSITS	0-2	▶ VERY SOFT
	5-10	▶ LOOSE		3-4	▶ SOFT
	11-29	▶ MEDIUM DENSE		5-8	▶ MEDIUM
	30-49	▶ DENSE		9-15	▶ STIFF
	>50	▶ VERY DENSE		16-30	▶ VERY STIFF
			>30	>4.0	▶ HARD

## COLOR

Use Standard Munsell Color Notation



## CLASSIFICATION

Unified Soil Classification System - adopted ASTM D2488

### COARSE-GRAINED DEPOSITS

>50% coarse-grained sediments, <50% fines

#### STEP 1:

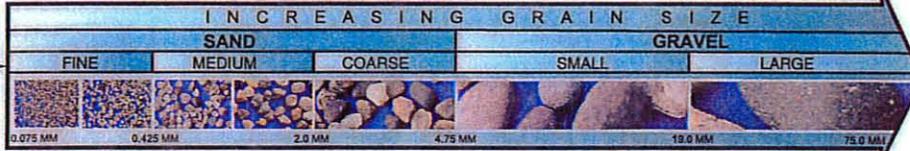
IS SEDIMENT COARSE GRAINED OR FINE GRAINED?

>50% fines, <50% coarse-grained sediments

### FINE-GRAINED DEPOSITS

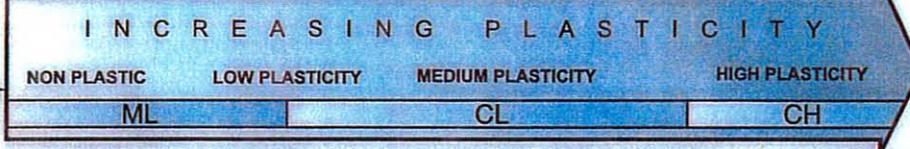
(organic and inorganic)

### STEP 2: DETERMINE SAND VS. GRAVEL RATIO



STEP 3:  
CONTINUE WITH SAND OR GRAVEL ON FLOW CHART (REVERSE)

### STEP 2: DETERMINE PLASTICITY AND ASSIGN USCS GROUP SYMBOL



STEP 3:  
CONTINUE WITH GROUP SYMBOL ON FLOW CHART (REVERSE)

## MOISTURE

MOISTURE ABSENT ▶ DRY  
DAMP ▶ MOIST  
VISIBLE WATER ▶ WET

FOR NON-PLASTIC FINES

WATER RISES TO SURFACE SLOWLY ▶ SLOW DILATENCY  
WATER RISES TO SURFACE QUICKLY ▶ RAPID DILATENCY

## PLASTICITY

(Use with CLASSIFICATION)

WILL NOT SUPPORT 6mm DIAMETER ROLL IF HELD ON END  
6mm DIA. ROLL CAN BE REPEATEDLY ROLLED AND SUPPORTS ITSELF, 4mm DIA. ROLL DOES NOT  
4mm DIA. ROLL CAN BE REPEATEDLY ROLLED AND SUPPORTS ITSELF, 2mm DIA. ROLL DOES NOT  
2mm DIA. ROLL CAN BE REPEATEDLY ROLLED AND SUPPORTS ITSELF

▶ NON-PLASTIC  
▶ LOW PLASTICITY  
▶ MEDIUM PLASTICITY  
▶ HIGH PLASTICITY



## COHESIVENESS

6mm DIAMETER ROLL CANNOT BE FORMED ▶ NONCOHESIVE  
6mm DIAMETER ROLL CAN BE FORMED ▶ COHESIVE

## SEDIMENTARY STRUCTURE

UNIFORM BEDS >30cm ▶ MASSIVE  
BEDS 3cm to 30cm ▶ THICKLY BEDDED  
BEDS 0.5cm to 3cm ▶ BEDDED  
BEDS <0.5cm ▶ THINLY BEDDED  
▶ LAMINATED

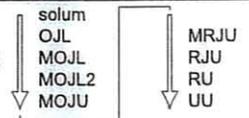
SECONDARY SOIL STRUCTURE (IN SOLUM ONLY)

Spheroidal peds or granules usually packed loosely ▶ GRANULAR  
Irregular, roughly cubelike peds with planar faces (angular or subangular) ▶ BLOCKY  
Flat and horizontal peds ▶ PLATY  
Vertical, pillarlike peds with flat tops ▶ PRISMATIC  
Vertical, pillarlike peds with curved tops (which are commonly "bleached") ▶ COLUMNAR

## WEATHERING ZONE ABBREVIATION

MODIFIER SYMBOL (if present)	1st SYMBOL	2nd SYMBOL	LAST SYMBOL (if present)
MOTTLED ▶ M	OXIDIZED ▶ O	LEACHED ▶ L	SECONDARY
JOINTED ▶ J	REDUCED ▶ R	UNLEACHED ▶ U	CARBONATE ▶ 2
	UNOXIDIZED ▶ U		

EXAMPLE



## SECONDARY GRAIN SIZE INFORMATION

< 5% ▶ TRACE  
6% to 15% ▶ LITTLE  
16% to 30% ▶ FEW  
31% to 49% ▶ SOME



▶ UNIFORM (poorly graded)  
▶ NON-UNIFORM (well graded)

▶ FINE SAND  
▶ MEDIUM-GRAINED SAND  
▶ COARSE-GRAINED SAND  
▶ FINE GRAVEL  
▶ COARSE GRAVEL

FOR GLACIAL DIAMICTONS ▶ CLAST FRACTION  
▶ CLAST LITHOLOGY

## DEPOSITIONAL ENVIRONMENT

VARIOUS DEPOSITIONAL ENVIRONMENTS (interpretation) ▶ EOLIAN (LOESS)  
▶ FLUVIAL  
▶ ALLUVIAL  
▶ LACUSTRINE  
▶ COASTAL  
▶ RESEDIMENTED

GLACIAL DEPOSITIONAL PROCESSES ▶ SUBGLACIAL  
▶ GLACIOFLUVIAL  
▶ GLACIOLACUSTRINE  
▶ RESEDIMENTED

GENERALIZED RESEDIMENTATION PROCESSES ▶ MASS SLUMP  
▶ SEDIMENT FLOW  
▶ COLLUVIUM

## STRATIGRAPHIC NAME

USE FORMAL STATE GEOLOGICAL SURVEY NOMENCLATURE WHEN POSSIBLE;  
IF NOT POSSIBLE, ASSIGN SITE-SPECIFIC UNIT NAME ACCORDING TO DEPOSITIONAL ENVIRONMENT / FACIES ASSEMBLAGE

## STRATIGRAPHIC CONTACT

< 10 cm ▶ SHARP (or ABRUPT for pedogenic alternation)  
> 10 cm (Note transition interval) ▶ GRADATIONAL (or TRANSITIONAL for weathering zone change)

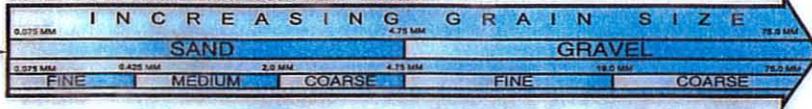
**STEP 1:**  
IS SEDIMENT  
COARSE GRAINED  
OR  
FINE GRAINED?

