Nye County Drilling, Geologic Sampling and Testing, Logging, and Well Completion Report for the Early Warning Drilling Program Phase III Boreholes

Prepared by:

Nye County Department of Natural Resources and Federal Facilities,
Nuclear Waste Repository Project Office, Grant No. DE-FC28-02RW12163

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EXECUTIVE SUMMARY

This report describes Phase III of Nye County's Early Warning Drilling Program, including the scope, methods, and results. Phase III activities included drilling 13 boreholes, collecting drill cuttings and core samples, geologic logging and laboratory testing of these samples, borehole geophysical logging, and constructing four multiple-screen monitor wells and five piezometers. Data and preliminary analyses are presented and, where applicable, data limitations are described. Since nearly all data included in this report are affected in some ways by drilling and sampling methods, an in-depth evaluation of these methods is also presented.

The focus of Phase III drilling was on the Fortymile Wash area downgradient of Yucca Mountain, in south-central Nye County. The primary goals of the EWDP are to gain a better understanding of the hydrogeologic system, to better define the potential risks to Nye County's drinking water supplies, and to begin to design a groundwater monitoring network along potential flow pathways between Yucca Mountain and populated areas in southern Nye County.

Boreholes and Wells Constructed

Nye County contractors initiated Phase III field activities in July 2001 by drilling, logging, sampling, and abandoning four small-diameter exploratory boreholes (NC-EWDP-19IM1A, -19IM2A, -22SA, and -10SA) ranging in depth from 900 to 1,200 ft below ground surface (bgs). The purpose of these boreholes was to sample and characterize the alluvial stratigraphy and underlying Tertiary rock units. These exploratory boreholes were drilled using air-rotary dual-wall reverse-circulation (RC) drilling methods.

Four larger-diameter monitor wells with multiple screens (NC-EWDP-10S, -19IM1, -19IM2, and -22S) were then drilled from August through October 2001 using flooded-mud (FM) methods and completed at the locations of the abandoned exploratory boreholes, to approximately the same depths. These wells were designed and constructed to permit determination of aquifer properties and water chemistries at different screened intervals. Westbay® packer and instrument monitoring systems were installed in each monitor well except NC-EWDP-19IM2 to isolate well screens and to facilitate water sampling and in situ monitoring of temperature and pressure.

Five intermediate-diameter boreholes were drilled to depths ranging from approximately 800 to 1,350 ft bgs in late 2001 and early 2002. Four of these boreholes were completed with nested, dual-completion piezometers (NC-EWDP-10P, -22PA, -22PB, and -23P) and one with a single-completion piezometer (-18P). RC drilling methods were used throughout NC-EWDP-22PB and -23P. Casing advance (CA) drilling methods and conventional-circulation rotary-drilling methods were used to advance the other piezometers. All piezometers were constructed to further characterize the alluvial stratigraphy, provide water level information, and to determine aquifer properties and chemistries at different depths in the uppermost aquifer. In addition, NC-EWDP-10P, -22PA, and -22PB were located near monitor wells to serve as observation wells during aquifer tests, and possibly as injection wells for cross-hole tracer tests.

Drilling Methods and Drilling Fluids

Drilling methods and drilling fluids were selected for Phase III boreholes based on a number of criteria, including their ability to yield drill cuttings that were as representative as possible of in situ formation rock, minimize the disturbance of the formation rock and groundwater chemistry, and produce boreholes suitable for completing multiple-screen monitor wells and piezometers.

The RC drilling method was chosen for exploratory and piezometer boreholes because it can provide representative drill cuttings that are relatively uncontaminated by drilling fluids, is relatively fast and inexpensive, and minimizes cross-contamination between formation units. The CA air-drilling method was selected for the remaining piezometer boreholes because it can also provide representative drill cuttings while minimizing the disturbance of the formation rock. In addition, it is ideally suited for collecting drive-core samples and for completing wells in unstable formation materials. Finally, the FM drilling method was used to drill relatively large-diameter monitor wells, primarily because it had been used successfully in Phase II to drill similar large-diameter, plumb, straight, and relatively stable boreholes.

Compressed air was used as the primary drilling fluid when possible. Clean water was added, when needed to facilitate the return of cuttings to the surface. When drilling additives were required, pure bentonite or bentonite with a small amount of polymer was used. The use of organic drilling fluids and additives, including foams, polymers, and lost circulation materials was minimized to the extent possible.

Geologic Sampling

Drill cuttings samples were collected over 2.5-ft intervals in the unsaturated zone and 5-ft intervals in the saturated zone from exploratory and piezometer boreholes to provide for continuous geologic logging and for laboratory testing. In addition, 2.5- and 2.0-ft-long drive cores were collected from 13 alluvial intervals in two CA boreholes (NC-EWDP-10P and -22PA) to demonstrate the feasibility of this method in relatively coarse-grained alluvial sediments in Fortymile Wash and for laboratory testing of flow-and-transport-related properties.

Sample handling and splitting procedures for drill cuttings were carefully selected to obtain representative subsamples for geologic logging, laboratory testing, and archiving for future use. All Phase III site locations have at least one exploratory or piezometer borehole where these subsampling procedures were strictly followed. The resulting samples are considered to be fully representative of the cuttings returned during drilling.

Geologic Logging

Field lithologic descriptions of each alluvium and non-alluvium (i.e., underlying rock) drill cuttings sample interval and selected 3- and 6-in.-long core segments were recorded on field logging forms. The alluvium logging form primarily includes soil classification parameters, many of which are related to flow-and-transport properties of alluvial sediments. The non-alluvium logging form contains mainly lithology-related parameters to support identification of lithostratigraphic units. Both forms include several drilling and coring related measurements, including rates of drilling and coring and water production.

Significant geologic logging results include the following:

- Moisture content depth profiles from above the water table in RC and CA piezometer boreholes provide evidence of lateral movement of lost circulation water from nearby FM boreholes, as well as evidence of the drying effects of the compressed air drilling fluid on drill cuttings collected 50 to 80 ft below the water table.

- Little evidence of cementation was observed in saturated zone drill cuttings samples from boreholes at Sites NC-EWDP-10 and -19; however, evidence of cementation was consistently observed in saturated zone drill cuttings samples from boreholes at Sites NC-EWDP-22 and -23.

- Both gravel and sand size fractions of core samples collected above and below the water table were found to contain a significant percentage of non-welded tuffs.

- Drilling rates were highest in RC exploratory boreholes, followed by those in CA piezometer boreholes, and lowest in RC piezometer boreholes.

- Finally, water production rates generally exceeded several gallons per minute at depths of less than about 100 ft below the water table and tended to increase at greater depths.

Geophysical Logging

Where appropriate and/or possible, suites of borehole geophysical logs were run in drill strings, open boreholes, and inside piezometer and monitor well casing. These logs provided valuable information on the impact of drilling fluids and additives on the formation fluids, the location of water production zones, and the integrity of grout seals between well screens. In addition, these logs provided confirmation of the location of the water table and the contacts between alluvium and underlying rock units.

Laboratory Testing of Alluvium Geologic Samples

In most cases, laboratory testing was performed on two or three core segments from each of the 13 core runs in NC-EWDP-10P and -22PA. Core segments were analyzed for saturated hydraulic conductivity, particle size distribution (PSD) by wet sieve and hydrometer methods, volumetric water content, dry bulk density, and grain density (specific gravity).

PSD by wet sieve methods, gravimetric water content, and electrical conductivity of soil-water extracts were determined for every other 2.5-ft sample of unsaturated alluvium drill cuttings in all exploratory and piezometer boreholes. In addition, wet sieve PSDs were determined for each 5-ft drill cuttings sample interval of saturated alluvium, and hydrometer PSD measurements were made on selected intervals of both unsaturated and saturated alluvium drill cuttings samples.

Major findings from laboratory testing of geologic samples regarding drilling impacts include:

- Gravimetric moisture contents, electrical conductivities of soil-water extracts, and PSDs of unsaturated drill cuttings appear to be disturbed from in situ conditions less by faster drilling rates than by slower drilling rates.

- Laboratory-measured PSDs of alluvium drill cuttings from RC boreholes drilled primarily with compressed air are reasonably representative of in situ formation conditions throughout the unsaturated zone and in the uppermost part of the saturated zone. This conclusion is based on a limited comparison of laboratory PSD data from minimally disturbed core samples versus drill cuttings samples collected from approximately the same depth intervals in nearby boreholes at Sites NC-EWDP-10 and -22; as well as the similarity in PSD depth profiles of drill cuttings between boreholes at these sites and at Sites NC-EWDP-19 and -23.

- However, once RC exploratory and RC piezometer boreholes begin to produce significant amounts of water at depths generally less than 100 ft below the water table, the laboratory-measured PSDs of drill cuttings deviate significantly from laboratory-measured PSDs of core samples and, by inference, the PSDs of in situ formation materials.

- The deviation of laboratory-measured drill cuttings PSDs from core sample PSDs below the water table is most likely due to the grinding action of the rotary drill bit on relatively soft non-welded tuffs. This grinding action is greatly facilitated by the production of large quantities of water at the drill bit.

- Further work is required to determine if CA drilling methods disturb the PSDs of drill cuttings samples below the water table similarly to RC drilling methods.

Major trends in lithostratigraphy, based primarily on laboratory testing, include:

- Depth profiles of laboratory-measured PSDs in drill cuttings from boreholes located along the primary axis of Fortymile Wash (NC-EWDP-19IM2A, -22SA, and -10SA) are nearly identical throughout the unsaturated zone and the upper approximately 100 ft of the saturated zone.

- In each of these boreholes, the alluvium becomes slightly finer-textured with depth, transitioning from a well-graded sand with silt and gravel (SW-SM) to a silty sand with gravel (SM) at depths ranging from approximately 300 to 450 ft bgs. The slightly finer-textured underlying SM alluvial unit extends down to various underlying volcanic rocks, with contacts ranging from approximately 800 to 1,100 ft bgs.

- Discontinuities in the alluvial and underlying bedrock sections between NC-EWDP-19IM2A and the Phase II borehole -2DB located approximately 1 mile to the southwest may be related to the presence of a fault (Highway 95 Fault) between these boreholes.

- A cross section perpendicular to the primary axis of Fortymile Wash through several Phase III boreholes (NC-EWDP-22SA and -23P) and a Phase I borehole (-5S) shows the presence of finer-grained alluvium sediments along the eastern portion of the wash. These finer-grained sediments may limit the eastward migration of possible future contaminants from Yucca Mountain and at the same time focus their transport in coarser-grained sediments along the primary axis of Fortymile Wash.

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ACRONYMS AND ABBREVIATIONS

ATC	Alluvial Testing Complex
bgs	below ground surface
BHA	bottom hole assembly
CA	casing advance (drill method)
DOE	U.S. Department of Energy
EC	electrical conductivity
EWDP	Early Warning Drilling Program
FM	flooded-mud reverse circulation drill method
ft	feet
gpm	gallons per minute
ID	inside diameter
ISIP	Independent Scientific Investigations Program
L	liter
LCM	lost circulation material
m	meter
NTS	Nevada Test Site
NWRPO	Nuclear Waste Repository Project Office
OD	outside diameter
PSD	particle size distribution
QA	quality assurance
QAPP	Quality Assurance Program Plan
QARC	Quality Assurance Records Center
RC	air-rotary dual-wall reverse-circulation drill method
SMF	Sample Management Facility
TP	technical procedure
USCS	Unified Soil Classification System
USGS	U.S. Geological Survey
WP	work plan
YMP	Yucca Mountain Project

NOTE: Measurements in this report are given in English units. To convert English units to the International System of units, use the following conversion factors:

- To convert inches to centimeters, multiply by 2.54.
- To convert feet to meters, multiply by 0.3048.
- To convert miles to kilometers, multiply by 1.609.
- To convert gallons to liters, multiply by 3.785.
- To convert pounds to grams, multiply by 453.59.

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TEXT

1.0 INTRODUCTION

1.1 BACKGROUND

Nye County is the host of the proposed U.S. Department of Energy (DOE) Yucca Mountain Project (YMP), high-level radioactive waste repository. Because Nye County retains limited local jurisdiction over the proposed repository site, the County has rights of participation, funding, and on-site representation in YMP policies and activities. Nye County began to exercise these rights in 1987 by creating the Nuclear Waste Repository Project Office (NWRPO). Major goals of this office have and continue to be providing independent evaluation and review of activities and policies related to the transport, disposal, and storage of nuclear waste within Nye County and supplementing federal studies of the potential impacts of the proposed Yucca Mountain repository.

To begin supplementing federal studies, the NWRPO in 1994 obtained a technical grant from DOE to initiate the Independent Scientific Investigations Program (ISIP). The specific objectives of this program are the independent evaluation of selected site characterization, repository design, and performance issues potentially affecting human health, safety, and the environment in southern Nye County. Since 1994, several additional grants have been obtained from DOE to continue the ISIP, including the 1998 Early Warning Drilling Program (EWDP) grant, which funded the work described in this report.

The EWDP is a subregional-scale hydrogeologic study and monitoring program designed to help protect Nye County's water supply interests. It has and will continue to focus primarily on the area between the proposed repository at Yucca Mountain and the populated areas of Amargosa Valley in southern Nye County, located approximately 20 km southeast of Yucca Mountain and downgradient along potential groundwater flow paths. Figure 1.1-1 shows the location of these geographic features, as well as the Nevada Test Site (NTS), private land ownership areas, and the principal population centers within southern Nye County. Lathrop Wells is the closest Amargosa Valley community to Yucca Mountain.

A major Nye County concern is whether future Yucca Mountain nuclear waste management activities have potential to impact the groundwater and surface water supplies within the Amargosa Valley and, in turn, potential to impact human health and the environment. Although Amargosa Valley is currently sparsely populated and largely undeveloped, future significant economic development and population growth will likely occur. Amargosa Valley also encompasses important sensitive natural environments and habitats, including Ash Meadows National Wildlife Refuge, Devils Hole, the Amargosa River, and various springs and their associated wetlands.

The first three phases of the EWDP, conducted from October 1998 through March 2002, were funded through DOE cooperative grant DE-FC08-98NV-12083. This report presents the results of Phase III of the EWDP groundwater investigation, conducted from July 2001 through March 2002. The NWRPO has used information derived from the first three phases of the EWDP to plan additional characterization work scheduled from April 2002 through March 2007 under another DOE grant, DE-FC28-02RW12163.

1.2 PROGRAM PURPOSE AND OBJECTIVES

The purpose of the EWDP is to provide essential data needed to: (1) better define the potential risk to Amargosa Valley drinking water supplies from high-level radioactive waste handling and disposal at the proposed Yucca Mountain high-level radioactive waste repository, and (2) design an appropriate "early warning" groundwater monitoring network between the repository and the existing and potential future populations in the Amargosa Valley area. A better understanding of the hydrogeologic system, including baseline hydrologic conditions, is a necessary first step toward achieving these goals and therefore has been the focus of the early phases of the EWDP.

Prior to initiating the EWDP, an evaluation of existing hydrogeologic data revealed a significant data gap encompassing part of Southern Jackass Flats, southern Crater Flat, western Rock Valley, and the northern Amargosa Desert. In short, there were few or no subsurface hydrogeologic data in these areas. The EWDP has and continues to target basic hydrogeologic data deficiencies in this region, including obtaining further information about the origin of the spring deposits, geologic and hydraulic properties of valley-fill sediments, distribution and rates of recharge, groundwater depths, gradients, and flow patterns, and baseline water chemistry.

The specific objectives of the EWDP are to provide:

- Flow and transport parameters needed to refine and reduce uncertainty in groundwater models and in performance assessment models that incorporate groundwater modeling results.

- Baseline water chemistry and water level data and the capability to monitor trends in these data over time in strategically placed wells.

- A better understanding of the flow paths between tuff and alluvium, the nature and continuity of alluvial textural layers, the hydrogeologic units underlying the alluvium, and hydraulic gradients within and between units.

Phases I and II, completed in 2000 and 2001, respectively, provided hydrogeologic and baseline water chemistry data south of the proposed repository and along Nevada Highway 95, which traverses the northern edge of Amargosa Valley. Phase III focused on filling data gaps along Fortymile Wash, within and outside of the NTS. Work outside the NTS included establishing further testing and monitoring capabilities at the Alluvial Testing Complex (ATC) site. The ATC was established for cooperative studies conducted by the DOE, U.S. Geological Survey (USGS), Los Alamos National Laboratories, the University of Nevada–Las Vegas, and Nye County to locally characterize the hydraulic and transport properties of the saturated alluvium near the southwest boundary of the NTS.

More specifically, Phase III activities included drilling boreholes, collecting drill cuttings and core samples, geologic logging and laboratory hydrologic property testing of selected samples, borehole geophysical logging, completion of multiple-screen monitoring wells and piezometers, installation of unsaturated zone instrumentation, water chemistry and water level monitoring, and aquifer testing.

This report focuses on describing the scope, methods, and results of these activities, except water chemistry and water level monitoring and aquifer testing. These activities will be described in future Nye County technical reports. An overview of previous phases of the EWDP can be found in the Nye County report for fiscal years 1996–2001 (NWRPO, 2001a); additional information on all EWDP phases can be obtained at the Nye County web page at www.nyecounty.com.

1.3 BOREHOLE LOCATIONS, OBJECTIVES, AND CONSTRUCTION

Phase III drilling locations are denoted by triangles on Figure 1.3-1. Survey coordinates and well completion or abandonment information for boreholes are summarized in Table 1.3-1. The following section provides an overview of the major types of Phase III boreholes and wells and their locations, objectives, and construction. Details of drilling, sampling, and logging are presented in Section 2, and completion details are given in Section 3.

1.3.1 Exploratory Boreholes

Nye County contractors initiated Phase III field activities in July 2001 by drilling, logging, sampling, and abandoning four small-diameter exploratory boreholes in the lower Fortymile Wash area. Boreholes NC-EWDP-10SA and -22SA were located on the NTS, and NC-EWDP-19IM1A and -19IM2A were located immediately adjacent to the NTS at the ATC. The technical objectives of these exploratory boreholes were to (1) characterize alluvial stratigraphy, including coarse-grained intervals that may serve as preferred flow paths, (2) sample and identify the underlying Tertiary rock units, and (3) obtain a preliminary estimate of the water table level. Exploratory boreholes were drilled using air-rotary dual-wall reverse-circulation (RC) drilling methods. These boreholes were plugged and abandoned in accordance with the requirements of the Nevada Division of Water Resources (NAC 534.360–4377).

1.3.2 Monitor Wells

Four larger-diameter monitor wells with multiple screens (NC-EWDP-10S, -22S, -19IM1, and -19IM2) were drilled and completed at the locations of the abandoned exploratory boreholes. These wells were designed and constructed to permit determination of aquifer properties and conditions and water chemistries at different screened intervals.

The primary technical objectives for the monitor wells were to (1) drill and complete the wells in the alluvial and upper Tertiary aquifer, (2) confirm lithostratigraphic contacts identified in the exploratory boreholes, (3) identify potential production zones and structural features, (4) screen and develop multiple zones of interest and obtain aquifer property data, and (5) obtain long-term pressure (water level), temperature, and water chemistry data versus depth.

Wells NC-EWDP-10S and -22S are located adjacent to the present-day channel of Fortymile Wash, along a potential alluvial flow path from Yucca Mountain toward populated areas and potential future development in Amargosa Valley. These monitoring wells are located near piezometers and were designed to be used as pumping wells for hydraulic tests and cross-hole tracer tests to characterize flow transport properties in the alluvium and underlying Tertiary deposits.

The monitoring wells installed at the ATC site, NC-EWDP-19IM1 and -19IM2, were constructed to support future cooperative studies with DOE and its contractors, including hydraulic and tracer tests. Figure 1.3-2 shows the layout of wells at the ATC site.

The boreholes for the monitor wells were drilled using flooded-mud reverse-circulation (FM) drill methods to provide relatively large-diameter boreholes suitable for the construction of permanent multiple-screen wells and the installation of removable Westbay® packer equipment and monitoring instrumentation. The Westbay® system includes packers to isolate screened intervals, removable pressure and temperature sensors to provide continuous monitoring data from the isolated intervals, and hydraulic pumping ports to the isolated screened intervals for collecting water chemistry samples and to permit aquifer testing.

1.3.3 Piezometers

Five intermediate-diameter boreholes were also drilled; four were completed with nested dual-completion piezometers (NC-EWDP-10P, -22PA, -22PB, and -23P) and one with a single-completion piezometer (-18P). Piezometer NC-EWDP-10P is near monitor well -10S, and piezometers -22PA and -22PB are located near monitor well -22S. The piezometers will be used as observation wells for aquifer tests conducted in monitor wells and possibly as injection wells for cross-hole tracer tests, with the monitor wells serving as pumping wells. Screens in piezometers were located at depths corresponding to screens in adjacent monitor wells to facilitate testing and monitoring. Figures 1.3-3 and 1.3-4 show the layout of monitor wells and piezometers at Sites NC-EWDP-10 and -22.

Piezometers NC-EWDP-18P and -23P were sited independently of monitor wells. NC-EWDP-18P is located along a potential fractured tuff flow path from Yucca Mountain to the alluvial deposits in Fortymile Wash in a highly faulted region where little is known about the occurrence and thickness of Tertiary tuff units beneath the ground surface. NC-EWDP-23P is located east of the current Fortymile Wash channel but within the alluvial flood plain and potential historic channel deposits. This borehole was to be completed as a deep piezometer; however, the bottom of the borehole had to be abandoned due to drilling problems.

Casing advance (CA) drilling methods were used to depths of 45, 791.8, and 709.2 ft below ground surface (bgs) in NC-EWDP-18P, -10P, and -22PA, respectively. Conventional-circulation air-rotary drilling methods were used in the remaining portions of each of these boreholes. RC drilling methods were used throughout NC-EWDP-22PB and -23P.

All piezometers were constructed to characterize valley-fill alluvial stratigraphy, identify and characterize the underlying Tertiary rock units when penetrated, help define groundwater flow paths downgradient of the proposed repository, and provide vertical hydraulic gradient and background water chemistry data. In addition to collecting drill cuttings for lithostratigraphic descriptions and laboratory analyses, minimally disturbed core samples were collected from selected intervals in the alluvium in NC-EWDP-10P and -22PA to provide small-scale estimates of flow-and-transport-related properties in both unsaturated and saturated zones. Finally, air piezometers were installed in the unsaturated zone in -10P and -22PA to permit future large-scale estimates of vertical air permeability by monitoring the subsurface response to atmospheric barometric pressure changes.

1.4 QUALITY ASSURANCE PLANS AND PROCEDURES

The *NWRPO Quality Assurance Program Plan* (QAPP) (NWRPO, 2001b) outlines quality assurance (QA) management procedures for the collection and documentation of scientific data. This plan helps to ensure that NWRPO scientific investigations provide valid data that are useful to Nye County and other potential users associated with the proposed Yucca Mountain repository. The U.S. Nuclear Regulatory Commission evaluated the QAPP and issued a formal acceptance statement (Reamer, 1999).

Table 1.4-1 lists the specific QA work plans (WPs) and technical procedures (TPs) pertinent to Phase III. The WPs referenced in this table outline technical objectives and describe methods and procedures for accomplishing these objectives (e.g., scopes of work). In addition, WPs reference applicable TPs, which in turn provide detailed instructions for performing routine technical activities or tasks. Some deviations from these WPs and TPs were found to be necessary due to conditions encountered in the field. Major deviations were documented on field change approval forms filed in the NWRPO Quality Assurance Records Center (QARC). These necessary deviations, as well as several other unplanned and unapproved deviations, are described in Sections 2 and 4. In general, these deviations did not affect the achievement of project objectives and goals.

1.5 SCOPE OF REPORT

This report summarizes Phase III drilling, sampling, geologic and geophysical logging, laboratory testing of geologic samples, and well construction. It is intended primarily as a data reference and includes data collection methods and results, data limitations, and preliminary analyses and interpretations. Since nearly all data presented herein are affected in some ways by drilling and sampling methods, this report also presents an in-depth evaluation of these methods.

Several Phase III activities are not addressed in this report. These activities include well rehabilitation activities at NC-EWDP-2DB, aquifer testing, and water level and water chemistry monitoring.

Section 1 provides pertinent background information and describes the purpose and scope of the Phase III fieldwork and the scope of this report. Section 2 summarizes drilling, sampling, and logging methods and procedures used. Section 3 describes well completion and development activities. Section 4 presents the results of geologic logging, laboratory testing of geologic samples, and geophysical logging. Section 5 summarizes major findings and recommendations. Section 6 provides supporting references.

2.0 BOREHOLE DRILLING, SAMPLING, AND LOGGING METHODS

This section briefly describes drilling, abandonment, water sampling during drilling, geologic sampling, geologic logging, laboratory testing, and geophysical logging methods. Further details can be found in the QA documents listed in Table 1.4-1. The NWRPO On-Site Geotechnical Representative was responsible for overall program oversight and approval of procedural and scope changes necessitated by field conditions and field findings. NWRPO field staff, including contract geologists and technicians (referred to as NWRPO in the following section), recorded site management information, equipment calibrations, general observations, and progress notes in scientific field notebooks. For organization, efficiency, and to help ensure complete data collection, forms were used to record key drilling and sampling data, including but not limited to geologic logging, depth control, and chain of custody data. Completed forms and scientific notebooks are on file at the NWRPO QARC.

2.1 DRILLING AND ABANDONMENT

Nye County drilling contractors performed drilling and abandonment related activities under oversight of the NWRPO. The drilling contractors were responsible for implementing the contracted drilling scope of work, compliance with all applicable permit conditions and well regulations, and compliance with their companies' health and safety plan and industry-standard good work practices.

2.1.1 Selection of Drilling Methods and Drilling Fluids

Drilling methods and drilling fluids were selected for Phase III boreholes based on a number of criteria, including their ability to (1) yield drill cuttings that are as representative as possible of in situ formation rock, (2) minimize the disturbance of the formation rock, and (3) yield boreholes suitable for completing multiple-screen monitor wells and piezometers. The following section gives reasons for selecting drilling approaches used in Phase III.

2.1.1.1 Drilling Methods

The RC method was chosen for exploratory boreholes because it can provide representative drill cuttings that are relatively uncontaminated by drilling fluids, is relatively fast and inexpensive, and minimizes cross-contamination between formation units. The contact of compressed-air drilling fluid with the formation is minimized by routing air flow down the dual-wall drill pipe annulus to the drill bit and up the center of the drill pipe to the ground surface. This RC air-flow design minimizes the erosion of borehole walls by the compressed air. Moreover, the relatively small-diameter requirement of exploration boreholes (5.375 in.) in combination with the 4.0 in. diameter drill pipe also works to increase borehole stability and limit borehole wall caving. Limiting borehole wall erosion and caving limits mixing of drill cuttings from different regions of the borehole, which in turn facilitates collection of representative drill cuttings samples and identification of unit changes.

Since very few borehole wall stability problems were encountered in the exploratory boreholes, the same RC method with 4.5-in. dual-wall drill pipe was used in two intermediate-diameter (8.5 in.) boreholes that were designed to be completed as piezometers. Minor caving problems were encountered in the first and more serious caving problems occurred in the second of these intermediate-diameter RC piezometer boreholes. It is believed that these additional caving problems were at least in part due to the greater instability of borehole walls in larger-diameter boreholes and the larger annular space between the 4.5-in. drill pipe and the walls of the 8.5-in. borehole. Borehole stability problems and their effects on data collection objectives in these and other boreholes are discussed in greater detail in Sections 2.1.2.2 and 2.1.3.3.

CA air-drilling methods were selected for the remaining intermediate-diameter (7.125 to 10 in.) piezometer boreholes for many of the same reasons that RC methods were selected. This method advances the drill casing as the borehole is deepened. This effectively seals off (in most cases) the borehole above the drill bit, thereby minimizing borehole wall erosion and caving and the resulting mixing of drill cuttings from different borehole regions. In addition, the central drill string can be removed from CA boreholes, leaving behind the drill casing that is open at the bottom to the underlying formation. This permits collecting drive-core samples of unconsolidated formation rock beneath the drill casing. Finally, the drill casing, if removed in stages, facilitates completing wells in unstable formation materials.

Finally, FM drilling methods were used to drill relatively large-diameter (14.75 in.) boreholes that were completed with multiple-screen wells. This method was selected primarily because it had been used successfully in Phase II to drill similar large-diameter, plumb, straight, and relatively stable boreholes. Borehole wall stability is enhanced by filling (i.e., flooding) the hole with bentonite mud drilling fluid during drilling and keeping the borehole partially full of mud during well completion activities. Drill cuttings are moved from the drill bit to the ground surface through the inside of the drill pipe using an air-lift tube within the drill pipe. This reverse flow helps to minimize mixing of drill cuttings and borehole erosion effects. Finally, this method is used to drill many municipal water wells. As a result, a number of drilling companies have this capability and competition between these companies helps to keep drilling costs at reasonable levels.

2.1.1.2 Drilling Fluids

Drilling fluids are required to move drill cuttings from the drill bit to the ground surface and to reduce friction and heat at the drill bit. Drilling fluids were selected in Phase III to have the least possible adverse impact on the drill cuttings, on the stability and permeability of formation rocks in the vicinity the borehole, and on water chemistry in the saturated zone. In general, compressed air was used when possible. When drilling mud was required, either untreated sodium bentonite or sodium bentonite coated with a polymer were used when possible. The use of organic drilling fluids and additives, including foams, polymers, and lost circulation materials (LCMs), were minimized to the extent possible. Potential adverse effects of drilling fluids are briefly summarized below. More details regarding the use of drilling fluids are presented in Section 2.1.3 and in Appendix A.

Generally, the use of air as a drilling fluid produces the least disturbance to formation rock permeability and water chemistry. However, air often erodes borehole walls and can create caving conditions in boreholes. Both RC and CA drilling methods are designed to minimize the contact of drilling fluid with the formation. As a result, it was possible to use compressed air as the primary drilling fluid in both RC and CA drilled boreholes.

On the other hand, drilling fluid composed of water and bentonite (i.e., bentonite mud) can help to stabilize borehole walls, and it was used for this purpose in large-diameter FM drilled boreholes. At the same time, this bentonite mud may result in reduced borehole permeability if not removed during well development. Bentonite may also have a slight effect on water chemistry as a result of its high cation exchange capacity.

Drilling fluids containing organic compounds, including foams, polymer additives, and bentonite coated with polymer, may adversely affect inorganic water chemistry measurements by altering the oxidation reduction potential in formation rocks located close to a borehole (USACE, 1998). Organic LCMs may also similarly affect water chemistry and reduce the permeability of formation rocks. In addition, LCMs may be more difficult to remove than foams or polymers during well development.

2.1.2 Drilling Impacts on Drill Cuttings

The impacts of drilling processes on particle size distributions (PSDs) and other flow-and-transport-related data determined from alluvium drill cuttings are discussed in Section 4. The following sections summarize impacts in a more conceptual manner.

2.1.2.1 Common Drilling Impacts

Most drilling methods mix subsurface unconsolidated formation sediments to varying degrees and therefore limit the usefulness of using drill cuttings to identify thinly bedded sediment layers with similar characteristics. Mixing occurs at both the drill bit and in the air stream between the drill bit and the ground surface. This mixing tends to average the characteristics of adjacent formation beds and makes it difficult to identify contacts between beds, especially if the PSDs and/or lithologies of the beds are not significantly different. However, if drill cuttings are moved directly from the drill bit to the ground surface with little or no fall-back and recirculation, drill cuttings can often be successfully used to identify gross changes in the PSD and lithology of unconsolidated sediments.

Although sharp contacts in consolidated rock are generally easier to identify from drill cuttings than bedding contacts in unconsolidated sediments, the same mixing process makes accurately locating these contacts difficult when lithology characteristics are similar. In some cases, other sources of data, such as drilling penetration rates and subsequent borehole geophysical logging, can provide information on depths of consolidated rock contacts and increase confidence in depths estimated from drill cuttings.

In addition, drill bits grind formation materials to varying degrees, causing the PSDs of drill cuttings of unconsolidated sediments to also differ by varying degrees from in situ sediments. For example, the grinding effect of drill bits on well-graded alluvial sediments is expected to reduce natural cobbles to gravel-size particles, gravel to sand-size particles, and sand to silt- and possibly clay-size particles. The amount of particle size reduction depends on the resistance of the sediments to grinding and the drilling method, rate, and fluid. For example, for a particular drilling method, rate, and fluid, the PSDs of alluvial sediment clasts composed of relatively soft, low density, non-welded ash-fall tuffs will be disturbed more than PSDs of sediment clasts of very hard, densely welded ash-flow tuffs. Similarly, for a particular drilling method in a particular alluvial sediment, a slower drilling penetration rate will generally produce more disturbance of PSDs than a faster penetration rate, assuming drill bit rotation rates are similar. Finally, all other factors being equal, water in a drilling fluid and/or in formation sediments will facilitate grinding and PSD disturbance more than a compressed-air drilling fluid and/or air in sediment voids.

In addition, when using air as a drilling fluid in unsaturated zone unconsolidated sediments, drilling-created and naturally-occurring small-size particles (e.g., silt- and clay-size particles) can in part be lost as dust from the sample collection system at the ground surface (e.g., cyclone separator). Again, the degree of PSD disturbance will depend on the drilling method and rate and the resistance of alluvial sediment clasts to the grinding action of the drill bit.

The net effect of the above processes on alluvial sediment PSDs is difficult to predict due to the large number and possible interdependence of the variables involved. Some general observations regarding Phase III drilling impacts on PSDs are presented in the following section; more details are presented in Section 4.

2.1.2.2 Drilling Impacts Specific to Phase III

FM drilling methods generally produce large particle size drill cuttings from consolidated rock, which facilitate its description after washing samples free of drilling mud. However, the drilling mud suspends the fine particles (fine sand-, silt- and clay-size particles) naturally present in alluvial sediments, making it difficult to sample and determine PSDs accurately. Because of this problem and because Phase III boreholes drilled by FM methods were expected to penetrate primarily alluvial sediments, drill cuttings were not in most cases collected from FM boreholes.

Instead, exploratory boreholes were drilled by RC air methods prior to drilling FM boreholes to provide continuous PSD and lithologic data at FM drill sites. This approach was satisfactory except in one exploratory borehole (NC-EWDP-22SA), where RC drill cuttings from well-cemented alluvium and consolidated rock proved to be too small in size to adequately describe cementation. In this case, larger particle size FM drill cuttings samples were collected from the FM borehole (NC-EWDP-22S) to supplement the RC drill cuttings samples.

RC (and CA) air drilling methods with optimum drilling fluid velocities will generally lift cuttings sequentially, and significant changes in formation PSDs and lithologies of unsaturated unconsolidated sediments can often be detected reasonably accurately from drill cuttings. In Phase III, it is believed that near optimum compressed air fluid velocities were achieved in exploratory RC boreholes, and therefore drill cuttings are reasonably representative of in situ alluvial bedding above the water table. That is, if significant differences in average PSDs occur in situ between adjacent sampling intervals (either 2.5 or 5 ft in this study) in unsaturated alluvium, these differences are reflected in a somewhat muted fashion in drill cuttings.

At the same time, it should be emphasized that the actual PSDs of drill cuttings, even from exploratory RC boreholes, in many cases do not fully represent in situ formation conditions due to the grinding action of the drill bit on sediment clasts and the disturbing effects of numerous other drilling-related factors (Section 2.1.2.1). More specifically, data presented and discussed in Section 4 suggest that the grinding of clasts of relatively soft non-welded tuff into smaller size fractions in both RC exploratory and piezometer boreholes likely significantly disturbs the PSDs of alluvium drill cuttings below the water table from in situ conditions. Although it is likely that the grinding action of CA drilling also disturbs the PSDs of non-welded tuff alluvium drill cuttings below the water table, geologic sample collection problems in CA boreholes (Section 2.3.1) preclude making this determination. It is interesting to note that workers on the Nevada Test Site have previously found that CA drilling in unsaturated tuffaceous alluvium generated drill cuttings with PSDs that closely matched PSDs of drive core samples, and by inference the PSDs of in situ sediments (Reynolds Electrical and Engineering Co., Inc., 1994). Dual-wall reverse-circulation drill pipe was used on the CA drill system to achieve adequate drilling fluid velocities and borehole cleaning capabilities.

If the drilling fluid velocities are not adequate, additional mixing of drill cuttings will occur in the return flow between the drill bit and the ground surface. Evidence for significant additional mixing of this type was observed in the unsaturated region of all CA boreholes. During CA drilling, poor drill cuttings removal from boreholes was consistently observed in the unsaturated zone, indicating that drill cuttings were being recirculated and mixed before reaching the ground surface. Reasons for the poor cuttings removal are presented in Section 2.1.3.3.1. As a result of this mixing, the drill cuttings from CA boreholes are believed to be less representative of subsurface bedding in unsaturated alluvium than RC exploratory borehole drill cuttings discussed above. Supporting evidence for this conclusion and its impact on the representativeness of drill cuttings from CA boreholes is provided in Section 4.

In addition, the caving problems associated with intermediate-diameter RC piezometer boreholes, especially those in NC-EWDP-23P (see Sections 2.1.1.1 and 2.1.3.3), also likely resulted in additional mixing of drill cuttings in these boreholes. Moreover, the much slower drilling rate in RC piezometer boreholes compared to RC exploratory boreholes in the unsaturated zone also likely further disturbed the alluvium drill cuttings PSD from in situ conditions. As a result, drill cuttings from these intermediate-diameter RC piezometer boreholes, like those from CA piezometer boreholes, are not considered as representative as cuttings from the smaller-diameter RC exploratory boreholes. Supporting evidence for these conclusions is presented in Section 4.

2.1.3 Details of Drilling Methods and Procedures for Phase III Borehole Types

For all borehole types, the NWRPO and drilling contractors maintained depth control during drilling via direct measuring and monitoring of drill strings and, where practicable, depth sounding. In addition, plumbness surveys were conducted during drilling in all boreholes except exploratory boreholes.

Drilling methods and procedures specific to different borehole types are described in the following sections.

2.1.3.1 Exploratory Boreholes

Eklund Drilling Company of Elko, Nevada, drilled 5.375-in. diameter exploratory boreholes (NC-EWDP-19IM1A, -19IM2A, -10SA, and -22SA) using a Formost 1500 drill rig and RC drilling methods. These small-diameter exploratory boreholes were drilled before drilling larger-diameter boreholes by FM methods. The exploratory boreholes provided geologic samples, first water samples, site stratigraphy, and cased borehole geophysical survey information.

After drilling and sampling the upper 22 to 22.5 ft of each exploratory borehole with a 5.125-in. hammer bit assembly by conventional circulation and water injection methods, the holes were reamed with a 8.75-in. tricone bit. A temporary 6.625-in. steel surface casing, approximately 20 ft in length, was installed and the annular space was filled with a water slurry of KWIK-PLUG® bentonite chips. These chips were coated with a polymer to slow hydration. This surface casing was necessary to prevent caving of relatively unstable near-surface sediments and to maintain borehole air pressure while drilling the remaining portion of each borehole. The temporary surface casing was removed when the borehole was abandoned.

Following the installation of temporary surface casing, a 5.375-in. tricone center-return bit was used with 4-in. dual-wall drill pipe to advance the exploratory boreholes to total depth. Air was used as the primary drilling fluid and the use of other drilling fluids and additives was minimized. Small volumes of injected water were used in the upper section of the saturated zone to facilitate sample return. In addition, small volumes of MAX GEL®, a common Wyoming sodium bentonite mud containing a small amount of organic polymer, were used to condition borehole walls to minimize hole erosion and caving during drilling alluvium sections of boreholes. Hole conditioning methods are described in detail in Appendix A. This appendix also summarizes quantities of hole conditioning materials used over specific depth intervals.

These methods of borehole conditioning were also designed and conducted in a manner to minimize the potential for bentonite contamination of drill cuttings samples. Any evidence of potential impacts to samples from the limited use of drilling additives was noted in the scientific notebook and the geologic sample log. Very few samples were impacted (see Appendix A).

After reaching total depth and completing geophysical logging in the drill pipe, each of the exploratory boreholes was plugged with a high-solids bentonite grout (Super-Plug®) to ground surface, in accordance with Nevada Administrative Code (NAC 534.4371) abandonment requirements. Some of this plug was subsequently drilled out during advancement of the FM boreholes for the monitor wells.

2.1.3.2 Monitoring Wells

The exploratory borehole locations were over-drilled and completed as multiple-screen monitoring wells (NC-EWDP-10S, -22S, -19IM1, and -19IM2). Allen Drilling of Las Vegas used a Watson 3160 telescoping-kelly auger drill rig and a 30-in. bit to drill a pilot hole in which to set conductor casing. Up to 80 ft of 18-in. OD Schedule 40 (0.375-in. wall) ASTM A53 Grade B API 5L-B steel conductor casing was set. At NC-EWDP-10S, the conductor casing was set at a shallower depth (about 63.1 ft), because the auger hole was unstable and there was evidence of caving below 55 ft. In all the monitor wells, 18-in. casing was used instead of the 16-in. casing specified in the WP (Table 1.4-1) to allow more room for recovery operations (e.g., wash-over of stuck drill pipe) if future drilling problems were encountered. At each monitor well location, the annulus between the borehole and the conductor casing was grouted with a concrete grout.

Beylik Drilling Company of La Habra, California, then used a Challenger 320 drill rig, a 14.75-in. tricone button bit, and FM drilling methods to drill to the desired total depth. This drilling method was selected for the monitoring wells because it provides straight, plumb, and relatively stable boreholes required for installation of 6.625- and 7-in. OD steel multiple-screen well completions suitable for installing Westbay® packer and monitoring systems. Drill cuttings samples were not collected from most of the FM boreholes because the exploratory boreholes drilled earlier at the same locations provided continuous samples and logging data. However, samples were collected at NC-EWDP-22S from 750 to 1,200 ft bgs to supplement the samples from -22SA.

Drilling fluids used for FM drilling included: AQUA GEL GOLD SEAL®, an untreated sodium bentonite, and QUIK-GEL®, a sodium bentonite coated with organic polymers. Lesser amounts of drilling fluid additives, including DrisPac®, a polyanionic cellulose polymer, and EZ-MUD®, a liquid polyacrylamide, were used for viscosity and fluid loss control. Finally, Magma Fiber®, a mineral-based extruded "wool", BENSEAL®, granular 8-mesh untreated bentonite, and Portland cement were variously used either alone or in combination to control lost circulation.

Untreated bentonite AQUA GEL GOLD SEAL® was used exclusively as the drilling mud in NC-EWDP-19IM1 and -19IM2. QUIK-GEL® was used in the drilling mud at NC-EWDP-22S down to about 528 ft bgs; AQUA GEL GOLD SEAL® was then used to drill into the aquifer. At NC-EWDP-10S, AQUA GEL GOLD SEAL ® was used together with QUIK-GEL® in the upper part of the hole, and QUIK-GEL® was used at depth. Soda ash (sodium carbonate) was used at NC-EWDP-22S and -10S to optimize the drilling fluid pH, particularly in conjunction with use of the QUIK-GEL® bentonite.

Use of drilling mud additives and LCMs, which might cake too thickly on the walls and reduce permeability of the native material around the borehole or locally affect groundwater chemistry, was minimized. However, use of some additives and LCMs was necessary, especially in NC-EWDP-10S and -22S, to maintain circulation, adequately lift cuttings, and proceed with drilling. Details regarding the use of these additives, LCMs, and drilling muds are presented in Appendix A.

Excess drilling mud, drilling additives, and LCMs were removed from the monitor wells by an extensive well development program (Section 3). As a result, it is likely that these materials do not significantly impact the permeability of saturated zone formation materials. The exclusive use of untreated sodium bentonite drilling mud in NC-EWDP-19IM1 and -19IM2 is not expected to have a significant impact on water chemistry measurements. The effect of using bentonite muds containing organic polymers and the use of pure organic polymer additives on water chemistry in NC-EWDP-10S and -22S is presently being evaluated.