# UNIFIED SOIL CLASSIFICATION SYSTEM

FOR COMMON INORGANIC AND ORGANIC SEDIMENTS

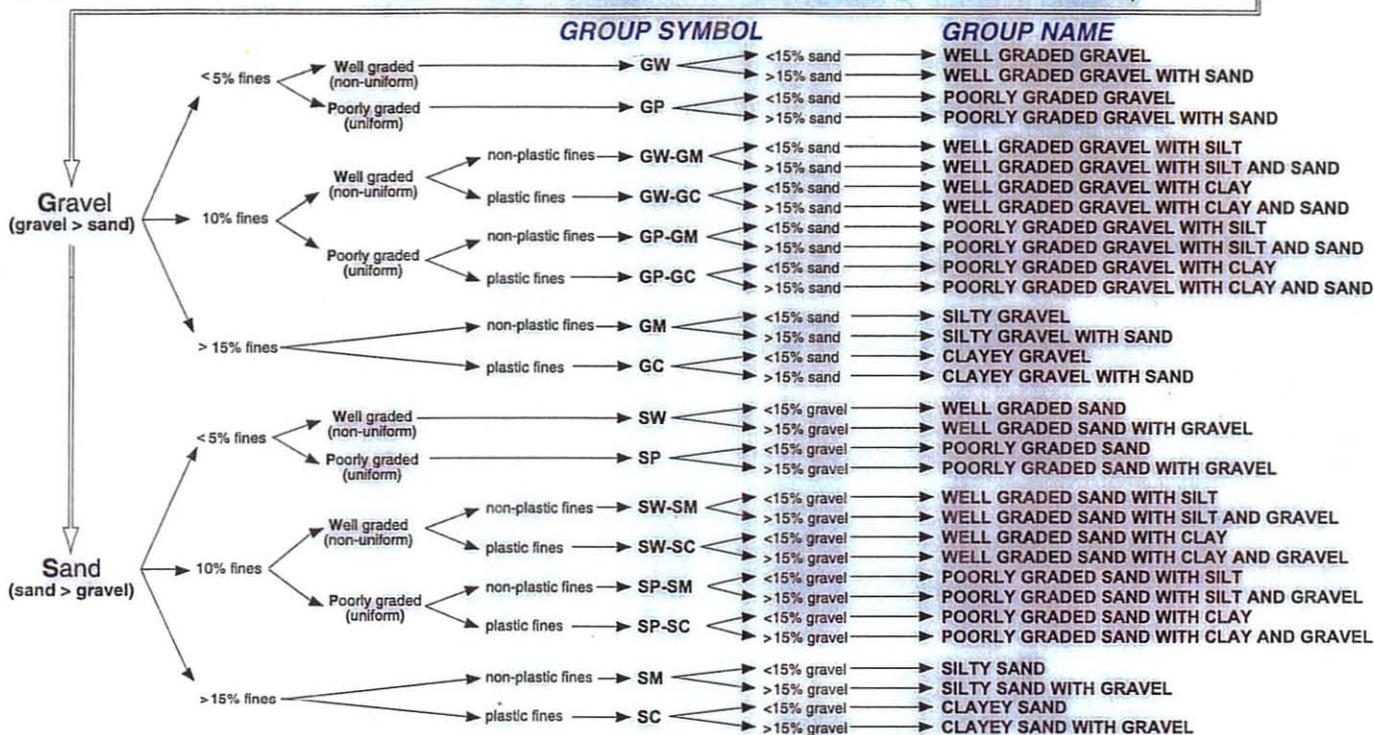
Modified from ASTM

**STEP 2: DETERMINE SAND VS. GRAVEL RATIO**



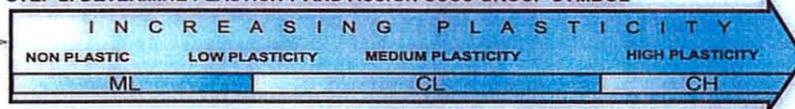
**STEP 3:**  
CONTINUE WITH  
"SAND" OR "GRAVEL"  
AND FOLLOW FLOW CHART  
TO ASSIGN A GROUP SYMBOL  
AND A GROUP NAME

**COARSE-GRAINED DEPOSITS**  
(>50% coarse-grained, <50% fine sediments)



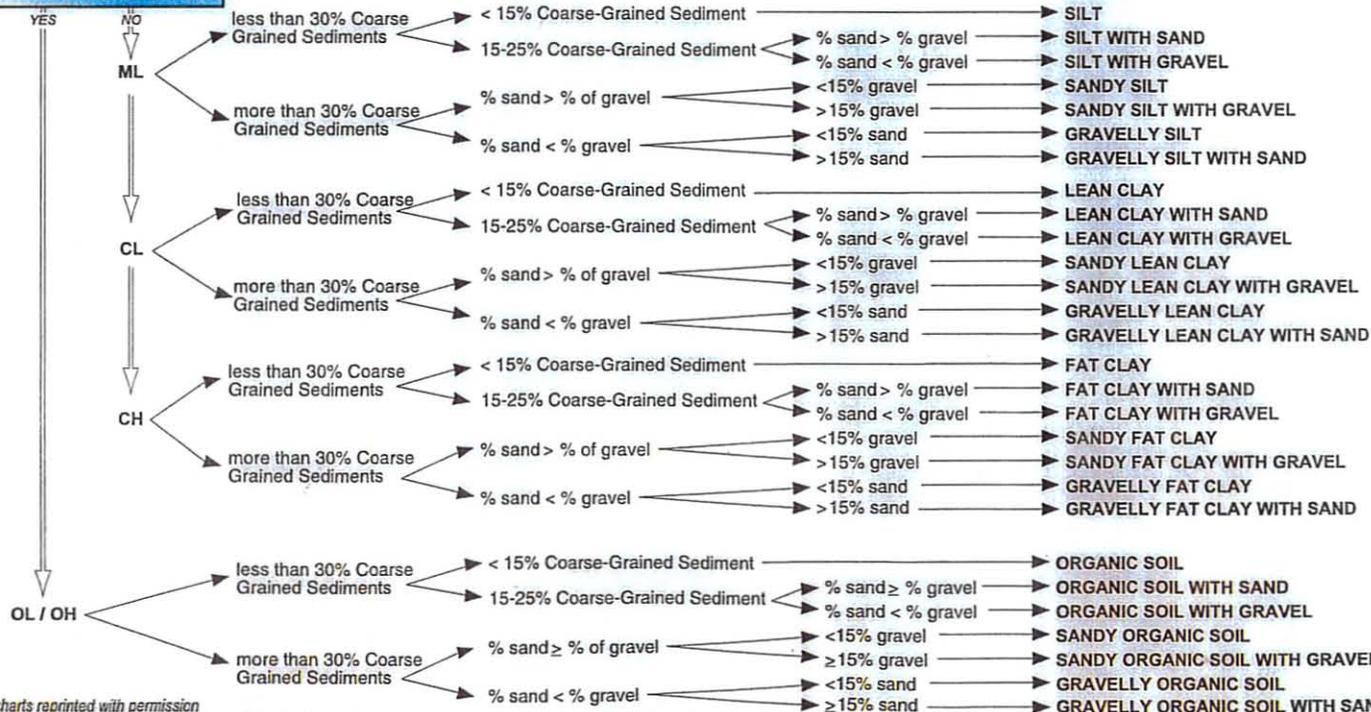
**FINE-GRAINED DEPOSITS**  
(>50% fines, <50% coarse-grained sediments)

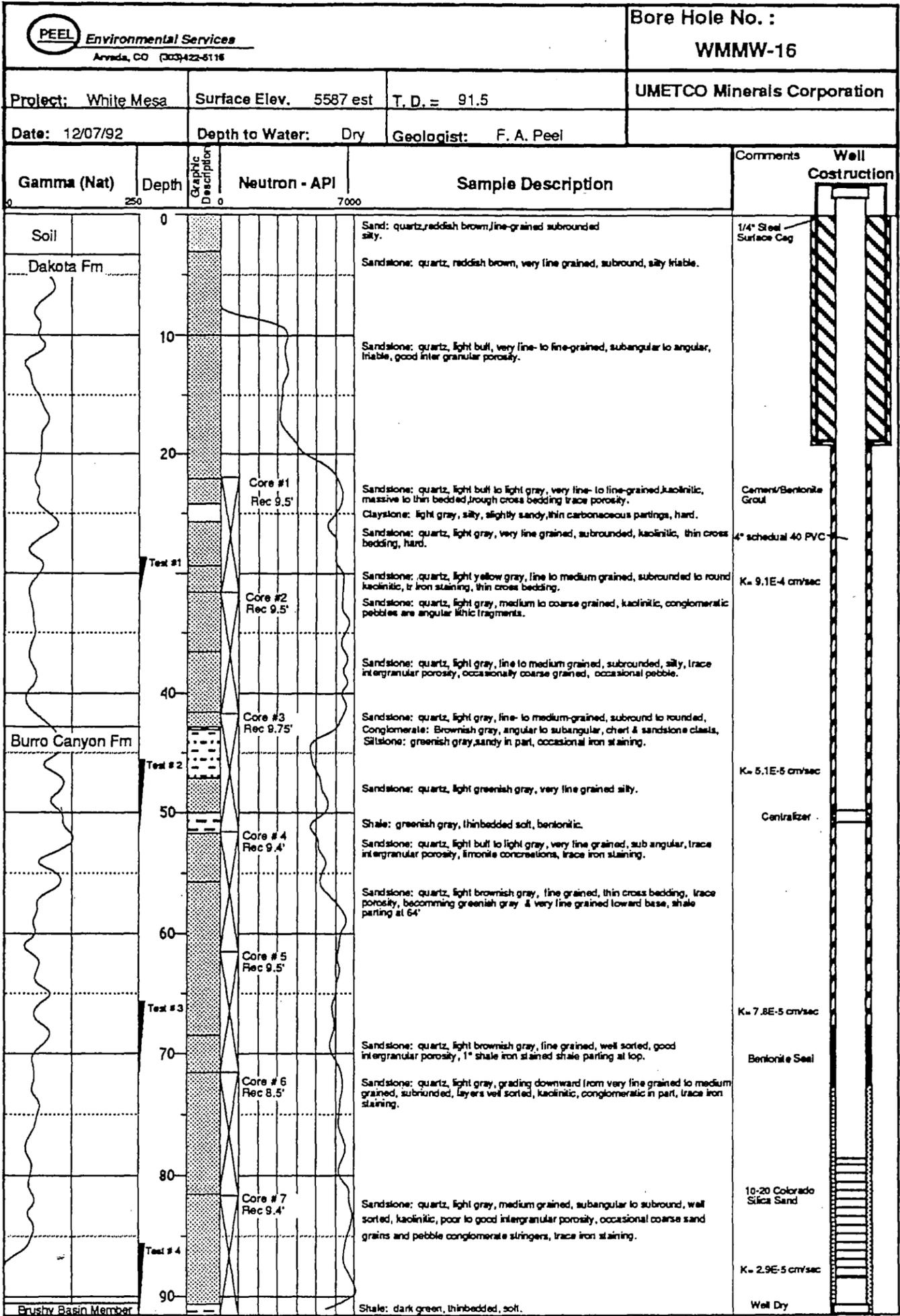
**STEP 2: DETERMINE PLASTICITY AND ASSIGN USCS GROUP SYMBOL**



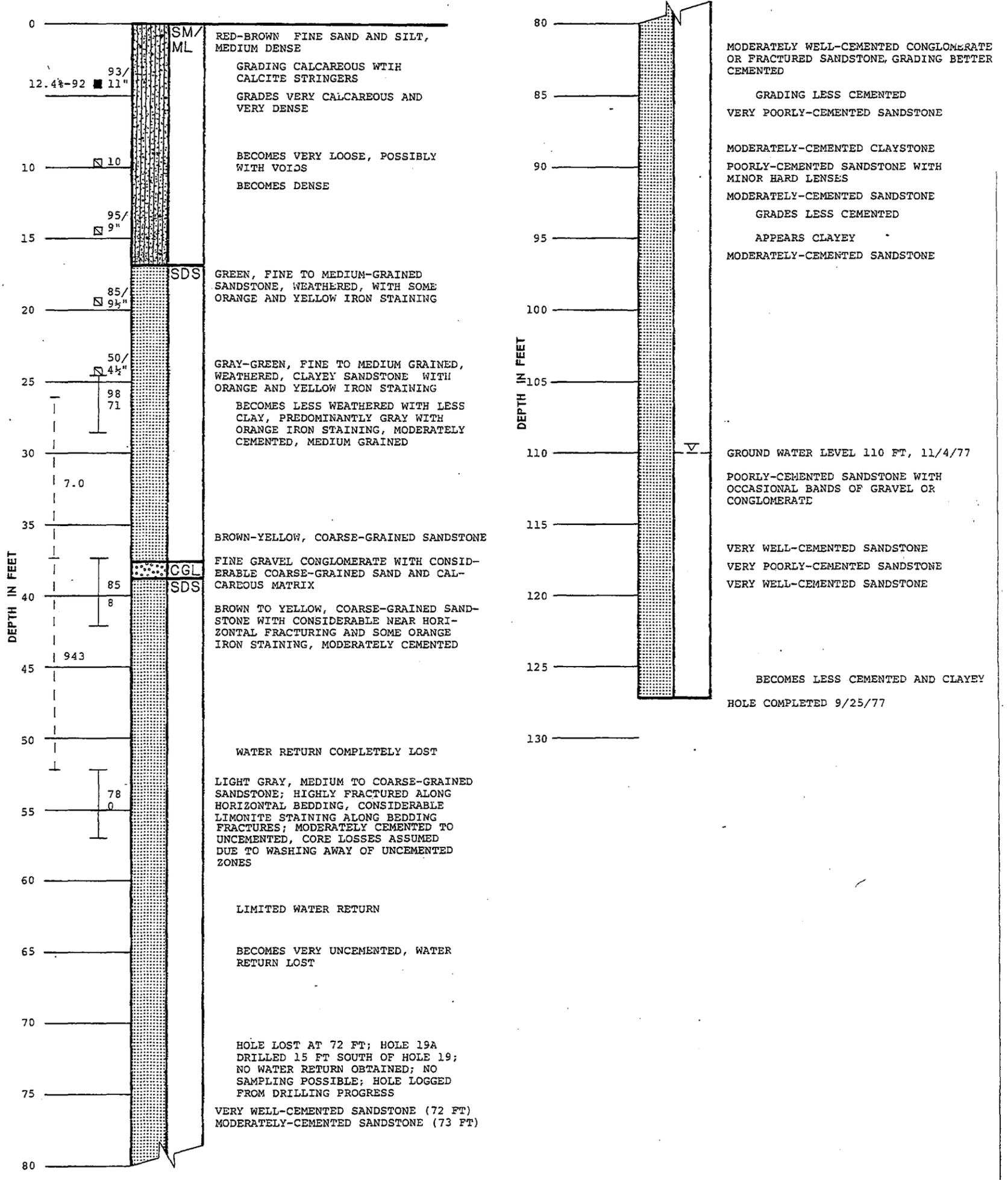
**STEP 3:**  
CONTINUE WITH  
GROUP SYMBOL  
AND FOLLOW FLOW CHART  
TO ASSIGN A GROUP NAME

**STEP 4:**  
DOES ORGANIC CONTENT  
INFLUENCE SOIL PROPERTIES?





**BORING NO. 19**  
EL. 5600.3 FT.



**LOG OF BORINGS**

## **APPENDIX C**

**ASTM E1689-95(2003)e1 Standard Guide for Developing Conceptual Site Models  
for Contaminated Sites**



# Standard Guide for Developing Conceptual Site Models for Contaminated Sites<sup>1</sup>

This standard is issued under the fixed designation E1689; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This guide is intended to assist in the development of conceptual site models to be used for the following: (1) integration of technical information from various sources, (2) support the selection of sample locations for establishing background concentrations of substances, (3) identify data needs and guide data collection activities, and (4) evaluate the risk to human health and the environment posed by a contaminated site. This guide generally describes the major components of conceptual site models, provides an outline for developing models, and presents an example of the parts of a model. This guide does not provide a detailed description of a site-specific conceptual site model because conditions at contaminated sites can vary greatly from one site to another.

1.2 The values stated in either inch-pound or SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 This guide is intended to apply to any contaminated site.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*<sup>2</sup>

**D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass**

2.2 *EPA Documents:*<sup>3</sup>

***Guidance for Data Useability in Risk Assessment (Part A)***

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee E47 on Biological Effects and Environmental Fate and is the direct responsibility of Subcommittee E47.05 on Risk Assessment, Communication and Management.

Current edition approved Feb. 1, 2008. Published February 2008. Originally approved in 1995. Last previous edition approved in 2003 as E1689-95(2003)<sup>\epsilon</sup>1. DOI: 10.1520/E1689-95R08.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> Available from Standardization Documents Order Desk, Bldg 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

***Final, Publication 9285.7-09A***, PB 92-963356, April 1992

***Guidance for Data Useability in Risk Assessment (Part B)***, OSWER Directive 9285.7-09B, May 1992

***Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA***, OSWER Directive 9355.3-01, October 1988

## 3. Terminology

3.1 *Definitions:*

3.1.1 *background concentration, n*—the concentration of a substance in ground water, surface water, air, sediment, or soil at a source(s) or nearby reference location, and not attributable to the source(s) under consideration. Background samples may be contaminated, either by naturally occurring or manmade sources, but not by the source(s) in question.

3.1.2 *conceptual site model, n*—for the purpose of this guide, a written or pictorial representation of an environmental system and the biological, physical, and chemical processes that determine the transport of contaminants from sources through environmental media to environmental receptors within the system.

3.1.3 *contaminant, n*—any substance, including any radiological material, that is potentially hazardous to human health or the environment and is present in the environment at concentrations above its background concentration.

3.1.4 *contaminant release, n*—movement of a substance from a source into an environmental medium, for example, a leak, spill, volatilization, runoff, fugitive dust emission, or leaching.

3.1.5 *environmental receptor, n*—humans and other living organisms potentially exposed to and adversely affected by contaminants because they are present at the source(s) or along contaminant migration pathways.

3.1.6 *environmental transport, n*—movement of a chemical or physical agent in the environment after it has been released from a source to an environmental medium, for example, movement through the air, surface water, ground water, soil, sediment, or food chain.

3.1.7 *exposure route, n*—the process by which a contaminant or physical agent in the environment comes into direct contact with the body, tissues, or exchange boundaries of an

environmental receptor organism, for example, ingestion, inhalation, dermal absorption, root uptake, and gill uptake.

3.1.8 *migration pathway, n*—the course through which contaminants in the environment may move away from the source(s) to potential environmental receptors.

3.1.9 *source, n*—the location from which a contaminant(s) has entered or may enter a physical system. A primary source, such as a location at which drums have leaked onto surface soils, may produce a secondary source, such as contaminated soils; sources may hence be primary or secondary.

## 4. Summary of Guide

4.1 The six basic activities associated with developing a conceptual site model (not necessarily listed in the order in which they should be addressed) are as follows: (1) identification of potential contaminants; (2) identification and characterization of the source(s) of contaminants; (3) delineation of potential migration pathways through environmental media, such as ground water, surface water, soils, sediment, biota, and air; (4) establishment of background areas of contaminants for each contaminated medium; (5) identification and characterization of potential environmental receptors (human and ecological); and (6) determination of the limits of the study area or system boundaries.