After reaching total depth at each monitoring well borehole, open-hole geophysical logs were run in NC-EWDP-10S, -22S, and 19IM2 (see Section 2.6). Borehole stability problems in NC-EWDP-19IM1 precluded open-hole geophysical logging. The boreholes were then completed as multiple-screen wells and developed (Section 3).

2.1.3.3 Piezometers

Nye County drilled and installed five piezometers in Phase III: three using a combination of CA methods and conventional air-rotary methods, and two using RC methods.

2.1.3.3.1 Piezometers Drilled Using Casing Advance Methods

THF Drilling of Phoenix, Arizona, used an Ingersoll Rand TH75W rig and CA air-rotary and/or air-percussion hammer CA methods to drill the upper 45 ft in NC-EWDP-18P, all but the lower 118.3 ft in -10P, and the lower 70.6 ft in -22PA. Compressed air was the primary drilling fluid used in CA boreholes, and drilling additives were not necessary with CA drilling.

Conventional drilling fluid circulation was used in all CA boreholes. That is, compressed air was routed from the ground surface down a central and relatively small-diameter single-wall drill pipe to the drill bit and then back up to the ground surface via a relatively large annular space between the small-diameter drill pipe and the much larger-diameter drive casing. As might be expected, problems were encountered moving drill cuttings through this large annular space. The driller found it difficult to clean drill cuttings from the drill bit using a 900 cfm at 350 psi air compressor. This resulted in considerable recirculation and mixing of drill cuttings, and as a result, drill cuttings from these boreholes are not considered representative of in situ conditions. This problem is discussed further in Section 4 in relation to PSD data.

At NC-EWDP-10P, THF used 9.625-in. OD Stradex drive casing using a 10-in. casing shoe bit with an internal drill string of 3.5-in. API drill pipe with a 7.875-in. tricone bit to a depth of 304 ft bgs. Leaving the 9.625-in. casing in place, the hole was advanced using a 6.625-in. Tubex casing with a downhole hammer and a 7.125-in. underreamer bit to a depth of 791.8 ft bgs. Open-hole drilling continued below this depth using a 5.875-in. tricone bit and conventional air-rotary methods to a total depth of 910.5 ft bgs. Borehole drift was significant in this lower section of hole, but did not preclude piezometer well construction.

NC-EWDP-22PA was drilled similarly. The 9.625-in. Stradex drive casing part of the hole extended to 356 ft bgs. From 356 to 709.2 ft bgs, a 7.125-in. underreamer bit and Tubex casing were used, and from 709.2 ft to the total depth of 779.8 ft bgs, an open hole was advanced with a 5.875-in. tricone bit using conventional air-rotary methods.

Boreholes NC-EWDP-10P and -22PA were drilled using air circulation and did not require the use of drilling fluid additives. However, it was necessary to inject water in NC-EWDP-10P in the unsaturated zone from 252.5 to 295 ft bgs to lift moist drill cuttings and flush these samples out of the drill string and sample return hoses. This interval was impacted from lost circulation water originating from FM borehole NC-EWDP-22S. No injection water was required during drilling of borehole NC-EWDP-22PA.

Consolidated rock penetrated from 45 to 900 ft bgs in NC-EWDP-18P was drilled using open-hole conventional rotary methods with a 7.875-in. drill bit and compressed air as the primary drilling fluid. However, due to the high instability and/or permeability of some formation intervals, it was necessary to use other drilling fluids and additives to restore circulation in several depth intervals. The use of these drilling fluids and additives is detailed in Appendix A.

After reaching total depth and prior to completion of NC-EWDP-18P, the drilling fluids and additives, including LCMs, were flushed out of the hole by air lifting. As a result of this flushing and because these substances were mostly used above the water table, these additives are unlikely to impact water production in this borehole. The effects of any residual drilling fluids and additives on water chemistry measurements are currently being evaluated.

Due to borehole instability problems encountered throughout NC-EWDP-18P, cased and open-hole geophysical logs were not conducted at this borehole; instead, the borehole was completed with a single piezometer as soon as possible after reaching total depth. However, geophysical logs were run both through the Tubex drill casing and the open-hole interval below this casing in both NC-EWDP-10P and -22PA (Section 2.6). Following this logging, these boreholes were each completed with two nested piezometers. Piezometer completion activities are described in detail in Section 3.

2.1.3.3.2 Piezometers Drilled Using Dual-Wall Reverse Circulation Methods

The last two piezometers drilled as part of Phase III, NC-EWDP-22PB and -23P, were drilled by Eklund Drilling using an Ingersoll Rand TH75E drill rig, an 8.5-in. bit, 4.5-in. diameter dual-wall drill pipe, and RC methods. This drilling/completion effort was essentially an experiment to determine if larger-diameter RC boreholes would remain open and stable long enough to complete open-hole geophysical logging and the installation of nested piezometers. The larger drill bit was required to provide sufficient annular space for completion of sand packs and grout plugs around nested piezometer strings at appropriate depth intervals.

After drilling and sampling the upper 22 to 22.5 ft of each piezometer borehole with the 5.25-in. bit, the boreholes were reamed with a 14.5-in. reamer bit. Steel surface casing (10.75-in. OD) was installed to a depth of approximately 15.1 ft bgs at NC-EWDP-22PB and to a depth of 16.9 ft bgs at -23P. The annular space between the borehole and the surface casing in both RC piezometer boreholes was filled with Portland Cement and Cal Seal using a ratio of 3 bags to 1, respectively. Cal Seal is primarily composed of Plaster of Paris (Calcium Sulfate Hemi-hydrate) and is used as a cement hardening accelerator. Surface casings were necessary to prevent caving of relatively unstable near-surface sediments and to maintain borehole air pressure while drilling the remaining portion of each borehole. After piezometer well completion, each surface casing was extended to 2 to 3 ft above ground surface to provide a protective well-head casing for the piezometers.

The remaining portions of these boreholes were drilled similarly to the exploratory boreholes described in Section 2.1.3.1. Air was used as the primary drilling fluid; however, bentonite drilling muds and additives were used periodically to stabilize borehole walls in a manner similar to that used for exploratory RC boreholes. The amount of drilling mud used in NC-EWDP-22PB was not significantly greater than the amount used in exploratory RC boreholes, taking into account differences in borehole diameter. However, the amount of bentonite mud required to condition NC-EWDP-23P during drilling was approximately five times greater than the amount used in RC exploratory boreholes. The actual quantities of mud used over different borehole intervals are listed in Appendix A.

Drilling progressed relatively smoothly in NC-EWDP-22PB, and a target depth of 1,199.7 ft bgs was achieved. Some caving of the borehole occurred, and it was necessary to spend time cleaning the hole of these cuttings after every 20 ft. After open-hole geophysical logs were run (Section 2.6), the installation of dual nested piezometers was completed (Section 3.2).

At NC-EWDP-23P, loose sand was encountered, and larger quantities of drilling mud (approximately 14,000 gal.) were needed to condition the borehole and to try to limit caving, especially below a depth of 540 ft bgs. Some sandy material had to be cleared out from the borehole each morning. Despite the loose alluvium, drilling initially went well, and the borehole was advanced to a depth of 1,340 ft bgs. At this depth, uphole caving caused the bottom hole assembly (BHA), including drill bit and stabilizers, to become stuck. The BHA could not be pulled back above 1,050 ft bgs, even after flooding approximately 5,000 gal. of bentonite mud down the borehole. After several failed attempts to free the BHA, a small explosive charge inside the drill pipe was used to sever the BHA from the drill pipe. Approximately 65 ft of drilling equipment was abandoned in situ. After the removal of the severed drill pipe from the borehole, it was found that the borehole had caved to approximately 712 ft bgs. The hole was then plugged up to 700 ft bgs with a grout seal consisting of a mixture of 8/12-mesh silica sand and 8-mesh granular sodium bentonite in a 3:1 ratio by weight. The dual nested piezometer string was then completed to shallower levels than proposed, as described in Section 3.

The experiment of using larger-diameter RC air methods to drill boreholes for piezometers was considered a partial success. Despite the major caving problem in NC-EWDP-23P and some caving in -22PB, this work demonstrated that boreholes can be drilled by RC air in alluvium to more than 1,000 ft bgs depth and can remain open and stable long enough to complete open-hole geophysical logging and install nested piezometers. However, more caving occurred in these intermediate-diameter boreholes (especially in NC-EWDP-23P) than in the smaller-diameter RC exploratory boreholes. The impact of this mixing of drill cuttings from different alluvial beds on the PSDs of these drill cuttings is difficult to quantify. However, based on data presented in Section 4, this mixing disturbance is expected to impact PSDs far less than drill-bit grinding of clasts of non-welded tuff at depths below the water table into smaller size fractions. Data presented in Section 4 also suggest that the very slow drilling rates in the unsaturated zone of these boreholes appear to impact the drill cuttings PSDs above the water table. In summary, drill cuttings from these RC piezometer boreholes are likely disturbed from in situ conditions to a greater extent than cuttings from RC exploratory boreholes.

2.2 FIRST WATER SAMPLING AND TESTING

The NWRPO sampled the first water encountered from one borehole at each of the drill sites according to applicable QA WPs and TPs listed in Table 1.4-1. Several 1-L bottles of first water were collected from each of the following boreholes for measurement of field water chemistry indicator parameters and for possible laboratory analysis of a comprehensive suite of water chemistry parameters: NC-EWDP-19IM1A, -10SA, -22SA, -18P, and -23P. These are boreholes where the unsaturated zone was drilled using primarily dry-drilling methods. The samples were collected in case the uppermost water proved to be a thin, perched zone that would be difficult to sample in the future. However, in all cases the first water was found to be from the upper part of a thick alluvial aquifer or from the upper volcanic aquifer, which would yield more representative water samples following well completion and development. Therefore, these less representative first water samples were not submitted for laboratory analysis. However, field water chemistry indicator parameters (e.g., temperature, pH, and electrical conductivity [EC]) were measured on one of the 1-L samples from each borehole except NC-EWDP-23P, where measurement equipment was unavailable.

2.3 GEOLOGIC SAMPLING

Drill cuttings samples were collected from exploratory and piezometer boreholes to provide for continuous geologic logging and for laboratory testing. In addition, drive-core samples were collected from selected alluvial intervals in two CA boreholes (NC-EWDP-10P and -22PA) to demonstrate the feasibility of this method in relatively coarse-grained alluvial sediments in Fortymile Wash, and for laboratory testing of flow-and-transport-related properties. Conditions that may affect the interpretation or testing of specific samples were noted on the geologic sample logs and in the scientific field notebooks.

For the purpose of discussing samples in this report and to be consistent with past EWDP documents, "alluvium" generally refers to unconsolidated rock and "non-alluvium" to consolidated rock. Sampling and sample handling methods generally conformed to applicable WPs and TPs (Table 1.4-1). Exceptions are noted in this section and/or are described in Section 4.

2.3.1 Drill Cuttings Sampling

Table 2.3-1 summarizes the drill cuttings samples, sample splits, and laboratory testing program. Continuous drill cuttings samples were collected at 2.5-ft intervals in unsaturated alluvium and at 5-ft intervals in saturated alluvium and other rock types. Sampling intervals in saturated alluvium were changed from 2.5 ft in WPs (Table 1.4-1) to 5 ft in the field because of difficulties encountered in handling the volumes of samples and return water. A total of 2,824 cuttings samples were collected, including 2,474 alluvial samples and 350 non-alluvial samples. Counting splits prepared for NWRPO, YMP, and the NWRPO contract hydraulic parameter testing laboratory, a total of approximately 7,141 cuttings samples were packaged, labeled, and handled.

Three split samples were collected from each sampling depth interval: two for Nye County and one for the DOE. One Nye County split was subsampled for field logging description and preparation of chip trays for future reference. The second Nye County split and the DOE split were collected for archiving at the DOE Sample Management Facility (SMF). A fourth split was collected from every second 2.5-ft sample interval in alluvium for Nye County laboratory analysis, except when sampling at 5-ft intervals, where every 5-ft interval sample was sent for laboratory hydraulic parameter analysis. Both Nye County and DOE splits sent to the SMF were contained in olefin bags. Splits designated for laboratory testing were sealed in double plastic bags. All samples were carefully labeled with appropriate identification information and shipped to their destinations under chain of custody.

All drill cuttings samples were collected at the ground surface in a cyclone separator. In the unsaturated portion of exploratory boreholes, the entire alluvium sample collected from the cyclone separator for a particular depth interval was emptied into 5-gal. buckets. In the unsaturated portion of intermediate-diameter RC and CA piezometer boreholes, a Gilson dry splitter was used beneath the cyclone separator to reduce alluvium sample sizes to more manageable volumes. Unsaturated zone samples were then placed on a tarpaulin and rolled to homogenize the sample prior to collecting subsample splits.

Unsaturated zone alluvium drill cuttings samples were weighed in the field to provide data for calculation of in-situ bulk densities. Samples were weighed on an electronic digital scale, which measures in 0.1 lb. or 0.01 kg increments to ±0.01 kg accuracy. A second small scale was used to measure gravel sieve weights for in-field percent gravel calculations. The field scientists checked and recalibrated the field scales at the start of each shift and as needed. Three 50-lb. weights were used to check the calibration of the larger scale at 50, 100, and 150 lb. loads. A 3.42-lb. weight was used to periodically check calibration of the small scale.

In the saturated portion of all exploratory and piezometer boreholes, an Anaconda rotating wet splitter was attached beneath the cyclone separator to reduce the sample volume (water plus drill cuttings) from a sample depth interval to a manageable number of 5-gal. buckets.

To maintain the fines fraction of alluvium samples collected below the water table, the cuttings samples were left in labeled plastic buckets in a secure area for settling, decanting, and drying, prior to homogenizing, subsampling, and logging. These samples were allowed to nearly dry to permit thorough homogenization, which produced representative subsamples.

All Phase III site locations have at least one exploratory or piezometer borehole where these subsampling procedures were strictly followed for both unsaturated and saturated alluvium drill cuttings, and the resulting subsamples are considered to be fully representative of the drill cuttings delivered to the ground surface. However, in boreholes NC-EWDP-10P, -22PA, and -22PB, standard procedures for sample handling were not strictly followed. In these piezometer boreholes, cold winter temperatures made it very difficult to dry samples sufficiently to permit thorough homogenization and consequently representative subsampling for field geologic logging, laboratory testing, and archiving. As a result, both the laboratory measurements and field estimates of PSDs made on the alluvium saturated zone samples from these piezometer boreholes are not as representative of in situ conditions as they may have been, had the standard procedures been followed. Consequently, these data have been censored. Examples of these data are presented in Section 4 to illustrate that they are not representative. These data will not otherwise be made available to the public. In the future, additional training and closer supervision will be used to ensure strict compliance with standard operating procedures.

2.3.2 Drive-Core Sampling

In addition to providing representative small-scale samples for laboratory analysis of flow-and-transport-related properties, core samples can potentially yield a very accurate picture of bedding in alluvium and lithologic contacts in hard rock. However, obtaining representative core samples is extremely difficult and costly in nearly all rock types. In Phase III, a limited coring program was conducted in several CA boreholes to demonstrate the feasibility of obtaining minimally disturbed drive-core samples from alluvium. Drive-core sampling was selected based on previous studies that demonstrated that this method provided good core recovery and minimized the disturbance of hydrologic conditions and physical properties of relatively dry coarse-grained alluvial sediments (Hammermeister et al., 1986).

In Phase III, this method involved driving an approximately 4-in. ID solid-tube core barrel (either 2.5- or 2.0-ft long) into formation sediments with a downhole air-percussion hammer. A beveled hardened-steel drive shoe was attached to the downhole end of the core barrel. The solid-tube core barrel was lined with thin-walled tubes (sleeves) cut into 6-in.- and 3-in.-long segments. Upon completion of the core run, core samples contained in brass sleeves were removed from the core barrel by means of hydraulic core extruder.

Table 2.3-2 summarizes drive-core samples, splits, and tests. Drive-core samples were collected at two of the three CA boreholes (NC-EWDP-22PA and -10P) in both unsaturated and saturated zone alluvium. Fewer core samples were collected than proposed in applicable WPs (Table 1.4-1) because of the types of materials encountered and budget limitations. For example, drive-core sampling proved infeasible in several gravel/cobble layers. No core sampling was attempted at NC-EWDP-18P, due to the presence of bedrock below 45 ft bgs.

At NC-EWDP-10P, cores were collected in 2.5-ft-long core barrels lined with seven 3.9-in. ID brass sleeves (rings): two 3-in.-long sleeves, followed by three 6-in.-long sleeves, and another two 3-in.-long sleeves. The original WPs (Table 1.4-1) called for five 6-in.-long brass sleeves, but the smaller length sleeves provided additional samples for laboratory testing and ensured that samples would be available for all interested parties even if core recovery was not optimal. New 2.0-ft core barrels were used at NC-EWDP-22PA except for the first core run, where the 2.5-ft barrel was used. The shorter barrels were easier to drive, while still providing enough core segments for users. NWRPO retained one 6-in.-long sleeve instead of two from these shorter cores. Sampling and testing objectives were unaffected by these coring modifications.

Initially, one 6-in.-long NWRPO core sample from each core run was sent directly with chain of custody to the Nye County contract testing laboratory for hydraulic parameter testing (Section 2.5). The rest of the core sleeves were labeled, sealed, and transmitted under chain of custody to the DOE YMP SMF for storage and use by authorized YMP contractors. At a later date, additional 6-in.- and 3-in.-long NWRPO core samples were transmitted from the SMF to the Nye County contract testing laboratory for future analyses.

2.4 GEOLOGIC LOGGING

Geologic logging methods are described in the field logging TP listed in Table 1.4-1. Geologic logging data were recorded on NWRPO QA forms, alluvial logging forms and non-alluvial drill cuttings forms. Lithology, color, PSD and cementation (alluvial sediments only), acid reaction, and other characteristics were noted on the field forms. Where feasible, volcanics were logged as formal units, based on the literature, data from adjacent areas, and consultation with USGS and DOE geologists.

Field estimates of PSD in alluvium samples are useful for estimating gross textural variability over the sample interval logged. Since these data are field estimates, they should not be analyzed in a quantitative manner. Instead, laboratory measurements of PSD (Section 2.5) should be used for this purpose.

In general, the continuous field logging observations are valuable for qualitatively identifying trends in logged parameters as the drilling and sampling progresses. Trends in several of these logged parameters are described in Section 4.

2.5 HYDRAULIC PARAMETER LABORATORY TESTING

Table 2.4-1 summarizes laboratory test methods. Tables 2.3-1 and 2.3-2 list the type and number of analytical tests run on drill cuttings and drive-core samples, respectively. Nevada Geo-Tech, Inc. of Pahrump, Nevada, conducted all laboratory tests on geologic samples in accordance with industry standard methods listed in Table 2.4-1.

Initially, 6-in.-long core segments in brass liners from all 13 of the core samples collected were analyzed for saturated hydraulic conductivity, PSD by wet sieve and hydrometer methods, volumetric water content, dry bulk density, and specific gravity. No soil-water extract EC tests were run on the drive-core samples.

Laboratory testing notes documented that a number of these 6-in.-long core samples (especially those from NC-EWDP-10P, which were collected in 2.5-ft-long core barrels) were loosely packed in their core liners, indicating the porosities of the core samples were significantly disturbed from in situ conditions. This disturbance likely resulted from not driving the core barrel a sufficient distance to completely fill and tightly pack the core barrel. When the core barrel is not driven far enough to completely fill the core barrel, the vibration and friction resulting from drive-coring generally increases the porosity and decreases the density of samples collected from deeply buried sediments. This results in samples that are difficult to retain in liners (e.g., they fall out of liners) and therefore are difficult to handle and test in the laboratory. This increase in porosity can be counteracted to some extent by driving the core barrel a distance slightly farther than the total length of the core barrel. WP procedures (Table 1.4-1) will be revised to ensure that core barrels will be driven in a manner to completely fill and tightly pack the core barrels in future EWDP phases.

As a consequence of not driving the core barrel far enough, porosity-related test data from these loosely packed core samples, including dry bulk density, volumetric water content, and saturated hydraulic conductivity, are considered significantly disturbed, and these data have been censored. Subsequently, to replace these censored data and to increase the total number of samples tested, additional NWRPO 6-in.- and 3-in.-long core samples were transported from the SMF to the Nevada Geo-Tech laboratory for additional testing. To attempt to minimize the porosity disturbance in these samples, each sample was compacted in its liner so that it would not fall out of the liner during testing. The intent of this compaction effort was not to achieve in situ conditions, but to eliminate most of the preferential flow paths in the core samples created during the coring process. It is likely that this compaction did not reduce porosities (increase bulk densities) sufficiently to approach in situ values where overburden pressures were equivalent to many hundreds of feet of sediments. As a result, the porosity-related parameters measured on these core samples should be considered preliminary in nature and should be re-evaluated and possibly replaced if and when additional core data become available at these sites.

This compaction was accomplished by placing the core upright on a solid surface, placing a wooden disk with an OD slightly less than the ID of the core liners on the top surface of the core, and then tapping the disk with a hammer until further sample consolidation was not visibly detected. This was repeated for the bottom surface of each core sample. Visual observation and subsequent laboratory measurements both indicated that the water content of core samples collected beneath the water table had decreased significantly below saturation levels as a result of handling and storage; however, the water content was still significantly higher than required for optimum compaction. Moreover, the water content of core samples above the water table was far less than optimum for compaction. As a result, the bulk densities of compacted core samples are likely far less than the maximum density achievable and likely significantly lower than in situ formation bulk densities.

Every other unsaturated zone alluvium drill cuttings sample collected over 2.5-ft depth intervals was analyzed for wet sieve PSD, gravimetric water content, and soil-water extract EC. Wet sieve analyses of PSD were conducted on alluvial composite samples from 5-ft intervals in the saturated zone.

Hydrometer analyses for determining percentages of silt and clay were performed on selected drill cuttings samples from each borehole, except NC-EWDP-18P.

In summary, the following number of laboratory hydraulic parameter-related tests were conducted on alluvium drill cuttings samples: 1,493 samples were analyzed for PSD by wet sieve and another 66 by hydrometer methods, 840 samples were analyzed for gravimetric water content, and 826 samples were analyzed for soil-water extract EC. No laboratory hydraulic parameter tests of non-alluvium cuttings have been conducted or are currently planned.

2.6 GEOPHYSICAL LOGGING

This section briefly describes the type of information obtained from different geophysical logs, as well as the combinations (suites) of logs that were run in the Phase III boreholes and wells. Further descriptions of methods, specifications, and quality controls are presented in the geophysical logging WP (Table 1.4-1). The contractor, Geophysical Logging Services of Prescott, Arizona, was responsible for conducting all downhole logging in accordance with industry standard procedures (ASTM D-5753-95 and API (1997).

2.6.1 Description of Borehole Geophysical Logs

Table 2.6-1 summarizes the types of logs, properties measured, and applications of the geophysical logs performed in the Phase III boreholes and wells. A number of these logs measure similar or related parameters and have similar applications. These logs are often run together in the same borehole to increase the level of confidence in trends identified in the logs. Individual logs are discussed in relation to major Phase III categories of use or application in the following section.

2.6.1.1 Lithology Identification and Correlation

Gamma, density, moisture, sonic, magnetic susceptibility, spectral gamma, spontaneous potential, fluid resistivity, formation-related resistivity (R8, R16, R32, R64, single point resistivity), and spontaneous potential logs can help identify and confirm formation contacts in areas where sample recovery is poor, lithologic units are similar or indistinct, or in bedded lithologic units that are thinner than the sample interval. For example, density, moisture, and sonic log outputs are related to formation/layer porosity. Gamma logs help identify clay layers and were useful in earlier EWDP boreholes in identifying anomalies associated with naturally occurring uranium deposits. Magnetic susceptibility logs indicate ferromagnetism of the rock and can help identify lithologic changes such as mafic volcanic flows within sedimentary deposits.

Spectral gamma logs can provide information about the amount and type of common radioactive materials (U, Th, and K) in formation layers. In addition, fluid resistivity, formation-related resistivity, and spontaneous potential log outputs may vary between formations and/or layers within a formation and can be used to identify and evaluate contacts between subsurface geologic units, thinly bedded sequences, and vertical facies changes in sedimentary sequences.

Caliper logs provide borehole diameter data that are necessary to interpret many of the logs. For example, log responses to wash-out zones (i.e., intervals of borehole with significantly larger diameters) can be separated from actual responses to changes in formation and/or borehole fluid parameters. In addition, changes in borehole diameter are often related to lithology changes, especially contacts between unconsolidated and consolidated materials.

It should also be noted that neither the density nor the moisture logging tools used in Phase III contain radioactive sources. However, a DOE YMP comparison of these tools with Schlumberger tools containing radioactive sources indicated that the outputs were comparable (Rael, 2003). Moreover, moisture logging tools used in this study responded to changes in formation moisture conditions in a manner similar to conventional neutron porosity logging tools. That is, counts per second decreased with increasing water-filled porosity.

2.6.1.2 Water Production Zone Identification

Many of these geophysical logs may provide information about water transmitting zones. For example, temperature logs may detect changes in subsurface temperature gradients at groundwater production zones (e.g., inflow from fractures). Fluid resistivity and formation resistivity logs may be able to identify salinity and total dissolved solid changes in water from different production zones. Formation resistivity logs can potentially also identify differences in groundwater chemistry at different distances outward from the borehole. Spontaneous potential logs in some cases can identify differences in borehole and formation fluid composition. Finally, formation porosity information, which may be related to aquifer production, can be obtained from density, moisture, and sonic logs.

2.6.1.3 Well Installation Support and Use

A number of logs also provide valuable information that can be used to design, verify, and utilize well installations. Caliper logs yield borehole diameter data, which are useful for the design and placement of well screens and sampling ports. Deviation logs provide information on the location of notable borehole deviations from the vertical (e.g., doglegs) that may complicate the completion process. Borehole deviation data are also necessary to provide accurate elevations of geologic contacts, screened intervals, and water table and piezometric surfaces. Following well installation, gamma, density logs, and (in some cases) sonic logs may also help confirm the location and integrity of bentonite seals and well-screen sand packs in completed wells.

2.6.2 Suites of Borehole Geophysical Logs

Table 2.6-2 summarizes the geophysical logging performed in Phase III boreholes and wells. In general, three suites of geophysical logging were performed. Open-hole geophysical logs were run in open, uncased boreholes where borehole stability was good and the drill pipe or casing could be removed for logging. In unstable boreholes, geophysical logs were run in drill pipe or drill casing (drill-string logs) in place of open-hole logging. After completion of the well casing strings with sand packs and seals, well-completion logs were run inside the well casing strings. Variations from this general protocol for logging are noted in Table 2.6-2 and reflect logger availability, borehole conditions, and technical priorities.

The drill-string geophysical logging suite generally includes temperature, gamma, density, moisture, deviation, and spectral gamma logs. These logs were run in the drill string of all exploratory RC boreholes upon reaching total depth and prior to their abandonment.

The open-hole geophysical log suite generally includes drill-string logs plus resistivity, fluid resistivity, spontaneous potential, caliper, magnetic susceptibility, and sonic logs. Temperature and fluid resistivity logs are typically run downhole in the first tool run to capture undisturbed temperature and salinity gradients in the water column. These open-hole logs were run in mud-filled FM monitor well holes (with the exception of NC-EWDP-19IM1), beneath the drill casing in CA boreholes -10P and -22PA, and in RC piezometer borehole -23P.

The well-completion suite generally includes temperature, natural gamma, density, deviation, and (in some cases) sonic logs. This suite of logs was run in all wells following completion with well casing and screen. Not all logs could be run to total depth in piezometer wells because of a combination of the small ID of their 2-in. Schedule 80 polyvinyl chloride (PVC) casing/screen (1.9 in.) and the deviations in this relatively flexible pipe.

3.0 WELL COMPLETION AND DEVELOPMENT

Well completion and development activities were performed by drilling contractors under oversight of the NWRPO. Work was conducted in accordance with the applicable QA drilling and well construction WP (Table 1.4-1) except where deviations from this WP were necessitated by field conditions and field findings. Well completion and development methods are described in the following sections.

3.1 WELL COMPLETION

Piezometers and monitoring wells were constructed in accordance with permit requirements and Nevada Administrative Code (NAC 534.60–534.90). Table 1.3-1 summarizes completion data for these wells, including casing sizes, screened and sand-packed intervals, and formation units adjacent to these intervals. Appendix B contains this same information (except formation units) in Phase III well completion diagrams. Table 3.1-1 contains reference point elevations (i.e., top of casing and ground surface) for water level measurements as well as preliminary water level measurements in piezometers and monitor wells. Depth data in Tables 1.3-1 and 3.1-1, and in Appendix B have not been corrected for borehole deviation.

3.1.1 Multiple-Screen Monitor Wells

Figure 3.1-1 presents a typical monitor well completion diagram. Beylik Drilling Company completed the multiple-screen monitoring wells under supervision of Nye County technical contractors and staff. Screen intervals were selected based on geologic logging, geophysical logging, and water production observations. The upper four screens in NC-EWDP-19IM1 and -19IM2 were completed in alluvial sediments and the lowest screen was completed in a weakly welded tuff. In NC-EWDP-22S, the upper three screens were completed in alluvium, and the lower screen was located in a bedrock unit logged as volcanic conglomerate. The lower screen in NC-EWDP-10S was also completed in this volcanic conglomerate, and a single screen was located in the overlying alluvium.

At NC-EWDP-22S and -10S, 6.625-in. OD, 0.28-in. wall thickness, A53 Grade B, 18.97-lb./ft, flush joint, steel casing was installed. The casing-based screen contains 0.5-in. diameter holes covered with 0.085-in. OD stainless wire wrap. The open area of perforated pipe is 42 in.^{2}/ft. At NC-EWDP-19IM1 and -19IM2, the casing consists of 7-in. OD, 0.317-in. wall thickness, J-55, 20.00-lb./ft, flush joint steel. The casing-based wire-wrap screen was constructed similarly to NC-EWDP-10S and -22S, and contains the same open area of perforated pipe: 42 in.^{2}/ft.

Depth control for the emplacement of sand packs, seals, and grout was carefully monitored by estimating downhole annular volumes, tracking volumes of emplaced materials, and frequently checking depths of emplaced materials by manual sounding methods. In all cases, these materials were emplaced with tremmie pipe methods. The bottom of the tremmie pipe was set approximately 10 to 30 ft above the level of completion materials to avoid plugging off the tremmie pipe.

Using tremmie pipe and centrifugal pump methods, 6/9-mesh silica sand was emplaced approximately 5 ft above and below screened intervals. In most cases, approximately 1.5 to 6 ft of transition 16-mesh silica sand was also emplaced via the tremmie pipe above and below the 6/9-mesh sand-pack intervals to help prevent bentonite from penetrating into the sand-pack zones. In NC-EWDP-19IM1 and -19IM2, an additional approximately 5-ft layer of 60-mesh silica sand was placed over the 16-mesh transition sand above the uppermost well screen to provide further protection against bentonite grout intrusion into the sand pack.

Grout seals consisting of a mixture of 10/16-mesh sand (8/12-mesh sand in NC-EWDP-22S) and BENSEAL® or equivalent (granular 8-mesh bentonite) at a ratio of approximately 2:1 by weight ("Bensand") were also emplaced using a tremmie pipe and centrifugal pump. Pumped water was used to carry both sand pack and Bensand completion materials through the tremmie. Generally, water was initially pumped through the tremmie at a rate of approximately 100 to 200 gpm, followed by the addition of dry completion materials to the water stream via an open Tee connection on the water-intake of the centrifugal pump.

Completion materials were generally emplaced in lifts approximately 5 ft thick, decreasing in thickness as target depths were approached. The final lift of grout sealant extending up to the ground surface was emplaced as a slurry that was pumped with a diaphragm (positive-displacement) pump.

Well-head protection features include the cement grout seal, concrete pad, and locking well cap. Details are presented in Appendix B. Each well head is labeled with the well name in the cement pad. The wells were surveyed by a DOE contractor under YMP QA standards to provide location and elevation data presented in Tables 1.3-1 and 3.1-1.

Westbay® packer and instrument monitoring systems (MP55 systems with PVC casings) were installed inside the 6.625-in. OD steel casing at NC-EWDP-10S and -22S, and inside the 7-in. OD steel casing at -19IM1. PVC was selected for chemical resistance. Inflatable packers were used to isolate discrete well-screen intervals. Within the isolated intervals, measurement ports were installed for in situ temperature/pressure sensors, and sampling ports were installed for purging, sampling, and aquifer testing. Appendix C contains the diagrams of the three Phase III Westbay® installations. Separate reports on Westbay® installation operations are available in the NWRPO QARC.

The Westbay® system is designed for monitoring of pressure and temperature, groundwater sampling, and pumping and injection of water (aquifer testing) at discrete well-screen intervals. Mosdax® pressure probes record temperature and pressure and transmit the data by cables to the data logger at the ground surface. The probes can be removed for recalibration and repair. After removal of the probes, sampling ports at discrete intervals can be accessed for the activities described above.

3.1.2 Piezometers

THF Drilling completed piezometers NC-EWDP-10P, -18P, and -22PA, and Eklund Drilling completed piezometers NC-EWDP-22PB and -23P. Figure 3.1-2 presents a typical piezometer completion. The piezometer casing strings are 2-in. Schedule 80 flush joint PVC (1.9-in. ID, 2.375 in. OD). The piezometer screens consist of the same flush joint 2-in. PVC casing with machined 0.020-in. horizontal slots. Slot configurations varied with open areas ranging from 7.0 to 9.5 in.^{2}/ft.

NC-EWDP-18P was completed as a single "deep" piezometer, screened from 835.8 to 895 ft bgs in Tertiary tuffs. Caving of the borehole precluded installation of a planned shallower piezometer string at this location. All other piezometers were completed as dual piezometer nests.

NC-EWDP-10P has two (dual) piezometer strings, one screened from 660.1 to 699.3 ft bgs in alluvium and the other at 801.2 to 860.0 ft bgs in a Tertiary volcanic conglomerate. NC-EWDP-22PA has both strings screened in alluvium, one at 520.7 to 579.7 ft bgs and the other at 661.5 to 759.8 ft bgs.

NC-EWDP-22PB and -23P were both completed as dual string piezometers. The screens at NC-EWDP-22PB are at 881.3 to 979.7 ft bgs in alluvium, and at 1,140.3 to 1,179.7 ft bgs in Tertiary volcanic conglomerate. The screens at NC-EWDP-23P are at 460.9 to 519.9 ft bgs and 650.5 to 689.8 ft bgs in alluvium.

NC-EWDP-10P and -22PA were also instrumented with unsaturated zone air piezometers. Each air piezometer consists of a 2-ft length of 1-in. ID slotted acrylonitrile butadiene styrene (ABS) tubing screen with glued end caps and a pair of 0.25-in. polyethylene tubes extending from the piezometer screen to the ground surface. The downhole ends of the 0.25-in. polyethylene tubing were inserted through holes drilled in one end cap and cemented in place with epoxy. The ABS screens and 0.25-in. polyethylene tubes were strapped at intervals to the 2-in. Schedule 80 piezometer casing strings with plastic cable ties for support and to prevent kinking. At the ground surface, the ends of each air piezometer polyethylene tubing pair were labeled with duct tape and a marker. They were then coiled and secured within the surface completion casing. In the future, tests will be performed to estimate the air permeability of alluvial sediments in the intervals between air piezometer screens.

At NC-EWDP-10P, the unsaturated zone air piezometers are centered at approximately 149.7, 249.6, 349.6, 499.6, and 549.6 ft bgs in alluvium. At NC-EWDP-22P, the air piezometers are centered at approximately 50.4, 150.3, 250.3, 350.3, and 451.1 ft bgs in alluvium.

Depth control for piezometer construction was similar to that described for multiple-screen monitor wells. The main difference was that at the boreholes drilled by CA methods, the casing was pulled back in 10- to 30-ft intervals to minimize the potential for the borehole to cave onto the well string. Following this pull-back, the bottom of the well was re-sounded to determine if there had been any caving of the borehole. Completion materials were then emplaced in the pull-back interval up to approximately 5 ft from the bottom of the casing.

Sand packs around slotted 2-in. Schedule 80 PVC piezometer screens consisted of washed 8/12-mesh sand tremmied to a depth within 1 to 2 ft of the specified target depth for the well design. Target depths were generally 5 to 10 ft above and below well screens. In NC-EWDP-18P, a 2- to 4-ft-thick interval of finer, 60-mesh transition sand pack was tremmied in place above the 8/12-mesh sand packs to help prevent bentonite infiltration into the coarser sand pack around the well screen.

Grout seal intervals in the piezometers were completed in a similar manner to those intervals in the monitoring wells. Within the saturated zone of all piezometers except NC-EWDP-18P, grout seals consisted of Bensand. Both the sand pack and Bensand seals were tremmied to the target depths using a centrifugal pump in a manner similar to that for multiple-screen monitoring wells. The only difference was that water was pumped through a smaller diameter tremmie pipe at a much slower rate (25 to 50 gpm).

At NC-EWDP-18P, the saturated zone annular grout seal consists of 0.25-in. time-release bentonite pellets emplaced by gravity feed through a tremmie pipe. Above the water table, the grout seal consists of 0.375-in. bentonite chips emplaced in a similar manner. The chips were hydrated by adding water from the surface down the annular space.

The type of grout seals above the water table in the remaining piezometers differed depending on whether air piezometers were installed. For completions without air piezometers (NC-EWDP-22PB and -23P), high solids bentonite grout was mixed at the ground surface and pumped down the tremmie line using positive displacement pumps. For the wells with air piezometers (NC-EWDP-10P and -22PA), the grout seals consisted of Bensand that was tremmied dry to the desired depth by gravity feed. The dry Bensand was then hydrated in the annular space by conducting water down the retreating drive casings. Care was taken not to over-hydrate the grout seals directly below and above the air piezometers. The 8/12-mesh sand pack for the air piezometers was emplaced by tremmie line and gravity feed.

Sand packs for air piezometers were designed to be approximately 5 ft thick, extending approximately 1.5 ft above and below the 2-ft-long piezometers. However, some difficulties were encountered with the deeper sand packs, whereby thicker sand packs were installed. Another difficulty encountered was that in several cases water, used in installation of saturated zone well screen sand packs and Bensand grout plugs, flooded the unsaturated annular space around deeper air piezometers. This excess moisture will be allowed to dissipate (i.e., drain and redistribute) before conducting any air-permeability-related tests with the air piezometers.

To protect the piezometer nest well heads, steel surface casing was set to depths ranging from 4.8 to 16.9 ft bgs with about 2 ft of stick-up. The annular space between the outer surface casing and the piezometers was sealed with bentonite grout or hydrated bentonite chips, and at NC-EWDP-18P with Portland neat cement grout. For further protection, an approximately 4-ft by 4-ft by about 0.5-ft-thick concrete pad was set around the surface casing. Well-head completions varied slightly between piezometer sites (see as-built details in Appendix B). All surface casings are capped with locking well caps.

3.2 WELL DEVELOPMENT

3.2.1 Multiple-Screen Monitor Wells

Two swabbing approaches were used by Beylik Drilling Company to develop each monitor well. First, development was conducted using a low-flow air-lift tool (similar to that used in FM drilling) with a swab at the bottom; second, swabbing and pumping was carried out using a Grundfos® 5HP pump suspended between two swabs. In both approaches the swab system was moved up and down across well screens while removing water. The rate of air-lifting water varied from 0.5 to 4 gpm, and the water pumping rate ranged from 5 to 35 gpm.

Well development methods varied somewhat between wells based on site-specific conditions, equipment availability, and field decisions. Work at the two wells located at the ATC site illustrates some of the development method variations. Before starting development, the water level and depth of sediment deposited were sounded in each well. At NC-EWDP-19IM2, after bailing 10 times to agitate and lift bottom sediments, the well screens were developed by moving the single swab system up and down in 20-ft strokes and simultaneously air lifting from a point above the swab. When this approach appeared to not clear the well up any further, the well was swabbed with the double swab and pump system in approximately 30-ft strokes on each screen from top to bottom until the water produced was clear. At NC-EWDP-19IM1, the well was not bailed initially. The well was air lifted with a single swab, and then swabbed and pumped similarly to NC-EWDP-19IM2.

In Phase III, development using swabbing methods continued in most cases until the water was free of suspended matter (i.e., clear), as subjectively determined by the NWRPO. In at least one case (NC-EWDP-10S), development was terminated due to budget constraints before acceptable clarity was achieved. This well was later further developed by air-lifting methods by Great Basin Drilling Company of Pahrump, Nevada. After this initial development, the wells were pump tested for 48 hr., which provided further development of the wells.

Nye County has found these monitor well development methods to be effective and adequate. Agitation and removal through bailing appears to be appropriate and effective at sites with significant initial sediment at the well bottom. The method involving air lifting and a single swab was insufficient at some wells. The double swab and pumping approach was more effective.

3.2.2 Piezometers

Piezometers drilled with CA and RC methods primarily used air as the drilling fluid in the saturated zone. As a result, these wells do not contain drilling fluids in the saturated zone that could impact well screen permeability and/or water chemistry measurements. The only exception is piezometer NC-EWDP-23P, where significant quantities of bentonite drilling fluids were used in the saturated zone during drilling and while attempting to remove the BHA that became stuck. Following the completion of dual piezometers in this well, a significant amount of suspended bentonite was observed in the lower piezometer screen.

Limited air-lifting development was then conducted in the lower piezometer screen by Great Basin Drilling Company over a period of approximately 3.3 hr. During this development, care was taken not to lower the water level to a point where head differences between the inside and outside of the 2-in. Schedule 80 PVC casing could cause the casing to collapse.

Following this air-lifting development, suspended bentonite was observed in both piezometer screens. This remaining suspended bentonite was removed by pumping the upper screen for approximately 32.5 hr. and the lower screen for approximately 9.5 hr. with a small piston sample pump at approximately 0.5 gpm.

4.0 RESULTS OF DATA COLLECTION AND ANALYSIS ACTIVITIES

The results of numerous field and laboratory data collection activities, as well as limited data analyses, are presented and discussed in this section. These activities include borehole geologic and geophysical logging, laboratory testing, and the development of summary lithologic logs. The vast majority of data produced from these activities are technically defensible and of value to the scientific and engineering communities concerned with Yucca Mountain. However, as in nearly all large hydrogeologic characterization efforts similar to Phase III, some collected data are unintentionally compromised or biased as a result of sampling, testing, and/or handling activities and therefore are not useful or are, at a minimum, potentially confusing to users. To the extent possible, these data have been censored and are identified and listed in Table 4.0-1.

Nye County has censored these data to avoid potential misuse. That is, these data will not be published by Nye County, or posted on the Nye County website. The only exception will be herein, where examples of censored data will be presented in several summary tables and figures that have been designed to illustrate the limitations of these data and the methods used to collect them. Censored data can be viewed in their entirety at the NWRPO QARC in Pahrump, Nevada.

Specific reasons for censoring different data types are listed in the footnotes to Table 4.0-1 and in the following sections. It is important to note that the censored data are only a relatively small subset of the uncensored data, and that the uncensored data are the primary focus of this section.

4.1 GEOLOGIC LOGGING RESULTS

Illustrative examples of geologic logging data and a discussion of their limitations, trends, correlations, and significance are presented in this section. This includes, where appropriate, a discussion of the possible bias that different drilling methods and sample handling procedures can introduce into geologic logging data and, therefore, the ability of these data to accurately characterize in situ formation conditions and properties.

4.1.1 Introduction to Geologic Logging and Drilling Data

Geologic logging field descriptions of alluvium and non-alluvium drill cuttings samples were recorded on field forms. Examples of these forms from exploratory RC borehole NC-EWDP-22SA are shown in Tables 4.1-1 and 4.1-2, for alluvium and non-alluvium samples, respectively. The alluvium logging form primarily includes soil classification parameters, many of which are related to flow and transport properties of alluvial sediments. The non-alluvium form contains mainly lithology-related parameters to support identification of lithostratigraphic units. In addition, both forms include sample density measurements and several drilling-and-coring-related measurements, including rates of drilling, coring, and water production.