4.2 The complexity of a conceptual site model should be consistent with the complexity of the site and available data. The development of a conceptual site model will usually be iterative. Model development should start as early in the site investigation process as possible. The model should be refined and revised throughout the site investigation process to incorporate additional site data. The final model should contain sufficient information to support the development of current and future exposure scenarios.

4.3 The concerns of ecological risk assessment are different from those of human-health risk assessment, for example, important migration pathways, exposure routes, and environmental receptors. These differences are usually sufficient to warrant separate descriptions and representations of the conceptual site model in the human health and ecological risk assessment reports. There will be elements of the conceptual site model that are common to both representations, however, and the risk assessors should develop these together to ensure consistency.

## 5. Significance and Use

5.1 The information gained through the site investigation is used to characterize the physical, biological, and chemical systems existing at a site. The processes that determine contaminant releases, contaminant migration, and environmental receptor exposure to contaminants are described and integrated in a conceptual site model.

5.2 Development of this model is critical for determining potential exposure routes (for example, ingestion and inhalation) and for suggesting possible effects of the contaminants on human health and the environment. Uncertainties associated with the conceptual site model need to be identified clearly so that efforts can be taken to reduce these uncertainties to acceptable levels. Early versions of the model, which are

usually based on limited or incomplete information, will identify and emphasize the uncertainties that should be addressed.

5.3 The conceptual site model is used to integrate all site information and to determine whether information including data are missing (data gaps) and whether additional information needs to be collected at the site. The model is used furthermore to facilitate the selection of remedial alternatives and to evaluate the effectiveness of remedial actions in reducing the exposure of environmental receptors to contaminants.

5.4 This guide is not meant to replace regulatory requirements for conducting environmental site characterizations at contaminated (including radiologically contaminated) sites. It should supplement existing guidance and promote a uniform approach to developing conceptual site models.

5.5 This guide is meant to be used by all those involved in developing conceptual site models. This should ideally include representatives from all phases of the investigative and remedial process, for example, preliminary assessment, remedial investigation, baseline human health and ecological risk assessments, and feasibility study. The conceptual site model should be used to enable experts from all disciplines to communicate effectively with one another, resolve issues concerning the site, and facilitate the decision-making process.

5.6 The steps in the procedure for developing conceptual site models include elements sometimes referred to collectively as site characterization. Although not within the scope of this guide, the conceptual site model can be used during site remediation.

## 6. Procedure

6.1 *Assembling Information*—Assemble historical and current site-related information from maps, aerial images, cross sections, environmental data, records, reports, studies, and other information sources. A visit(s) to the site by those preparing the conceptual site model is recommended highly. The quality of the information being assembled should be evaluated, preferably including quantitative methods, and the decision to use the information should be based on the data's meeting objective qualitative and quantitative criteria. For more information on assessing the quality and accuracy of data, see *Guidance for Data Useability in Risk Assessment (Part A)* and *Guidance for Data Useability in Risk Assessment (Part B)*. Methods used for obtaining analytical data should be described, and sources of information should be referenced. A conceptual site model should be developed for every site unless there are multiple sites in proximity to one another such that it is not possible to determine the individual source or sources of contamination. Sites may be aggregated in that case. A conceptual model should then be developed for the aggregate.

6.2 *Identifying Contaminants*—Identify contaminants in the ground water, surface water, soils, sediments, biota, and air. If no contaminants are found, the conceptual site model should be used to help document this finding.

6.3 *Establishing Background Concentrations of Contaminants*—Background samples serve three major functions: (1) to establish the range of concentrations of an analyte attributable to natural occurrence at the site; (2) to establish the range of concentrations of an analyte attributable to source(s)

other than the source(s) under consideration; and (3) to help establish the extent to which contamination exceeds background levels.

6.3.1 The conceptual site model should include the naturally occurring concentrations of all contaminants found at the site. The number and location of samples needed to establish background concentrations in each medium will vary with specific site conditions and requirements. The model should include sufficient background samples to distinguish contamination attributable to the source(s) under consideration from naturally occurring or nearby anthropogenic contamination. The procedures mentioned in 6.2 and 6.3 are sometimes grouped under the general heading of contaminant assessment and may be performed as a separate activity prior to the development of a conceptual site model.

6.4 *Characterizing Sources*—At a minimum, the following source characteristics should be measured or estimated for a site:

6.4.1 Source location(s), boundaries, and volume(s). Sources should be located accurately on site maps. Maps should include a scale and direction indicator (for example, north arrow). They should furthermore show where the source(s) is located in relationship to the property boundaries.

6.4.2 The potentially hazardous constituents and their concentrations in media at the source.

6.4.3 The time of initiation, duration, and rate of contaminant release from the source.

6.5 *Identifying Migration Pathways*—Potential migration pathways through ground water, surface water, air, soils, sediments, and biota should be identified for each source. Complete exposure pathways should be identified and distinguished from incomplete pathways. An exposure pathway is incomplete if any of the following elements are missing: (1) a mechanism of contaminant release from primary or secondary sources, (2) a transport medium if potential environmental receptors are not located at the source, and (3) a point of potential contact of environmental receptors with the contaminated medium. The potential for both current and future releases and migration of the contaminants along the complete pathways to the environmental receptors should be determined. A diagram (similar to that in Fig. X1.4) of exposure pathways for all source types at a site should be constructed. This information should be consistent with the narrative portion and tables in the exposure assessment section of an exposure or risk assessment. Tracking contaminant migration from sources to environmental receptors is one of the most important uses of the conceptual site model.

6.5.1 *Ground Water Pathway*—This pathway should be considered when hazardous solids or liquids have or may have come into contact with the surface or subsurface soil or rock. The following should be considered further in that case: vertical distance to the saturated zone; subsurface flow rates; presence and proximity of downgradient seeps, springs, or caves; fractures or other preferred flow paths; artesian conditions; presence of wells, especially those for irrigation or drinking water; and, in general, the underlying geology and hydrology of the site. Other fate and transport phenomena that should be considered include hydrodynamic dispersion, inter-

phase transfers of contaminants, and retardation. Movement through the vadose zone should be considered.

6.5.2 *Surface Water and Sediment Pathway*—This pathway should always be investigated in the following situations: (1) a perennial body of water (river, lake, continuous stream, drainage ditch, etc.) is in direct contact with, or is potentially contaminated by a source or contaminated area, (2) an uninterrupted pathway exists from a source or contaminated area to the surface water, (3) sampling and analysis of the surface water body or sediments indicate contaminant concentrations substantially above background, (4) contaminated ground water or surface water runoff is known or suspected to discharge to a surface water body, and (5) under arid conditions in which ephemeral drainage may convey contaminants to downstream points of exposure.

6.5.3 *Air Pathway*—Contaminant transport through the air pathway should be evaluated for contaminants in the surface soil, subsurface soil, surface water, or other media capable of releasing gasses or particulate matter to the air. The migration of contaminants from air to other environmental compartments should be considered, for example, deposition of particulates resulting from incineration onto surface waters and soil.

6.5.4 *Soil Contact Pathway*—Contaminated soils that may come into direct contact with human or ecological receptors should be investigated. This includes direct contact with chemicals through dermal absorption and direct exposure to gamma radiation from radioactively contaminated soil. There is a potential for human and ecological receptors to be exposed to contaminants at different soil depths (for example, humans may be exposed to only surface and subsurface soils, whereas plants and animals may encounter contaminants that are buried more deeply). This should be considered when contaminated soils are being evaluated.

6.5.5 *Biotic Pathway*—Bioconcentration and bioaccumulation in organisms and the resulting potential for transfer and biomagnification along food chains and environmental transport by animal movements should be considered. For example, many organic, lipophilic contaminants found in soils or sediments can bioaccumulate and bioconcentrate in organisms such as plankton, worms, or herbivores and biomagnify in organisms such as carnivorous fish and mammals or birds. The movement of contaminated biota can transport contaminants.

6.6 *Identifying Environmental Receptors*—Identify environmental receptors currently or potentially exposed to site contaminants. This includes humans and other organisms that are in direct contact with the source of contamination, potentially present along the migration pathways, or located in the vicinity of the site. It is advisable to compile a list of taxa representative of the major groups of species present at the site. It will rarely be possible or desirable to identify all species present at a site. It is recommended that the conceptual site model include species or guilds representative of major trophic levels. The complexity and iterative nature of the conceptual site model has already been mentioned in 4.2.

6.6.1 *Human Receptors*—The conceptual site model should include a map or maps indicating the physical boundaries of areas within which environmental receptors are potentially or currently exposed to the source(s) or migration pathways;

separate maps may be prepared to illustrate specific contaminants or groups of contaminants. In addition, the human receptors should be represented in a figure similar to Fig. X1.4, which is based on *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. Fig. X1.4 shows the potentially exposed populations, sources, and exposure routes. It represents a clear and concise method of displaying exposure information.

**6.6.2 Ecological Receptors**—The conceptual site model should include a map or maps identifying and locating terrestrial and aquatic habitats for plants and animals within and around the study area or associated with the source(s) or

migration pathways. Consult local and state officials, U.S. Environmental Protection Agency regional specialists, and Natural Resource Trustees to determine whether any of the areas identified are critical habitats for federal- or state-listed threatened or endangered species or sensitive environments. Identify all dominant, important, declining, threatened, endangered, or rare species that either inhabit (permanently, seasonally, or temporarily) or migrate through the study area.

## 7. Keywords

7.1 conceptual site model; ecological; hazardous waste site; human health; risk assessment; site characterization

## APPENDIX

### (Nonmandatory Information)

#### X1. OUTLINE FOR A CONCEPTUAL SITE MODEL FOR CONTAMINATED SITES

X1.1 The conceptual site model should include a narrative and set of maps, figures, and tables to support the narrative. An outline of the narrative sections, along with an example for each section, is given below. The example is based on an hypothetical landfill site at which only preliminary sampling data are available. *The landfill site example is intentionally simplified and is for illustrative purposes only. Conceptual site models may contain considerably more detail than provided in this example.*

**X1.1.1 Brief Site Summary**—Summarize the information available for the site as this information relates to the site contaminants, source(s) of the contaminants, migration pathways, and potential environmental receptors. A brief description of the current conditions at the site (photographs optional) should be included. The inclusion of a standard 7.5-min United States Geological Survey topographic quadrangle map or geologic quadrangle map, or both, that shows the location of the site is recommended. All maps should contain directional information (for example, north arrow) and a scale.

**Example**—Geophysical surveys, aerial photographs, and subsurface exploration at Landfill No. 1 (LF-1) reveal the presence of at least one northeast-southwest trending waste trench. The trench is 300-ft (91-m) long and 100-ft (30-m) wide. Maximum depth of the trench indicated by the soil borings is 22 ft (7 m). As determined from the soil boring program, the waste material samples indicated that metal concentrations were at or below background concentrations, with the exception of cadmium and manganese in one sample. However, solvents (methylene chloride and trichloroethene (TCE) and pesticides (DDE, DDT, and DDD) were found at concentrations above background in soil boring samples. Soil samples taken from beneath the fill indicate that downward migration of contaminants has occurred. The surficial aquifer (ABC Formation) contains naturally high dissolved solids (>2000 mg/L) with yields of less than 4 gpm. Ground water flow in the surficial aquifer is toward the southeast at a rate of approximately 15 ft (5 m) per year. The terrain is flat with

seeded and natural grasses and small (15-ft (5-m)), widely spaced loblolly pine tress covering the site. The site is fenced and unused currently.

#### X1.1.2 Historical Information Concerning the Site:

**X1.1.2.1 Site Description**—Describe the history of the site, paying particular attention to information affecting the present environmental condition of the site.

**Example**—LF-1, operated from 1960 to 1968. This trench-type landfill was reportedly used for the disposal of construction rubble and debris, packing material, paper, paints, thinners, unrinsed pesticide containers, oils, solvents, and contaminated fuels. Most of the trenches for waste disposal were reportedly oriented east-west and were 75-ft (23-m) wide, 350-ft (107-m) long, and an estimated 20-ft (6-m) deep. A few empty containers presumably buried in the landfill have worked their way to the surface and are partially exposed at the site. The site was partly covered by an unpaved industrial haulage road. The site was fenced in 1985 and has been unused since.

**X1.1.2.2 Source Characterization**—Present site-specific information to identify and define the location, size, and condition of the source(s) of contamination at the site.

**Example**—Four soil borings were used to characterize the waste disposal units at LF-1. Fig. X1.1 illustrates the soil boring locations. The depth of the soil borings were SB05 = 28 (9 m), SB06 = 30 ft (9 m), SB07 = 30 ft (9 m) and SB08 = 30 ft (9 m) below ground surface. Two of the borings, SB07 and SB08, encountered refuse/waste material. In SB08, the refuse was encountered from approximately 8 to 22 ft (2 to 7 m) below ground surface. The material was noted to be burnt debris, glass, and organic matter. A much dryer and thinner waste zone was encountered at SB07. The base of the excavation at this location was approximately 10 ft (3 m). Material that appeared to be burnt trash was noted in the backfill. The remaining two borings, SB05 and SB06, did not encounter waste. One sample was collected from each of these borings (SB05 and -06). These samples were used as background samples. Additional samples were collected from SB07 and

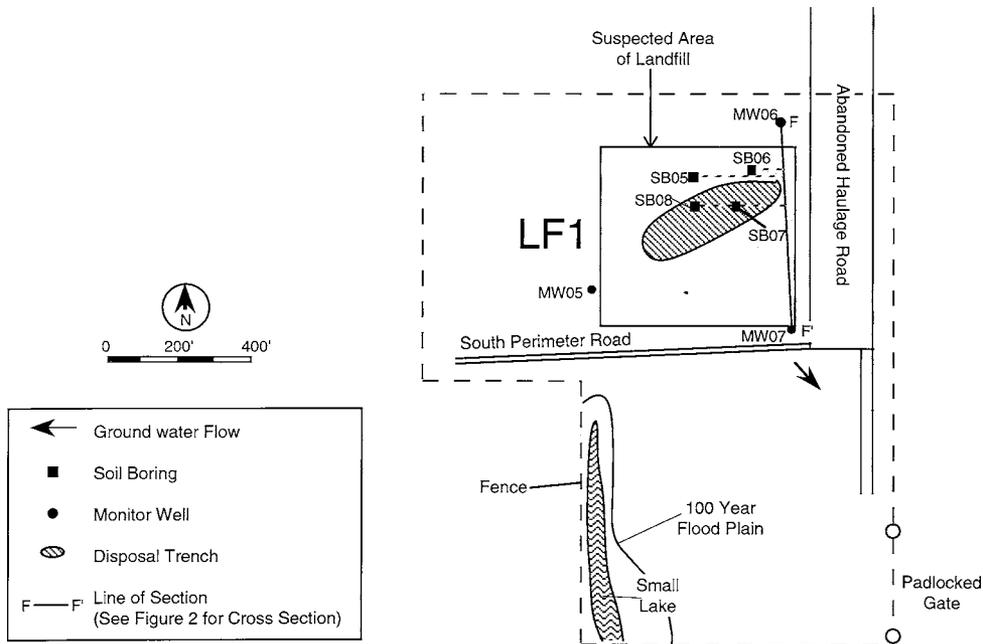


FIG. X1.1 Location Map for Landfill Number 1; Contours Showing the Potentiometric Surface from which Ground Water Flow Direction was Determined Could be Included in a Separate Figure to Avoid Clutter

SB08, within the landfill, to characterize the source. Analytical results are summarized in Table X1.1.

Petroleum hydrocarbons, which were suspected of being contaminants based on the site history, were not detected in any of the samples.

Volatile organic compounds found in the samples included methylene chloride and TCE. Methylene chloride was found in all soil samples in trace amounts (0.005 to 0.008 mg/kg).

The field quality control information suggests that methylene chloride may be a field artifact. The chlorinated solvent, TCE, was found significantly above background only at SB08 at a concentration of 0.05 mg/kg.

Organochlorine pesticides (DDE, DDD, and DDT), which were suspected of being present based on the site history, were not present above the detection limit in any of the samples.

Comparing metal concentrations of soil samples from SB05 and SB06 (background samples) with the remaining soil samples (SB07 and SB08) reveals that SB08 metals data exceeded the background soils data substantially for one analyte. That analyte was manganese (4320 mg/kg).

X1.1.2.3 Migration Pathway Descriptions—Describe the route(s) potentially taken by contaminants from the site as they migrate away from the source through the environmental media (ground water, surface water, air, sediment, soils, and food chain).

**Example: Ground Water Migration**—Three monitor wells (MWs) were installed at LF-1. The bedrock formation is typically nonwater-bearing and consists of thick clay and clay-stone (Fig. X1.2). The unconsolidated materials above the bedrock include a layer of fluvial terrace deposits. The sand

TABLE X1.1 Summary of Analytical Results at LF-1<sup>A</sup>

Parameter (Method)	Field Identification Number					
	DL <sup>B</sup>	Units	SB05 <sup>C</sup>	SB06	SB07	SB08
Moisture (Test Method D2216)	N/A <sup>D</sup>	%	20.6	19.1	12.7	21.1
Petroleum hydrocarbons (SW3550/E418.1)	25	mg/kg	ND <sub>25</sub> <sup>E</sup>	ND <sub>25</sub>	ND <sub>25</sub>	ND <sub>25</sub>
Volatile organics (SW8240)						
Methylene chloride <sup>F</sup>	0.005	mg/kg	0.008	ND <sub>0.0050</sub>	ND <sub>0.0050</sub>	ND <sub>0.0050</sub>
Trichloroethene	0.005	mg/kg	0.006	ND <sub>0.0050</sub>	ND <sub>0.0050</sub>	0.05
Organochlorine pesticides (SW3550/8080)		mg/kg				
4,4-DDE	0.0033	mg/kg	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>
4,4-DDD	0.0033	mg/kg	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>
4,4-DDT	0.0033	mg/kg	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>	ND <sub>0.0033</sub>
Metals (SW3050/6010)						
Cadmium	0.5	ND <sub>0.5</sub>	ND <sub>0.5</sub>	ND <sub>0.5</sub>	ND <sub>0.5</sub>	ND <sub>0.5</sub>
Manganese	2	mg/kg	284	178	228	4320

<sup>A</sup> All results are expressed on a dry weight basis.