All geologic logging and drilling parameter data on the logging forms are considered to be useful in helping to characterize in situ hydrogeologic conditions and properties in an approximate manner, with several exceptions. These exceptions include alluvium PSD estimates of percent gravel, sand, silt, and clay; the related Unified Soil Classification System (USCS) group symbol data; sample density and sample recovery data for drill cuttings; and water production rates. The field PSD data significantly underestimate percent fines content (silt plus clay) and overestimate percent sand compared to laboratory PSD measurements in nearly all Phase III boreholes, where laboratory data are considered to accurately represent drill cuttings PSDs. Estimated percent gravel is generally more reasonable for reasons described in Section 2.4. The underestimation of fines is clearly shown in Table 4.1-3, which includes summary statistics for both field-estimated and laboratory-measured percent fines in exploratory RC boreholes. An example of this underestimation for exploratory RC borehole NC-EWDP-22SA is presented in Figure 4.1-1. The area to the left of the "percent passing No. 200 sieve" curves represents the fines content in this plot. Since the USCS group symbol data are based on PSD data, they are also considered to be in error.

Because the field PSD estimates of fines, sand, and related USCS group symbols contain significant errors, these data have been censored and will not be discussed further in this report. Discussion of PSD data from drill cuttings in this report will be limited to laboratory-measured values (Section 4.3.1).

Drill cuttings sample density data have also been censored because a significant and variably sized portion of the total drill cuttings sample from each sample interval was not collected and weighed. This portion of drill cuttings was removed from the borehole during hole cleaning operations, which occurred after each 10- or 20-ft interval of drilling was completed. Not having an accurate total weight of the drill cuttings removed from a particular drilled interval precluded calculation of meaningful in situ densities in cases where accurate water contents and borehole volumes were known. The TP that governs the collection and weighing of drill cuttings (Table 1.4-1) has been modified to include collecting drill cuttings during hole cleaning operations to avoid these problems in future EWDP phases of work.

Water production rates were estimated rather than measured throughout exploratory borehole NC-EWDP-19IM1A and in the non-alluvium sections of several other boreholes. In addition, a significant amount of air-lift water produced during water production rate measurements was likely lost to the thick, uncased unsaturated zone exposed in NC-EWDP-18P. Finally, sample recovery data for drill cuttings were not consistently adjusted for sample splitting when water production was greater than zero. For these reasons, the affected water production and sample recovery data were censored, as listed in Table 4.0-1.

4.1.2 Trends in Geologic Logging and Drilling Parameters

Depth profiles of selected geologic logging and drilling parameters illustrate important trends with depth are shown in Appendix D for all Phase III boreholes. Examples of these depth profiles and their use and significance are presented in the following sections. Geologic logging parameter data presented include field estimates of moisture content, HCl reaction, and cementation in every drill cuttings sample interval of alluvium and HCl reaction in every sample of non-alluvium. Drilling parameter data presented are limited to measured drilling and water production rates.

The criteria used to describe geologic logging parameters are qualitative or semi-quantitative at best, and are subject to human error and inconsistency in judgment. Therefore, trends in these parameters must be considered approximations and simplifications of in situ conditions. At the same time, geologic descriptions are useful for identifying drilling impacts and relative changes in hydrogeologic parameters with depth for both drill cuttings and the formation rock.

Drilling parameters are actual measurements. However, it should be noted that these measurements are in some cases approximate quantities. For example, water volumes are calculated from the number of nearly or partially full 5-gal. buckets containing varying amounts of drill cuttings sediment.

4.1.2.1 Moisture Content Depth Profiles

The moisture contents of alluvial drill cuttings collected from Phase III exploratory and piezometer boreholes were disturbed from in situ conditions to varying degrees by drilling. Moisture content information proved to be useful in determining location depths for air piezometers in the unsaturated sediments during well completion activities at NC-EWDP-10P and -22PA. Air piezometers were located outside zones of high water content, when possible.

Some examples of drilling-induced disturbance caused by using water or water-based drilling fluids are illustrated for exploratory borehole NC-EWDP-10SA and CA piezometer borehole -10P in Figure 4.1-2. For example, the peak of increased moisture in the upper 20 ft of NC-EWDP-10SA is a result of injecting water with air when drilling the upper 20 ft of all exploratory boreholes. A similar peak was not observed in NC-EWDP-10P, where only air was used to drill the CA borehole. Moreover, the increase in moisture content between approximately 250 and 450 ft bgs in NC-EWDP-10P is likely due to lost circulation water that moved laterally from nearby FM borehole -10S. In NC-EWDP-10SA, which was drilled before the FM borehole, this same interval was dry.

Similar evidence of lateral movement of lost circulation water from FM borehole NC-EWDP-22S is seen in Figure 4.1-3. This figure shows an increase in moisture content above the water table in CA piezometer borehole NC-EWDP-22PA compared to -22SA. Elevated moisture contents were also observed above the water table in piezometer RC borehole NC-EWDP-22PB. Both piezometer boreholes exhibiting elevated moisture contents above the water table were drilled after the FM boreholes. Exploratory borehole NC-EWDP-22SA, which did not exhibit these elevated moisture contents, was drilled prior to the FM borehole.

Both of these figures show the drying effects of air-drilling due to heat generated at the drill bit, the elevated temperature of the compressed air, and air movement around the drill cuttings as they are brought to the ground surface from immediately below the water table. Drill cuttings in these boreholes show evidence of drying approximately 50 to 80 ft below the water table. Drill cuttings throughout the unsaturated zone are also dried to some extent by air drilling; however, the very general criteria used to describe moisture (dry, moist, wet) do not permit estimation of this drying. The extent of this drying is discussed in relation to core data in Section 4.3.

4.1.2.2 Cementation and HCl Reaction Depth Profiles

Weak to moderate zones of cementation were generally observed in the upper approximately 50 to 150 ft of alluvium in boreholes located within Fortymile Wash. Few if any zones of cementation (weak) were observed in alluvium below the water table in boreholes NC-EWDP-10P, -10SA, -19IM1A, and -19IM2A. However, weak to strong cementation was observed in alluvium below the water table in boreholes NC-EWDP-22SA, -22PA, -22PB, and -23P. This observation may in part be due to the much thicker section of alluvium present at Sites NC-EWDP-22 and -23 compared to Sites NC-EWDP-10 and -19. Examples of these trends in cementation with depth are shown on Figure 4.1-4.

Trends in cementation are nearly mimicked by trends in HCl reaction. This is illustrated by comparing cementation data in Figure 4.1-4 with HCl reaction data for the same boreholes in Figure 4.1-5. This correlation between cementation and HCl reaction is in part due to the difficulty in identifying cementation in drill cuttings by visual examination and the fact that HCl reaction was used in many cases as an indication of cementation in this study. Regardless, HCl reaction indicates the presence of calcium carbonate, which is often an important cementing agent in alluvial sediments in arid climates.

Figure 4.1-5 also shows that the strong HCl reaction observed in saturated alluvium at Site NC-EWDP-22 also extends into the non-alluvium (volcanic conglomerate) penetrated at this site from 1,110 to 1,200 ft bgs. In contrast, HCl reaction was not observed in non-alluvium (weakly-welded ash-flow tuff) penetrated in either RC exploratory borehole at Site NC-EWDP-19 from approximately 820 to 900 ft bgs. In addition, HCl reaction plots in Appendix D show that HCl reaction is not present in volcanic conglomerate penetrated between 790 and 1,200 ft bgs in NC-EWDP-10SA and -10P.

4.1.2.3 Drilling Rates and Water Production Depth Profiles

Drilling rates in unsaturated alluvium were generally highest in exploratory RC boreholes, followed by CA piezometer boreholes (including open-hole conventional-circulation rotary-drilled portions), followed by RC piezometer boreholes (Table 4.1-4). Examples of these trends in drilling rates are presented in Figure 4.1-6, which compares drilling rates in exploratory RC and CA piezometer boreholes at Site NC-EWDP-10, and in Figure 4.1-7, which compares rates in RC and CA piezometer boreholes at Site NC-EWDP-22.

Drilling rates were as high as 5 ft/min. in portions of 5.375-in. diameter exploratory RC boreholes and as low as 0.1 ft/min. near the deepest depth of advancement of the 9.625-in. diameter Stradex system in CA piezometer boreholes NC-EWDP-10P and -22PA. The generally high rates achieved in exploratory RC boreholes are likely due to a combination of favorable design and operating factors, many of which were listed in Section 2.1.1.1 as necessary to produce representative drill cuttings. The very slow rates in CA boreholes were mainly due to increased friction resistance and increased problems with circulation as the 9.625-in. diameter Stradex drive casing was advanced to maximum depths achievable between approximately 300 and 350 ft bgs.

Figure 4.1-7 shows that average drilling rates above the water table were even lower in RC piezometer borehole NC-EWDP-22PB than those measured in CA piezometer -22PA. Reasons for this are unknown, but may in part be related to precautions taken by the RC driller to avoid caving in NC-EWDP-22PB, where a relatively large 8.5-in. OD drill bit was used with a relatively small-diameter (4.5-in. OD) dual-wall drill pipe.

The higher drilling rates observed in all boreholes in saturated alluvium (Table 4.1-4) are in part related to the addition of water from the formation to the compressed air drilling fluid and the subsequent improvement in hole cleaning capabilities.

The rate of water production in boreholes drilled using compressed air as the drilling fluid is a complicated function of a number of formation-and-drilling-related parameters, including the variation in formation permeability with depth, depth below the water table, rate of drill bit advancement, drill bit diameter, air pressures and flow velocities, borehole conditioners and methods of conditioning, and the extent to which the drill bit and casing assembly seals off water from the overlying formation. The evaluation of water production data from Phase III boreholes is further complicated by the fact that two different methods were used to measure production rates. In all boreholes water production rates were measured at one or more depths in both alluvium and non-alluvium by determining flow volume per unit time at the end of widely spaced drill runs. In these cases, the drill string was raised several feet off the bottom of the borehole and air was injected for several minutes to lift water from the borehole. In NC-EWDP-10P, a total of seven air-lift measurements were made in saturated alluvium and non-alluvium at depth intervals ranging from 27.5 to 60 ft. These measurements provided a reasonable basis for estimating water production at 5-ft intervals between the widely spaced air-lift depths. Water production data in NC-EWDP-10P using this approach of air-lift measurements supplemented with estimates are illustrated in Figure 4.1-8.

In boreholes NC-EWDP-10SA, -19IM2A, -22SA, -22PA, -22PB, and -23P, water production rates in alluvium (and in some cases in non-alluvium) were determined from the volume of water collected in 5-gal. buckets during drilling each 2.5- and 5-ft depth interval. This 5-gal. bucket method of determining water production had the potential to capture at least some of the variation in flow rates between major coarse- and fine-grained alluvial layers. Figure 4.1-8 illustrates this variation in saturated alluvium and a portion of saturated non-alluvium (volcanic conglomerate) in borehole NC-EWDP-10SA. In contrast, the limited number of air-lift measurements, even when supplemented by field estimates as in NC-EWDP-10P (Figure 4.1-8), failed to capture much of this variation.

Figure 4.1-8 also shows that water production rates determined by different methods both generally increase with depth. However, production rates are considerably higher in NC-EWDP-10P compared to -10SA. This difference in water production rates is likely in part due to the larger borehole diameter in NC-EWDP-10P compared to -10SA (Section 2.1.3). In addition, the different water production measurement methods likely contributed to the observed differences in water production rates. In the 5-gal. bucket measurement method used in RC borehole NC-EWDP-10SA during drilling, the drill bit was in direct contact with the bottom of the borehole, thereby restricting water inflow from the formation into the center of the drill bit. In the air-lift method used in CA borehole NC-EWDP-10P, the drill bit was pulled back from the bottom of the borehole, allowing water to flow freely into the drill string from an exposed formation interval (i.e., between the bottom of the borehole and drive casing).

Comparison of water production rates in NC-EWDP-22PB and -23P (Figure 4.1-9) with drilling rates in the same boreholes (Table 4.1-1 and Figure 4.1-10) suggests that other factors affect water production rates in addition to drilling rates. For example, water production is generally higher in NC-EWDP-23P compared to -22PB in saturated alluvium down to 1,120 ft bgs

(Figure 4.1-9), while average drilling rates are approximately equal in both boreholes over the same intervals (Table 4.1-4). In addition, water production rates generally increase with depth in both NC-EWDP-22PB and -23P (Figure 4.1-9), while drilling rates remain relatively constant with depth (Figure 4.1-10). Finally, Figures 4.1-9 and 4.1-10 indicate most peaks in water production rates appear to correlate with low drilling rates in NC-EWDP-22PB but with high drilling rates in -23P.

4.2 FIELD AND LABORATORY CORE TESTING RESULTS

If collected using appropriate equipment and procedures, drive-core samples of alluvium can provide geologic samples of subsurface formation materials that are much less disturbed from in situ conditions than drill cuttings. For example, laboratory measurements of PSD on approximately 4-in.-diameter core samples collected in this study provide a reasonably representative picture of in situ PSDs of gravel and smaller size fractions over the cored interval. Moreover, if it is assumed that the coring process does not significantly disturb the layering and arrangement of alluvial particles, other hydrologic-related core properties that can be measured in the laboratory such as porosity, bulk density, and saturated hydraulic conductivity, may provide insight into in situ conditions.

Because core samples are generally more representative of in situ conditions than drill cuttings, they can be used as a standard by which to estimate the disturbing effects of drilling on drill cuttings. Thus, conducting the same laboratory measurements on core samples and drill cuttings (i.e., PSDs and gravimetric water content) from the same depth interval provides a means to gauge the disturbing effects of drilling on drill cuttings. Core recovery and laboratory test results are presented in the following sections. Comparison of core test results with drill cuttings test results are presented in Section 4.3.

4.2.1 Core Barrel Recoveries and Bulk Densities

Drive-core run intervals and recoveries for Phase III are summarized in Table 4.2-1. Three core runs each in unsaturated and saturated sediments were successfully completed in NC-EWDP-10P. In NC-EWDP-22PA, one core run was completed in unsaturated sediments and six in saturated sediments. Core depth intervals in the saturated zone in both NC-EWDP-10P and -22PA were located within screened intervals in nearby previously completed large-diameter monitor wells -10S and -22S, respectively. Errors in recording core recovery lengths from three core runs were identified while verifying the data in Table 4.2-1. For this reason, these data were censored and not included in Table 4.2-1.

In addition, it is possible that the core recovery lengths for the remaining core runs also err on the low side. Evidence supporting this hypothesis is found in the unreasonably high dry bulk densities of the total core recovered in each core run as calculated from field weights of the empty and full core barrels, field measurements of core recovery, and laboratory measurements of average volumetric water content. These total core-run bulk densities were significantly higher (10 to 20%) than laboratory measurements (Section 4.2.3) made on 3-in.- and 6-in.-long core segments. As a result, the former bulk density data have been censored.

Of all the input parameters into the total core-run bulk density calculation, field measurements of length of core recovery are most likely in error. Moreover, if these measurements are in error, it is also likely that the "total cut" lengths in Table 4.2-1 are also in error, since the percent recovery data appear reasonable. For these reasons, both total recovery and total cut lengths have been identified as possibly being in error in Table 4.2-1. They have not been censored because evidence from the total core-run bulk density data is not conclusive. That is, it is possible (although less likely) that errors in the measurement of other parameters such as the full and empty core barrel weights may be responsible for the unreasonably high total core-run bulk densities.

Coring procedures will be revised to avoid future potential errors with core length recovery measurements and related handling and laboratory testing problems resulting from samples being too loosely packed in core barrels (see Section 2.5). This revision involves driving the core barrel a distance that is slightly farther than the total length of the core barrel plus drive shoe. It is unlikely that the bulk densities obtained by coring in this revised manner will equal or exceed the in situ formation bulk densities. Regardless of the disturbance from in situ bulk densities, overdriving will eliminate coring-related preferential flow paths and coring-induced excess porosity; as a result, laboratory tests of flow-related parameters (e.g., saturated hydraulic conductivity) will provide more realistic results and approximate in situ conditions more closely.

This limited coring program was designed to demonstrate the feasibility of collecting core samples from alluvium along potential flow paths south of Yucca Mountain. The apparent good core recoveries shown in Table 4.2-1 and the reasonable uncensored results obtained from laboratory testing of core samples (Section 4.2.3) indicate that this demonstration was successful. In fact, this demonstration provided the first-ever alluvium core samples from Fortymile Wash alluvial sediments downgradient from Yucca Mountain.

4.2.2 Geologic Logging Descriptions of Core Samples

Geologic logging descriptions were made using the alluvium core logging form (Table 4.1-1) on core segments sent to the laboratory for testing. This logging was conducted on the gravel fraction following PSD testing for core samples included in the first phase of laboratory testing. In a second phase of core testing, geologic logging descriptions were made on the entire sample (i.e., all size fractions) prior to laboratory PSD testing. The results of this second phase of logging for selected core segments from NC-EWDP-10P and -22PA are presented in Appendix E.

One of the primary purposes of this logging was to identify the presence of different rock and mineral components in different coarse-grained size fractions that could be easily ground into smaller size fractions (e.g., medium and fine sand, silt, and clay) by the drilling process. Table 4.2-2 summarizes the relative percentage of major rock and mineral components in gravel and various sand fractions. The data in this table indicate that relatively soft non-welded tuffs are present in significant percentages in all of the coarse fractions examined. The significance of this finding in relation to the representativeness of PSDs of drill cuttings samples is discussed in Section 4.3.1.1.

In addition, the logging of these core segments provided more direct information on cementation. Clasts from NC-EWDP-22PA showed evidence of strong cementation, and those from -10P showed only slight cementation.

4.2.3 Laboratory Measurement Results on Core Segments

Table 4.2-3 summarizes results from two phases of laboratory testing on selected 6-in.- and/or 3-in.-long core segments. As described in Section 2.5, a number of the 6-in.-long core samples from NC-EWDP-10P used in the initial phase of testing were loosely packed in their liners, contained preferential flow paths, and exhibited densities that were likely much lower and porosities that were likely much higher than in situ values. As a consequence, porosity-related test data from the initial testing of these core samples, including dry bulk density, volumetric water content, and saturated hydraulic conductivity, are also considered significantly disturbed and have been censored, as shown in Table 4.2-3. Subsequently, to replace these censored data and to increase the sample population of testing results, additional NWRPO 6-in.- and 3-in.-long core samples were transported from the SMF to the Nye County hydraulic property testing laboratory. As described in Section 2.5, these samples were compacted prior to testing to minimize coring-induced porosity disturbance.

4.2.3.1 Dry Bulk Density, Porosity, and Volumetric Water Content Results

A comparison of uncensored dry bulk densities of cores from the initial core testing program with dry bulk densities of adjacently located core samples from the second phase of testing (i.e., compacted samples) in Table 4.2-3 indicates that in the majority of cases the former dry bulk densities are noticeably lower than the latter ones. A similar comparison of calculated porosity data determined from dry bulk density and grain density data generally shows higher porosities generated in the initial core testing program. These trends may indicate that the uncensored dry bulk density data (and therefore porosity data) from the initial phase of testing also may be disturbed from in situ conditions, but not to the extent of those samples that have been previously censored in Table 4.2-3.

In addition, the lower bulk densities noted in the lower portion of NC-EWDP-10P compared to -22PA are probably related to differences in mineralogy. Table 4.2-2 shows that the percentage of higher-porosity non-welded tuffs increases significantly with depth in NC-EWDP-10P, particularly in the coarser size fractions. This trend in mineral composition is not observed in NC-EWDP-22PA, where low-porosity welded tuffs predominate in the coarse size fractions.

Table 4.2-3 also shows that initial volumetric water content data from saturated zone core samples are generally lower in value than saturated volumetric water contents measured immediately after saturated hydraulic conductivity tests. It is likely that water was lost (i.e., drained) from these samples as they were brought to the ground surface and in several cases when core barrel samples were stored (in plastic bags) one or more days on the ground surface before the individual core segments were split from the core barrel, labeled, capped, and sealed. Finally, saturated volumetric water contents are in all cases larger than calculated porosity data. This finding is commonly observed when laboratory tests are conducted on unconfined samples. Some expansion (i.e., volume increase) of samples is possible during testing, and it is very difficult to wipe excess free water from core samples prior to determining the weight of saturated core samples.

4.2.3.2 Saturated Hydraulic Conductivity Results

Supporting evidence for coring-related disturbance of porosity and bulk density is found in a comparison of hydraulic conductivity data generated from the initial testing effort with subsequently generated hydraulic conductivity data in Table 4.2-3. In all cases hydraulic conductivity values measured in the former testing program are larger in magnitude (usually by more than an order of magnitude) than in the latter testing program. This may indicate that preferential flow paths exist in the former and not in the latter. Since preferential flow paths are not expected in well-graded relatively coarse-grained alluvial sediments under hundreds of feet of overburden, they are therefore likely a result of the disturbance of sample porosity during the drive-coring process.

It should also be noted that the significantly higher hydraulic conductivities measured on core samples in the initial phase of testing may in part be due to the generally lower fines content in these samples. In general, when both phases of testing are considered together, saturated hydraulic conductivity data in Table 4.2-3 appear generally to decrease with increasing percentage of fines. Figure 4.2-1 illustrates this trend and suggests a linear correlation between the logarithm of saturated hydraulic conductivity and percentage of fines. This figure contains all data pairs except those containing the two lowest hydraulic conductivity values and one containing the highest percent fines. Similar trends of decreasing hydraulic conductivity with increasing percent fines have been found in numerous other studies in a variety of sediments (Todd, 1980).

It is interesting to note that the core samples exhibiting the lowest saturated hydraulic conductivity values in both boreholes also exhibit the highest bulk densities and by definition the lowest porosities. These core samples also contain the smallest amount of fines of all cores tested in each borehole. If these data are included in Figure 4.2-1, the coefficient of determination (R^2) decreases significantly, to a value of 0.05. Clearly, fines are not creating all of the resistance to flow in these core samples. Instead, laboratory notes and PSD data show that these core samples contain a number of large-size gravel clasts, along with well-graded smaller gravel and sand clasts. It is likely that flow in the relatively small, approximately 3.9-in. ID core liners is impeded to some extent by these larger gravel clasts. In addition, it is possible that the grading in smaller gravel and sand clasts facilitates the close packing of clasts around the larger gravels, thereby reducing porosity and increasing resistance to flow.

Table 4.2-4 also shows that there is a significant difference between the arithmetic and geometric means of the saturated hydraulic conductivity values of core samples collected below the water table. If saturated hydraulic conductivity values were normally distributed, the geometric and arithmetic mean values would be approximately equal (Davis, 1986). The fact that the arithmetic and geometric means are significantly different suggests that saturated hydraulic conductivity values are log-normally distributed.

Table 4.2-4 also shows that the means of the small-scale core test results in NC-EWDP-10P and -22PA are significantly lower than average values obtained from large-scale aquifer test results in screened intervals in nearby wells -10S and -22S, respectively (NWRPO, 2002a, 2002b). This finding is consistent with the findings of other workers who have compared hydraulic conductivity values made on different size samples (i.e., different measurement scales) (Schulze-Makuch et al., 1999).

4.2.3.3 Particle Size Distribution Results

PSD data in both phases of testing in Table 4.2-3 indicate a general trend of increasing fines with depth in NC-EWDP-10P but not in -22PA. Moreover, gravel contents are nearly constant with depth, and in most cases are nearly as high as sand contents. These PSD trends with depth in general differ from those observed for drill cuttings (Section 4.3).

One of the most remarkable findings from both phases of laboratory testing is the very large difference in PSD data obtained from core samples collected from the same core run, and in all cases separated by 6 in. or less. In many cases, the fines content in adjacent core segments may differ by more than a factor of two, and the gravel content may differ by a factor of nearly two. This finding has important implications for laboratory testing of flow and transport parameters. Clearly, a number of core segments must be tested from each core run to give a realistic picture of the variability in parameters measured over a 2.0- to 2.5-ft depth interval. On the relatively small scale of a core run, fluvial sedimentary processes clearly create a highly layered flow system with contrasting properties. Nye County single- and cross-hole tracer tests and associated hydraulic testing planned to begin by mid-2003 will be useful in characterizing the alluvial flow system on a much larger scale. Once these data are collected, additional evaluations will be done to determine if the use of "lumped" parameter values for modeling thick sequences of these highly variable alluvial sequences is appropriate, or if the more coarse-grained and well-sorted sequences represent fast pathways for groundwater flow that should be accounted for in the modeling.

In summary, despite the seemingly consistent and logical trends in laboratory testing data noted above, the results of laboratory testing of core samples should be considered preliminary and re-evaluated if additional core data become available from these sites for the following reasons. First, core samples from the initial phase of testing may have porosities that are significantly higher than in situ formation conditions and consequently may contain preferential flow paths not present in the subsurface. Second, although core samples tested in the second phase of testing were compacted prior to testing to eliminate some of the excess coring-induced porosity, it is likely that this compaction of core samples prior to the second phase of testing did not reduce porosities (increase bulk densities) sufficiently to approach in situ values where overburden pressures were equivalent to many hundreds of feet of sediments.

4.3 LABORATORY MEASUREMENTS ON ALLUVIUM DRILL CUTTINGS

Laboratory measurements conducted on alluvium drill cuttings samples included PSDs, EC of soil-water extracts, and gravimetric water content analyses. The results of these measurements from exploratory RC boreholes NC-EWDP-10SA, -19IM1A, -19IM2A, and -22SA; CA air-rotary piezometer borehole -18P; and RC piezometer borehole -23P are presented in Appendix F. Although alluvium drill cuttings from CA and RC piezometer boreholes are considered more disturbed than drill cuttings from exploratory RC boreholes (Section 2.1), they are the only boreholes located at these sites and are included in Appendix F as preliminary data that are subject to revision when additional boreholes are constructed at these sites.

Laboratory PSD data from the lower regions of saturated alluvium in each borehole except NC-EWDP-18P, which does not penetrate saturated alluvium, have been censored and are not included in Appendix F. The PSDs of drill cuttings samples from these boreholes are considered to exhibit an unacceptable degree of disturbance from in situ conditions caused by drilling and/or improper sample handling. In addition, all laboratory measurements on all alluvium drill cuttings samples from piezometer boreholes NC-EWDP-10P, -22PA, and -23PB have been censored due to a number of drilling-and-sampling-related factors and are not included in Appendix F. Finally, EC and gravimetric water content measurements on saturated zone alluvial drill cuttings samples are not meaningful and therefore have been censored. Table 4.0-1 lists censored laboratory data and the reasons for their exclusion.

4.3.1 Trends in Laboratory Measurements of Particle Size Distributions in Alluvium Drill Cuttings

Laboratory PSD measurements on alluvium drill cuttings samples were used to develop summary lithologic logs of alluvial sections in boreholes. These PSD data have been and will be used elsewhere to support the interpretation of single and multiple well aquifer and tracer tests. The extent to which these drill cuttings PSD measurements represent in situ formation conditions are estimated in the following section by comparing these data with PSD measurements made on relatively undisturbed drive-core samples collected from the same depth intervals. Such comparisons provide insight into the disturbance of geologic samples from in situ conditions caused by drilling and/or improper sample handling related factors.

This section begins with a comparison of PSDs from core and drill cuttings samples, followed by examples of trends in both representative and unrepresentative drill cuttings PSD data. Also included are discussions of the disturbing effects of drilling and/or sample handling in different types of boreholes and the censoring of data that are significantly disturbed from in situ conditions.

4.3.1.1 Comparison of Reverse Circulation Exploratory Borehole Drill Cuttings Particle Size Distribution Data with Core Data from Nearby Casing Advance Piezometer Boreholes

As described in Sections 1 and 2, the PSDs of alluvial drill cuttings samples from the small-diameter RC exploratory boreholes are considered to be relatively representative of in situ alluvial conditions both above and below the water table where the sediments exhibit a high degree of hardness and are not easily crushed into finer size fractions by a drill bit. However, data presented in this section indicate that in each exploratory RC borehole at depths generally beginning less than 100 ft below the water table, relatively soft non-welded formation sediments covering a range of particle sizes were easily ground into even smaller particle sizes by drilling and, as a result, the PSDs for drill cuttings are not representative of in situ conditions.

Core PSD data obtained from CA borehole NC-EWDP-10P are plotted versus drill cuttings PSD data from nearby RC exploratory borehole -10SA in Figure 4.3-1. Similarly, core PSD data from

CA borehole NC-EWDP-22PA are plotted versus drill cuttings PSD data from nearby RC exploratory borehole -22SA in Figure 4.3-2. The percent passing #200 sieve data in these figures is equivalent to percent fines (i.e., percent silt plus percent clay); the percent passing #4 sieve data subtracted from 100 equals the percent gravel, and the difference between percent passing #200 and #4 sieve data equals percent sand.

The aboveground separation of CA and exploratory RC boreholes at each of these sites is approximately 60 ft (Figures 1.3-3 and 1.3-4) and the PSDs of in situ sediments penetrated are, on the average, not expected to differ significantly. However, it would seem advantageous when evaluating the impact of drilling on the PSD of drill cuttings to compare cuttings and core from the same borehole rather than between boreholes separated by approximately 60 ft. Such comparisons are in fact possible since both drill cuttings PSD data and core PSD data were obtained from both CA piezometer boreholes NC-EWDP-10P and -22PA. However, sampling-related disturbance of drill cuttings in these CA boreholes (Section 4.3.1.4) complicated the core versus drill cuttings comparison and made it difficult to distinguish drilling-related impacts. Thus, these comparisons are not shown or discussed herein.

Figures 4.3-1 and 4.3-2 show that below the water table fines percentages are in most cases lower and gravel percentages are noticeably higher in core samples than in drill cuttings samples. Taking into account that core PSD data are reasonably representative of in situ conditions, these data suggest that the drilling process below the water table reduces gravel and larger size clasts to smaller size fractions. At the same time, naturally occurring sand- and silt-size particles may also be reduced to smaller size fractions.

Better agreement is found between the PSDs of core and drill cuttings above the water table, especially at Site NC-EWDP-10, where three of the six core runs were completed above the water table. This suggests that water may play an important role in facilitating the grinding of larger size fractions into smaller size fractions.

Further evidence that water plays a key role in disturbing drill cuttings PSDs from in situ conditions during drilling is found from the observation that drill cuttings PSDs in NC-EWDP-10SA and -22SA begin to significantly deviate from core PSDs in -10P and -22PA at depths where water production in the former boreholes becomes significant. Figure 4.3-3 shows that water production rates increase to approximately 4 gpm in boreholes NC-EWDP-10SA and -22SA at approximately 665 and 550 ft bgs, respectively, and correspond approximately to the depths where core and drill cuttings PSDs begin to deviate significantly (Figures 4.3-1 and 4.3-2). This correlation suggests that water may facilitate the grinding of softer sediments by the drill bit into smaller particle sizes.

A detailed listing of the rock and mineral components of different size fractions of core samples from NC-EWDP-10P and -22PA both above and below the water table is summarized in Table 4.2-2. These data indicate that relatively soft non-welded tuffs are present in significant percentages in all coarse (gravel and sand) size fractions. The data also show that there is large variability in the relative amount of different rocks and minerals in core samples located immediately adjacent to each other. This widespread distribution of non-welded tuffs across all coarse size fractions indicates that there is at least a potential for all coarse size fractions to be impacted by the grinding action of the drill bit below the water table. With the exception of gravel size fraction, the present data set does not permit determining which (if any) of the fractions are preferentially impacted.

Several other apparent trends can be seen in the data in Table 4.2-2; however, it should be noted that these trends may be artifacts of the small number of core samples and their distribution with depth. Moreover, the effect that these apparent trends may have on the resulting disturbed PSD is unknown. These apparent trends include the percentage of non-welded tuffs generally increasing with decreasing particle size, and the percentage of non-welded tuffs appearing to increase with depth in NC-EWDP-10P but not in -22PA.

In summary, it can be reasonably concluded that drill cuttings PSDs from NC-EWDP-22SA and -10P are disturbed to a significant extent in the gravel and possible other size fractions beginning less than 100 ft below the water table. Because of these drilling-related disturbances, these data have been censored and will not be published by Nye County, other than in the graphs presented in this report to demonstrate the very significant impact that drilling may have on the PSD of alluvial sediments that are relatively soft and easily ground into smaller size fraction formation clasts.

Figures 4.3-1 and 4.3-2 also show that core data below approximately 745 ft bgs are not available to gauge drill cuttings disturbance at deeper depths. However, the consistency noted in gravel and fines content in drill cuttings from approximately 100 ft below the water table down to the base of alluvium in both NC-EWDP-10SA and -22SA suggests that both the core sediment composition and drilling effects can be extrapolated below 745 ft bgs down to the contact between alluvium and non-alluvium. This extrapolation is made in developing summary lithologic logs (Section 4.5).

4.3.1.2 Comparison of Data from Adjacent Exploratory Reverse Circulation Boreholes

Depth profiles of alluvium PSD laboratory data from RC exploratory boreholes NC-EWDP-19IM1A and -19IM2A are plotted in Figure 4.3-4. These boreholes are located approximately 60 ft apart (Figure 1.3-2), and it was expected that PSD data from these boreholes would agree reasonably well. In fact, relatively good agreement in PSD data between these boreholes down to a depth of approximately 420 ft bgs can be observed in Figure 4.3-4.

Below approximately 420 ft bgs, there is a noticeable difference in PSD data between boreholes. In general, at this depth percent fines in NC-EWDP-19IM2A begin to be consistently higher and percent gravel starts to be consistently lower than in -19IM1A. Percent fines continue to be higher in NC-EWDP-19IM2A throughout the remaining thickness of alluvium, while percent gravel remains lower down to approximately 520 ft bgs.

The change in PSD profiles at approximately 420 ft bgs correlates with an increase in water production from approximately 2 to 8 gpm in NC-EWDP-19IM2A (Figure 4.1-9). Water production in NC-EWDP-19IM1A was still zero at 420 ft bgs and remained zero until a depth of approximately 522.5 ft bgs. Drill cuttings samples between 420 and 522.5 ft bgs from -19IM2A were delivered to the ground surface in a water slurry and split into manageable size samples with an Anaconda rotating wet splitter. In contrast, because -19IM1A was not producing measurable quantities of water, drill cuttings that were in a saturated state downhole were dried slightly during drilling and were delivered to the surface in an unsaturated state.

It is possible that these unsaturated drill cuttings samples produced from NC-EWDP-19IM1A from approximately 420 to 522.5 ft bgs are more representative of in situ conditions than the saturated samples produced from -19IM2A over this same depth interval. It is further proposed that the water produced in NC-EWDP-19IM2A facilitated the grinding of softer sediment clasts into finer size fractions in a manner similar to that proposed for -10SA and -22SA in Section 4.3.1.1, and that the lack of water in -19IM1A helped to minimize this disturbance.

Alluvium drill cuttings samples below 522.5 ft bgs in NC-EWDP-19IM1A are not considered representative of in situ conditions. These samples were homogenized and split using methods that likely contributed bias in PSD laboratory measurements; as a result, these PSD data have been censored. This was the first borehole drilled in Phase III and not enough 5-gal. buckets were on hand to contain saturated zone alluvium drill cuttings samples collected from the Anaconda rotating wet splitter. In order to free up additional buckets, a field decision was made to attempt to further split existing samples by manually taking subsamples from three to five buckets collected from a single 5-ft-long sample interval and combining these samples into a single bucket. Subsampling was conducted by attempting to manually collect an approximately 1-gal. column of representative water and sediment from each full 5-gal. bucket. As might be expected, it was difficult (if not impossible) to collect a representative subsample by this method.

Figure 4.3-4 also shows that there are missing PSD data from approximately 557.5 to 605 ft bgs in NC-EWDP-19IM1A. Samples from this interval were contaminated with bentonite drilling fluid used to condition borehole walls (Section 2.1.3.1), and therefore were excluded from PSD laboratory analyses.

In summary, PSD data below 522.5 ft bgs in NC-EWDP-19IM1A have been significantly biased by inappropriate homogenization and subsampling methods and therefore have been censored. Also, it is likely that PSD data from NC-EWDP-19IM2A below 420 ft bgs contain more fines and less gravel than in situ sediments as a result of drill bit impacts on clasts of softer sediments. The disturbance of PSD data from -19IM2A does not appear to reach a maximum until a depth of approximately 750 ft bgs. For this reason, and because no other alluvium PSD data are available below 522.5 ft bgs at Site NC-EWDP-19, PSD data from -19IM2A have been censored only between 750 ft bgs and the base of alluvium at 825 ft bgs. The uncensored data in -19IM2A between 522.5 and 750 ft bgs should, however, be considered preliminary and replaced when more reliable data become available.

4.3.1.3 Comparison of Data from Widely Spaced Exploratory Reverse Circulation Boreholes

Figure 4.3-5 compares alluvium PSD data from NC-EWDP-19IM2A and -22SA, and Figure 4.3-6 compares -22SA and -10SA data. As described in Section 3, each of these boreholes was drilled, sampled, and logged in a similar manner. Borehole NC-EWDP-19IM2A is located slightly to the west and south of the point where Fortymile Wash spreads out into a number of shallowly incised braided channels (Figure 1.3-1). Borehole NC-EWDP-22SA is located approximately 3 mi. upstream immediately to the east of the deeply incised main channel of Fortymile Wash, and -10SA is located roughly 2 mi. further upstream in a similar setting as -22SA.

Figures 4.3-5 and 4.3-6 show that the PSD depth profiles from these boreholes are remarkably similar in shape and magnitude in the unsaturated zone and the upper region of the saturated zone. Over these depth intervals, each borehole shows a trend of generally increasing percent fines and deceasing percent gravel with depth. In contrast, below approximately 750 ft bgs in NC-EWDP-19IM2A and below approximately 665 ft bgs in both -22SA and -10SA, gravel contents decrease rather sharply to values of less than 10% and remain at this low level through the remaining portion of alluvium in each borehole. At the same depths in these boreholes, a corresponding increase in fines content occurs to a relatively constant value of approximately 30 percent in NC-EWDP-19IM2A, approximately 35 percent in -22SA, and approximately 40 percent in -10SA. These trends in PSDs beginning approximately 100 ft below the water table may reflect softer clasts of sediments being ground into finer size fractions by the drilling process (Sections 4.3.1.1 and 4.3.1.2). For this reason, these data have been censored.

4.3.1.4 Comparison of Data from Closely Spaced Exploratory Reverse Circulation and Casing Advance Boreholes

Alluvium PSD laboratory data from exploratory RC borehole NC-EWDP-10SA and CA piezometer borehole -10P are shown in Figure 4.3-7. Similarly, data from exploratory borehole NC-EWDP-22SA and CA piezometer borehole -22PA are plotted in Figure 4.3-8. Both figures show that over the depth interval from approximately 100 ft bgs down to approximately 300 to 350 ft bgs, the percent gravel data from the CA piezometers are significantly lower in magnitude (and for percent sand, larger in magnitude) than in nearby RC boreholes. The depths at which the percents gravel begin to agree in nearby RC and CA boreholes appears to coincide with the depths at which drilling systems in the CA boreholes were switched from a 9.625-in. OD Stradex drive casing to a 6.625-in. OD Tubex drill casing. As discussed in Section 2.1.2.2, drilling fluid velocities in the portions of CA boreholes drilled with the larger-diameter Stradex systems were not sufficient to efficiently clean drill cuttings from the boreholes. This poor circulation may have resulted in a significant quantity of gravel-size drill cuttings falling back down on the drill bit, where they were ground into sand-size particles.

A comparison of the fines data above the water table in Figures 4.3-7 and 4.3-8 indicates noticeable differences in data between NC-EWDP-10SA and -10P, with much better agreement between NC-EWDP-22SA and -22PA. The reason for these differences may in part be related to the much slower average rate of drilling in the CA piezometer NC-EWDP-10P compared to the rate in -22PA (Table 4.1-4). The slower drilling rate would mean larger volumes of air were used to drill the same interval, which would in turn encourage a greater loss of fines as dust from the cyclone separator.

This slower drilling rate in NC-EWDP-10P was in part due to a saturated interval encountered between approximately 250 and 300 ft bgs and a number of near-saturated intervals occurring between 300 ft bgs and the water table located at approximately 580 ft bgs (Figure 4.1-2). This moisture is believed to result primarily from laterally migrating lost circulation water from the FM monitor well borehole NC-EWDP-10S. Supporting evidence for this is found in Figure 4.1-

2, which shows that most of these wet and moist intervals are not present in exploratory RC borehole NC-EWDP-10SA, which was drilled prior to the FM monitor well borehole -10S.

The wet and moist fine drill cuttings produced when drilling these intervals tended to stick to the inside of the CA drive casing during drilling (advancement) of each 10-ft section of drill casing. This made it more difficult to remove drill cuttings from the borehole, reduced drilling rates, and increased the loss of fines via dust from the cyclone separator. In addition, some fines remained stuck to the inside of the drill casing until the hole and casing were cleaned at the end of each 10-ft drill interval. As a result, a portion of the fines were not collected as part of the drill cuttings sampled during active drilling, thus contributing to the apparent loss in fines in drill cuttings from NC-EWDP-10P from approximately 300 to 580 ft bgs compared to NC-EWDP-10SA.

The increase of fines and loss of gravel below the water table in NC-EWDP-10SA and -22SA observable in Figures 4.1-6 and 4.1-7 have been discussed in preceding sections, are thought to be artifacts of drilling, and will not be discussed further here. Somewhat similar trends would be expected below the water table in NC-EWDP-10P and -22PA even though different drilling methods were used. However, the opposite trends in fines and gravel content were observed, as shown in Figures 4.1-6 and 4.1-7. These unexpected trends in the CA boreholes are thought to be due mainly to the failure to follow appropriate standard-operating sample-handling procedures (described in Section 2.3.1) that were designed to obtain representative geologic samples from regions of the borehole producing large volumes of water. Instead, in NC-EWDP-10P, the split from the Anaconda wet splitter was funneled into a single bucket, which was allowed to overflow over the entire sample interval. This overflow procedure is used successfully to obtain representative mineral samples in mineral exploration, but does not yield representative PSD samples. In NC-EWDP-22PA, 5-gal. bucket samples from the wet splitter were not allowed to dry sufficiently to permit thorough homogenization, and consequently the subsamples obtained did not contain representative PSDs.

4.3.1.5 Comparison of Data from Nearby Reverse Circulation Exploratory and Reverse Circulation Piezometer Boreholes

Figure 4.3-9 presents alluvium PSD depth profile data from NC-EWDP-22SA and -22PB, small-diameter RC exploratory and intermediate-diameter RC piezometer boreholes, respectively. In general, drill cuttings from above the water table in the RC piezometer borehole contain noticeably less fines than the RC exploratory borehole. At the same time, there is reasonable agreement in average gravel content between the boreholes to a depth of approximately 300 ft bgs, but significantly more gravel in RC piezometer boreholes between 300 ft bgs and the water table at approximately 475 ft bgs, with the exception of an approximately 50-ft interval between 375 and 425 ft bgs.

The apparent loss in fines in drill cuttings from the unsaturated portion of NC-EWDP-22PB compared to -22SA may in part be related to the significantly slower drilling rates measured in -22PB (Table 4.1-4), as described in Section 4.1.2.3. It is thought that the much slower average drilling rate (more than four times slower) in the RC piezometer borehole caused drill cuttings present in the vicinity of the drill bit to be impacted by more drill bit rotations per unit volume of sample, longer exposure time to the air drilling fluid, and consequently a greater loss of fines as dust from the cyclone separator than in RC exploratory boreholes. Thus, although the PSDs of unsaturated alluvial drill cuttings from small-diameter RC exploratory boreholes are disturbed to some degree by the drilling action of the bit and the air drilling fluid, it is possible and even likely that drill cuttings PSDs from intermediate-diameter RC piezometer boreholes are disturbed to an even greater extent from in situ conditions.