<sup>B</sup> DL = detection limit.

<sup>C</sup> SB = soil boring.

<sup>D</sup> N/A = not applicable.

<sup>E</sup> ND<sub>x</sub> = not detected at concentration x.

<sup>F</sup> Suspected laboratory contaminant.

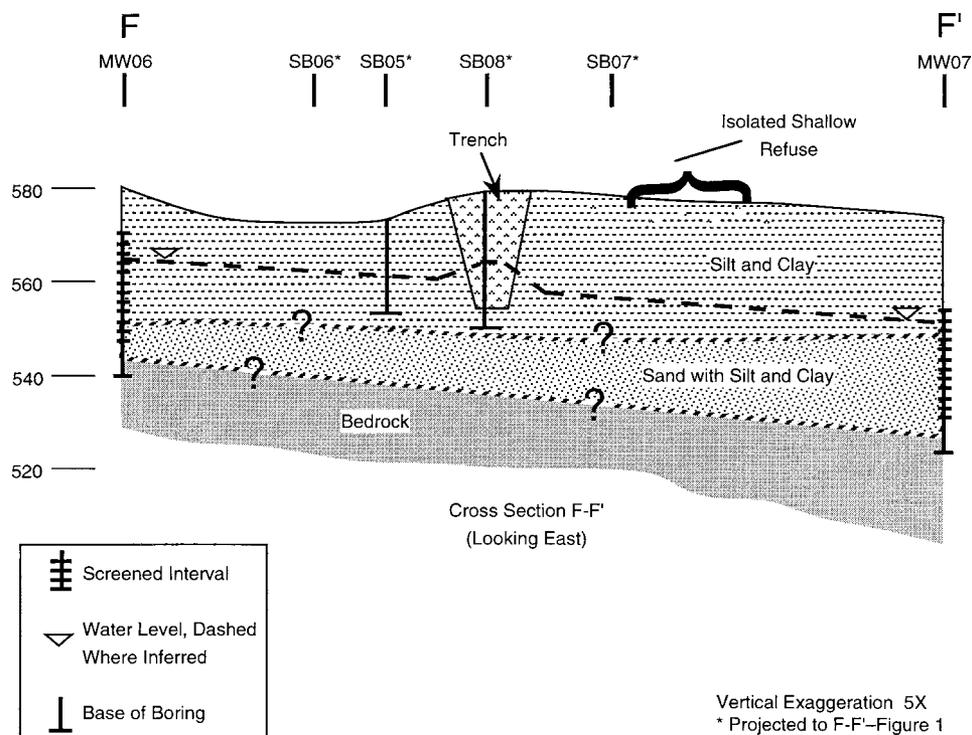


FIG. X1.2 Cross Section of Landfill Number 1

and gravels that lie above the bedrock contain water with flow velocities of approximately 13 to 18 ft/year (4 to 5 m/year). Flow velocities were estimated from permeability tests conducted at MW06. Recharge at the site is from runoff associated with the nearby area that pools and stagnates at and near the site. Table X1.2 contains the water quality analyses from samples of MW05, MW06 (upgradient), and MW07 (downgradient). The upgradient samples contained no contaminants

at concentrations above the detection limits, while the down-gradient sample contained organic contaminants (pesticides). A comparison of metals from the downgradient and upgradient samples indicates that the concentration of metals in the downgradient ground water does not exceed background (up-gradient) concentrations.

**Example: Surface Water and Sediment Migration**—The site surface water drainage map is shown in Fig. X1.3. Three

TABLE X1.2 Ground and Surface Water Quality Analysis at LF-1

Parameter	Field Identification Number						
	DL <sup>A</sup>	MW-05 µg/L	MW-06 µg/L	MW-07 µg/L			
<b>Volatile organics</b>							
Trichloroethene	5	ND <sub>5</sub> <sup>B</sup>	ND <sub>5</sub>	ND <sub>5</sub>			
Methylene chloride	5	ND <sub>5</sub>	ND <sub>5</sub>	ND <sub>5</sub>			
<b>Organochlorine pesticides</b>							
4,4-DDE	0.1	ND <sub>0.1</sub>	ND <sub>0.1</sub>	1			
4,4-DDD	0.1	ND <sub>0.1</sub>	ND <sub>0.1</sub>	3			
4,4-DDT	0.1	ND <sub>0.1</sub>	ND <sub>0.1</sub>	4			
<b>Metals</b>							
Cadmium	5	ND <sub>5</sub>	ND <sub>5</sub>	ND <sub>5</sub>			
Manganese	15	ND <sub>15</sub>	ND <sub>15</sub>	ND <sub>15</sub>			
	DL Water	µg/L SW-02	µg/L SW-03	µg/L SW-04	mg/kg SD-02	mg/kg SD-03	mg/kg SD-04
<b>Petroleum hydrocarbons</b>							
	1000	ND <sub>1000</sub>	ND <sub>1000</sub>	ND <sub>1000</sub>	ND <sub>1000</sub>	ND <sub>1000</sub>	ND <sub>1000</sub>
<b>Volatile organics</b>							
Trichloroethene	1	ND <sub>1</sub>	ND <sub>1</sub>	ND <sub>1</sub>	ND <sub>1</sub>	ND <sub>1</sub>	ND <sub>1</sub>
Methylene chloride	2	ND <sub>2</sub>	ND <sub>2</sub>	ND <sub>2</sub>	ND <sub>2</sub>	ND <sub>2</sub>	ND <sub>2</sub>
<b>Organochlorine pesticides</b>							
4,4-DDE	0.04	ND <sub>0.04</sub>	ND <sub>0.04</sub>	ND <sub>0.04</sub>	ND <sub>0.04</sub>	ND <sub>0.04</sub>	ND <sub>0.04</sub>
4,4-DDD	0.1	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>
4,4-DDT	0.1	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>	ND <sub>0.1</sub>
<b>Metals</b>							
Cadmium	5	ND <sub>5</sub>	ND <sub>5</sub>	ND <sub>5</sub>	ND <sub>0.5</sub>	ND <sub>0.5</sub>	ND <sub>0.5</sub>
Manganese	20	ND <sub>20</sub>	ND <sub>20</sub>	ND <sub>20</sub>	ND <sub>2</sub>	ND <sub>2</sub>	ND <sub>2</sub>

<sup>A</sup> DL = detection limit.

<sup>B</sup> ND<sub>x</sub> = not detected at concentration x.

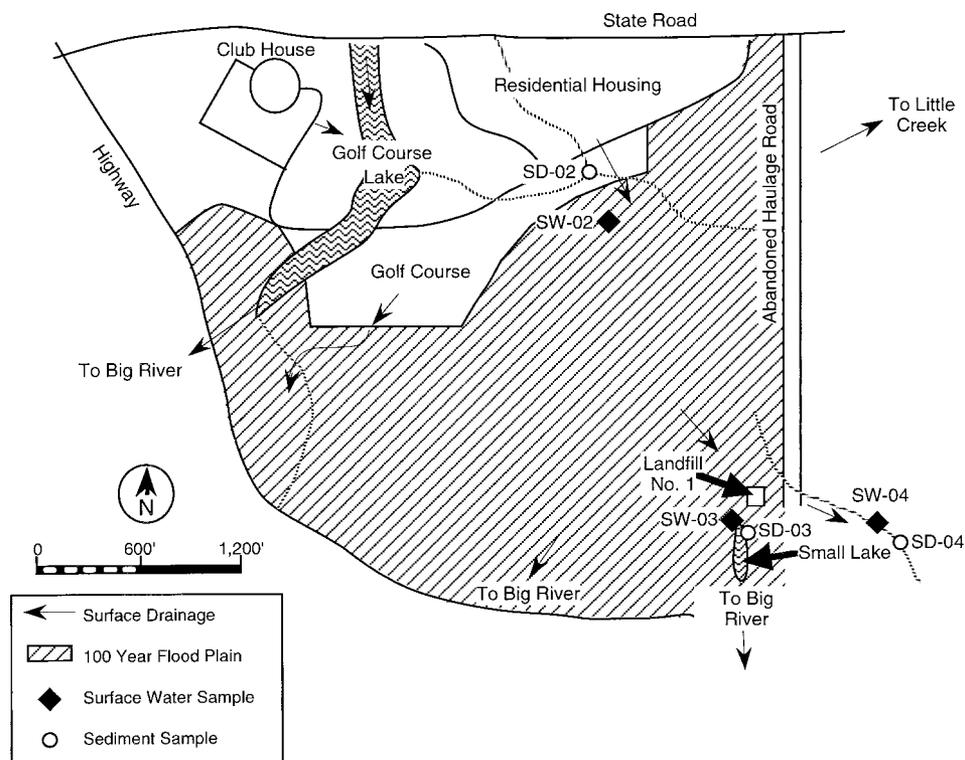


FIG. X1.3 Surface Drainage Pattern around Landfill Number 1

surface water runoff samples and three sediment samples were collected at locations shown on the map. Samples SW-02 and SD-02 were collected to determine background, while SW-03, SW-04, SD-03, and SD-04 were placed downstream of the site. The analytical results given in [Table X1.2](#) indicate that no contaminants are present above background in any of the samples. There appears to be no contamination entering the surface water pathway from the site.