The slower drilling rate in intermediate-diameter piezometer NC-EWDP-22PB also appears to correlate with higher gravel percentages in alluvium drill cuttings in the region just above the water table. Evidence supporting this correlation is found by comparing drilling rates (Figure 4.3-10) and PSD data (Figure 4.3-9) in the approximately 175-ft-thick interval above the water table (i.e., from approximately 300 to 475 ft bgs). Over the intervals from approximately 300 to 375 ft bgs and from 425 to 475 ft bgs, drilling rates average far less than 0.5 ft/min., and gravel percentage in drill cuttings is significantly elevated compared to the small-diameter RC exploratory -22SA. In contrast, in the region between 375 and 425 ft bgs, the drilling rates in -22PB are the highest recorded in the unsaturated zone (approximately 1.5 ft/min.), and the gravel percentage in drill cuttings is significantly lower and comparable to that measured in -22SA. It is also interesting to note that fines content is slightly higher over most of the interval from 375 to 425 ft bgs compared to intervals directly above and below.

This observed inverse relationship between drilling rate and gravel content and the direct relationship between drilling rate and fines content between 300 and 475 ft bgs in NC-EWDP-22PB are not intuitively obvious. For example, it would seem logical that faster drilling rates would result in fewer drill bit rotations per unit volume of drill cuttings (assuming a constant bit rotation rate), which in turn would result in less grinding of gravel size particles into smaller size fractions and thus higher gravel content than for slower drilling rates. In fact, it appears that the opposite occurs. Reasons for this apparent relationship are not known.

One possible explanation may be that the formation in the 175-ft-thick interval of interest in NC-EWDP-22PB is composed of coarser-grained sediments (e.g., predominantly cobbles and coarse gravels) than penetrated in -22SA. However, it seems unlikely that boreholes located only 60 ft apart at the ground surface could penetrate alluvial sediments that differ in such a significant manner over the depth intervals of interest.

Alternatively, one or more currently undefined factors may work in conjunction with drilling rate to affect gravel content, or there may be no causal relationship between drilling rate and gravel content in NC-EWDP-22PB. For example, the higher gravel content in the region of concern in -22PB may be a result of caving of unstable coarse-grained regions of borehole above the drill bit. The fact that it was necessary to spend time cleaning the borehole after each 20 ft drill run (Section 2.1.3.3.2) suggests that some caving was occurring in this borehole. Whether this caving was predominantly from gravel layers and was significant enough to impact PSDs is unknown.

Finally, comparison of PSD drill cuttings data below the water table in these boreholes is not meaningful because data from both boreholes have been significantly disturbed from in situ conditions. For example, PSD data in NC-EWDP-22SA began to be significantly impacted by drilling below approximately 550 ft bgs, and below approximately 665 ft bgs the data are impacted to such a large degree that they have been censored (see Section 4.3.1.1). Moreover, in NC-EWDP-22PB, drill cuttings samples were not split in a representative manner. Splitting procedures followed were similar to those followed for NC-EWDP-22PA, where samples were not allowed to dry sufficiently to permit the collection of representative subsamples. As a result, PSD data from the entire length of NC-EWDP-22PB have been censored; their presentation herein will be limited to depth-profile graphs.

4.3.1.6 Comparison of Data from Widely Spaced Reverse Circulation Exploratory and Reverse Circulation Piezometer Boreholes

Figure 4.3-11 compares PSD data from alluvium drill cuttings in small-diameter exploratory borehole NC-EWDP-22SA with intermediate-diameter RC piezometer borehole -23P. There is remarkable agreement between borehole PSDs presented in this figure both above and below the water table. Only slight differences are discernible, including fines data in NC-EWDP-23P that are slightly lower above the water table and slightly higher below the water table compared to -22SA and gravel data that are generally lower in -23P than in -22SA except in the near-surface and in the region directly above the water table. Appropriate standard operating procedures for sample handling similar to those followed in RC exploratory boreholes were followed for samples collected below the water table in NC-EWDP-23P.

PSD data from drill cuttings collected above the water table in NC-EWDP-23P were likely impacted by drilling in a manner similar to -22PB, as discussed in Section 4.3.1.5. That is, since both are intermediate-diameter RC piezometer boreholes drilled with the same methods at approximately the same relatively slow rates (Table 4.1-4), the disturbance of drill cuttings PSDs is expected to be similar. As proposed in Section 4.3.1.5, slower drilling rates above the water table produce less fines than faster drilling rates. Therefore, it is possible that a hypothetical rapidly drilled exploratory RC borehole at Site NC-EWDP-23 could contain slightly more fines in the unsaturated zone than shown for -23P in Figure 4.3-11. It is expected that actual in situ formation materials similarly contain slightly more fines.

The similarity in PSD data from alluvium drill cuttings collected below the water table in both NC-EWDP-22SA and -23P suggests that PSDs from the latter borehole are similarly disturbed by the drilling process (Section 4.3.1.1). It is proposed that this drilling related disturbance significantly decreased gravel content and increased fines content compared to in situ formation conditions. Due to this likely significant disturbance of PSDs below the water table in NC-EWDP-23P, these data have been censored.

The similarity in PSD data from alluvium drill cuttings collected below the water table in both NC-EWDP-22SA and -23P suggests that it is reasonable to assume that the average fines and gravel content of core samples below the water table in -22PA also apply in an approximate manner to this interval in -23P, as well as to the interval in -22SA (Section 4.3.1.1). The only difference is that the true PSDs in NC-EWDP-23P likely contain slightly more fines and less gravel than shown in the core from -22PA. The above assumptions permit the development of a preliminary summary lithology log over the total depth of NC-EWDP-23P (Section 4.5).

4.3.2 Trends in Laboratory Measurements of Electrical Conductivity of Soil-Water Extracts in Unsaturated Alluvium Drill Cuttings

EC measurements on soil-water extracts from unsaturated zone alluvium sediments can provide an approximate estimate of the quantity of readily soluble salts present and therefore possible insight into the location of paleo-soils and/or the terminus of wetting fronts from paleo-recharge events along Fortymile Wash. Similar to PSD data, these EC measurements can be impacted by a number of drilling-related factors. The effects of some of these factors are discussed in the following section, along with major EC trends within and between boreholes.

4.3.2.1 Electrical Conductivity of Soil-Water Extracts in Closely Spaced Reverse Circulation Exploratory Boreholes

Figure 4.3-12 shows the presence of a relatively large number of peaks (10 or more) in soil-water extract EC depth profiles for boreholes NC-EWDP-19IM1A and -19IM2A, with maximum values generally ranging between 1,000 and 1,800 µmhos/cm. In addition, there is relatively good agreement between the location and magnitude of peaks and valleys (maximum and minimum values) in these boreholes. The primary difference between boreholes is that -19IM2A contains several more peaks in EC than does -19IM1A.

The width (thickness) of the peaks in EC are relatively narrow, ranging from 10 to 20 ft at their widest point to possibly as thin as 5 ft or less at their maximum EC. The width of valleys in these data are generally broader, ranging up to approximately 75 ft. The magnitude of peaks and valleys consistently differ by approximately a factor of 10.

Reasons why peaks in EC in these boreholes are so narrow and pronounced are unknown. Several possible explanations are are presented below. It should be noted that EC peaks are not related to the addition of drill fluids during hole conditioning activities conducted in the unsaturated zone (described in Section 2.1 and summarized in Appendix A). Comparison of the depths where drilling fluids were added with the depths of peaks in EC in RC boreholes indicates no evidence of a positive correlation.

A possible flow path-related explanation for narrow and pronounced peaks in EC is that soluble salts are concentrated in finer-texture lower-permeability layers, and that infiltration and percolation waters preferentially bypass these layers and move downward in a stair-step fashion primarily through interconnected coarser-texture higher-permeability layers. However, a comparison of EC data in Figure 4.3-12 with percent fines data in Figure 4.3-4 shows no evidence of a correlation, indicating that this explanation is incorrect.

Another possible explanation is related to patterns in historic precipitation events and related run-off and infiltration events. That is, long-duration precipitation events and associated long-duration surface flows and infiltration, percolation, and recharge events that could flush soluble salts from the unsaturated zone have not occurred recently in lower Fortymile Wash. Instead, surface water flow and associated infiltration, percolation, and recharge events must have had characteristic short durations and low magnitudes that do not encourage spreading of soluble salts from their concentration points (e.g., paleo-soils) through the unsaturated zone resulting in broadening and flattening of the observed narrow and pronounced peaks in EC.

It also may be possible that soluble salts at concentration points are somehow physically protected from direct contact with infiltrating and percolation waters. The mechanism of protection is unknown; however, it is possible that the drilling processes somehow break down this protection. Perhaps more insoluble secondary minerals coat the more soluble minerals and the drilling process physically breaks down this protective coating and permits laboratory extract water to come in direct contact with the soluble salts.

Clearly, additional work is required to understand the processes responsible for the wide variations in soil-water extract EC at NC-EWDP-19IM1A and -19IM2A.

4.3.2.2 Electrical Conductivity of Soil-Water Extracts in Widely Spaced Reverse Circulation Exploratory Boreholes

EC data from borehole NC-EWDP-22SA (Figure 4.3-13) show only approximately one-half the number of major peaks of the type observed in -19IM1A and -19IM2A, and these peaks are concentrated between approximately 240 and 290 ft bgs. Moreover, borehole NC-EWDP-10SA exhibits only four peaks in the upper 300 ft (Figure 4.3-14) and their maximum (approximately 600 to 800 μmhos/cm) is considerably less than observed for peaks found in -19IM1A and -19IM2A. However, the difference between maximum and minimum values is still a factor of approximately 10 and is similar to that found for NC-EWDP-19IM1A and -19IM2A. Below 300 ft bgs, peaks and valleys are less pronounced and generally form a "bulge" with a maximum value at approximately 475 ft bgs.

In summary, the number and maximum value of peaks in EC tend to decrease progressively from the NC-EWDP-19IM1 and -19IM2 boreholes to -22SA to -10SA. Reasons for the progressive difference in the depth profiles of EC may be related to the fact that each of these sites is located progressively further upstream. As a result, the duration of ephemeral surface water flow and associated infiltration and percolation events increase in the upstream direction. Thus, flushing of salts from the unsaturated zone possibly increases progressively in the upstream direction.

4.3.2.3 Electrical Conductivity of Soil-Water Extracts in Closely Spaced Reverse Circulation Exploratory and Casing Advance Piezometer Boreholes

Figures 4.3-15 and 4.3-16 compare electrical conductivities in RC exploratory and CA piezometer boreholes at Sites NC-EWDP-10 and -22, respectively. In both figures, the CA piezometer borehole shows fewer EC peaks and lower magnitude peaks than the exploratory RC borehole. It is possible that the slower drilling rates and drilling fluid circulation problems observed in the CA boreholes impact soluble salt concentrations in a manner similar to the way slower drilling rates impact the fine particle size fraction in drill cuttings (Section 4.3.1.4). That is, the slow drilling rate (Table 4.1-4) and inadequate drilling fluid velocities encourage the loss of fines and soluble salts as dust from the cyclone separator, and/or high moisture content regions may cause fines and soluble salts to stick to walls of the drill pipe, return hoses, and cyclone separator and therefore are not captured in drill cuttings. They are only removed from the drilling system when the borehole is cleaned at the end of a drill run.

4.3.2.4 Electrical Conductivity of Soil-Water Extracts in Closely Spaced Reverse Circulation Exploratory and Reverse Circulation Piezometer Boreholes

Figure 4.3-17 illustrates that the width and magnitude of EC peaks are reduced in intermediate-diameter RC piezometer boreholes compared to small-diameter RC exploratory boreholes. Again, it is likely that the approximately four-fold slower unsaturated zone drilling rate in the former borehole (Table 4.1-4) is responsible for the difference observed. Moreover, the drilling-rate-related physical processes that are responsible for decreasing EC are the same as those causing a decrease in the fines content of drill cuttings (Sections 4.3.1.4 and 4.3.1.5). That is, the slower drilling rate would result in the use of larger volumes of air to drill the same interval, which in turn would encourage a greater loss of fines and soluble salt secondary minerals as dust from the cyclone separator. In addition, it is possible that slower drilling rates would result in a greater number of bit rotations per unit volume of borehole, possibly increasing the grinding of drill cuttings (including water soluble secondary minerals) into smaller size fractions and the possible loss of these finer size fractions as dust.

4.3.2.5 Electrical Conductivity of Soil-Water Extracts in Widely Spaced Reverse Circulation Exploratory and Reverse Circulation Piezometer Boreholes

Soil-water extract EC profiles for NC-EWDP-22SA and -23P are shown in Figure 4.3-18. Virtually no peaks are present in the latter borehole. This may in part be due to the effects of slower drilling rates in the latter borehole (Table 4.1-4) as well as the fact that these boreholes may be located in different depositional environments as a result of being separated by more than 2 mi. in a direction approximately perpendicular to the primary axis of Fortymile Wash.

4.3.3 Trends in Laboratory Measurements of Gravimetric Water Content of Unsaturated Alluvial Drill Cuttings

Trends in gravimetric water content profiles in the unsaturated zone for Phase III boreholes generally mimic the field logging estimates (Section 4.1.2.1). Some of these trends and several additional insights are presented in the following section. In addition, the amount of drying that occurs in drill cuttings as a result of drilling with compressed air will be determined from the difference between the gravimetric water content of drill cuttings and that of core samples from similar depth intervals.

4.3.3.1 Gravimetric Water Content Data in Reverse Circulation Exploratory Boreholes

Figure 4.3-19 compares gravimetric water content depth profiles for unsaturated alluvium in boreholes NC-EWDP-19IM1A and -19IM2A. Elevated water contents found in the upper 20 ft in both boreholes are due to the use of water as the drilling fluid in the upper 20 ft prior to setting a temporary surface casing. The even higher water contents observed for NC-EWDP-19IM1A between approximately 50 to 80 ft bgs reflect the experimental use of water as the drilling fluid in this first RC exploratory borehole to be drilled. The remaining portion of the unsaturated zone in this borehole was drilled with air.

Water contents between approximately 100 and 200 ft bgs are noticeably higher in NC-EWDP-19IM1A than in -19IM2A (Figure 4.3-19). This may in part be due to the finer texture of sediments found in the former borehole over this depth interval compared to the latter borehole

(Figure 4.3-4). That is, slightly higher fines content, noticeably higher sand content, and significantly lower gravel content are present in the former borehole compared to the latter borehole. Between 200 and 300 ft bgs, PSDs of the sediments are very similar (Figure 4.3-4), and there is reasonable agreement in water content profiles (Figure 4.3-19), with the exception of a peak in borehole NC-EWDP-19IM2A at approximately 225 ft bgs related to the addition of drilling fluid for hole conditioning (described in Section 2.1). Elevated water contents below approximately 300 ft bgs in this borehole are also related to borehole conditioning.

Water content profiles for boreholes NC-EWDP-22SA and -10SA are shown in Figure 4.3-20. Water contents in -10SA are generally slightly higher than those observed in -22SA despite higher average drilling rates in -22SA (Table 4.1-4). These findings suggest that other factors, such as a slightly higher percentage of fines in -10SA may be responsible for the higher water contents in this borehole. The importance of fines content is supported by the fact that peaks in -10SA water content (Figure 4.3-20) occur in the same vicinity as peaks in fines content (Figure 4.3-6). In three of the four cases where there appears to be a correlation between fines content and water content, the peak in fines content occurs 5 ft below (next lower sample interval) the peak in water content, suggesting that capillary barrier effects may be holding water in the overlying coarser-textured interval.

4.3.3.2 Gravimetric Water Content Data in Reverse Circulation Exploratory Boreholes Compared to Nearby Casing Advance and Reverse Circulation Piezometer Boreholes

Figures 4.3-21 and 4.3-22 compare water content profiles for alluvium drill cuttings in RC exploratory boreholes and CA piezometer boreholes at Sites NC-EWDP-10 and -22, respectively. Both plots show higher water contents in CA piezometer boreholes compared to RC exploratory boreholes. These differences are mainly due to the impact of lost circulation from nearby FM boreholes on CA piezometer boreholes (Section 4.1). RC exploratory boreholes were drilled prior to FM boreholes and therefore were not impacted by lost circulation fluids.

Figure 4.3-23 shows water content profiles for RC exploratory and RC piezometer boreholes at Site NC-EWDP-22. The presence of lost circulation water in the RC piezometer borehole is clearly not as evident as in the two previous figures. It is likely that the four-fold slower drilling rate in NC-EWDP-22PB compared to -22SA (Table 4.1-4 and Figure 4.3-10) is responsible for the lower-than-expected water contents in -22PB. It appears that the slow drilling rate effectively removed from drill cuttings much of the excess lost circulation water originating from the FM borehole -22S.

Finally, Figure 4.3-24 compares water contents in RC exploratory borehole NC-EWDP-22SA with RC piezometer borehole -23P. Agreement between profiles is relatively good. However, because the drilling rate was much slower in -23P than observed in -22SA (Table 4.1-4), it is likely that actual in situ water contents in -23P are higher than shown in Figure 4.3-24.

4.3.3.3 Gravimetric Water Content in Drill Cuttings Compared to Core Samples in Casing Advance Piezometer Boreholes

Gravimetric water contents of drill cuttings and core samples for boreholes NC-EWDP-10SA and -10P and for boreholes -22SA and -22PA are compared in Figures 4.3-25 and 4.3-26, respectively. In every depth interval in the unsaturated zone where both types of data are available, the water contents of drill cuttings samples are lower than the water contents of core samples. Since the physical and hydrologic properties of alluvium drive-core samples are generally considered to be more representative of in situ conditions than drill cuttings produced using compressed air as the drilling fluid, these figures show that drill cuttings have undergone significant drying during drilling. Reasons for this drying are described in Section 4.1.2.1.

Figure 4.3-25 also shows that drilling-related drying of drill cuttings occurs in the upper part of the saturated zone where little if any water is produced. The water contents of drill cuttings collected in the upper approximately 50 ft of the saturated zone in NC-EWDP-10P are in most cases lower than saturated levels found in core samples at deeper depths. Similar observations were made in drill cuttings geologic logs, as described in Section 4.1.2.1.

However, below approximately 640 ft bgs in NC-EWDP-10P (Figure 4.3-25), the water contents of drill cuttings appear to be equivalent to or slightly higher in magnitude than underlying saturated core samples. This is most likely due to excessive and unrepresentative amounts of free water that get mixed with drill cuttings when the boreholes begin to produce significant amounts of water during drilling.

In summary, it is nearly impossible to collect alluvial drill cuttings both above and below the water table that have water contents that are representative of in situ conditions. As a result, it is necessary to rely on core samples for providing more quantitative measurements of in situ water contents.

4.4 MAJOR TRENDS IN GEOPHYSICAL LOGS

Geophysical logs conducted in Phase III are classified in Table 2.6-2 into one of three logging suites: drill string, open hole, and well completion. Appendix G contains selected logs from the drill-string suite conducted in exploratory boreholes NC-EWDP-10SA, -19IM1A, -19IM2A, and -22SA, selected logs from the open-hole suite in FM boreholes -10S, -19IM2, and -22S, as well as RC piezometer borehole -23P, and selected well-completion logs from NC-EWDP-18P. Note that the drill-string suite was run at each Phase III drill location except Sites NC-EWDP-18 and -23, and the open-hole suite was conducted at each drilling location except Site NC-EWDP-18. Scheduling problems with the geophysical logging company and/or borehole stability problems precluded conducting the aforementioned suites at Sites NC-EWDP-18 and -23.

Drill-string logs were run in exploratory boreholes that were drilled primarily with air and only very small amounts of bentonite-based drilling mud were used to condition borehole walls (Appendix A). In contrast, all open-hole logs, with one exception, were run in drilling mud-filled boreholes to maintain stable borehole conditions during geophysical logging and subsequent well completion activities. The exception is NC-EWDP-23P, where the fluid level in the borehole was approximately the same as the groundwater level. The fluid in this borehole was composed primarily of formation water with some residual drilling mud left over from attempting to free the stuck drill string, as described in Appendix A.

Responses of open hole suite logs to changes in formation conditions are dampened to various degrees by drilling fluid mud and responses of drill string logs are dampened by steel drill casing. In spite of this dampening, logs in the drill-string suite clearly show the location of the water table and zones that may be producing or taking water, changes in water-filled porosity immediately above and below the water table, and where present, the contact between alluvium and tuff. The dampening effects also do not prevent open-hole suite logs from providing useful information regarding water production zones and confirmatory information on the depth of the alluvium-tuff and the alluvium-volcanic conglomerate contacts, where present. Finally, both drill-string and open-hole logs yield valuable information regarding the impact of drilling fluids and additives on the formation fluids. Specific examples of these log responses will be described in more detail in the following sections.

Although the well-completion suite helps to confirm the location and integrity of sand packs and bentonite seals, it shows few if any trends related to formation lithology and/or water production. As a result they will not be discussed further herein. These well-completion logs may be downloaded from the Nye County website or viewed at the QARC.

4.4.1 Examples of Drill-String Logs

Drill-string logs, with the exception of borehole deviation logs, for boreholes NC-EWDP-19IM1A and -19IM2A are presented in Figure 4.4-1. These logs illustrate several important changes in formation conditions with depth found in most of the other drill-string logs presented in Appendix G. For example, each of the logs presented in Figure 4.4-1 shows notable changes at and near the water table located at approximately 350 ft bgs. The only exception is found in the fluid temperature log for NC-EWDP-19IM2A, where there is only a very slight slope change in the temperature log at 350 ft bgs. This lack of response is likely related to the fact that fluid temperature logs were conducted approximately 0.5 hr. after total depth was reached and drilling activities ceased in this borehole, and both air and water temperatures did not have sufficient time to equilibrate with formation conditions. In contrast, approximately 13 hr. elapsed between the end of drilling activities and the start of fluid temperature logging in NC-EWDP-19IM1A. The significant temperature log response at the water table in this borehole suggests that a greater degree of equilibration had occurred between formation and borehole temperatures.

Each of the other logs shown in Figure 4.4-1 shows a gradual change in logging output beginning approximately 10 to 40 ft above the water table and extending 10 to 20 ft below the water table. In both boreholes in the region of the water table, the moisture log (referred to as "neutron log" in Figures 4.1-1 and 4.1-2 and in Appendix G) shows a very marked decrease in counts indicating an increase in saturated porosity; density log counts increase indicating an increase in density which reflects increasing water content; and both gamma and spectral gamma decrease in counts over variable intervals that straddle the water table, suggesting the dampening influence of water on gamma radiation.

The fluid temperature log below the water table in NC-EWDP-19IM1A exhibits noticeable slope changes between approximately 560 and 620 ft bgs and again between approximately 680 and

740 ft bgs (Figure 4.4-1). These slope changes may indicate the inflow of warmer water from the formation into the borehole. Similar slope changes were not observed in NC-EWDP-19IM2A, where the very short time between the completion of drilling and the start of logging was insufficient for borehole fluid temperatures to reflect formation temperatures.

The observed differences in the moisture (neutron) logs in the unsaturated zone portion of these boreholes (Figure 4.4-1) is probably due primarily to differences in borehole conditioning methods used. In NC-EWDP-19IM1A, bentonite additives were flooded down the annular space after about every 100 ft penetrated, while in -19IM2A borehole conditioning was conducted only after penetrating beneath the water table by pumping bentonite additives directly down the drill string through the drill bit. The former method may wet the unsaturated zone more than the latter method. Hence, generally lower counts were observed in this region in NC-EWDP-19IM1A, which reflects a higher water-filled porosity.

The differences in the time (13 hr. versus 0.5 hr.) between the end of drilling and the start of logging in NC-EWDP-19IM1A versus -19IM2A may affect water contents slightly (i.e., by gravity drainage from coarse-textured layers), but are not expected to be responsible for the apparent differences observed in the logs. Moreover, large natural differences in water content profiles are not expected between boreholes separated by approximately 60 ft in the Fortymile Wash alluvial setting.

Finally, several of the logs shown in Figure 4.4-1 also reflect the transition from alluvium to welded tuff at approximately 820 ft bgs. Moisture (neutron), spectral gamma, and natural gamma all exhibit lower counts beginning at approximately 810 ft bgs. The former log indicates an increase in saturated porosity, which is consistent with the relatively high porosities of weakly welded tuffs and the geologic log description of this unit (Figure H2 in Appendix H) as exhibiting "an open/porous sugary texture."

4.4.2 Examples of Open-Hole Logs

Selected open-hole logs for FM boreholes NC-EWDP-19IM2 and -23P are presented in Figure 4.4-2. These logs illustrate some of the important changes in formation conditions with depth found in most of the other open-hole logs presented in Appendix G.

4.4.2.1 Logs from NC-EWDP-19IM2

The logs for NC-EWDP-19IM2 clearly show significant response changes through the basal alluvium aquifer unit as well as in the transition from this basal unit to the tuff aquifer. For example, the increase in borehole diameter noted in the caliper log beginning at approximately 740 ft bgs and ending at the alluvium bedrock contact at approximately 820 ft bgs correlates with the lowest formation resistivities observed in the borehole. The larger-diameter borehole may indicate a lost circulation zone resulting in an accumulation of bentonite drilling fluids in the formation, which in turn may yield lower resistivities.

At the alluvium-tuff contact, the caliper log for NC-EWDP-19IM2 indicates that the borehole diameter decreases to a value approximating the drill bit diameter and resistivities increase to relatively constant values. In addition, both gamma and moisture (neutron) counts drop at the alluvium-bedrock contact between 815 and 825 ft bgs and then both show very little change to total depth. These same trends in gamma and moisture (neutron) logs were also observed at the alluvium-tuff contact in the drill-string logs. The smooth and constant response (near vertical logs) below the contact likely reflect relatively constant properties of the upper portion of the tuff aquifer penetrated in this borehole.

Between approximately 830 and 875 ft bgs in NC-EWDP-19IM2, the caliper log shows that the borehole diameter again increases significantly and exhibits sharp peaks that suggest the presence of fracture zones and the possibility that the rock is more brittle (i.e., more welded) than surrounding rock. The maximum borehole diameter occurs at approximately 875 ft bgs, which correlates with the beginning of a slope change in the fluid temperature log. This rough correlation may indicate that warmer formation fluids are moving into the borehole at depths below this apparent fracture zone.

Finally, each of the NC-EWDP-19IM2 logs shown in Figure 4.4-2, with the exception of the caliper log, shows a different response above the water table than below. In general, these logs change more rapidly with depth between the bottom of the surface casing and the water table than below the water table. This may in part be a result of drilling mud properties changing with depth, as well as different distances of penetration of mud into the unsaturated formation materials as a function of increasing pressure head with borehole depth.

4.4.2.2 Logs from NC-EWDP-23P

Gamma, temperature, and density logs for NC-EWDP-23P in Figure 4.4-2 indicate the water level in this borehole is approximately 425 ft bgs. The water within the borehole contains a significant quantity of suspended drilling fluid additives (Appendix A) used to try to free the BHA in the lower portion of the hole. The low formation resistivities observed between 600 and 700 ft bgs likely reflect the presence of these drilling additives. Moreover, the formation resistivity curves coalesce into almost a single curve in this region, indicating constant values extending laterally into the formation. This may suggest that drilling fluids have penetrated a large distance into the formation over this depth interval.

A small change in slope of the fluid temperature log at approximately 660 ft bgs suggests that warmer water may be entering the borehole below this depth. Peaks in formation resistivities between 660 and 670 ft bgs roughly correlate with the fluid temperature log peak and suggest that fresh water may be entering at this depth interval. However, the borehole fluid resistivity log shows no indication of fresh water, which may indicate that the fresh water is being held back by drilling fluids and has not yet entered the borehole. A peak in the spontaneous potential at approximately this same interval supports this hypothesis by indicating a difference in the composition of fluids in the borehole and in the formation. Finally, the decrease in the moisture (neutron) log counts over this depth interval indicates an increase in water-filled porosity, possibly suggesting a higher permeability zone.

The caliper log shows a significant increase in the borehole diameter and numerous wash-out zones beginning at the water table and extending to approximately 570 ft bgs. In addition, the caliper log also indicates a significant increase in borehole diameter at approximately 690 ft bgs. Data on the volume of Bensand added between 712 and 700 ft bgs to seal off the caved portion of the borehole prior to well completion indicate that this significant wash-out zone extends to at least 712 ft bgs. It is likely that these regions of borehole continued to erode and cave while the remaining portion of the borehole was drilled. Caving from these regions may have been responsible for sticking the BHA in the borehole and ultimately requiring "shooting off" this assembly and abandoning the portion of the borehole below 700 ft bgs.

4.5 SUMMARY LITHOLOGY LOGS AND CROSS SECTIONS

Summary lithologic logs from one borehole from each Phase III drill site are presented in Appendix H. An example of a log from a borehole along the major axis of Fortymile Wash (NC-EWDP-10SA) is presented in Figure 4.5-1, and a log from a borehole located adjacent to volcanic outcrops on the western margin of Fortymile Wash (-18P) is presented in Figure 4.5-2. The alluvium section of each log is divided into major textural units based on the USCS texture group names, as determined from the laboratory analysis of PSDs of drill cuttings and drive-core samples (Sections 4.2 and 4.3). The soil classification parameters used to describe each unit in more detail are listed on the alluvium logging form (Table 4.1-1). Rock units underlying the alluvium were classified by major rock type and distinguishing features, as listed on the non-alluvium logging form (Table 4.1-2). Where possible, the formal unit names for volcanics are listed, primarily based on consultation with USGS and DOE geologists.

4.5.1 Trends in Lithologic Units in Individual Logs

Figure 4.5-1 shows that the alluvial section in borehole NC-EWDP-10SA becomes slightly finer-textured with depth, transitioning from a well-graded sand with silt and gravel (SW-SM) to a silty sand with gravel (SM) at approximately 350 ft bgs. The upper SW-SM unit is found in all EWDP boreholes drilled to date in Fortymile Wash; its thickness varies from approximately 289 to 450 ft bgs depending on location. The slightly finer-textured underlying SM alluvial unit in borehole NC-EWDP-10SA extends down to the contact with Tertiary volcanic conglomerate sediments and is also found in Phase III boreholes located at Sites NC-EWDP-19 and -22 along the current Fortymile Wash channel. This SM unit has been replaced by a significantly finer-textured clayey sand with gravel unit in NC-EWDP-23P, located approximately 1 mile east of the current Fortymile Wash channel. The potential impact of this finer-textured lower alluvial unit at NC-EWDP-23P on future contaminant migration from Yucca Mountain is discussed in the following section.

The texture classification for the lower part of this SM unit in Figure 4.5-1 is based on laboratory-measured PSDs from drill cuttings and core samples from the upper portion of the unit. PSD data from drill cuttings from the lower part of this unit were highly disturbed by drilling and therefore censored (Section 4.3). Moreover, PSD data from cores in nearby borehole NC-EWDP-10P do not extend below 745 ft bgs.

Similar extrapolations were necessary in the lower part of the SM unit in boreholes NC-EWDP-19IM2A and -22SA and in the lower part of the clayey sand with gravel (SC) unit in -23P. Notes are included on each summary lithology log to explain the specific extrapolations. Finally, the textural classification of the lowest most alluvial unit extending from 1,200 to 1,340 ft bgs in NC-EWDP-23P is uncertain because the drill cuttings samples were originally classified as a volcanic conglomerate bedrock unit and the fines were accordingly washed from the sample to facilitate describing the bedrock clasts. Subsequently, this interval was determined to be alluvial sediments rather than volcanic bedrock sediments.

Tuffaceous bedrock units penetrated in NC-EWDP-18P may potentially belong to the Paintbrush Tuff and Crater Flat groups (Figure 4.5-2). However, definite assignment of a specific unit name to each rock type logged is not possible because the conventional-circulation rotary-drilling method used to penetrate these units produced only very fine particle size drill cuttings. Many of the features that distinguish these units were not observable on these fine particle size drill cuttings. However, tentative preliminary assignments of formal tuff unit names have been assigned to bedrock units penetrated from top to bottom as follows: Topopah Spring Tuff, Calico Hills Formation, Prow Pass Tuff, Bullfrog Tuff, an unnamed pre-Bullfrog volcanic sandstone, and Tram Tuff. These preliminary assignments will be revised if and when additional data become available from Site NC-EWDP-18 during future phases of the EWDP.

4.5.2 Cross Sections of Alluvium and Upper Volcanic Rock Units in Fortymile Wash

The plan view of two cross-section lines prepared from summary lithology logs from EWDP boreholes in Fortymile Wash is shown in Figure 4.5-3. The two cross sections are shown in Figure 4.5-4. Summary lithology logs for all boreholes shown in these cross sections are found in Appendix H. These include logs from boreholes NC-EWDP-5S and -2DB that were drilled in Phases I and II, respectively.

The original logs for boreholes NC-EWDP-5S and -2DB were revised to be consistent with USCS textural group terminology used in Phase III. The resulting revised summary lithology logs for these boreholes presented in Appendix H do not contain all the detail found in Phase III summary lithology logs because detailed logging forms (Tables 4.1-1 and 4.1-2) were not used in earlier phases, the sample interval was larger, and laboratory PSD measurements were not routinely run. Moreover, all alluvium samples were washed free of fines prior to archiving, and therefore it was not possible to re-log the archive samples in a manner consistent with Phase III. Despite these difficulties, it is believed that the revised summary lithology logs for NC-EWDP-2DB and -5S are reasonable approximations of subsurface conditions.

The cross-section A-A' line in Figure 4.5-4 that approximately parallels the primary axis of Fortymile Wash and the current channel indicates the alluvial textural units are reasonably consistent among NC-EWDP-10SA, -22SA, and -19IM2A. However, between NC-EWDP-19IM2A and -2DB there is a discontinuity in the alluvial units underlying the uppermost SW-SM unit. This discontinuity may be related to a subsurface fault, as proposed in Figure 4.5-4. This fault may be the poorly defined Highway 95 Fault (Potter et al., 2002).

The volcanic sediments located at depth in NC-EWDP-2DB (only the uppermost layer of these sediments is shown in Figure 4.5-4) are commonly found in other EWDP boreholes located on the south side of the Highway 95 fault. These thick intervals of volcanic sediments differ significantly from the thick intervals of welded tuffs present closer to Yucca Mountain. Although the boreholes upgradient from NC-EWDP-2DB along cross section A-A' do not extend deep enough to penetrate welded tuffs, it is expected that these units or their equivalents are present at depth.

The B-B' cross section through boreholes NC-EWDP-5S, -23P, and -22SA is almost perpendicular to the primary axis of Fortymile Wash (Figure 4.5-4) and shows the presence of finer-grained alluvium sediments along the eastern portion of the wash. These finer-grained sediments may be older lake deposit sediments that have been eroded away in the central region of Fortymile Wash. Alternatively, the discontinuity may be related to faulting. These finer-grained sediments may help to limit the possible migration of contaminants from Yucca Mountain to alluvial sediments located on the eastern portion of Fortymile Wash. The coarser-grained higher-permeability sediments located in the central portion of Fortymile Wash may serve as preferential conduits for groundwater flow.

5.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

5.1 FINDINGS

The following findings are from Phase III drilling, logging, and testing of alluvial sediments and uppermost underlying bedrock units in lower Fortymile Wash.

5.1.1 Drilling, Coring, and Well Construction

Findings include:

- Borehole conditioning methods using small amounts of bentonite-based drilling mud in Phase III RC exploratory and RC piezometer boreholes successfully stabilized borehole walls and, with a few exceptions, did not contaminate drill cuttings samples; the exception was in NC-EWDP-23P, where conditioning methods failed to prevent caving of the borehole, sticking the BHA in the lower portion of the borehole.

- Well drilling, installation, and development approaches used in Phase III produced monitor wells and piezometers that showed little evidence of residual drilling fluids and additives. The exceptions were NC-EWDP-10S and -23P, which required additional development work.

- Well development in FM boreholes using the double swab and pumping approach was more effective than the single swab and low-volume air-lift approach.

- Core samples were successfully collected from both unsaturated and saturated alluvium in CA boreholes using drive-core methods with 2.0- and 2.5-ft-long by approximately 4-in. ID solid-tube core barrels.

5.1.2 Geologic and Borehole Logging

Findings include:

- Field estimates of the PSDs of the sand and fines fractions of drill cuttings samples (and the related USCS group symbols) differ significantly from lab measurements; therefore, these field estimates were censored for use in quantitative analyses. The field estimates and classifications made in earlier EWDP phases should only be used as an approximation of the general alluvial lithologies and are not suitable for quantitative analyses.

- Moisture content depth profiles in RC and CA piezometer boreholes provide evidence of lateral movement of lost circulation water from nearby FM boreholes.

- Little evidence of cementation was observed in saturated zone drill cuttings samples from boreholes at Sites NC-EWDP-10 and -19; however, evidence of cementation was consistently observed in saturated zone drill cuttings samples from boreholes at Sites NC-EWDP-22 and -23.

- Drilling rates were generally highest in exploratory RC boreholes, followed by CA boreholes, followed by RC piezometer boreholes. This trend is related to borehole diameter as well as drilling system design and operating factors.

- Examination of a limited number of core samples indicates that clasts of relatively soft non-welded tuffs that are easily disturbed by drilling are present in significant percentages in gravel and various sand fractions in all depths sampled.

- Borehole geophysical logs provide valuable information on the impact of drilling fluids and additives on the formation fluids, the location of water production zones, and grout seals between well screens. In addition, these logs provide confirmation of the location of the water table and the contacts between alluvium and underlying rock units.

5.1.3 Laboratory Measurements on Geologic Samples and Drilling and Sampling Impacts

Findings include:

- Gravimetric water contents, ECs of soil-water extracts, and PSDs of unsaturated drill cuttings appear to be disturbed from in situ conditions less by faster drilling rates than by slower drilling rates.

- Saturated hydraulic conductivity measurements on core samples correlate inversely with percent fines data and are significantly lower in magnitude than values calculated from much larger scale aquifer test measurements. Both of these trends are consistent with the findings of other workers.

- Adjacent 3-in.- and 6-in.-long core samples show a wide variation in laboratory-measured PSD, bulk density, porosity, and saturated hydraulic conductivity values. These limited data indicate that fluvial sedimentary processes created a highly layered alluvial sequence with contrasting lithologic and hydraulic properties.

- The magnitude and the number of narrow, well-defined peaks in the EC of soil-water extracts of drill cuttings from boreholes located along the primary axis of Fortymile Wash appear to decrease in the upstream direction. This may be related to increases in the duration of ephemeral surface water flows and associated increases in downward infiltration and percolation flux in the upstream direction.

- Laboratory-measured drill cuttings PSDs from RC exploratory and RC piezometer boreholes drilled primarily with compressed air are reasonably representative of in situ formation conditions throughout the unsaturated zone and in the uppermost part of the saturated zone. This conclusion is based on a limited comparison of laboratory PSD data from minimally disturbed core samples versus drill cuttings samples collected from approximately the same depth intervals in nearby boreholes at Sites NC-EWDP-10 and -22, as well as the similarity in PSD depth profiles between boreholes at these sites and at Sites NC-EWDP-19 and -23.

- However, once RC exploratory and RC piezometer boreholes begin to produce significant amounts of water at depths generally less than 100 ft below the water table, the laboratory-measured PSDs of drill cuttings deviated significantly from laboratory-measured PSDs of core samples and, by inference, the PSDs of in situ formation materials. As a result, laboratory-measured PSDs of drill cuttings beginning approximately 100 ft below the water table were censored in NC-EWDP-10SA, -19IM1A, -19IM2A, -22SA, and -23P.

- The deviations of laboratory-measured drill cuttings PSDs from core sample PSDs below the water table are most likely due to the grinding action of the rotary drill bit on relatively soft non-welded tuffs that is greatly facilitated by the production of large quantities of water at the drill bit generally beginning within the upper 100 ft of the saturated zone.

- Inadequate drilling fluid velocities in the unsaturated zone portion of all CA boreholes and sample handling errors in the saturated zone portion of these boreholes caused laboratory-measured PSDs of drill cuttings samples from these boreholes to be significantly disturbed from in situ conditions.

- As a result, it is not known if CA drilling disturbs samples below the water table to the same degree as RC drilling. However, other workers have found that CA drilling can yield drill cuttings samples from the unsaturated zone with laboratory-measured PSDs that are reasonably similar to drive-core samples and therefore to in situ conditions.

- Unsaturated zone alluvial drill cuttings from smaller-diameter exploratory RC boreholes appear to be slightly less disturbed from in situ conditions than similar drill cuttings from intermediate-diameter RC piezometer boreholes.

5.1.4 Trends in Lithostratigraphy

Findings include:

- Depth profiles of laboratory-measured PSDs in drill cuttings from boreholes located along the primary axis of Fortymile Wash (NC-EWDP-19IM2A, -22SA, and -10SA) are nearly identical throughout the unsaturated zone and the upper approximately 100 ft of the saturated zone.

- In all Phase III boreholes along the primary axis of Fortymile Wash, the alluvial section becomes slightly finer-textured with depth, transitioning from a well-graded sand with silt and gravel (SW-SM) to a silty sand with gravel (SM) at depths ranging from approximately 300 to 450 ft bgs The slightly finer-textured underlying SM alluvial unit extends down to various underlying volcanic rocks with contacts ranging from approximately 800 to 1,100 ft bgs. The texture classification for the lower part of this SM unit was extrapolated from laboratory-measured PSDs from drill cuttings and core samples from the upper portion of the unit. PSD data from drill cuttings from the lower part of this unit were highly disturbed from in situ conditions by drilling.

- Discontinuities in the alluvial and underlying bedrock sections between NC-EWDP-19IM2A and Phase II borehole -2DB, located approximately 1 mi. to the southwest, may be related to the presence of a fault (Highway 95 Fault) located between these boreholes.

- A cross section perpendicular to the primary axis of Fortymile Wash through several Phase III boreholes (NC-EWDP-22SA and -23P) and Phase I borehole (-5S) shows the presence of finer-grained alluvium sediments along the eastern portion of the wash. These finer-grained sediments may limit the eastward migration of possible future contaminants from Yucca Mountain and focus their transport in coarser-grained sediments along the central portion of Fortymile Wash.

5.2 RECOMMENDATIONS

Recommendations include:

- As a result of drilling-related disturbances to drill cuttings in Phase III RC boreholes (and possibly in CA boreholes), the collection of saturated alluvium geologic samples in future EWDP boreholes should be modified as follows: Drive-core samples should be collected at regular depth intervals (e.g., 20 to 40 ft) beginning approximately 100 ft below the water table. This will ensure the production of geologic samples from saturated alluvium with flow-and-transport-related parameters that are (to the extent possible) representative of in situ conditions.

- The possibility that the PSDs of drill cuttings collected below the water table in Phase I and II RC boreholes were also significantly disturbed should be considered. For example, the analysis and interpretation of laboratory tests of flow-and-transport-related parameters conducted by the NWRPO and DOE contractors on drill cuttings samples from NC-EWDP-19D should take into account the possibility that these samples contain elevated percentages of fines and reduced amounts of gravel compared to in situ conditions.

- To facilitate field and laboratory measurements, and to ensure core samples are as representative of in situ conditions as possible, core samples should be driven a sufficient distance to completely fill and tightly pack each core barrel. Core samples collected in this manner are more likely to approximate in situ conditions than core samples collected from partially full core barrels.

- To obtain a realistic small-scale picture of layering in alluvial sediments and the variability in hydraulic parameters measured on these layers, a number of adjacent core segments from each 2.0- to 2.5-ft core run must be subjected to laboratory tests.

- To facilitate developing future FM monitor wells, more aggressive double swab and pumping development methods, rather than single swab methods, should be used.

- To support bulk density calculations from drilling-related data in the unsaturated zone in future EWDP phases, drill cuttings should be collected and weighed both during drilling and hole cleaning operations to ensure the total drill cuttings sample from each drilled interval is available for total weight and water content measurements.

6.0 REFERENCES

API (American Petroleum Institute). 1997. Recommended Practice 31A, Standard Form for Hardcopy Presentation of Downhole Well Log Data, First Edition, American Petroleum Institute.

ASTM D-422. Standard method for Particle Size Analysis of Soils. In: *1996 Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.

ASTM D-854-92. Standard test method for specific gravity of soils. In: *1996 Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.

ASTM D-1140-97. Standard test method for amount of material in soil finer than the No. 200 (75 um) sieve (Method B for wet sieve analysis). In: *1997 Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.

ASTM D-2216-92. Method for laboratory determination of water (moisture content) of soil, rock, and soil-aggregate mixtures. In: *1996 Annual Book of ASTM Standards,* Vol. 04.08, American Society for Testing and Materials.

ASTM D-5753-95. Standard Guide for Planning and Conducting Borehole Geophysical Logging.

Blake, G. R. and K. H. Hartge. 1986. "Bulk Density." In: Klute, A. (ed), *Methods of Soil Analysis,* Part 1, Physical and Mineralogical Methods (2nd ed.), American Society of Agronomy, Chapter 13, pp. 363-367.

Davis, J. C. 1986. *Statistics and Data Analysis in Geology.* 2nd Edition. John Wiley & Sons, Inc.

Hammermeister, D. P., D. O. Blout, and J. C. McDaniel. 1986. "Drilling and coring methods that minimize the disturbance of cuttings, core, and rock formations in the unsaturated zone, Yucca Mountain, Nevada." In *Proceedings of the NWWA Conference on Characterization and Monitoring of the Vadose (Unsaturated) Zone, Denver, Colorado,* 507-541. Worthington, Ohio: National Water Well Association.

Keys, W. S. 1990. "Techniques of Water-Resource Investigations of the United States Geological Survey," *Borehole Geophysics Applied to Ground-Water Investigations,* Book 2, Chapter E2. Denver, Colorado: U.S. Geological Survey.

Klute, A. , and C. Dirksen, 1986. "Hydraulic Conductivity and Diffusivity: Laboratory Methods." In: Klute, A. (ed), *Methods of Soil Analysis,* Part 1, Physical and Mineralogical Methods (2nd ed.), American Society of Agronomy, Chapter 28, pp. 694-700.

NAC (Nevada Administrative Code) 534.

NWRPO. 2001a. *NWRPO Independent Scientific Investigations Program Final Report, Fiscal Years 1996–2001.* Technical Report No. NWRPO-2001-04. Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

NWRPO. 2001b. *NWRPO Quality Assurance Program Plan,* Rev. 3. Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities. 37 pp.

NWRPO. 2002a. *Preliminary Analysis of 48-Hour Pump Tests in Well NC-EWDP-10S, Near Yucca Mountain, Nevada.* Technical Report No. NWRPO-2002-07. Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

NWRPO. 2002b. *Preliminary Analysis of Pump-Spinner Tests and Pump Test in Well NC-EWDP-22S, Near Yucca Mountain, Nevada.* Technical Report No. NWRPO-2002-06. Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

Potter, C. J., R. P. Dickerson, D. S. Sweetkind, R. M. Drake II, E. M. Taylor, C. J. Fridrich, C. A. San Juan, and W. C. Day. 2002. *Geologic Map of the Yucca Mountain Region, Nye County, Nevada.* Geologic Investigations Series I–2755. Denver, Colorado: U.S. Geological Survey.

Rael, H. 2003. "Comparison of Schlumberger, EDCON, and GLS wireline data acquired in borehole NC-EWDP-19D." E-mail communication from H. Rael (BSC) to D. Hammermeister (Nye County), January 23, 2003.

Reamer, C. W. 1999. "Review of Nye County Quality Assurance Program for the Early Warning Drilling Program." Letter from C. W. Reamer (NRC) to L. Bradshaw (NWRPO), April 12, 1999, with enclosures, "Acceptance Evaluation of NWRPO Quality Assurance Program Plan."

Reynolds Electrical and Engineering Co., Inc. 1994. *Site Characterization and Monitoring Data from Area 5 Pilot Wells, Nevada Test Site,* Nye County Nevada. Special Projects Section, Environmental Management Division, Las Vegas, NV. DOE/NV/11432-74.

Rhoades, J. D. 1986. Soluble salts—Electrical conductivity of saturation extract. In: Page, A. L. (ed), *Methods of Soil Analysis,* Part 2, Chemical and Microbiological Properties (2nd ed.), American Society of Agronomy, pp. 172-173.

Schulze-Makuch, D., D. A. Carlson, D. S. Cherkauer, and P. Malik. 1999. "Scale Dependence of Hydraulic Conductivity in Heterogeneous Media." *Ground Water*, Vol. 37, No. 6, pp. 904-919.

Todd, D. K. 1980. *Groundwater Hydrology.* New York: Wiley. pp. 69–71.

Technical Procedure TP-7.0, Rev. 02. *Drill Site Management.* Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

Technical Procedure TP-8.0, Rev. 03. *Field Logging and Handling of Borehole Samples.* Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

USACE (U.S. Army Corps of Engineers). 1998. *Engineering and Design–Removal of Underground Storage Tanks (USTs).* U.S. Army Corps of Engineers Report EM 1110-1-4006.

Work Plan 5, Rev. 02. *Early Warning Drilling Program Phase III Drilling and Well Construction Work Plan.* Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

Work Plan 6, Rev. 01. *Early Warning Drilling Program Geophysical Logging Work Plan.* Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

Work Plan 8, Rev. 2. *Sample Management Plan.* Pahrump, Nevada: Nye County Department of Natural Resources and Federal Facilities.

FIGURES

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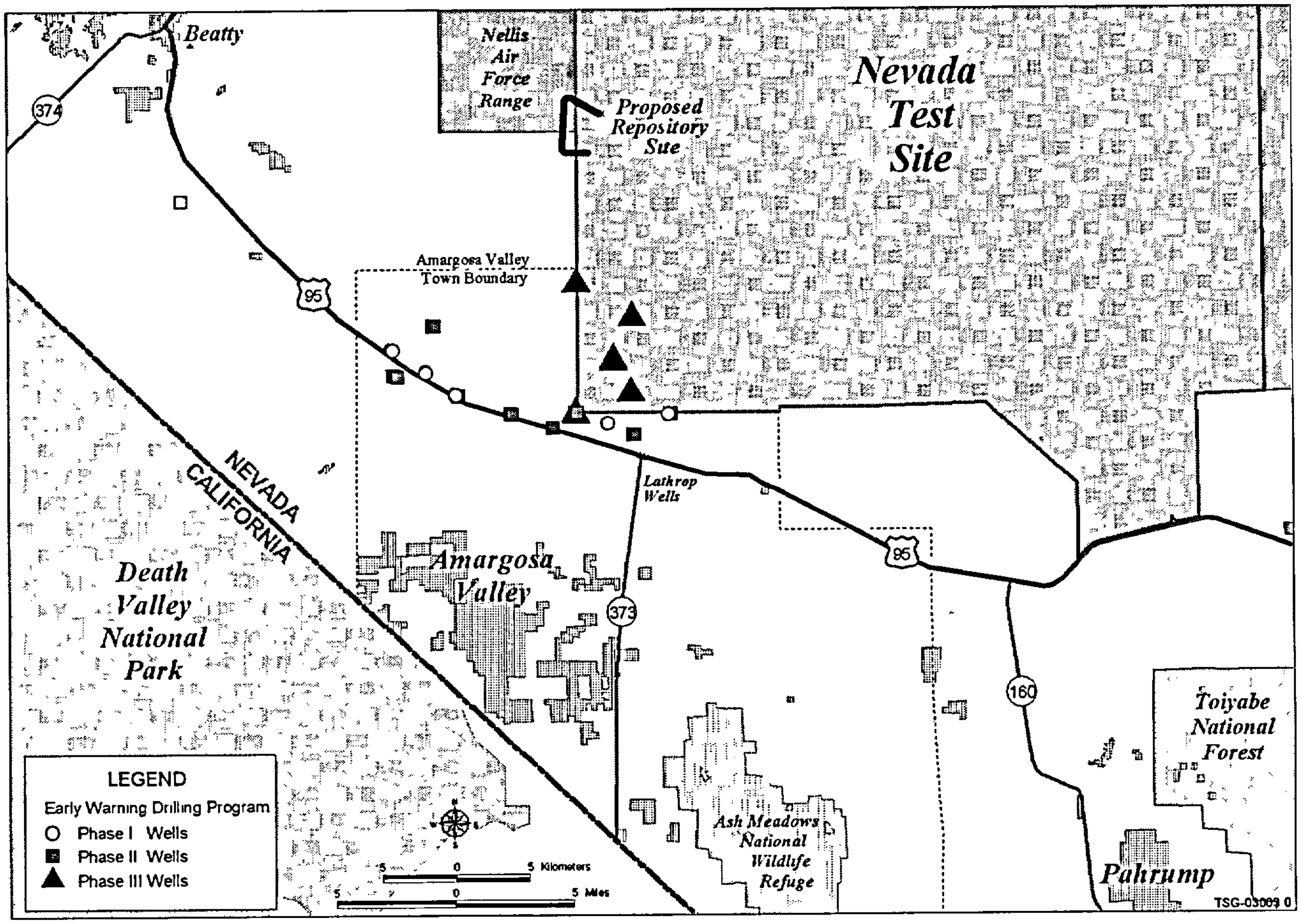
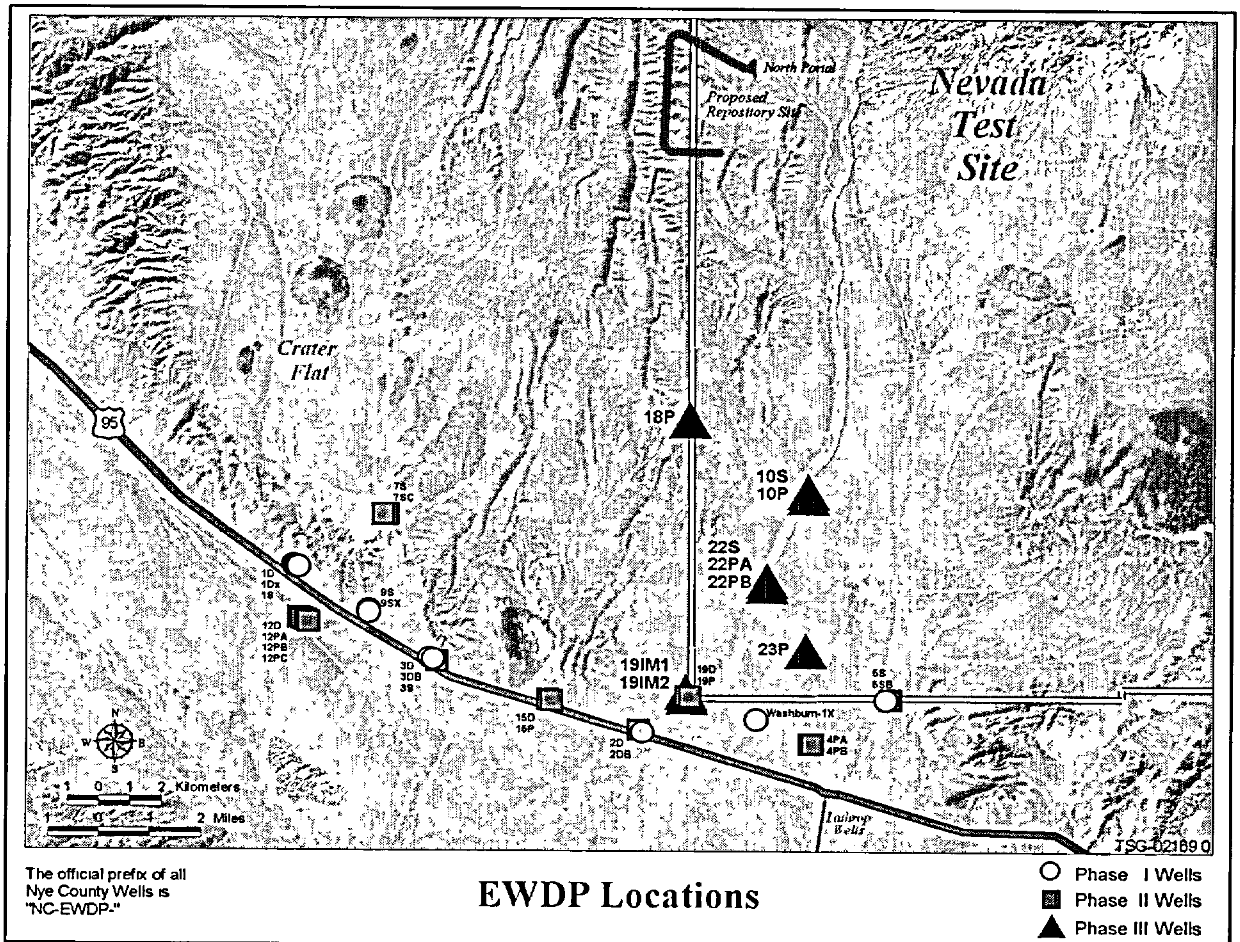


Figure 1.1-1
Early Warning Drilling Program Region



NOTE: EWDP = Early Warning Drilling Program

Figure 1.3-1
Early Warning Drilling Program Phase III Well Locations

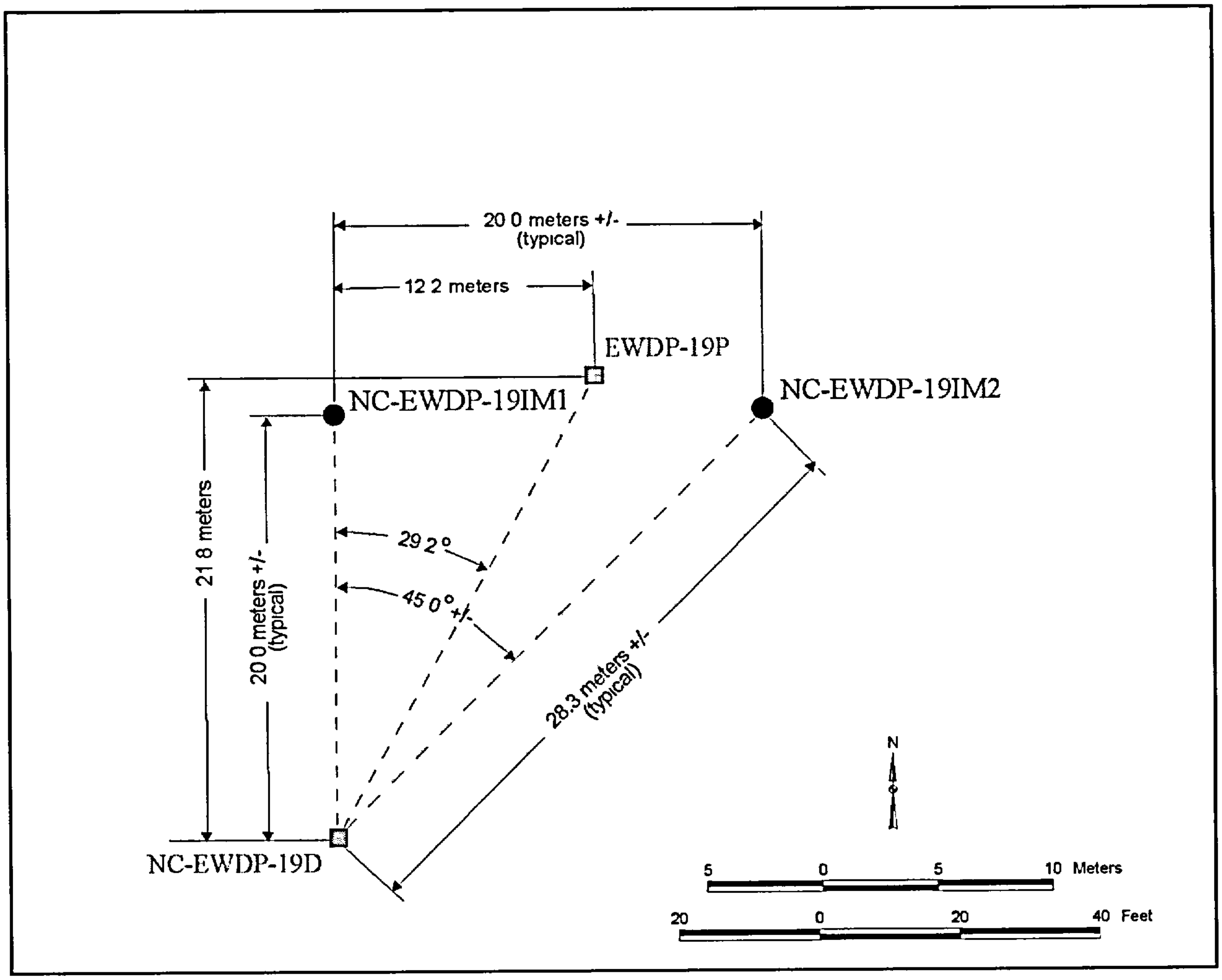


Figure 1.3-2
Alluvial Testing Complex Site Layout

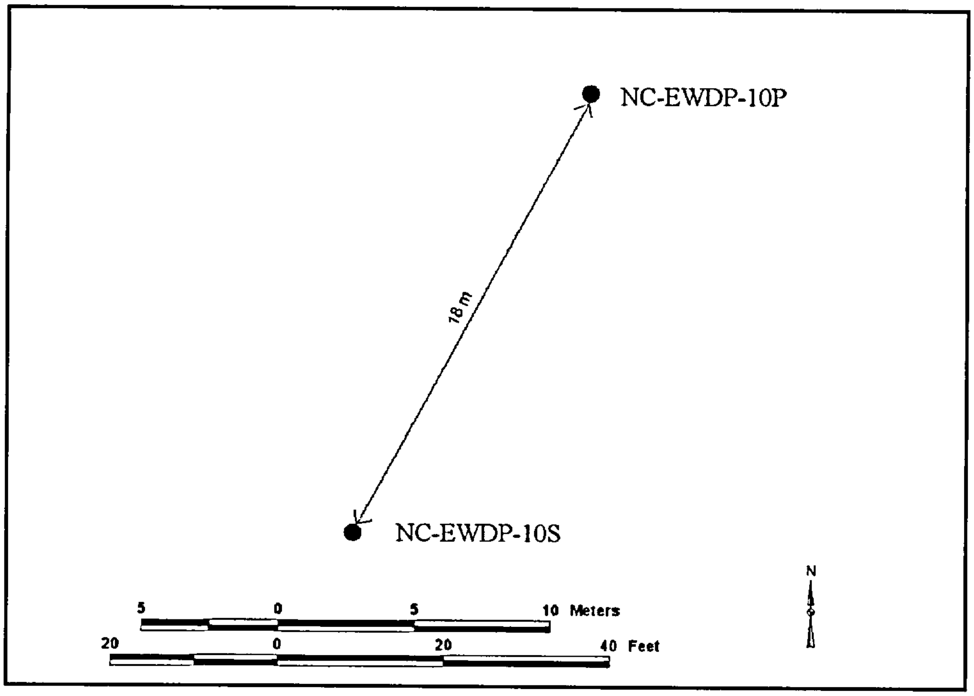


Figure 1.3-3
Well NC-EWDP-10 Site Layout

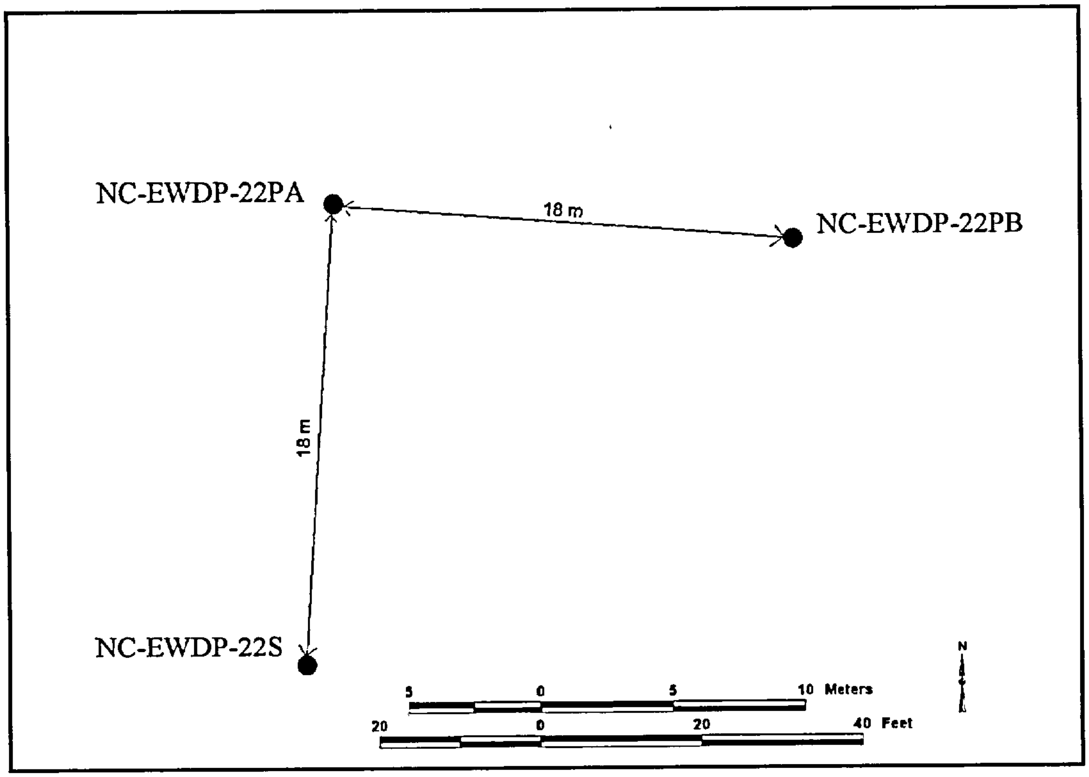
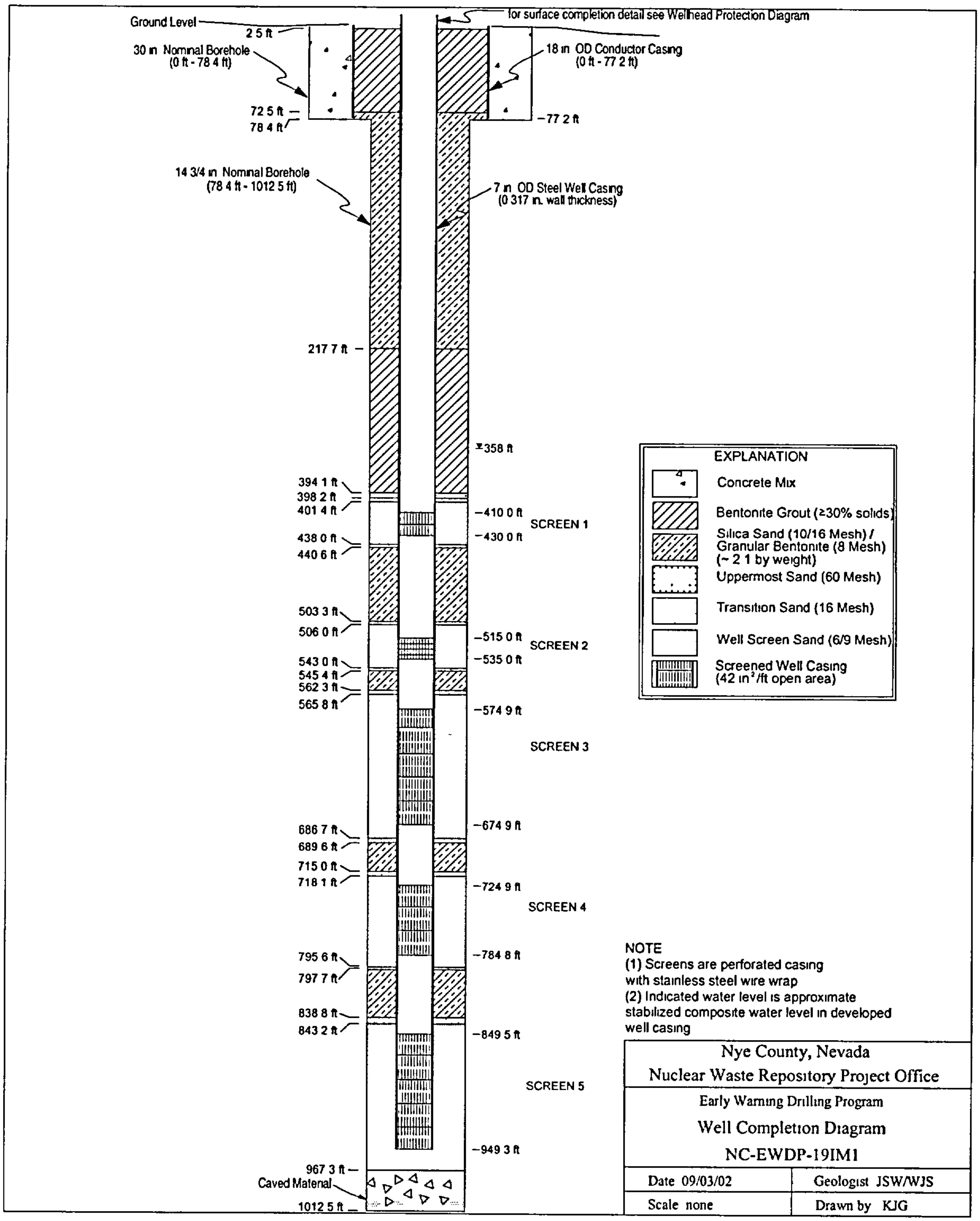
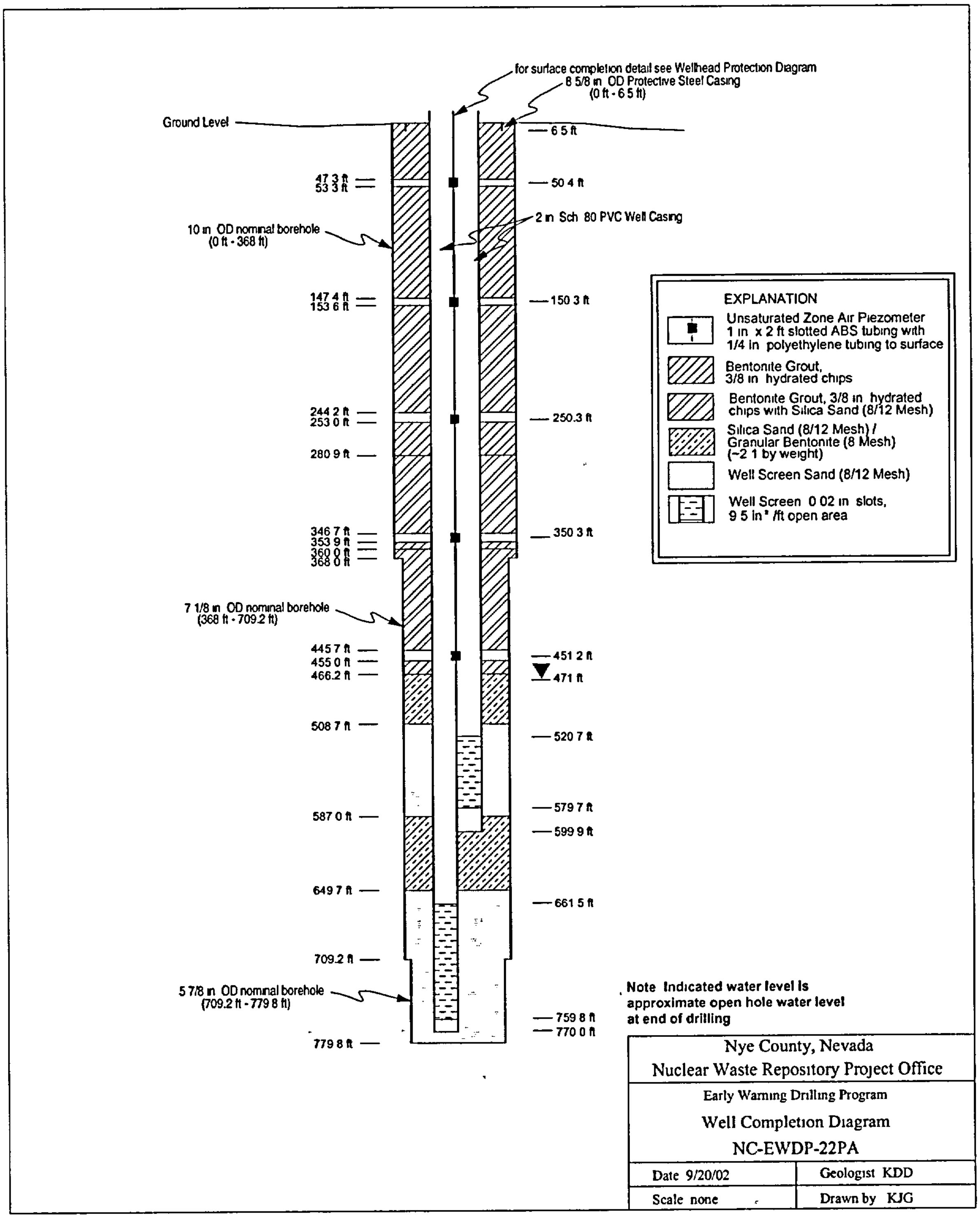


Figure 1.3-4
Well NC-EWDP-22 Site Layout



NOTE: OD = outside diameter

Figure 3.1-1
Typical Monitor Well Completion Diagram



NOTE: OD = outside diameter

Figure 3.1-2
Typical Piezometer Well Completion Diagram

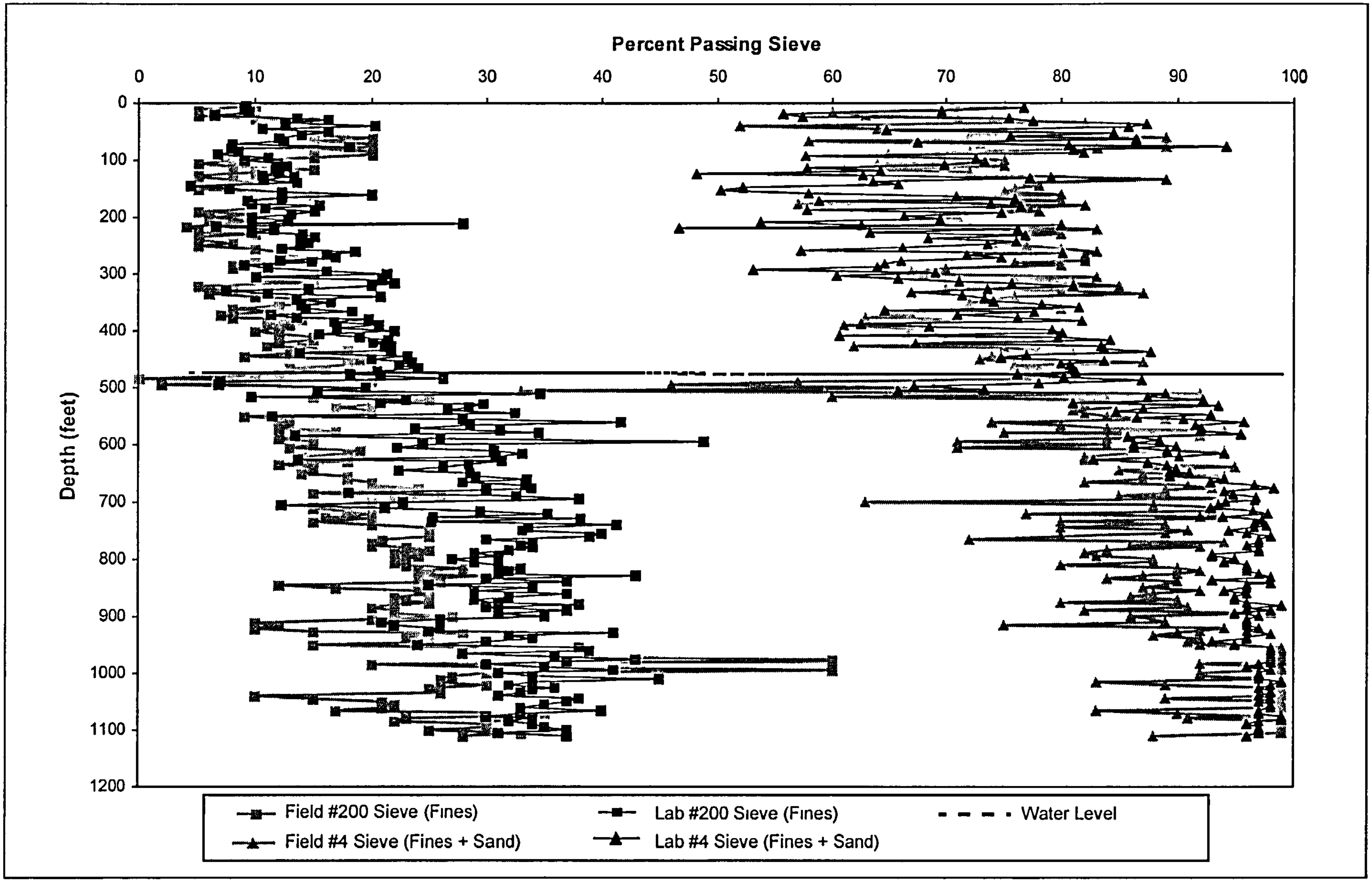


Figure 4.1-1
Field and Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Borehole NC-EWDP-22SA

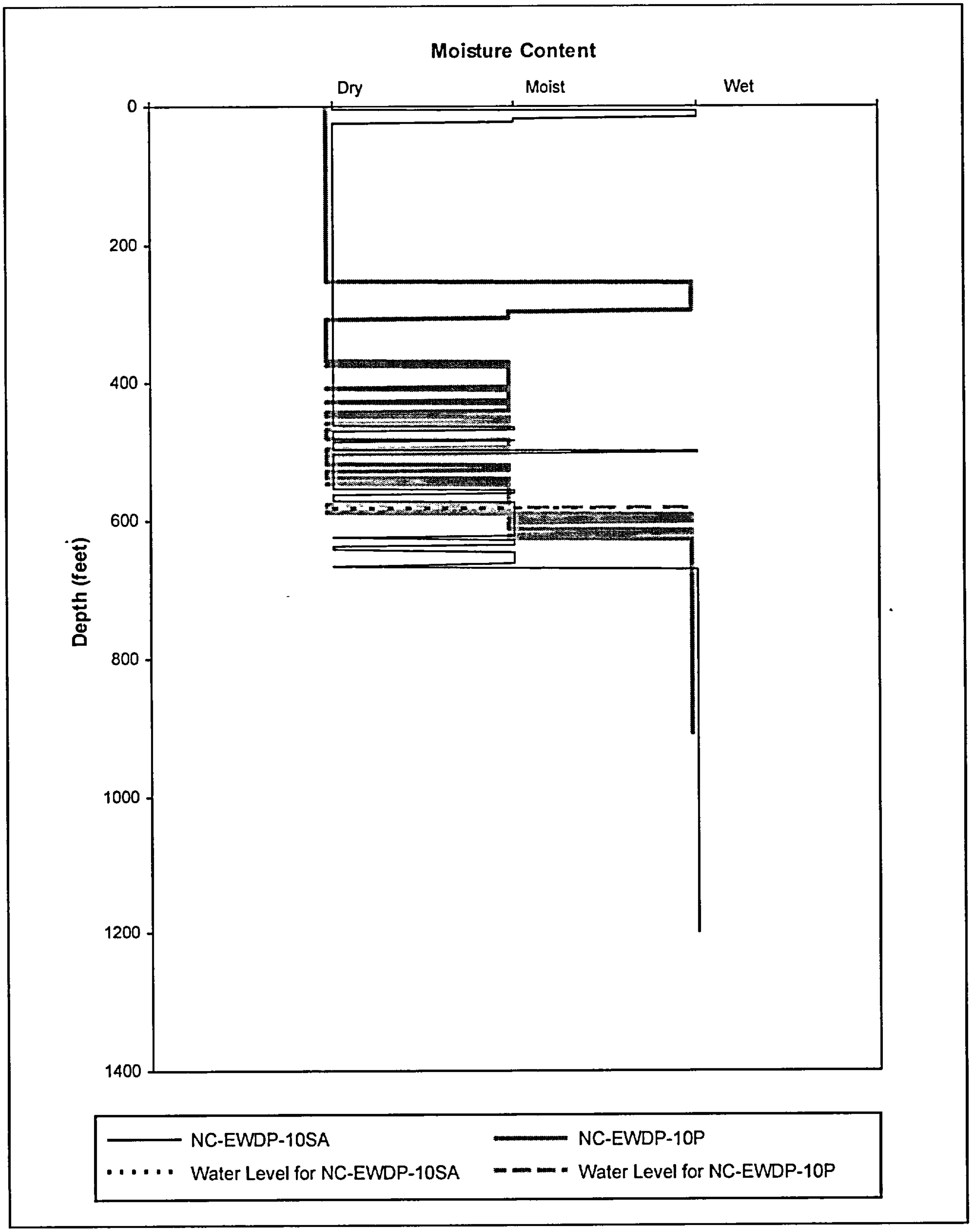


Figure 4.1-2
Moisture Content versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-10P

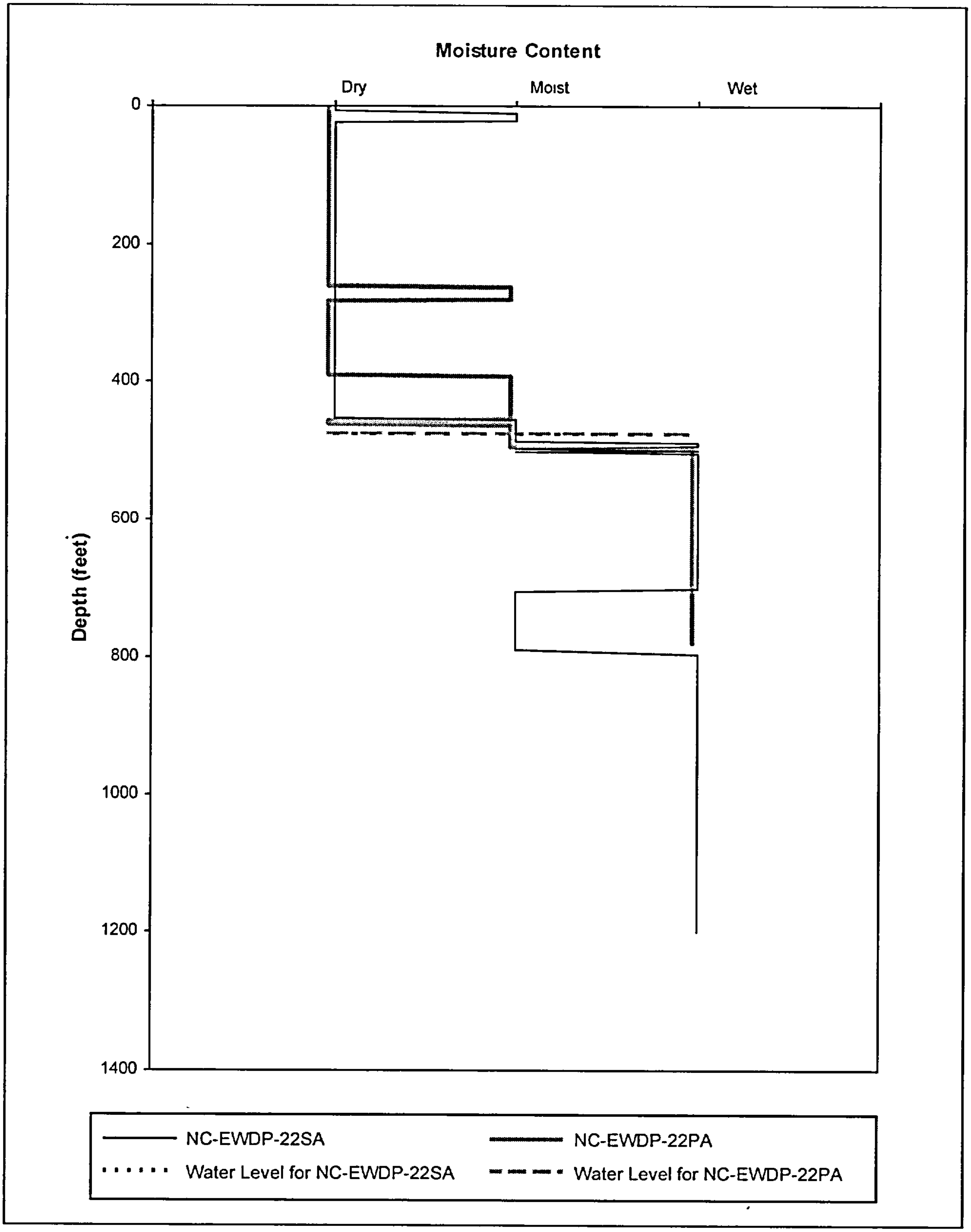


Figure 4.1-3
Moisture Content versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-22PA

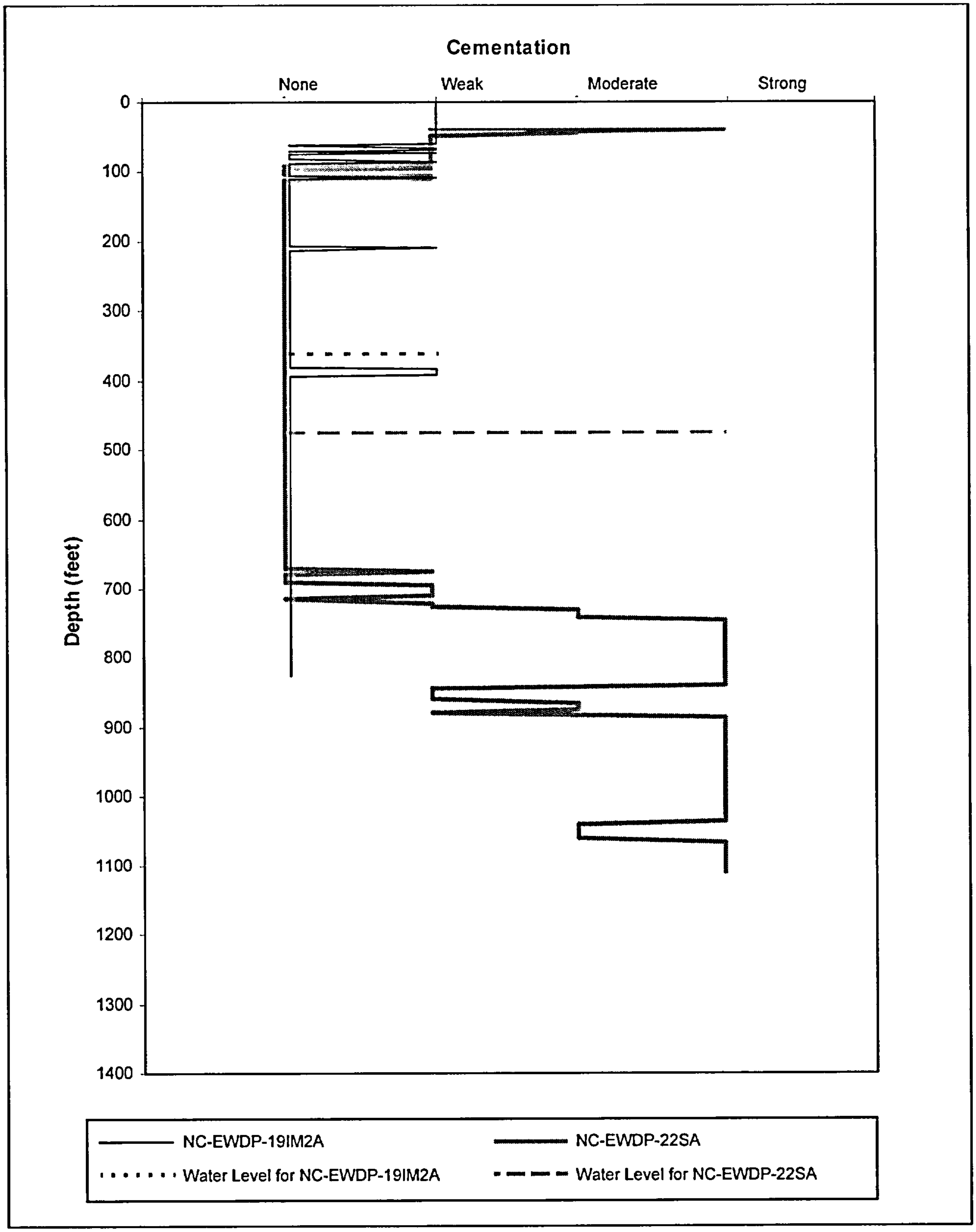


Figure 4.1-4
Cementation versus Depth in Alluvium
for Boreholes NC-EWDP-19IM2A and NC-EWDP-22SA