**Example: Air Migration**—No air samples were taken since there was no indication that vapor or dust can enter the air pathway. The contamination is buried and effectively prevented from reaching the air pathway, and the site is covered by a thick layer of vegetation, which effectively acts as a natural cap and prevents dust from becoming airborne. Qualitative air monitoring showed no evidence of any organic vapors being present at the site during the initial stages of the site investigation.

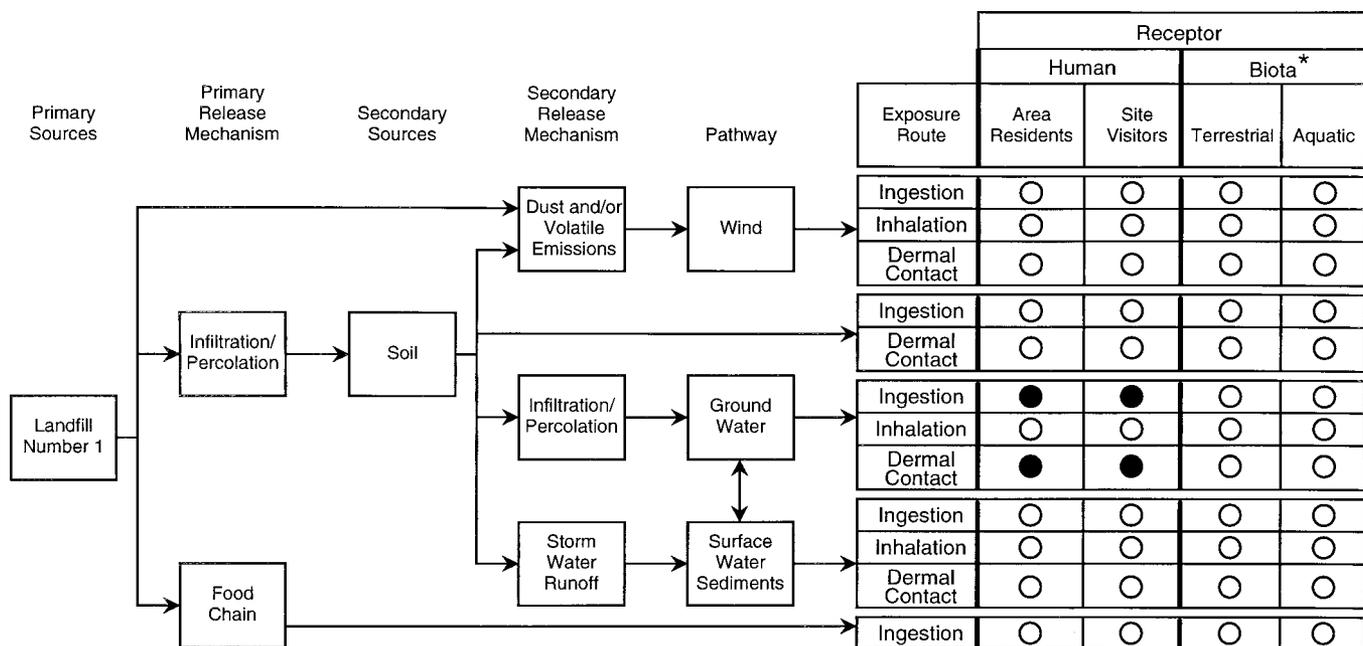
**Example: Soils**—This pathway is not complete for humans because the site is surrounded by a 6-ft (2-m) fence with a padlocked gate and posted with no trespassing signs. Soil and sediment samples taken for the surface water pathway did not indicate the presence of contamination above background concentrations. Also, there was no loose soil at the site since the site was covered by a thick layer of vegetation. Exposed, empty containers have been tested for the presence of contaminant residues, and none have been found. The site was inspected for evidence of burrowing mammals and other small mammals, reptiles, amphibians, or birds that might not be deterred by the fence. There was no evidence of any threat to ecological receptors from the soils or direct contact.

**Example: Food Chain Transfer**—Samples collected from surface water, sediment, and soils indicate that there are no

contaminants present at concentrations above background. There is therefore no concern for food chain transfer (biomagnification) in and around the landfill.

**X1.1.2.4 Environmental Receptor Identification and Discussion**—Current and future human and ecological receptor groups should be identified and located on site maps. The migration pathways and source(s) that place or potentially place the environmental receptors at risk should be discussed.

**Example:** The only residential housing in the vicinity of the site is approximately 2100 ft northwest of the landfill. The surficial aquifer is not used as a source of drinking water by the residents, and the ground water flow is toward the southeast and away from the residential housing. There is an active golf course just to the west of the residential housing. Golf Course Lake is recharged from north of the lake and is not influenced by LF-1. The golf course does not use the surficial aquifer for a drinking water source or for irrigating the golf course. There are no other human receptors in the vicinity of the site. There are no local, state, or federally designated declining, endangered, or rare species that inhabit or migrate through the vicinity of the study area. Other wildlife species that were observed on-site show no evidence of harm from the site. Plants on-site include seeded, cool-season grasses, and volunteer native grasses; herbian vegetation; upland shrubs; and coniferous trees. None of the vegetation shows signs of stress. The most likely potentially threatened aquatic habitats are Small Lake and Big River, south of the landfill. However, environmental sampling of surface water and sediments ([Table X1.2](#)) has not shown any evidence of contaminant migration from the landfill to the lake or river. [Fig. X1.4](#) illustrates the relationships among the elements of the conceptual site model,



- = Pathway complete, further evaluation recommended
- = Pathway evaluated and found incomplete, no further evaluation recommended
- \* = The terrestrial and aquatic columns can be subdivided as appropriate.  
Examples of terrestrial receptors are: plants, insects, worms, mammals, and birds.  
Examples of aquatic receptors are: periphyton, benthic invertebrates, insects, and fish

NOTE 1—This example is based on Figure 2-2 of *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*.

FIG. X1.4 Example Diagram for a Conceptual Model at Landfill Number 1

including the sources, release mechanisms, pathways, and environmental receptors.

X1.2 Examples of Maps, Tables, and Figures:

X1.2.1 Maps—The use of maps in a conceptual site model is important. The maps may include United States Geological Survey topographic and geologic maps, site sketch maps, and maps drawn to scale. The maps should identify and locate key elements of the conceptual site model including source(s); ground water, surface water, sediment, soil and air pathway routes (direction of flow); and areas covered by environmental receptor populations and migration pathways. Morphological and geological features relevant to the environmental assessment of the site should be included on a map.

Example: Figs. X1.1-X1.3 are examples of sketch maps that contain a scale, a north arrow, and a legend.

X1.2.2 Tables and Figures—Tables and figures should be simple and easy to read, with explanations of qualified data and abbreviations. All tables and figures should be referred to in the narrative.

Examples: Tables X1.1 and X1.2 and Figs. X1.1-X1.3 are examples of simple summary tables and site maps. Fig. X1.4 is an example of a diagram illustrating the relationships between primary and secondary sources, release mechanisms, exposure routes, and environmental receptors.

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## **APPENDIX D**

### **Standard Operating Procedures for Isotope Analysis**



## *Standard Operating Procedures*

### **Ammonia Nitrogen Isotope Analysis**

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Standard operating procedures on how to collect water/soil samples and how to perform isotope analysis have been prepared at ZymaX Forensic Isotope Laboratory:

#### **Sample Collection**

Soil samples are collected in the field into 4-8 oz. glass jars. Water samples are collected in the field into 500-1000mL poly bottles. Sample containers are provided free of charge upon our clients' request.

Keep samples refrigerated until shipping them on ice overnight to the lab. Once samples arrive at the lab, they will be logged in and kept refrigerated at ~4°C until isotope analysis, which should be done within 14 days.