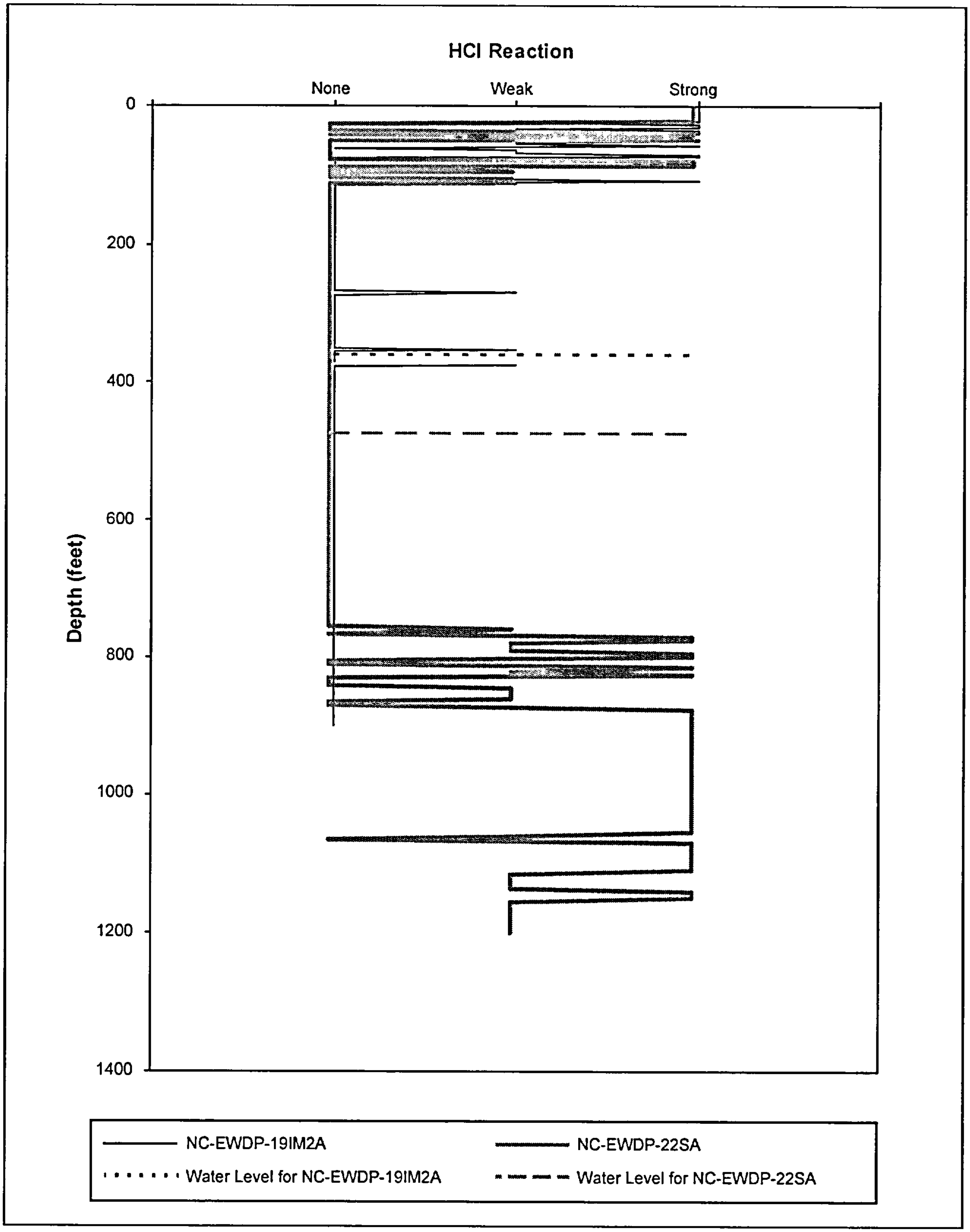


Figure 4.1-5
HCl Reaction versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-19IM2A and NC-EWDP-22SA

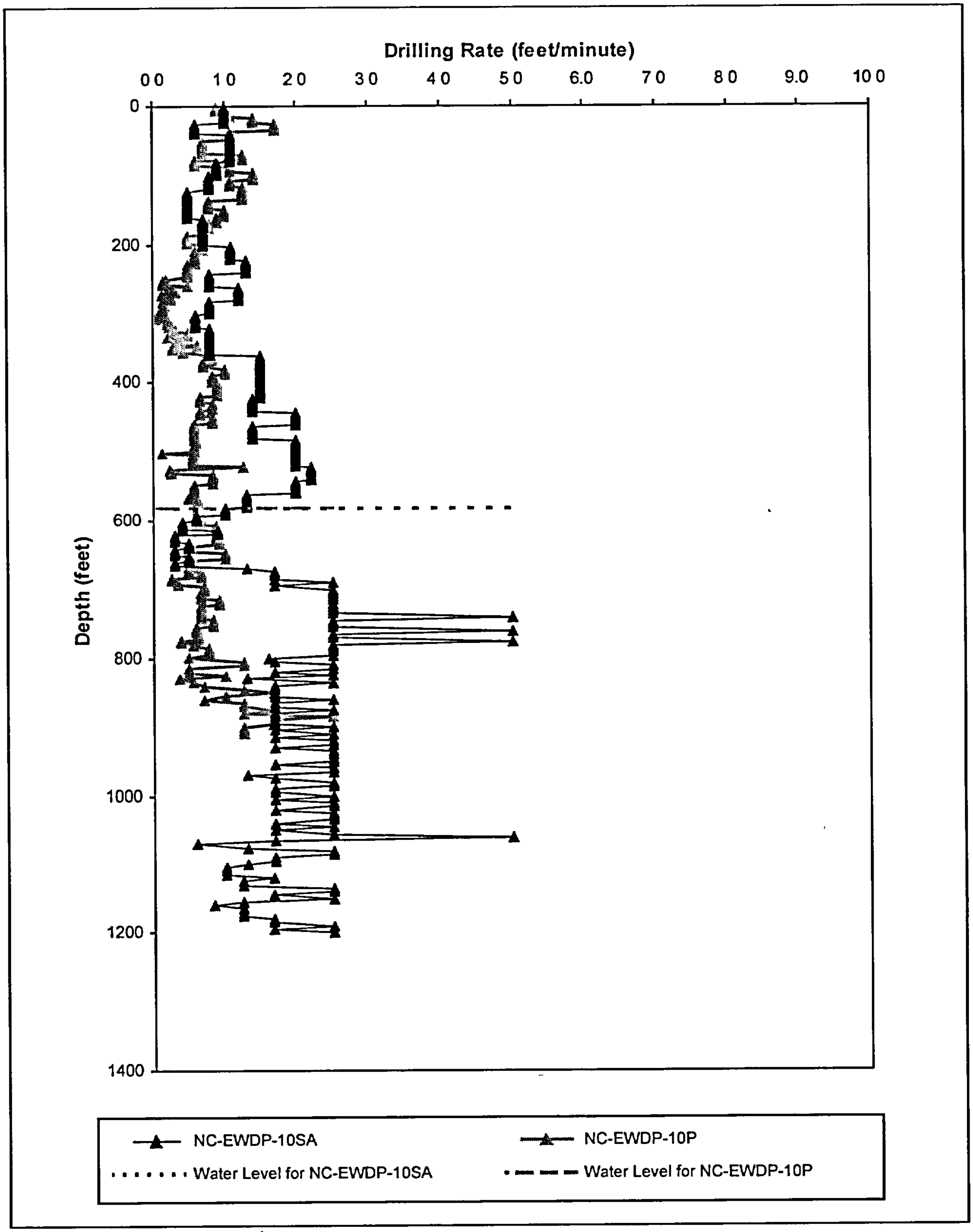


Figure 4.1-6
Drilling Rate versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-10P

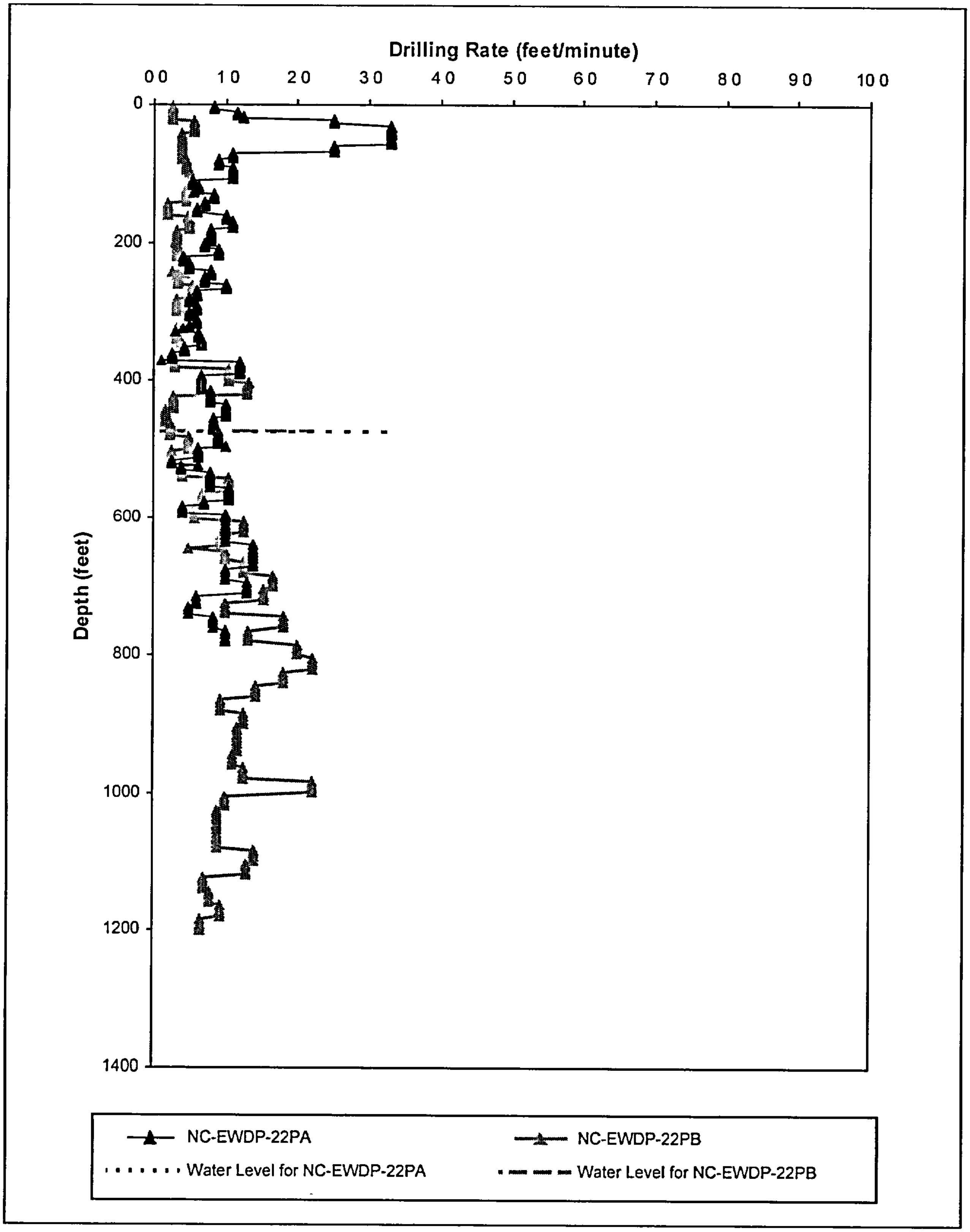


Figure 4.1-7
Drilling Rate versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-22PA and NC-EWDP-22PB

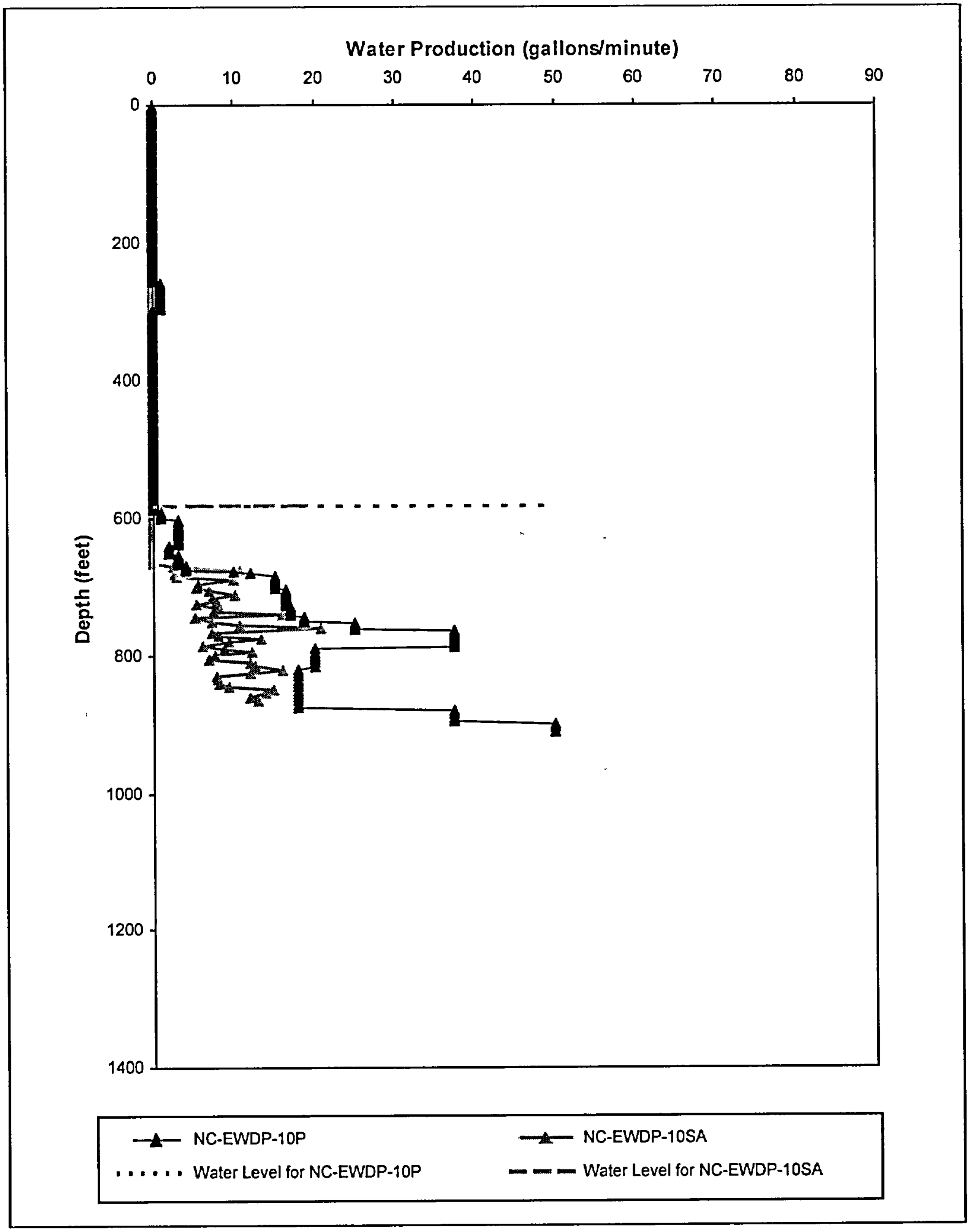


Figure 4.1-8
Water Production versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-10P and NC-EWDP-10SA

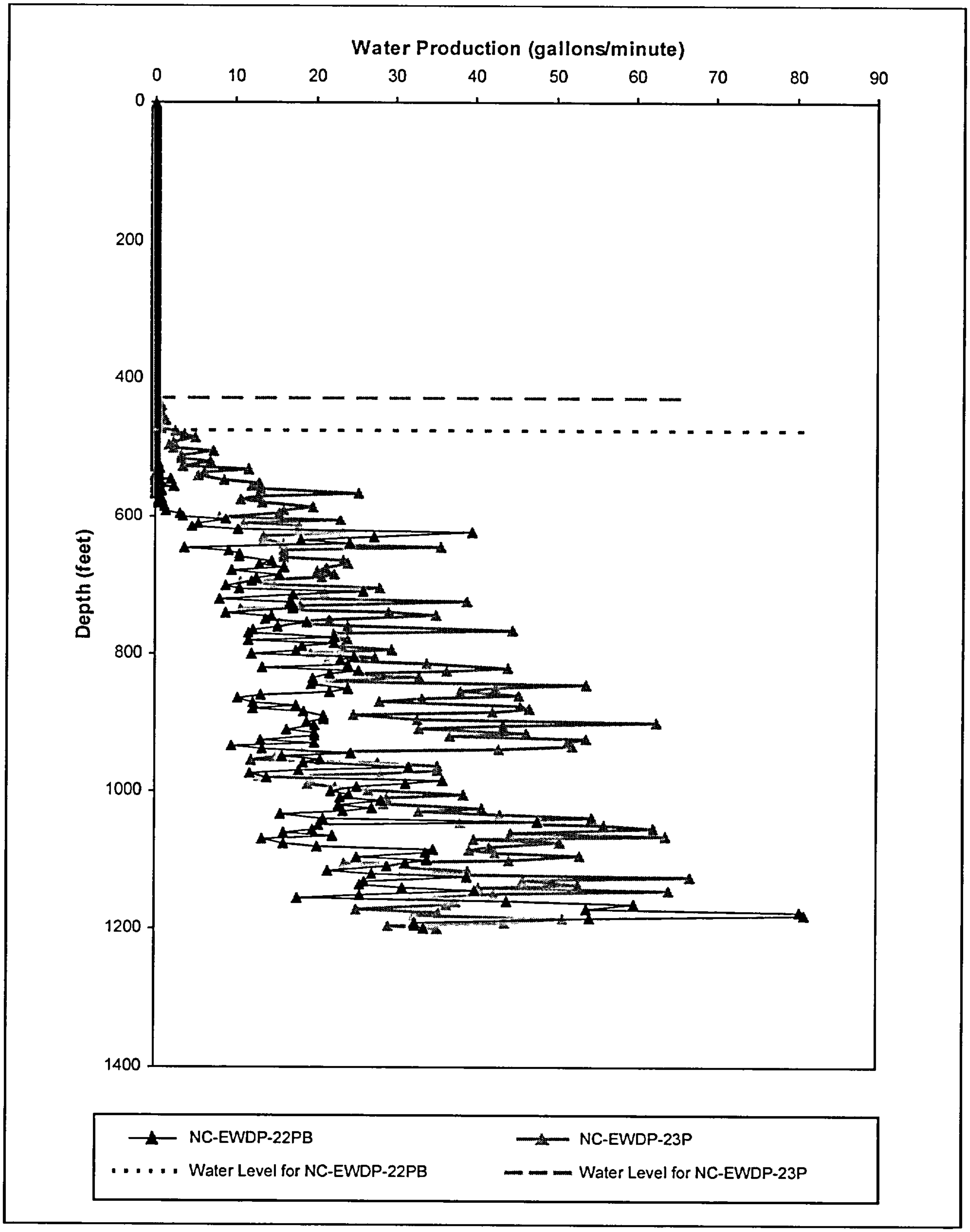


Figure 4.1-9
Water Production versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-22PB and NC-EWDP-23P

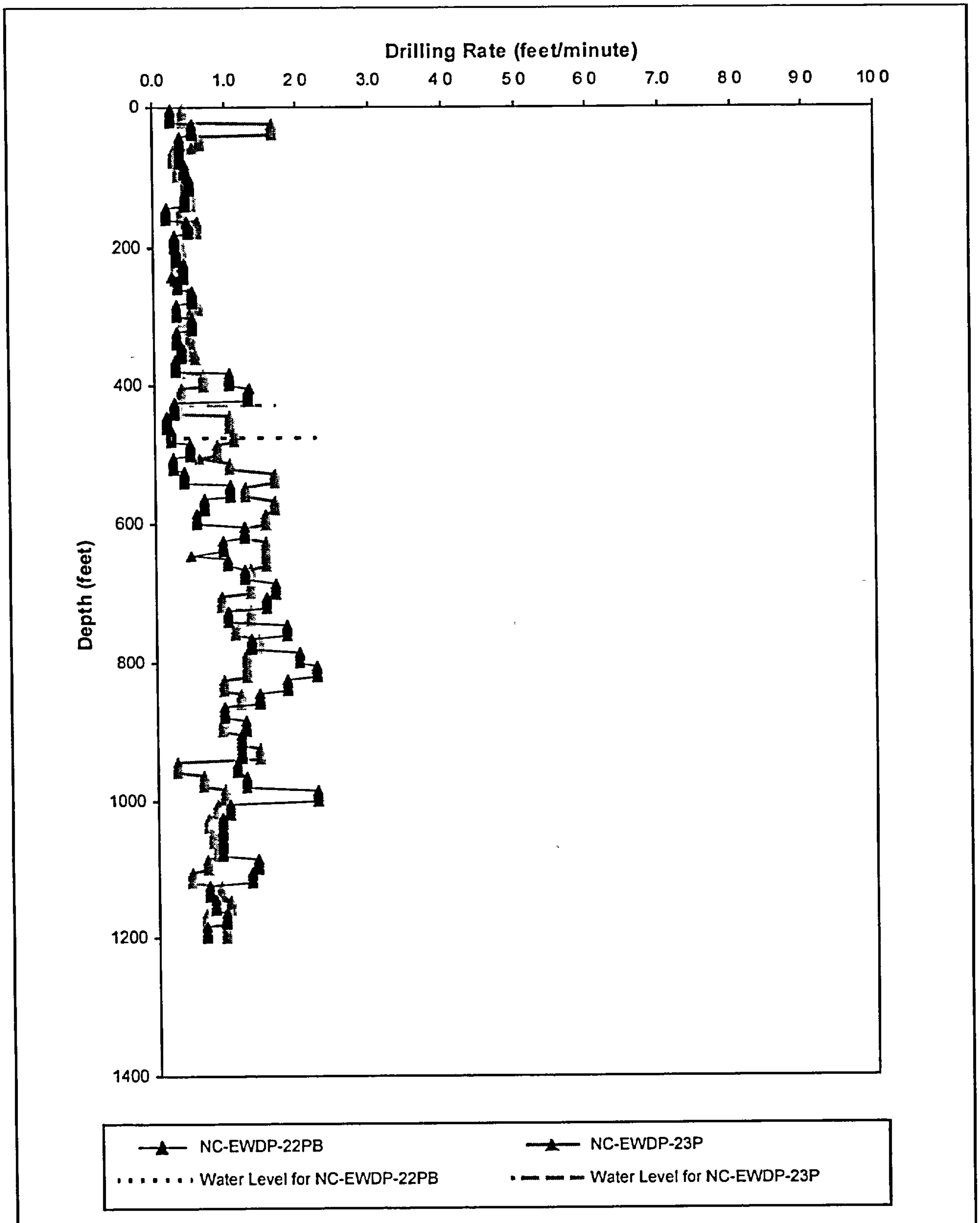


Figure 4.1-10
Drilling Rate versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-22PB and NC-EWDP-23P

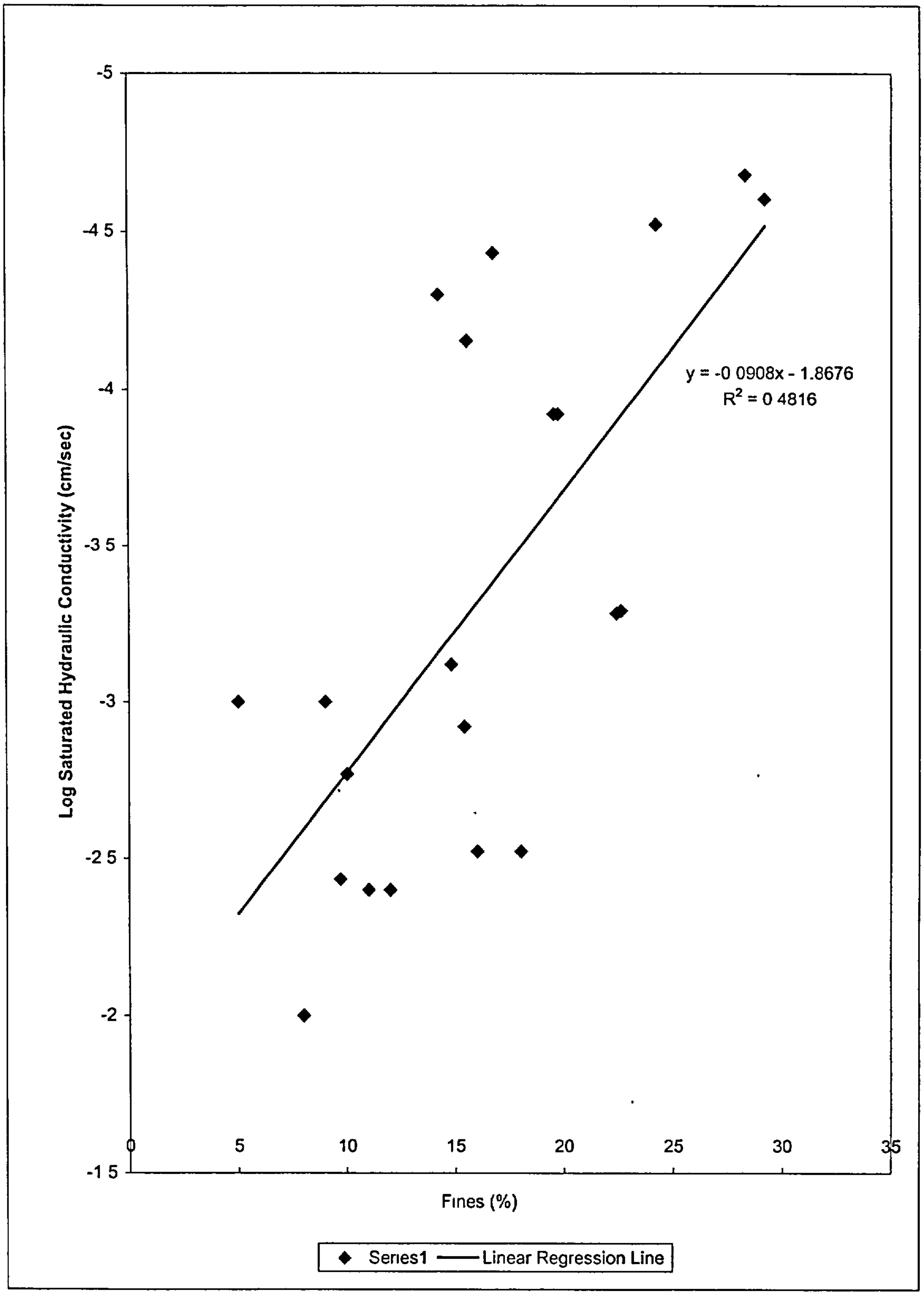


Figure 4.2-1
Comparison of Saturated Hydraulic Conductivity Data with Fines Data from Core Samples from Boreholes NC-EWDP-10P and NC-EWDP-22PA

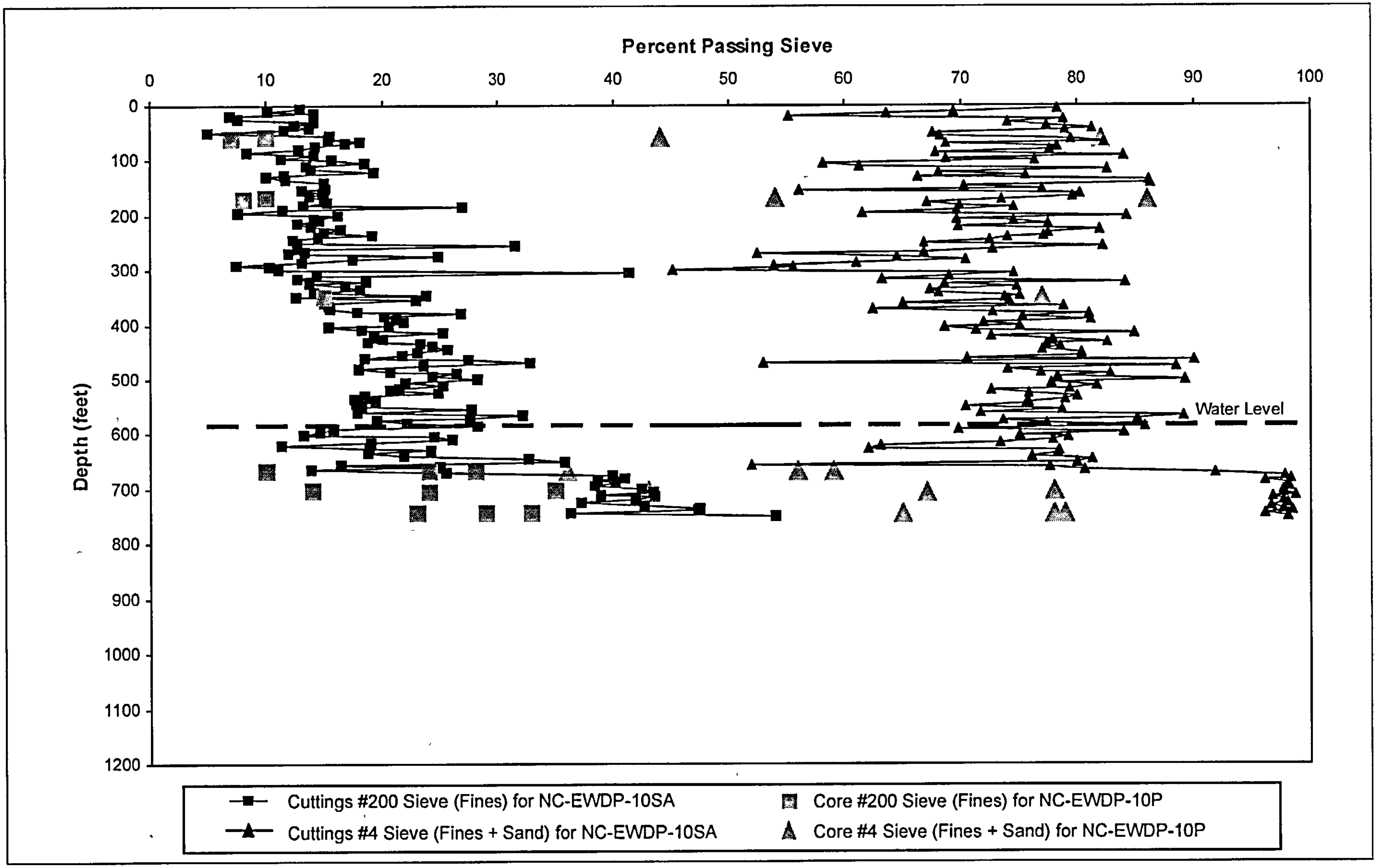


Figure 4.3-1
Laboratory Drill Cuttings and Core Particle Size Distributions versus Depth in Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-10P, respectively

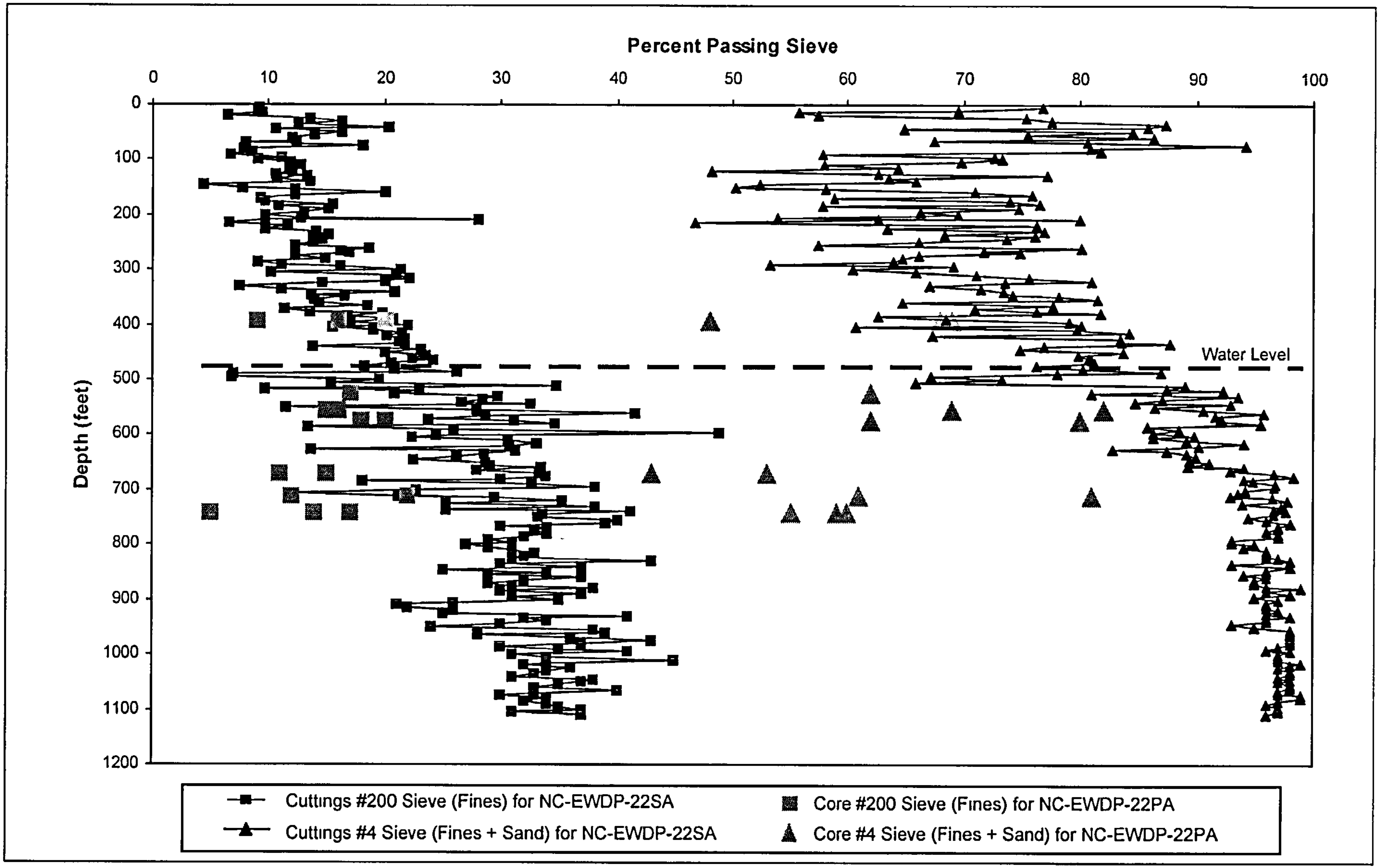


Figure 4.3-2
Laboratory Drill Cuttings and Core Particle Size Distributions versus Depth in Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-22PA, respectively

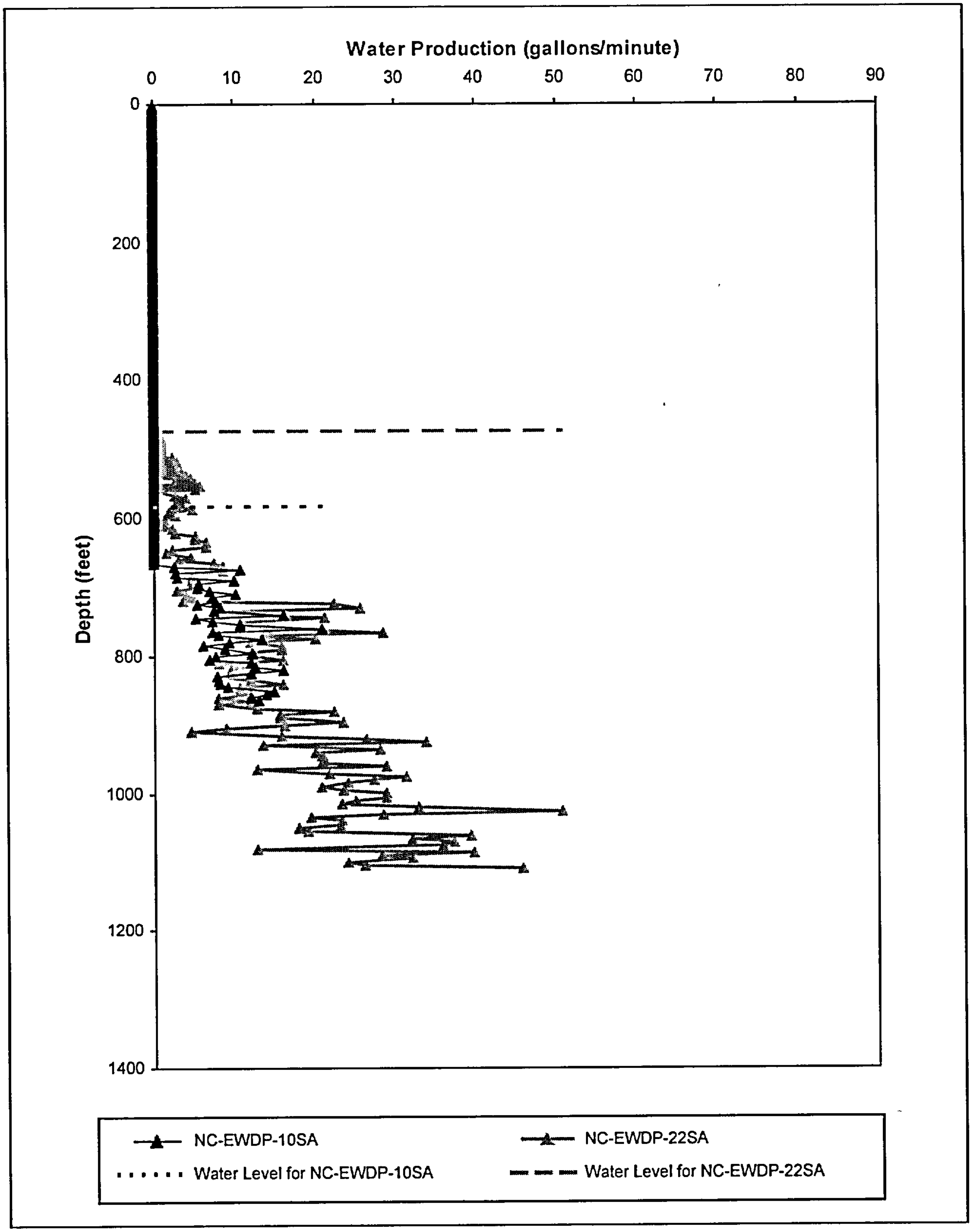


Figure 4.3-3
Water Production versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-22SA

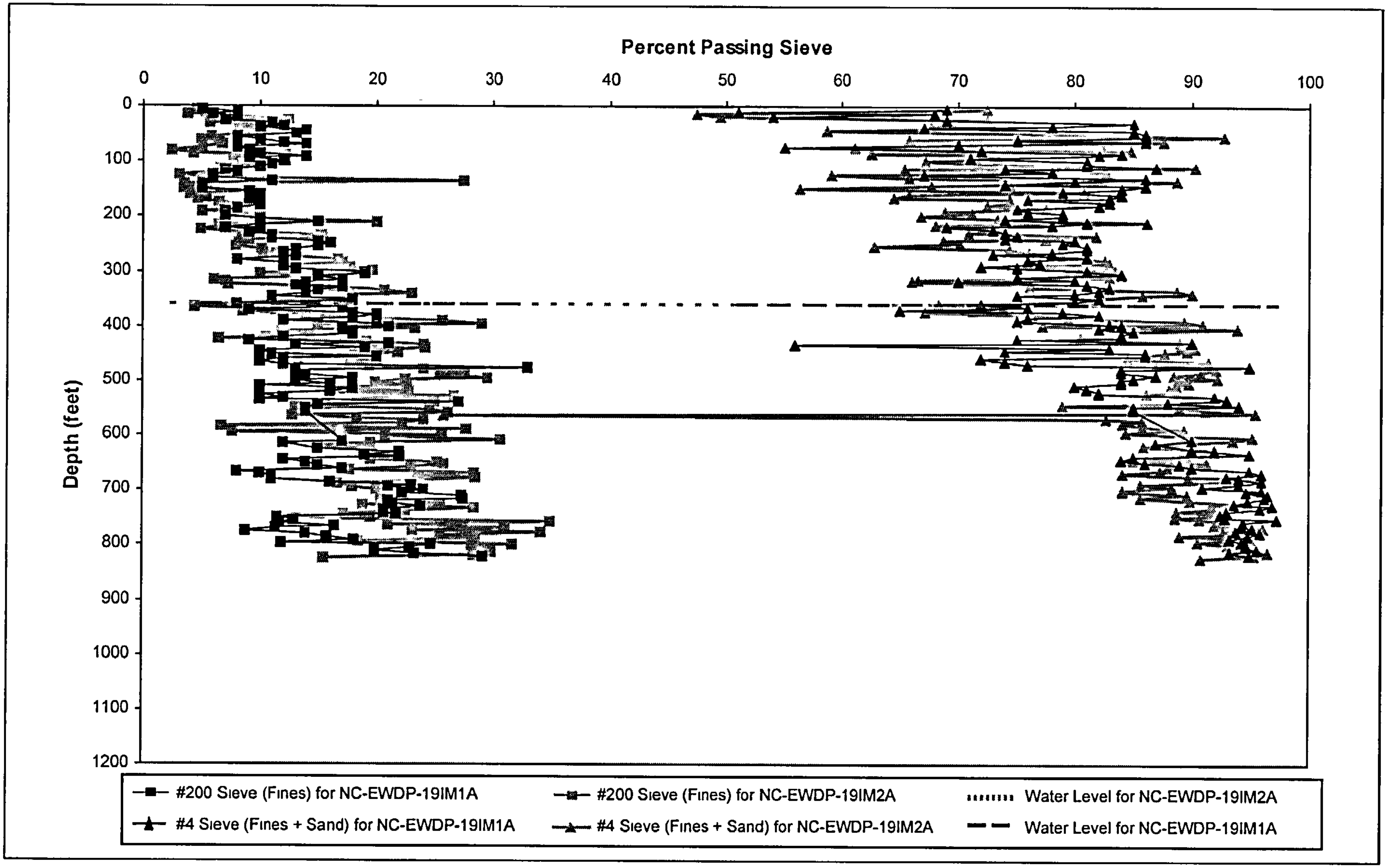


Figure 4.3-4
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-19IM1A and NC-EWDP-19IM2A

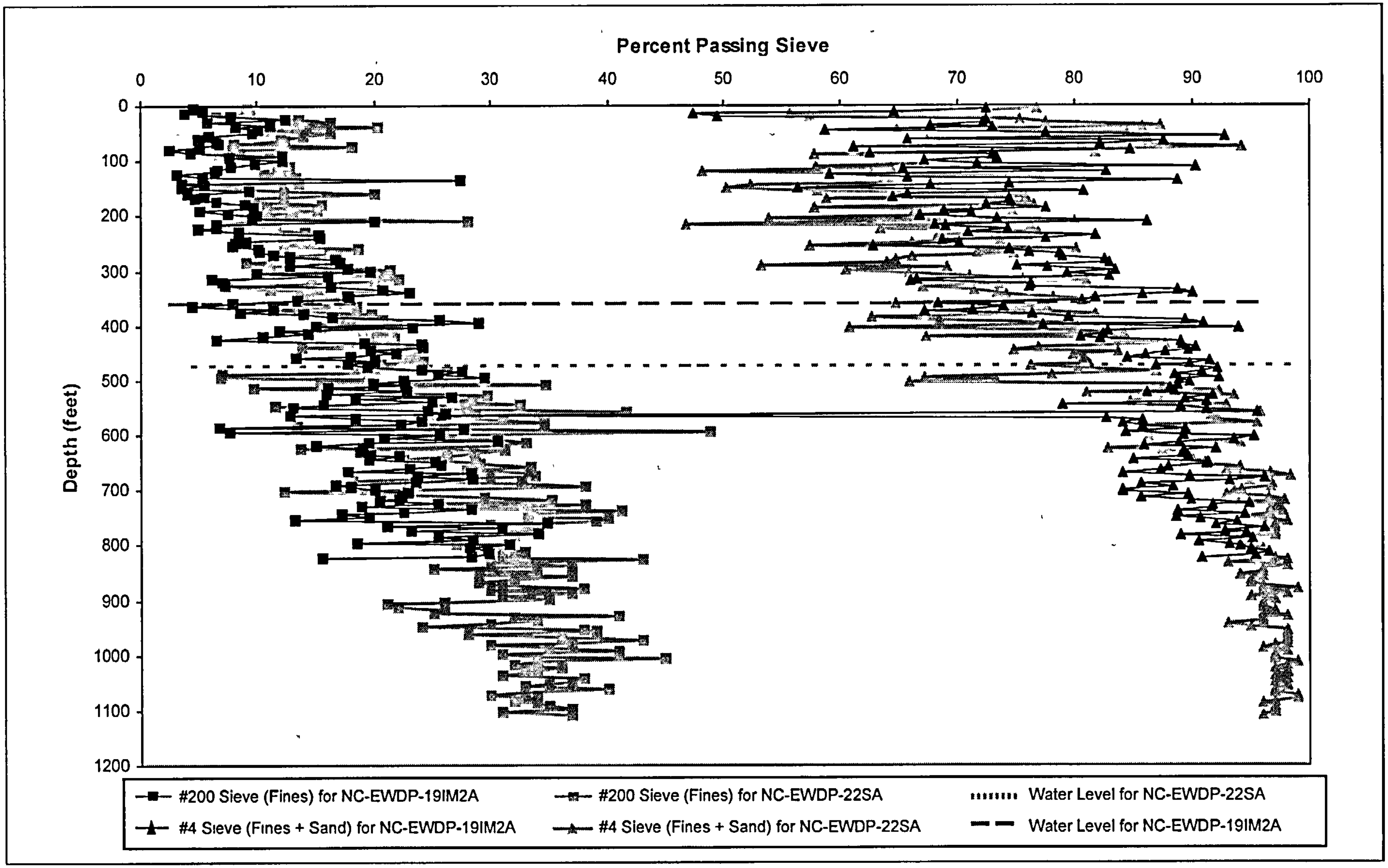


Figure 4.3-5
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-19IM2A and NC-EWDP-22SA

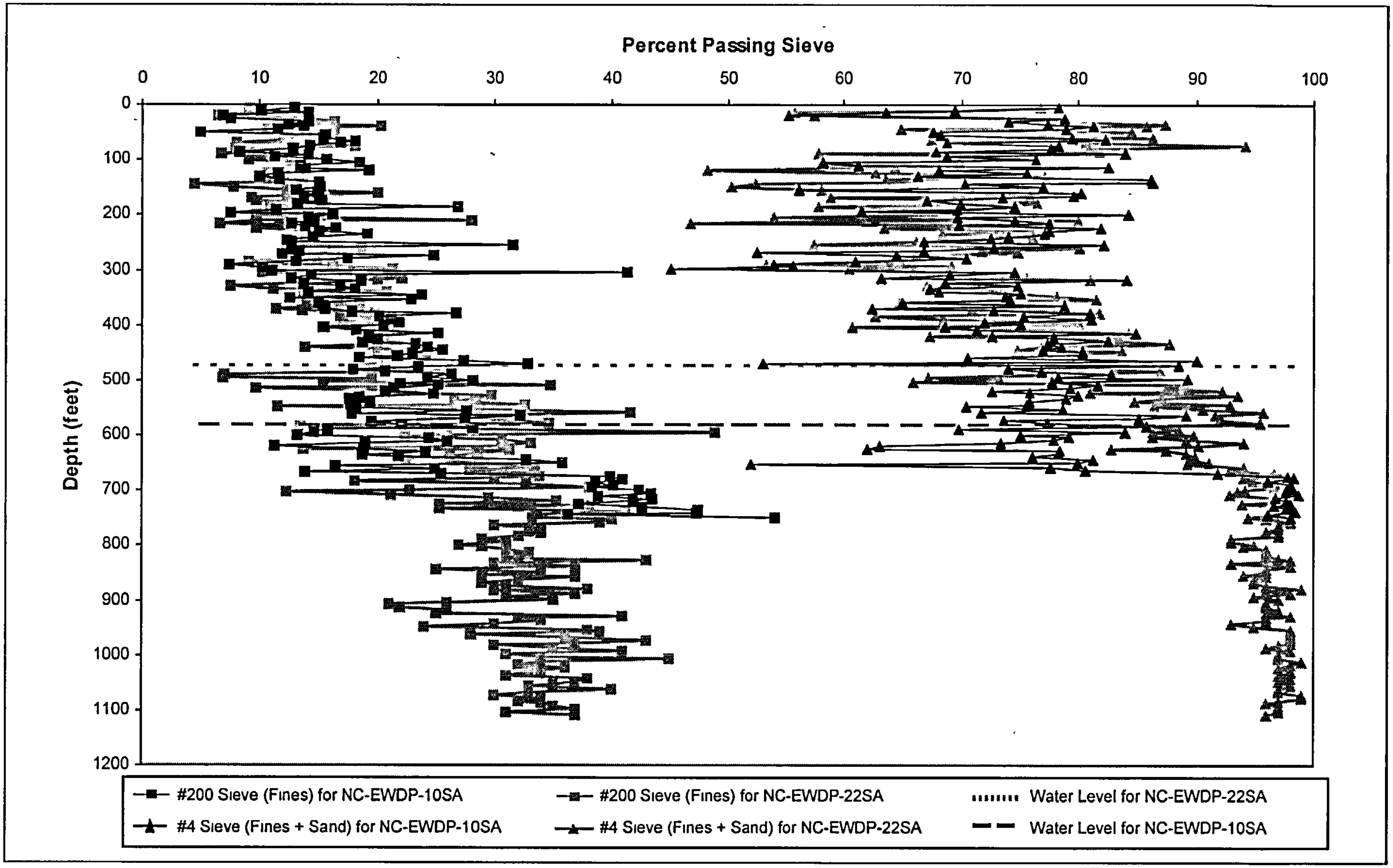


Figure 4.3-6
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-22SA

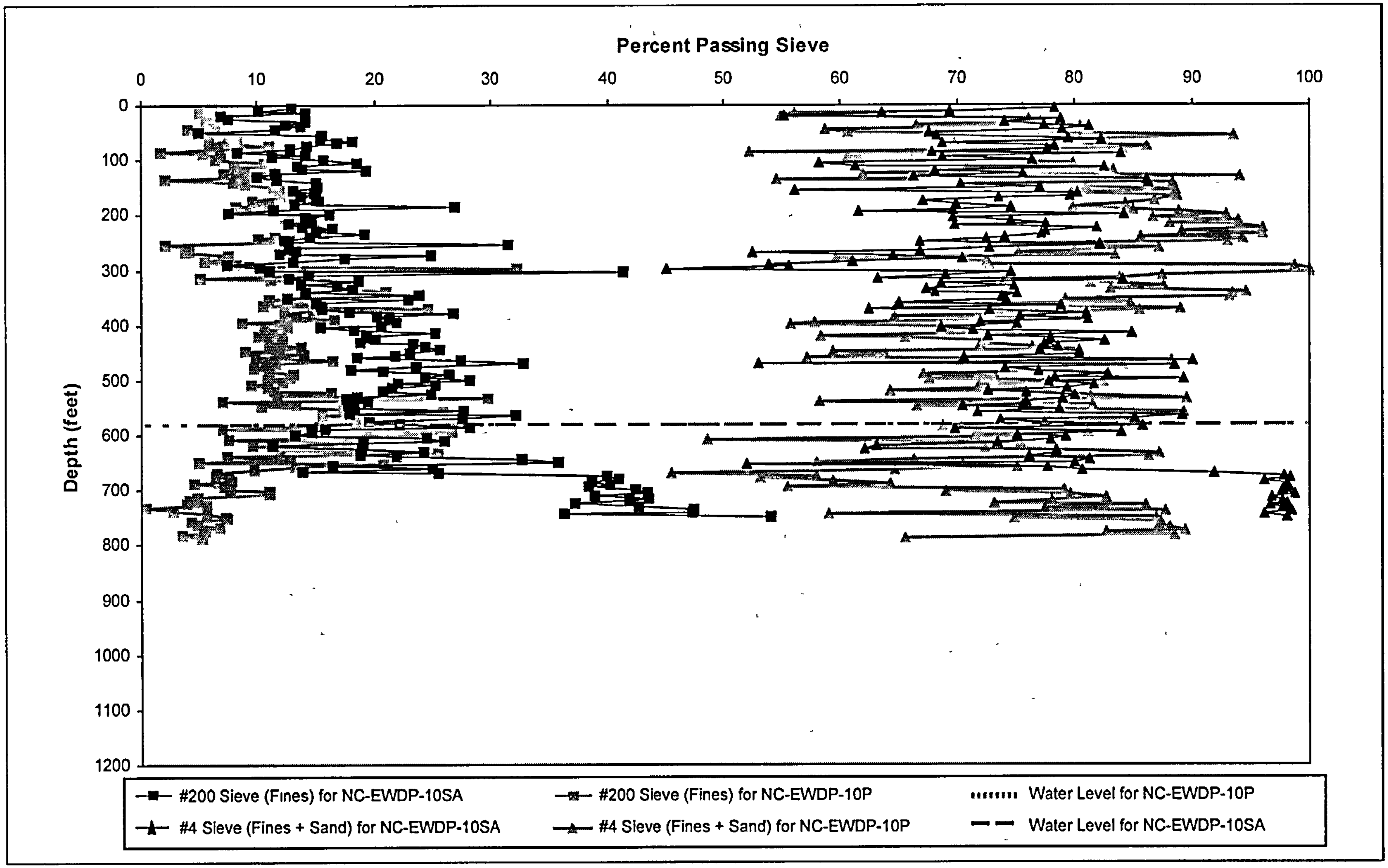


Figure 4.3-7
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-10P

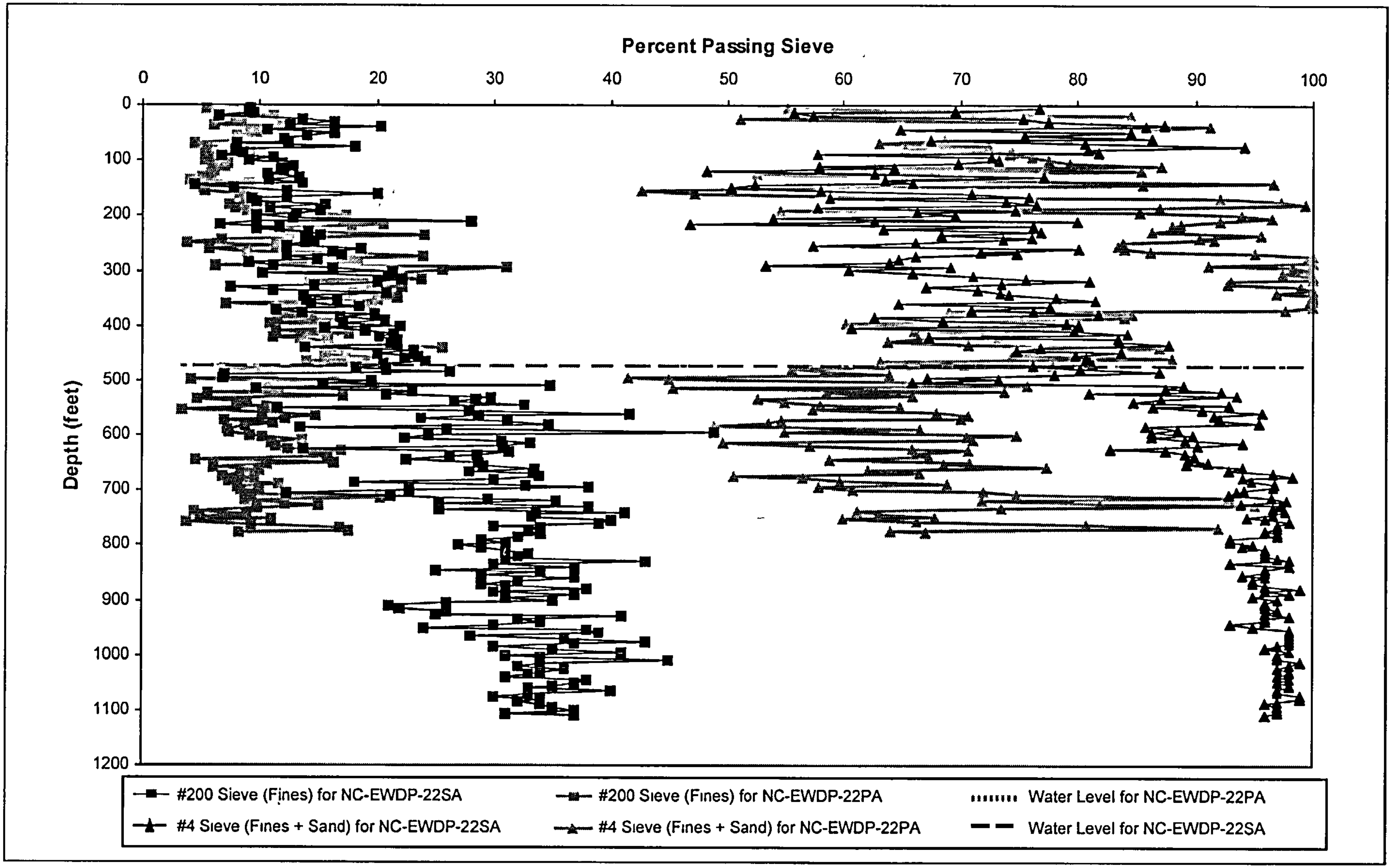


Figure 4.3-8
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-22PA

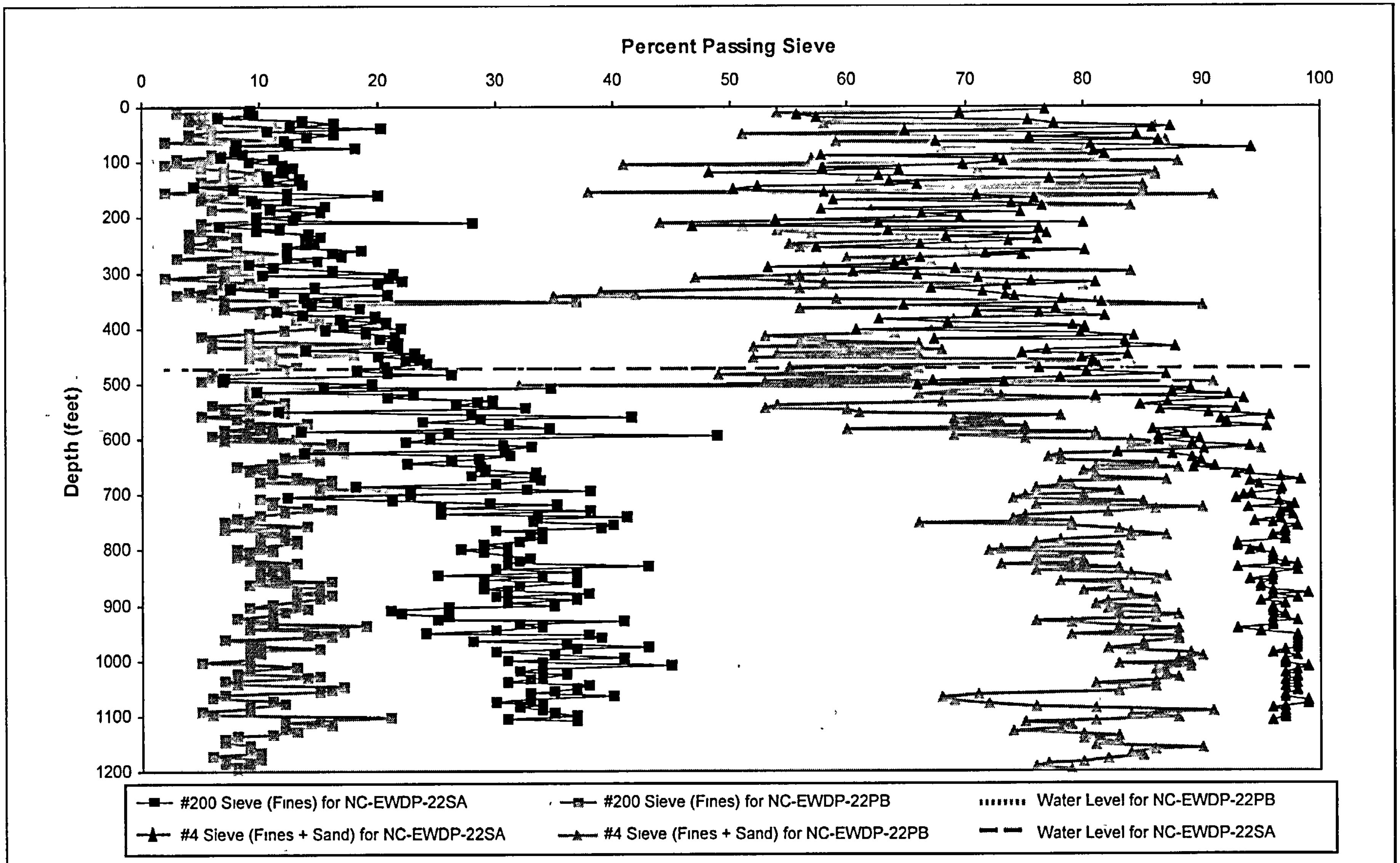


Figure 4.3-9
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-22PB

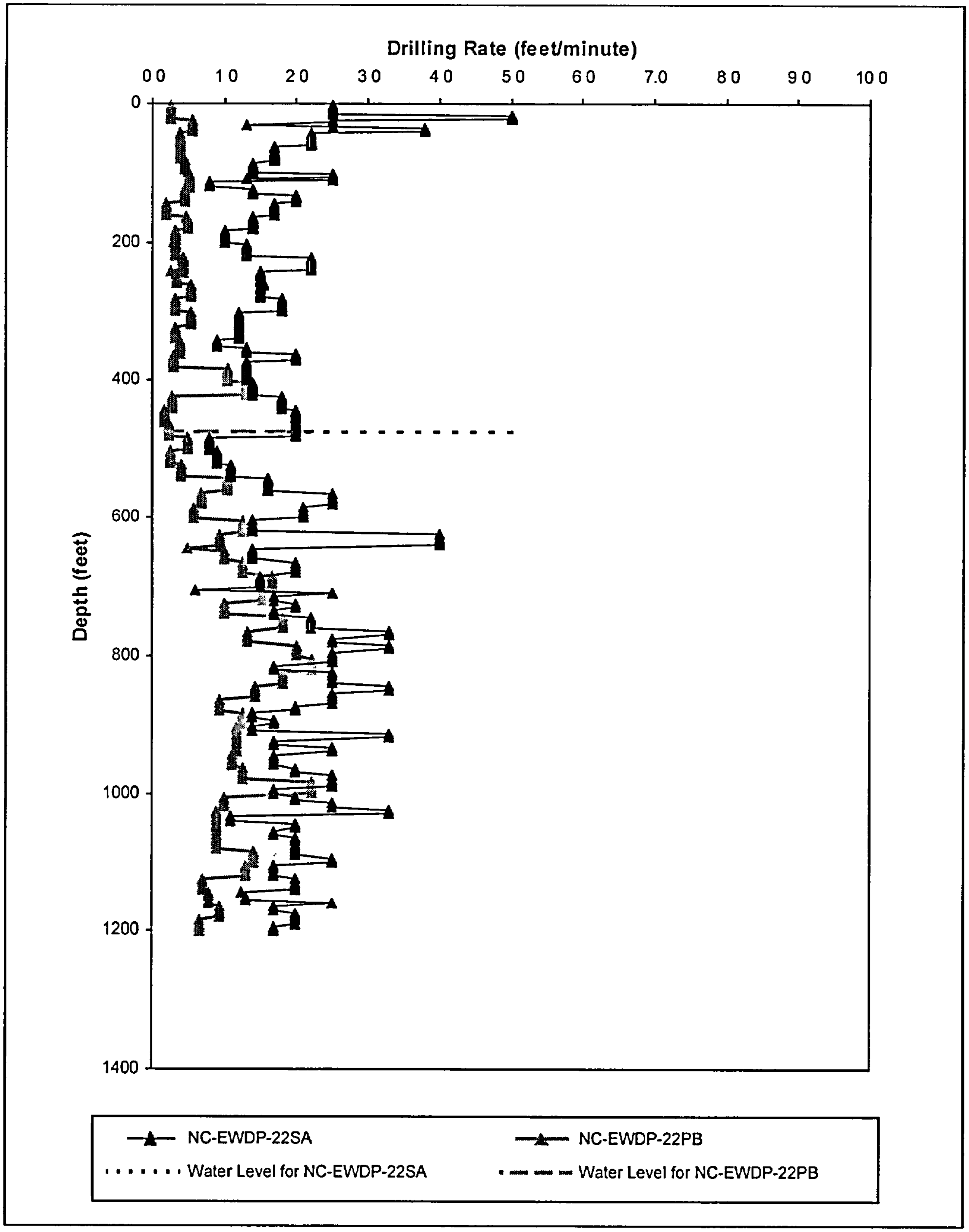


Figure 4.3-10
Drilling Rate versus Depth in Alluvium and Non-Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-22PB

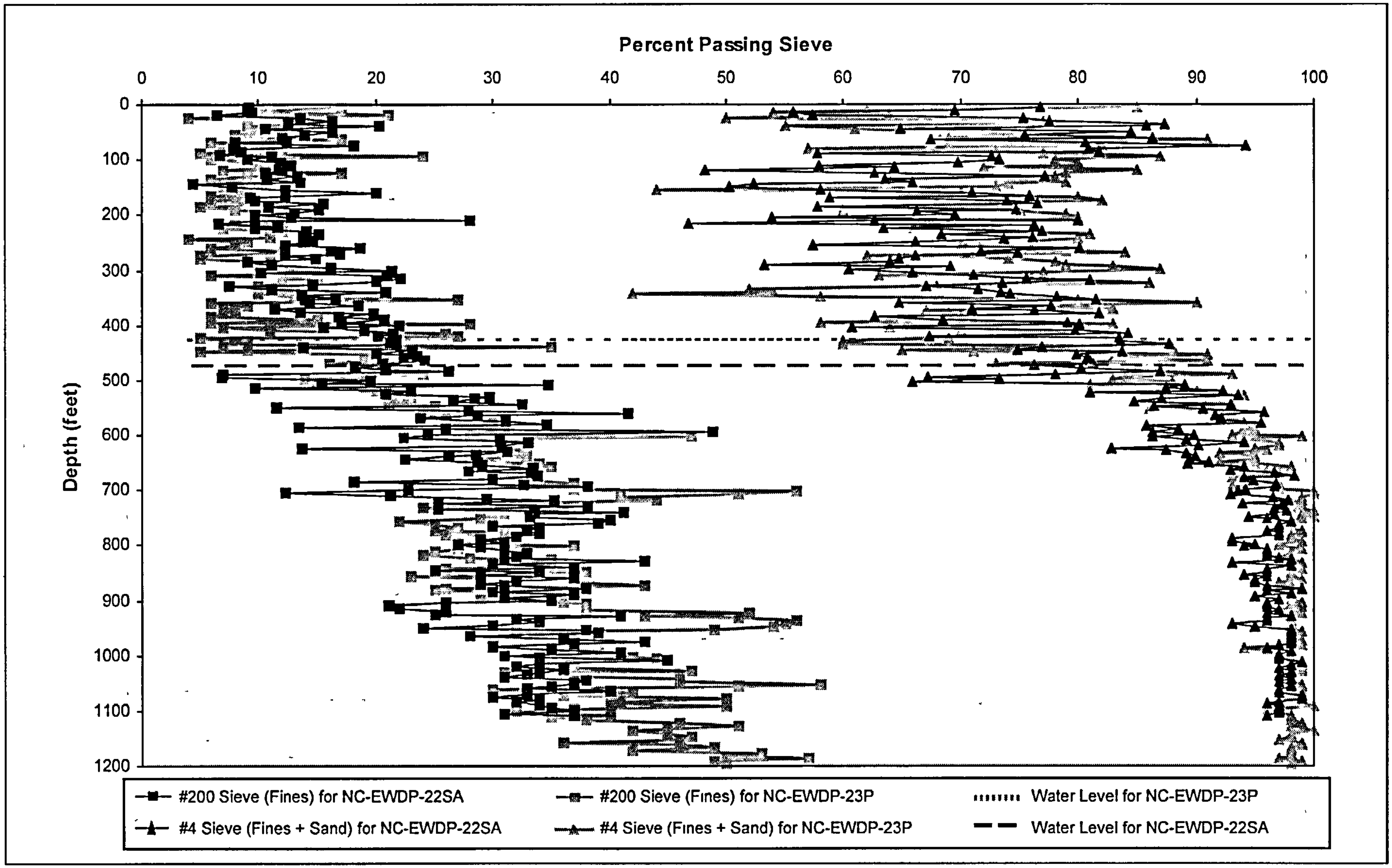


Figure 4.3-11
Laboratory Particle Size Distributions of Drill Cuttings versus Depth in Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-23P

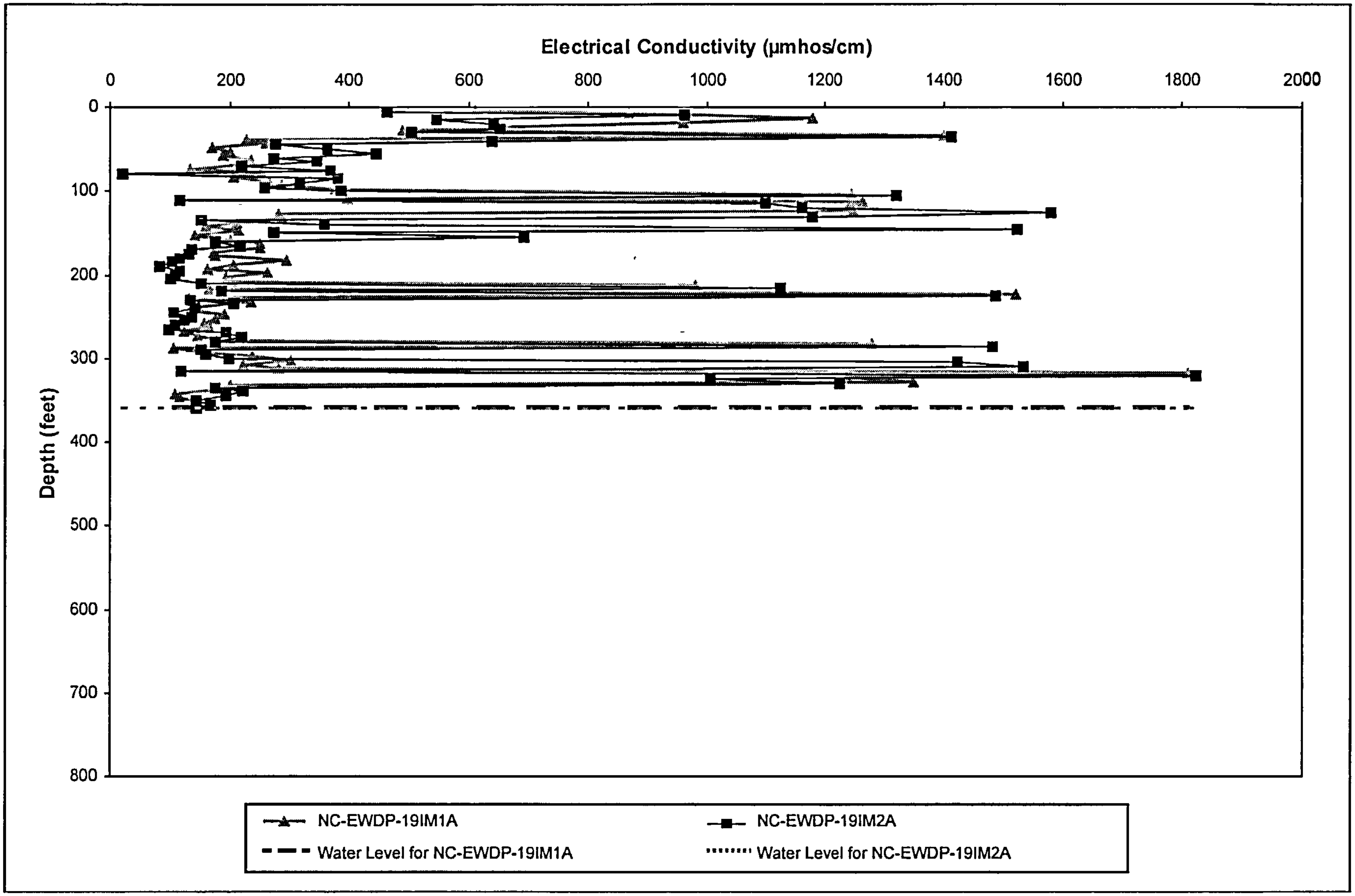


Figure 4.3-12
Electrical Conductivity versus Depth in Alluvium
for Boreholes NC-EWDP-19IM1A and NC-EWDP-19IM2A

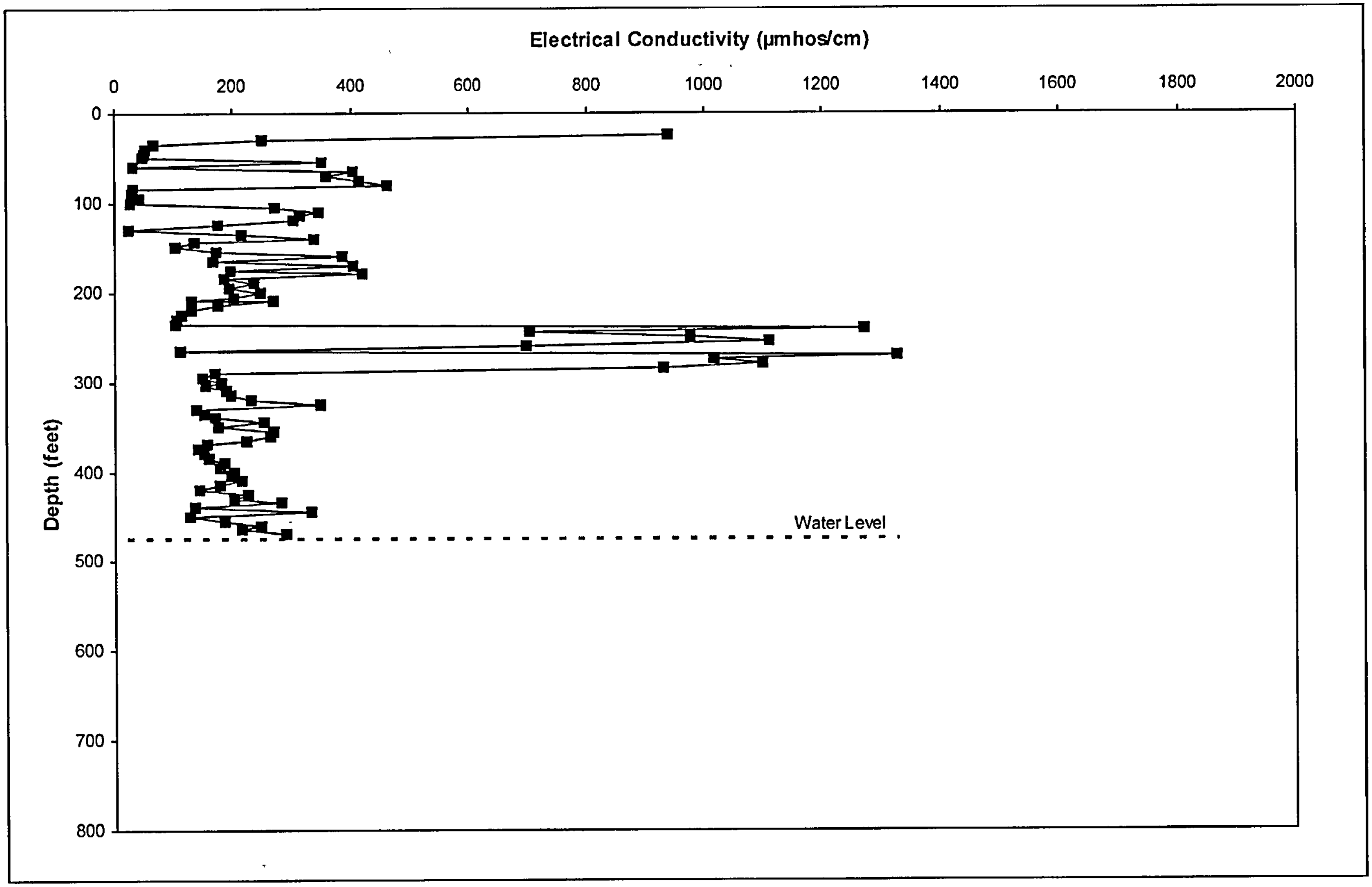


Figure 4.3-13
Electrical Conductivity versus Depth in Alluvium for Borehole NC-EWDP-22SA

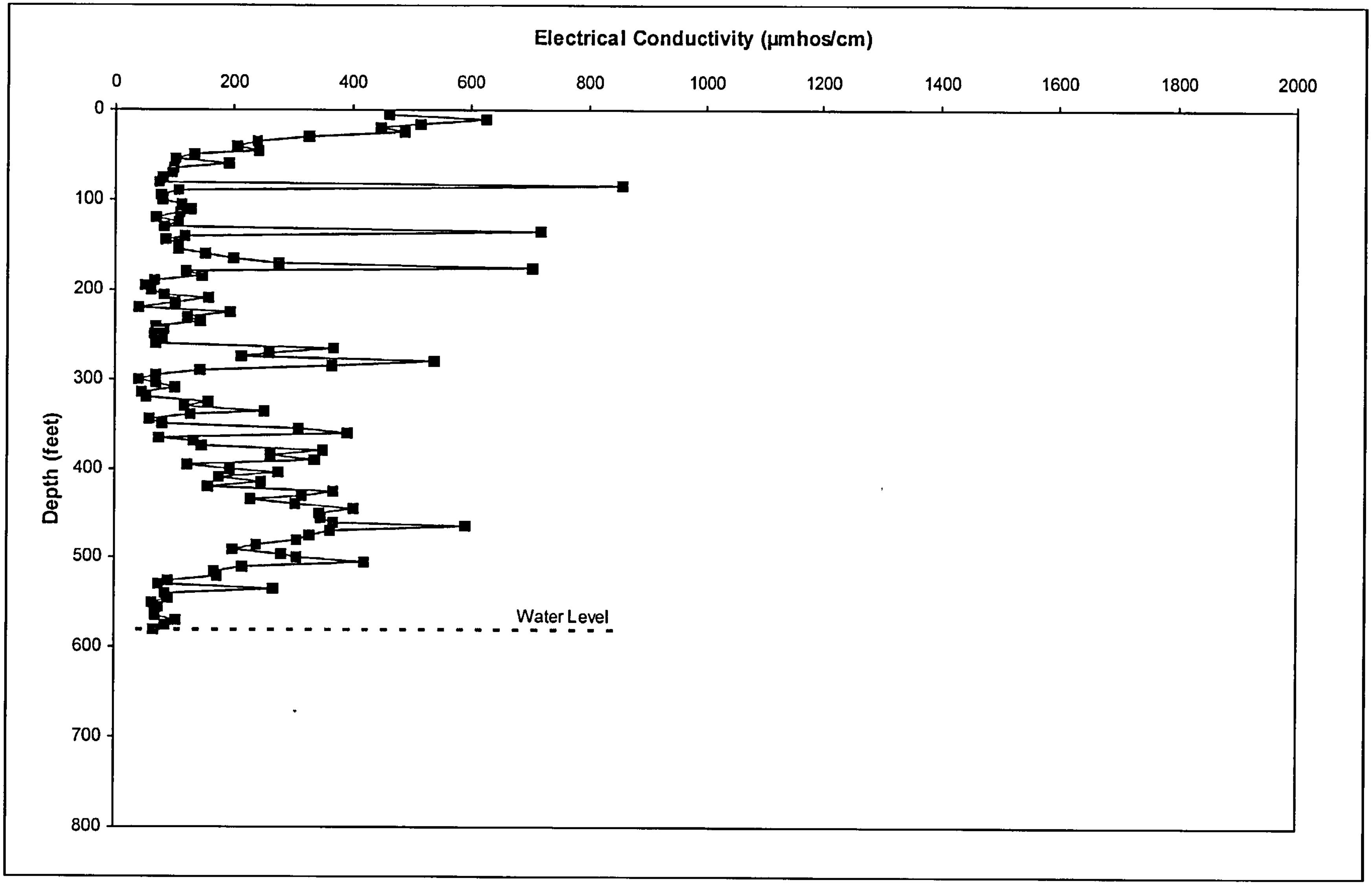
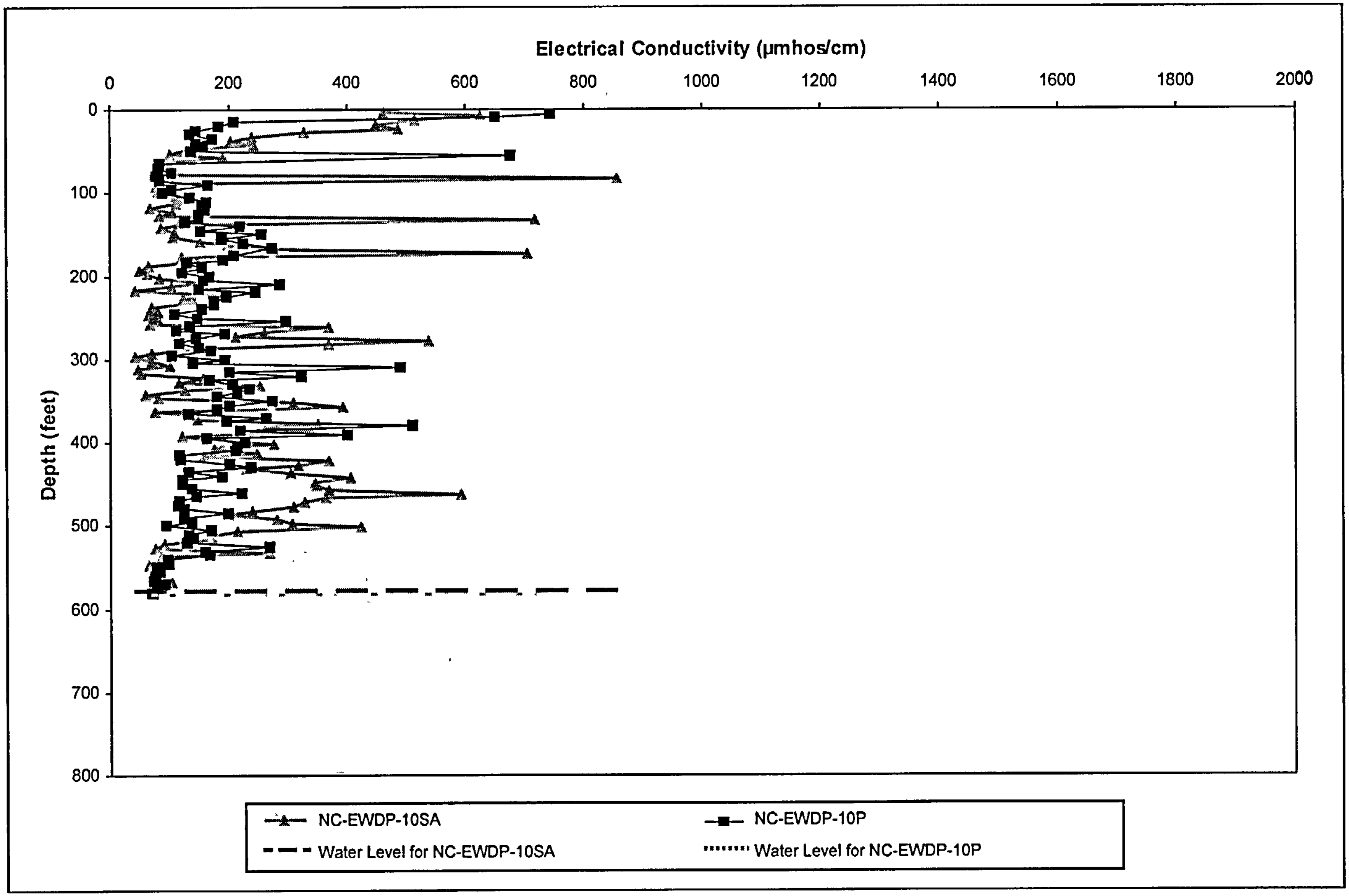


Figure 4.3-14
Electrical Conductivity versus Depth in Alluvium for Borehole NC-EWDP-10SA



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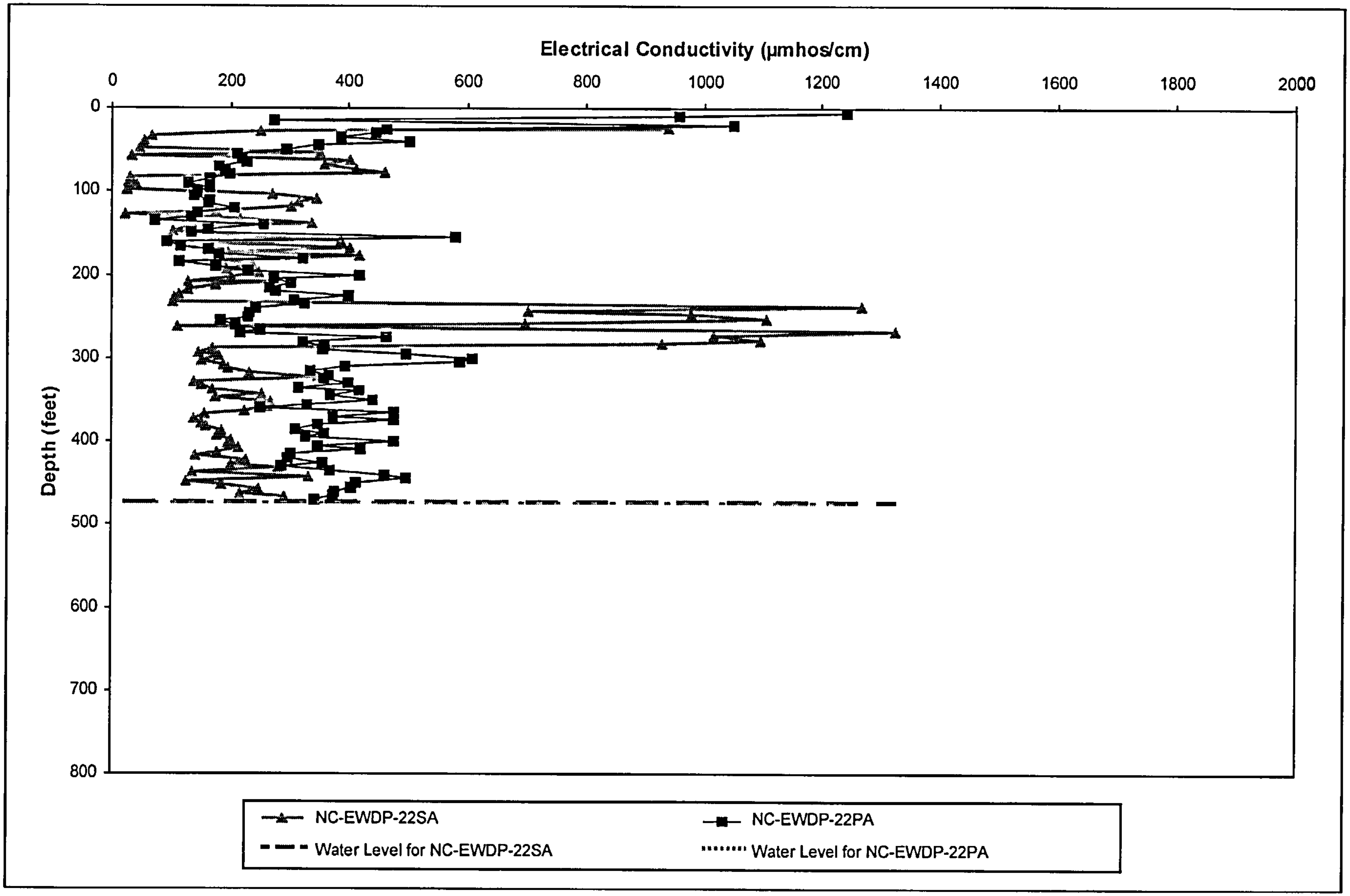
Electrical Conductivity versus Depth in Alluvium for Boreholes NC-EWDP-10SA and NC-EWDP-10P