#### **Sample Preparation**

1. Make sufficient volume of solution of 2M H<sub>2</sub>SO<sub>4</sub>-each sample needs 25uL.
2. Combust GF/D filters (1 per sample); MgO (3g/L sample); GF/F filters (1 per sample); NaCl (50g/L for freshwater samples only) in high temperature oven at 400°C for 4 hours.
3. Add 250mL of water sample into Mason jars and also add required NaCl for each sample. Add stir bar and stir Mason jar on stir pad for about 5min to help dissolve some of the NaCl.
4. Create "ammonia trap filter pack" and let it sit on watch glass in Mason jar in the following steps: Fold 2 paper towels into 5x7 in squares; Cover the paper towels in tin foil; Clean tin foil with ethanol or methanol; Place 2.5cm Teflon disk down on tin foil; Place a combusted GF/D disk on top of the Teflon disk in the center; Pipette 25uL of 2M H<sub>2</sub>SO<sub>4</sub> solution onto the GF/D disk; Place another Teflon disk on top of the GF/D like creating a sandwich; Use a 10mL VOA vial with cap

removed to press shut the sandwich and to create a seal around the GF/D filter disk. The pressure along with the “cushion’ from the paper towels will be enough to seal the Teflon.

5. Place sandwich filter paper onto watch glass and make sure when the lid is screwed on the watch glass is high enough so that the water does not splash onto the filter. While filter is on watch glass, remove lid and add MgO (0.75g/0.25L) to sample water. Close lid immediately after adding MgO as vapor given off is NH<sub>4</sub>.
6. Place Mason jars on stir plate once more to incorporate all the MgO into the sample water then place Mason jars in shaker.
7. Leave jars in there for 2 weeks at 40°C. After that, remove lid and remove filter paper sandwich and place on clean watch glass in dessicator with a small beaker containing 10mL of sulfuric acid (to keep the dessicator free of trace ammonia).
8. On the day of nitrogen isotope analysis, cut the GF/D filter into small sections and analyzed in the Elemental Analyzer.

## Isotope Analyses

GF/D filter sample is introduced into an elemental analyzer by EuroVector (EuroEA3028-HT). The EA is used to convert ammonia sulfate on the filter into nitrogen gas, and the EA is connected to a continuous flow isotope ratio mass spectrometer (Micromass Isoprime), which determines the differences in the isotope-amount ratios of stable nitrogen isotopes (<sup>15</sup>N/<sup>14</sup>N) of the product N<sub>2</sub> gas. The pyrolysis is quantitative, no isotopic fractionation is involved. Samples are placed in tin capsules and loaded into the EuroCAP solid auto-sampler. Under computer control, samples are introduced into a heated tube (1030°C) called reaction tube then a reduction tube (650°C). All reaction takes place in a He atmosphere (90mL/min). Reaction products are transported by a He carrier. The gas-phase products, mainly N<sub>2</sub> are purified by a gas chromatograph.

The gas is then introduced into the mass spectrometer through an interface, which is also used to inject N<sub>2</sub> reference gas and He for sample dilution. The mass spectrometer is capable of measuring mass/charges (m/z) 28, 29 and 30 simultaneously. The ion beams from N<sub>2</sub> are as follows: m/z 28 = <sup>14</sup>N<sup>14</sup>N; m/z 29 = <sup>15</sup>N<sup>14</sup>N primarily. ISOPRIME software is capable of processing data automatically.

Stable isotope ratios are conventionally referenced to an internationally recognized standard, and are expressed in the δ notation, for nitrogen,

$$\delta^{15}\text{N} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000, \text{ and } R = {}^{15}\text{N}/{}^{14}\text{N}$$

Units are per mil (‰). The standard, by definition, has a  $\delta$  value of 0‰, and samples may have positive or negative  $\delta$  values depending on whether the sample is enriched or depleted in the heavier isotope. The international standard for nitrogen is the atmosphere air (Air).

All water samples are analyzed in batches of a maximum of 40 per day. Three internationally distributed isotopic reference materials with different values are analyzed at the beginning of a batch and also among the samples, which shall have the same acceptance criteria as acceptance criteria for the unknown samples ( $\leq 0.3\%$ ).

### **Isotope Data Reporting and Turnaround Time**

Analytical precision and laboratory quality controls (QCs) are reported with sample results. Promised standard turnaround time at ZymaX Forensic Isotopes is 60 days, further, rush services (30 days) is possible upon request, with additional charges.



## *Standard Operating Procedures*

### **Dissolved Sulfate for Isotope Analysis**

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At ZymaX Forensic Isotope Laboratory, dissolved sulfate samples for isotope analysis are collected and analyzed according to the USGS RSIL method (Lab Code 1951) published in 2006: For more information, please see the following link:

<http://pubs.usgs.gov/tm/2006/tm10c10/pdf/tm10C10.pdf>

Standard operating procedures on how to collect samples and how to perform isotope analysis have been prepared at ZymaX Forensic Isotope Laboratory:

#### **Sample Collection**

Dissolved sulfate samples are collected in the field into poly bottles. Sample size required depends on the sulfate concentration determined in the field (this information is required at sample submission). When sulfate is more than 50mg/L, 1L of water is sufficient; when sulfate is less than 50mg/L, use 2-4L of water. Sample containers are provided free of charge upon our clients' request.

Holding time for sulfate isotope analysis is 14 days. Keep unpreserved samples refrigerated until shipping them on ice overnight to the lab. Once samples arrive at the lab, they will be logged in and kept refrigerated at ~4°C until sample preparation, which should be done within 14 days of holding time.

#### **Sample Preparation**

Dissolved sulfate is precipitated with 10% BaCl<sub>2</sub> at pH 3 to 4 as BaSO<sub>4</sub>, which is filtered through 47mm diameter 0.45µM filter paper and dried at 90°C in an oven overnight, before introduction into an elemental analyzer by EuroVector (EuroEA3028-HT). Scrape off the BaSO<sub>4</sub> from filter into sample vial. Store on the shelf for isotopic analysis, discard the filter.

## Isotope Analyses

The EA is used to convert S in an BaSO<sub>4</sub> solid sample into SO<sub>2</sub> gas, and the EA is connected to a continuous flow isotope ratio mass spectrometer (Micromass Isoprime), which determines the differences in the isotope-amount ratios of stable sulfur isotopes (<sup>34</sup>S/<sup>32</sup>S) of the product SO<sub>2</sub> gas. The combustion is quantitative, no isotopic fractionation is involved. Samples are placed in a tin capsule and loaded into the EuroCAP solid auto-sampler. Under computer control, samples are dropped into a heated tube (1030°C) called reaction or oxidation tube. Combustion takes place in a He atmosphere (90mL/min) containing an excess of oxygen gas (5mL, purged at 35mL/min) at the top of the reaction tube. Combustion products are transported by a He carrier through the reduction tube (650°C) to remove excess oxygen and through a drying tube (Mg(ClO<sub>4</sub>)<sub>2</sub>) to remove any water. The gas-phase products, mainly CO<sub>2</sub>, N<sub>2</sub>, and SO<sub>2</sub>, are separated by a gas chromatograph.

The gas is then introduced into the mass spectrometer through an interface, which is also used to inject SO<sub>2</sub> reference gas and He for sample dilution. The mass spectrometer is capable of measuring mass/charge (m/z) 64 and 66 simultaneously. The ion beams from SO<sub>2</sub> are as follows: m/z 64 = <sup>32</sup>S<sup>16</sup>O<sup>16</sup>O; m/z 66 = <sup>34</sup>S<sup>16</sup>O<sup>16</sup>O primarily. ISOPRIME software is capable of processing data automatically.

Stable isotope ratios are conventionally referenced to an internationally recognized standard, and are expressed in the δ notation, for sulfur,

$$\delta^{34}\text{S} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000, \text{ and } R = {}^{34}\text{S}/{}^{32}\text{S}$$

Units are per mil (‰). The standard, by definition, has a δ value of 0‰, and samples may have positive or negative δ values depending on whether the sample is enriched or depleted in the heavier isotope. The international standard for sulfur is Troilite (FeS) phase of the Canon Diablo meteorite (CDT), for oxygen it is Standard Mean Ocean Water (SMOW).

All BaSO<sub>4</sub> samples precipitated from water samples are prepared and analyzed in batches of a maximum of 80 per day, and all samples are analyzed in duplicate. Three internationally distributed isotopic reference materials with different δ<sup>34</sup>S values (NBS127, IAEA S-1, IAEA S-2) are analyzed at the beginning of a batch and also among the samples. The amount of sulfur in the reference materials must be in the same range as that of the samples. Pyrite-1 and WQ-1 are analyzed as QC samples, which have the same acceptance criteria as acceptance criteria for the unknown samples (= < 0.3‰).

## Isotope Data Reporting and Turnaround Time

Analytical precision and laboratory quality controls (QCs) are reported with sample results. At ZymaX Forensics Isotope, the lower limit for sulfate isotope analysis is ~5mg/L. Promised standard turnaround time at ZymaX Forensic Isotopes is 30 days, further, rush services (3, 7, 14, 21 days) are available upon request, with additional charges.