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Electrical Conductivity versus Depth in Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-22PA

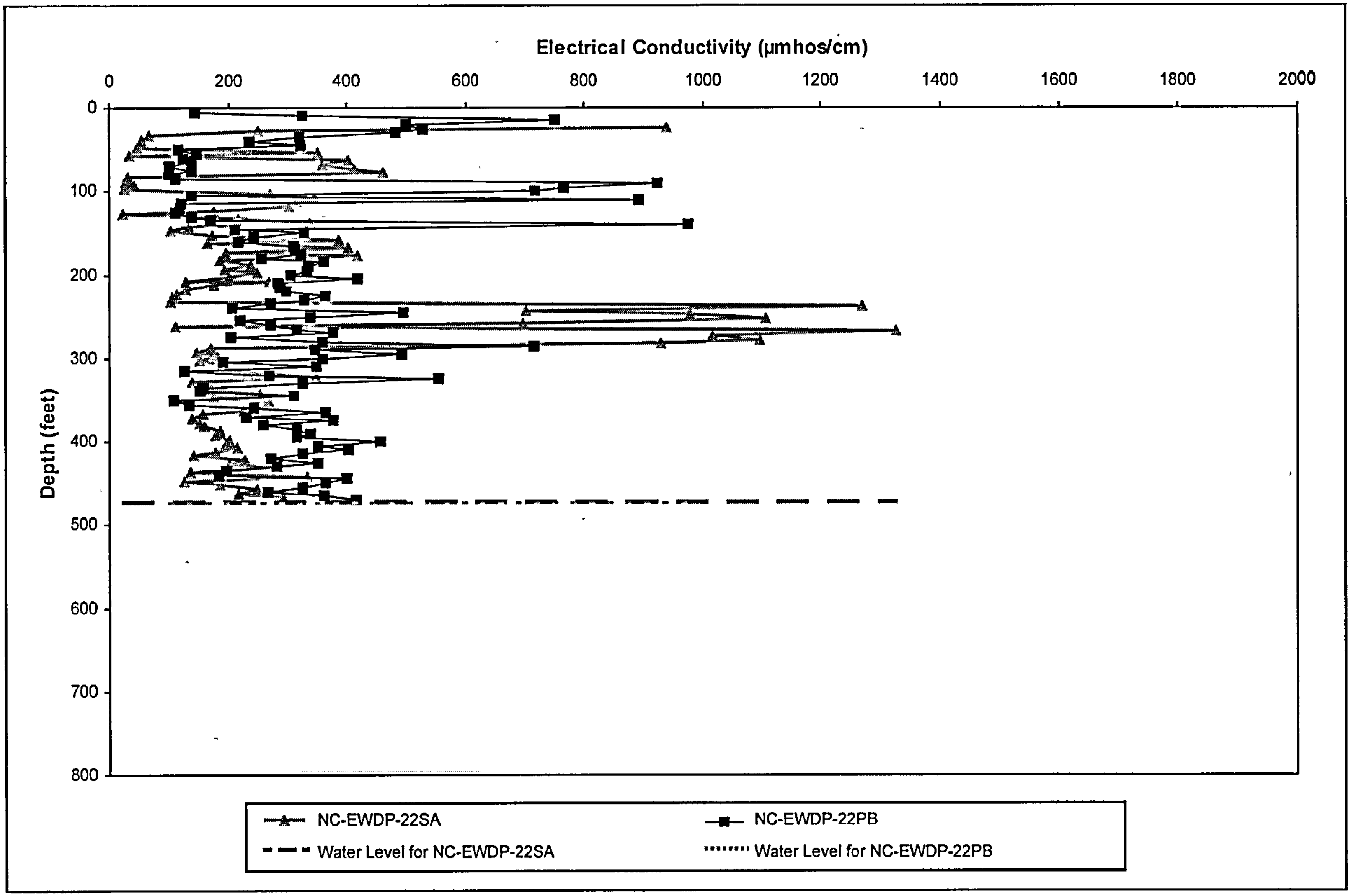


Figure 4.3-17
Electrical Conductivity versus Depth in Alluvium
for Boreholes NC-EWDP-22SA and NC-EWDP-22PB

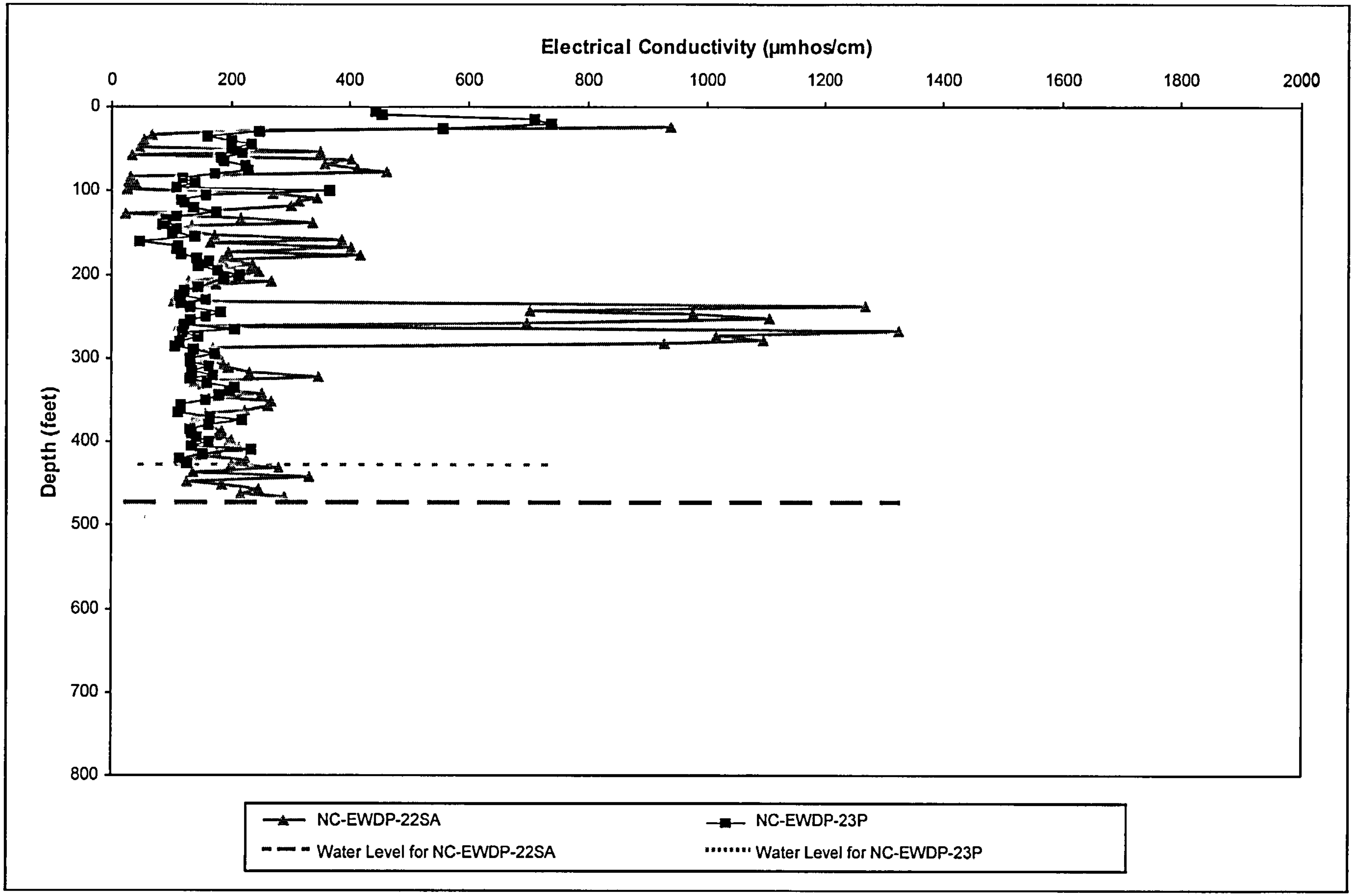


Figure 4.3-18
Electrical Conductivity versus Depth in Alluvium for Boreholes NC-EWDP-22SA and NC-EWDP-23P

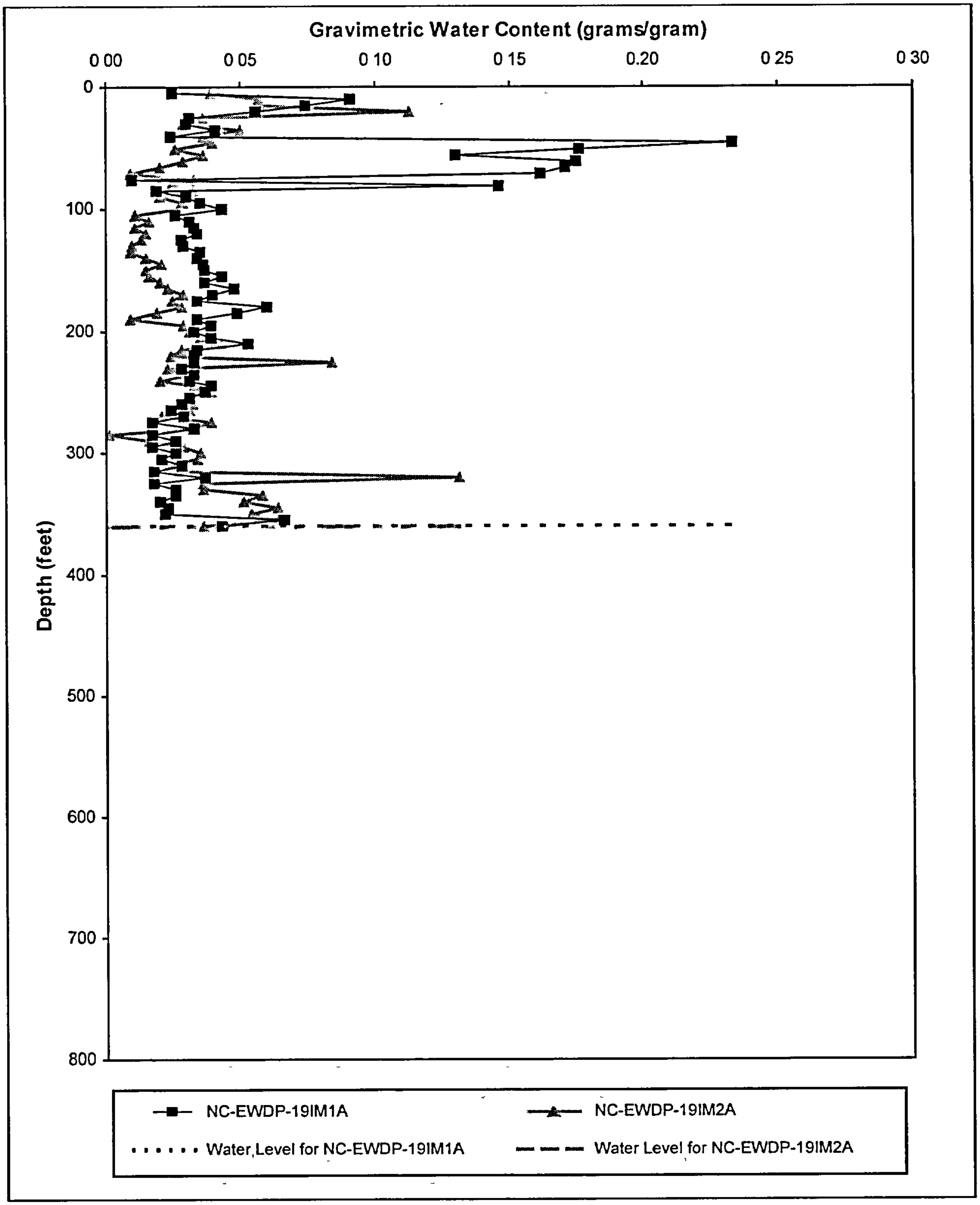


Figure 4.3-19
Gravimetric Water Content versus Depth
for Boreholes NC-EWDP-19IM1A and NC-EWDP-19IM2A

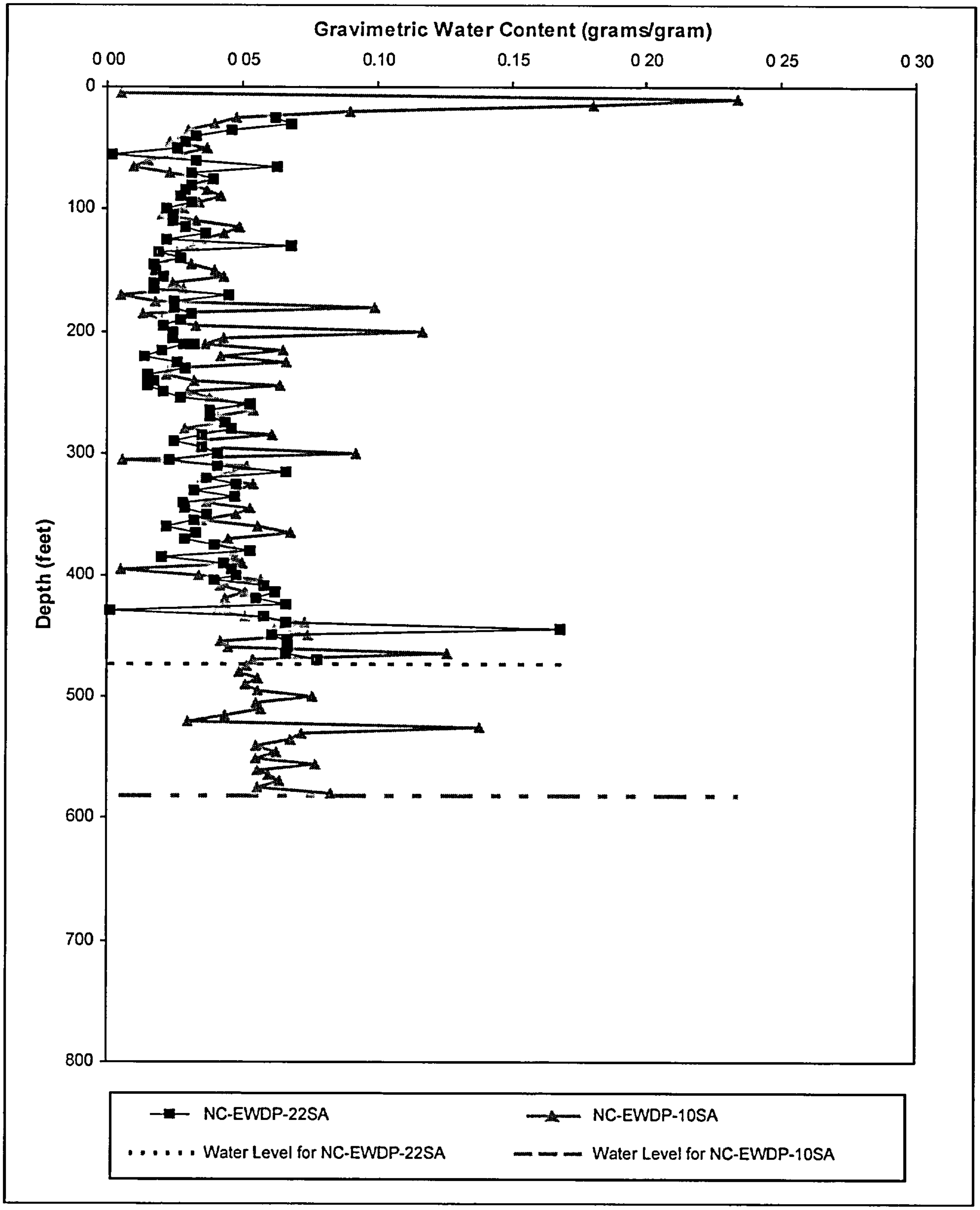


Figure 4.3-20
Gravimetric Water Content versus Depth
for Boreholes NC-EWDP-22SA and NC-EWDP-10SA

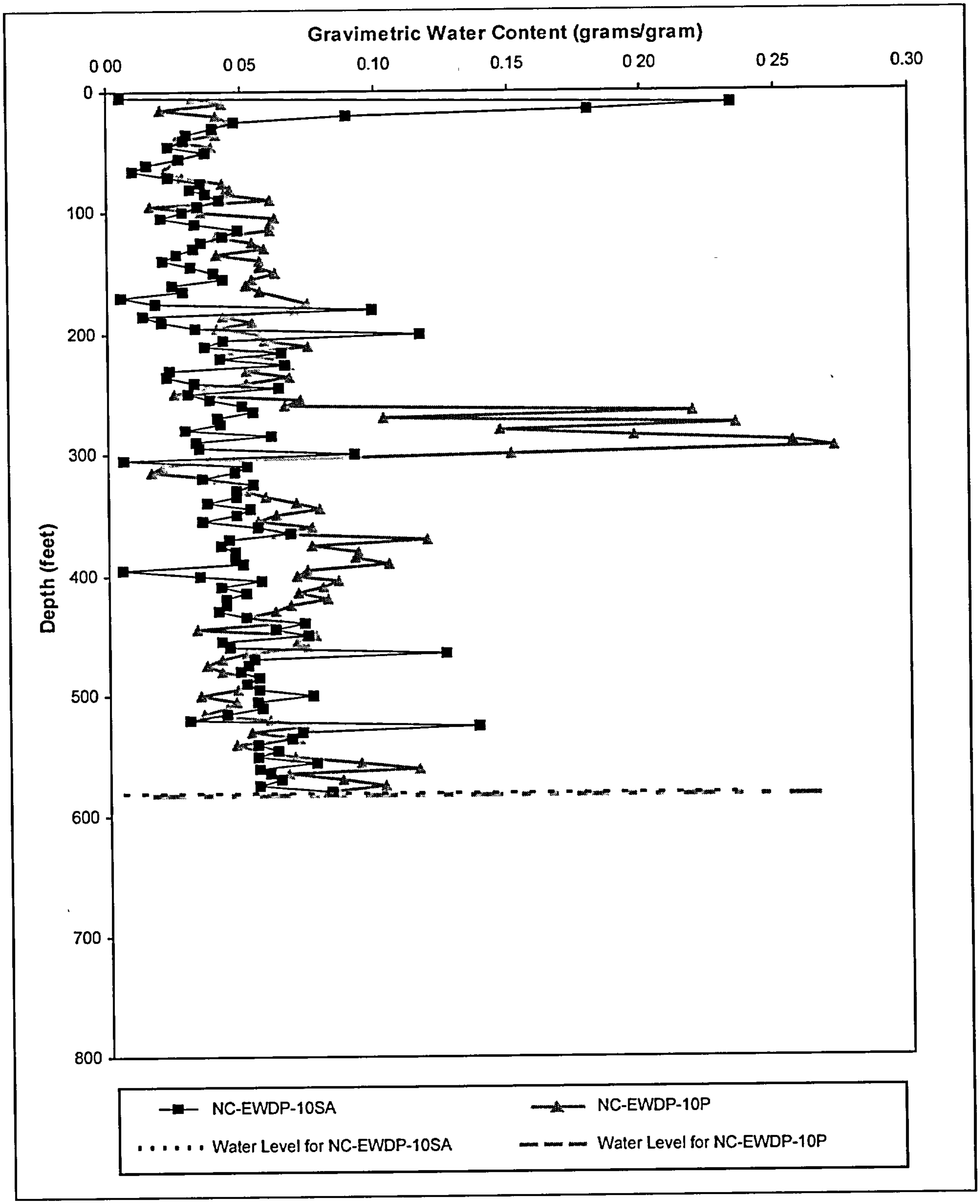


Figure 4.3-21
Gravimetric Water Content versus Depth
for Boreholes NC-EWDP-10SA and NC-EWDP-10P

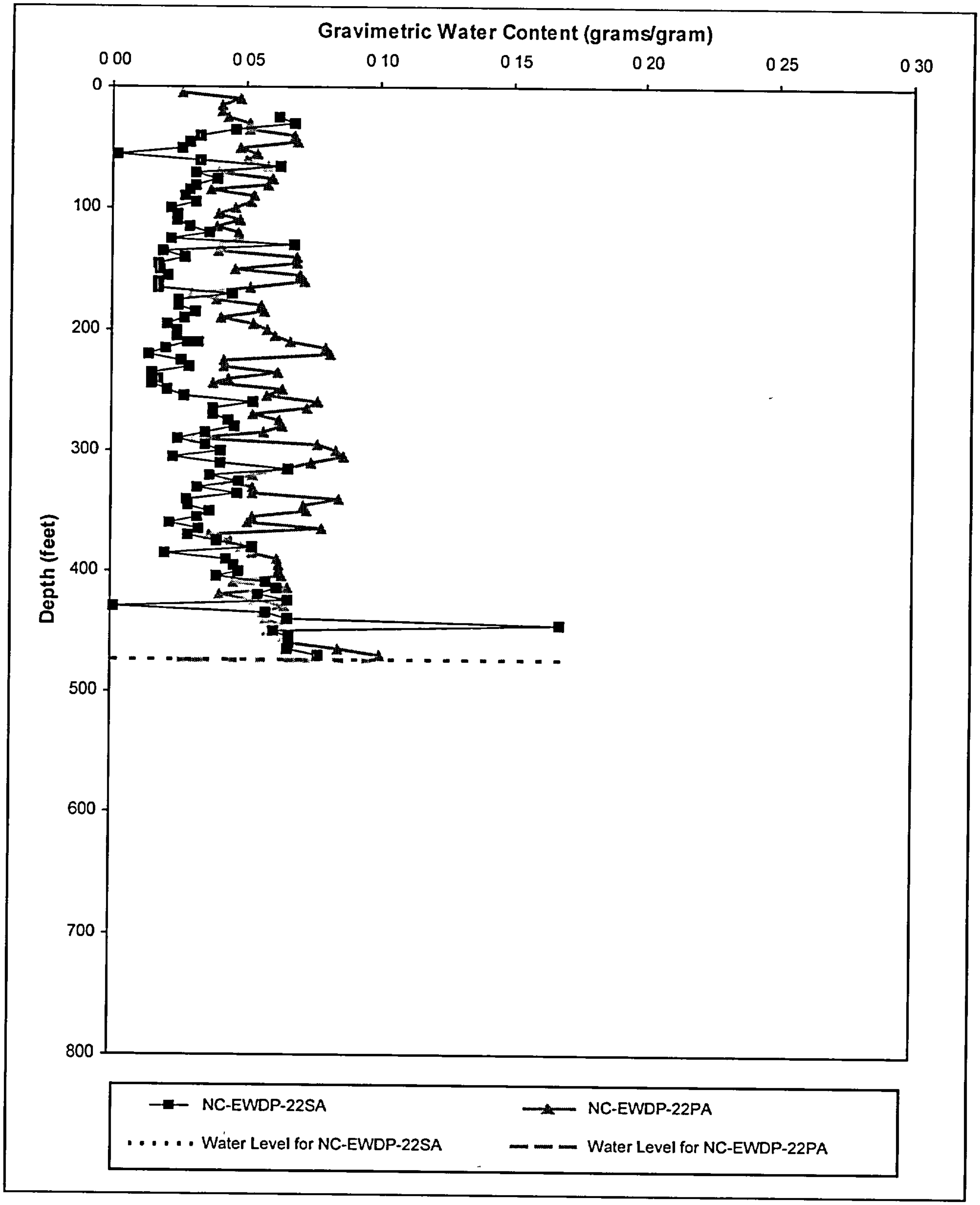
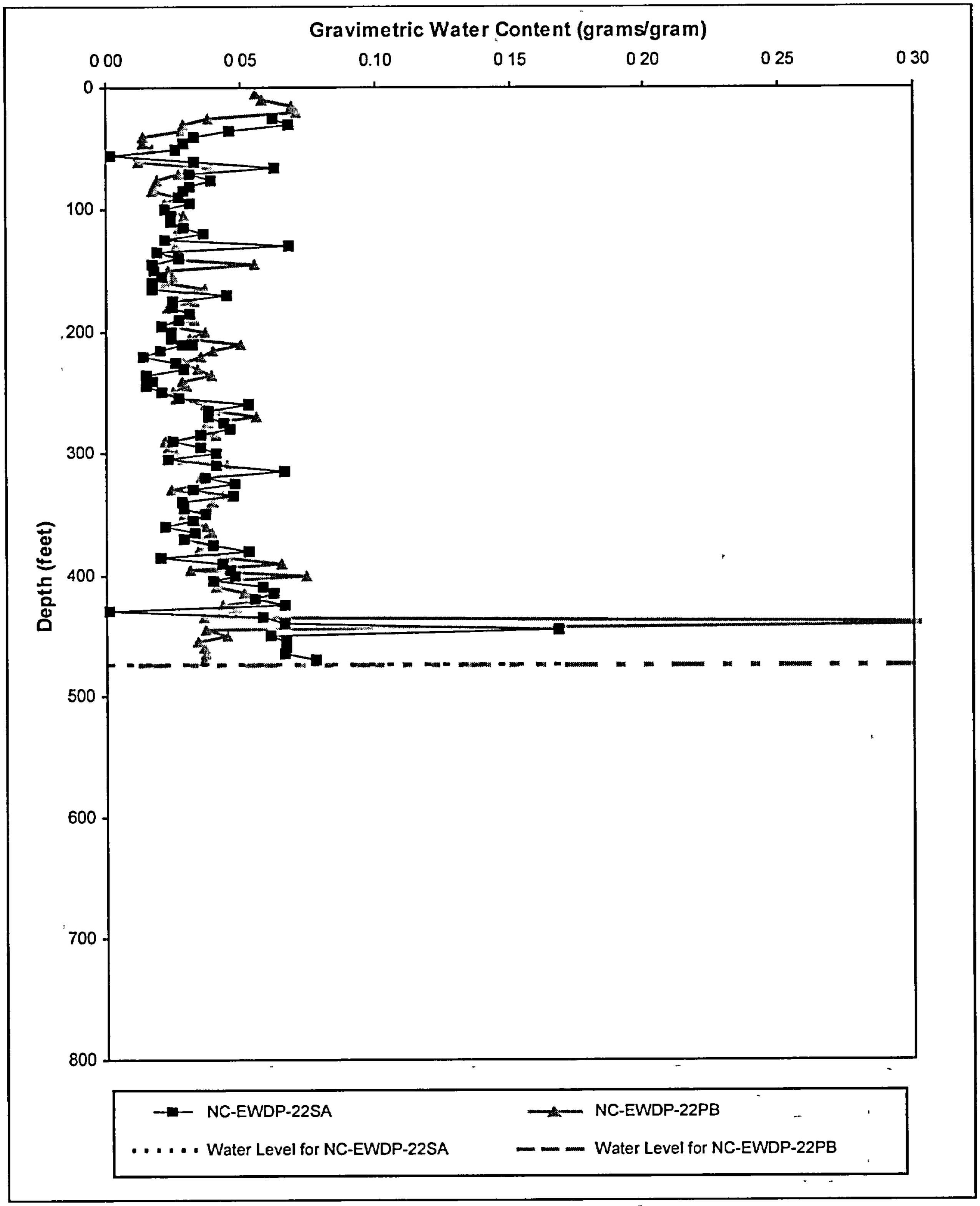


Figure 4.3-22
Gravimetric Water Content versus Depth
for Boreholes NC-EWDP-22SA and NC-EWDP-22PA



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Gravimetric Water Content versus Depth
for Boreholes NC-EWDP-22SA and NC-EWDP-22PB

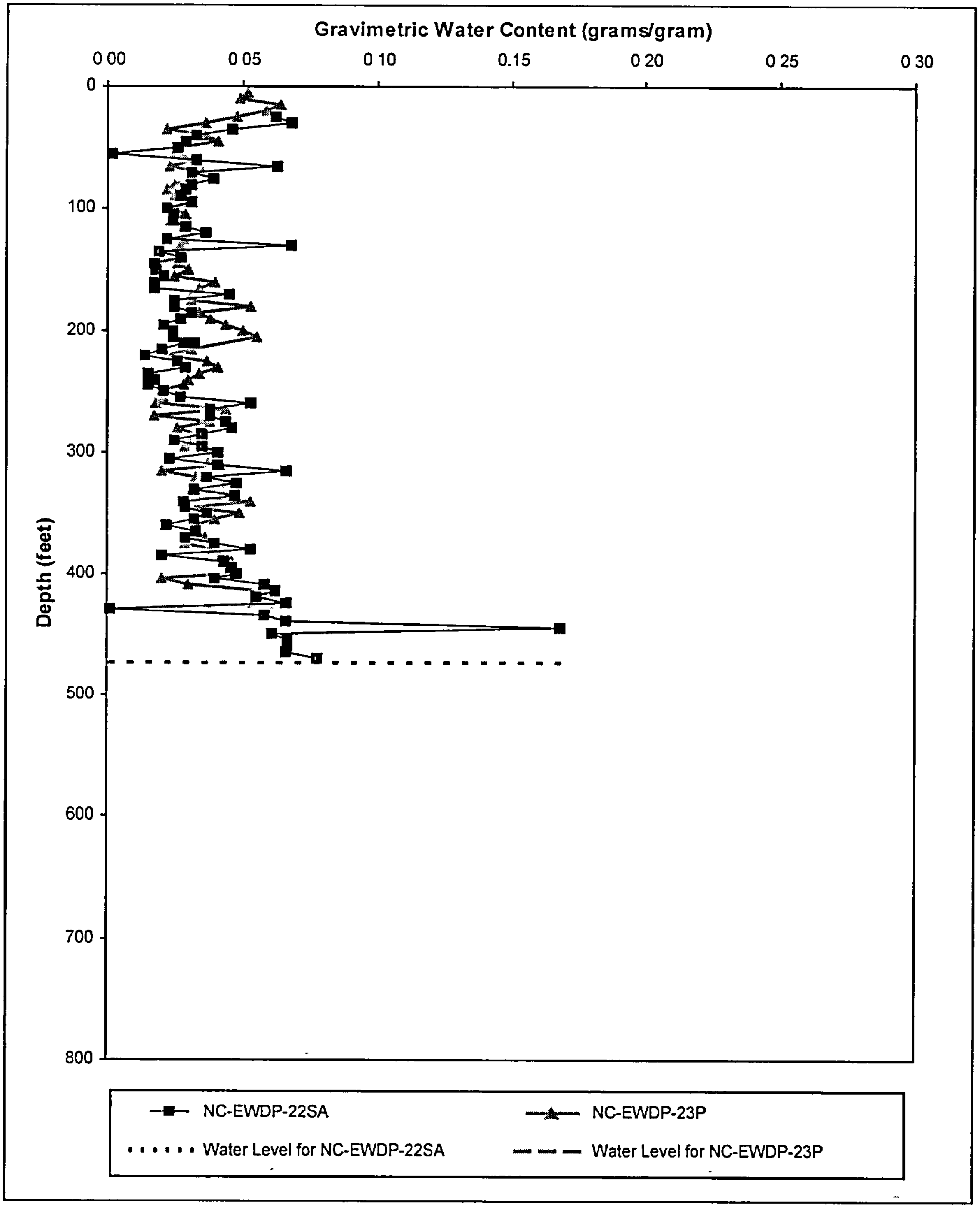


Figure 4.3-24
Gravimetric Water Content versus Depth
for Boreholes NC-EWDP-22SA and NC-EWDP-23P

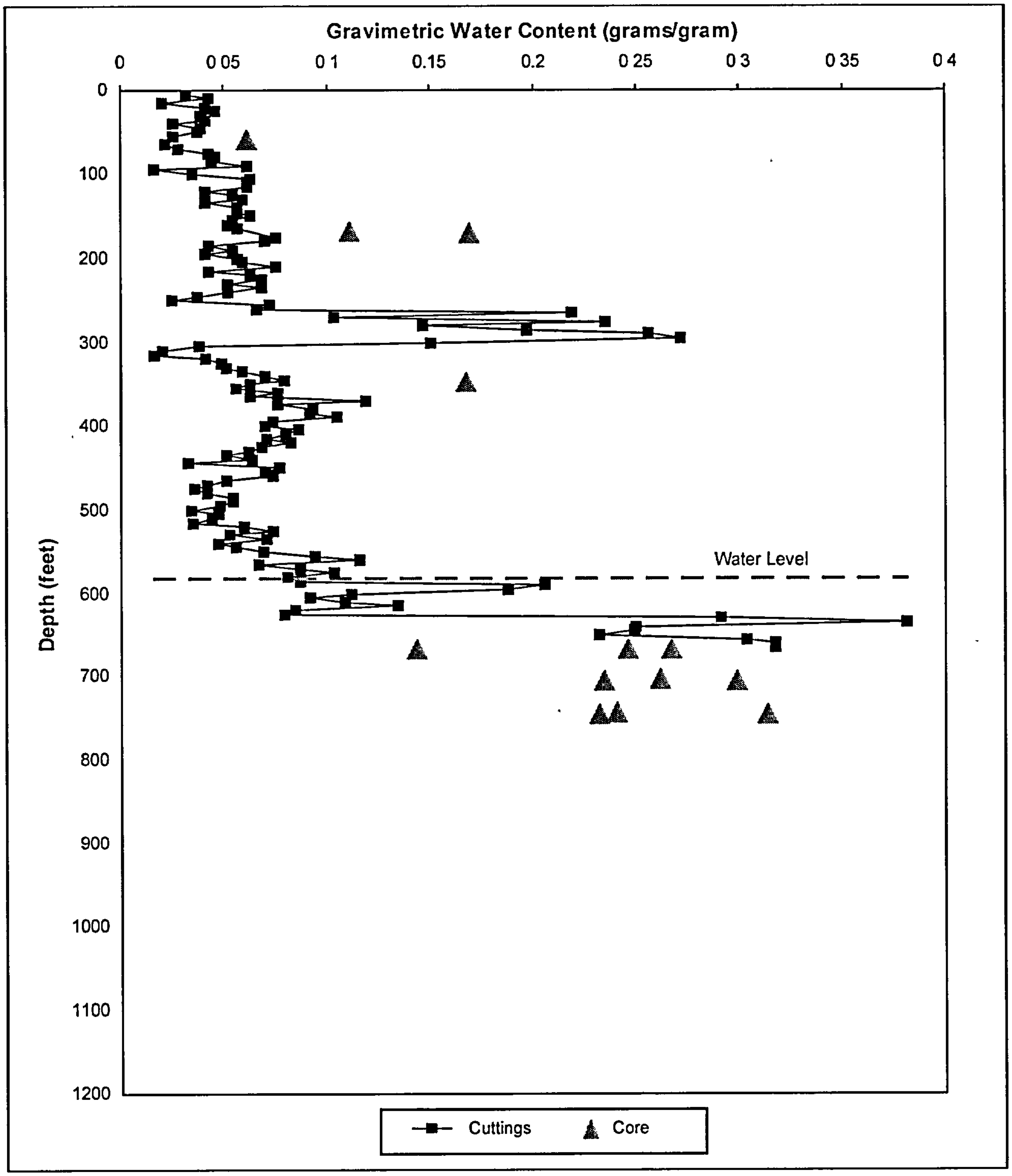


Figure 4.3-25
Gravimetric Water Content versus Depth in Core and Cuttings for Borehole NC-EWDP-10P

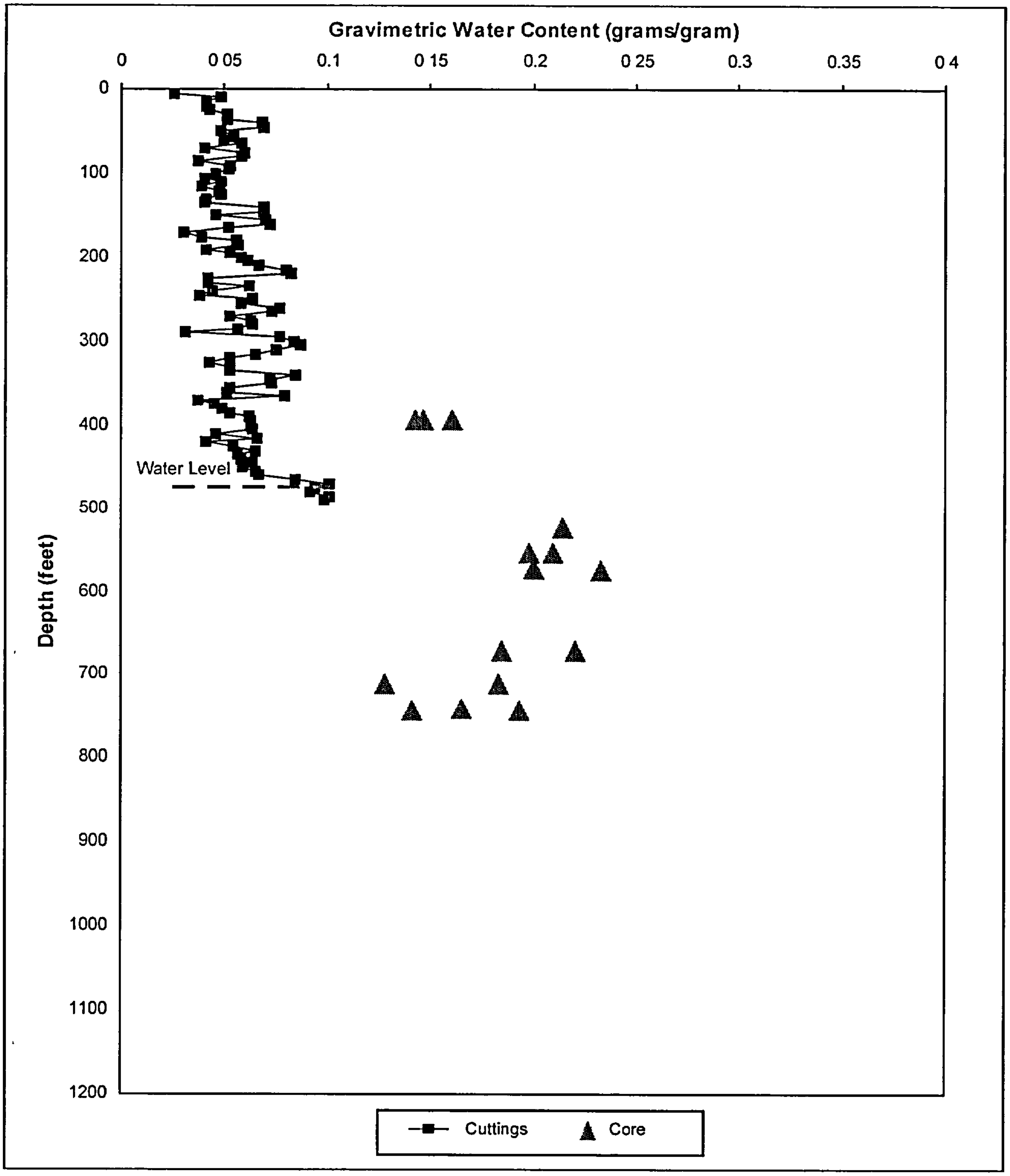


Figure 4.3-26
Gravimetric Water Content versus Depth in Core and Cuttings for Borehole NC-EWDP-22PA

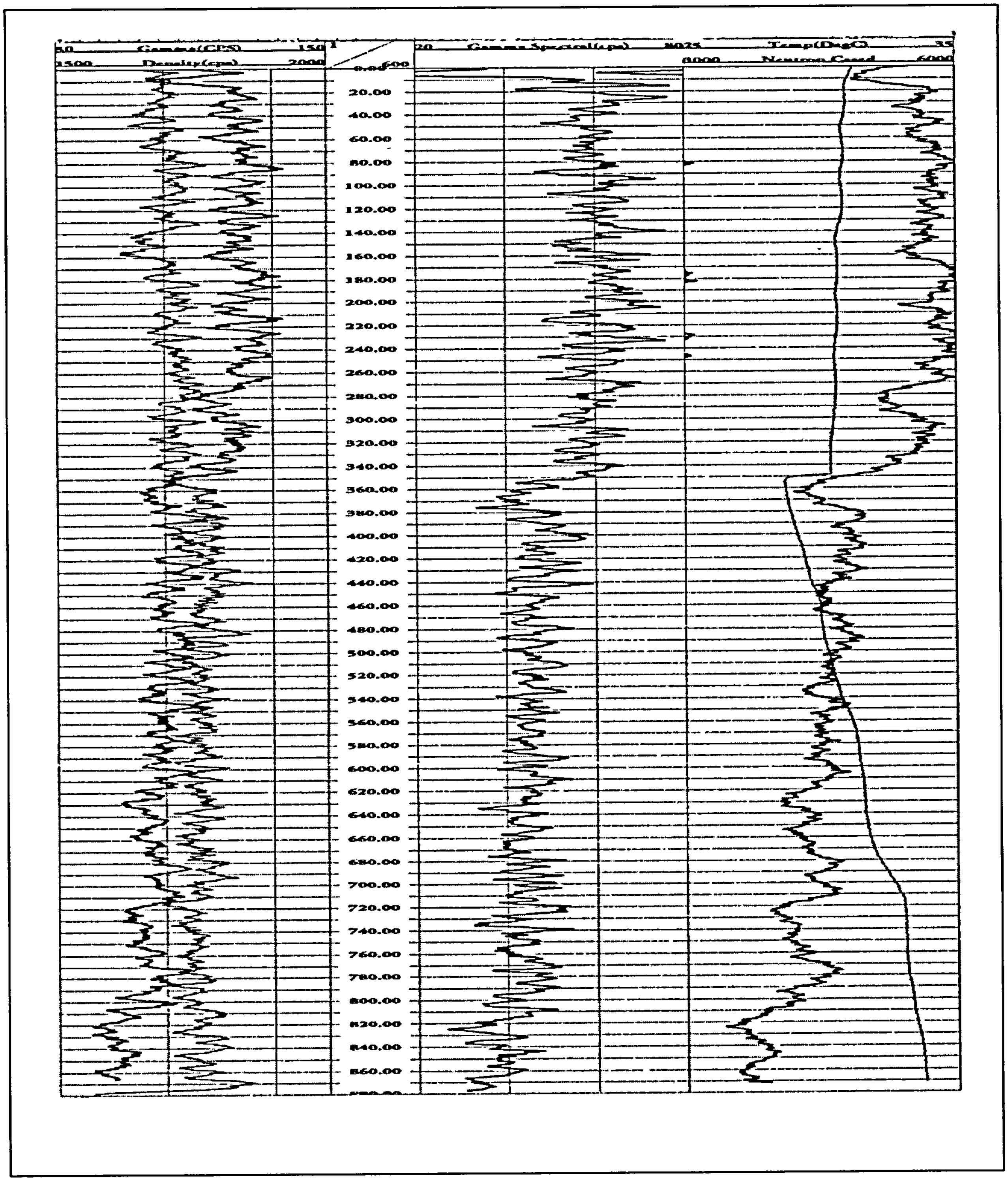


Figure 4.4-1a
Drill-String Geophysical Logs for Wells NC-EWDP-19IM1A (a) and NC-EWDP-19IM2A (b)

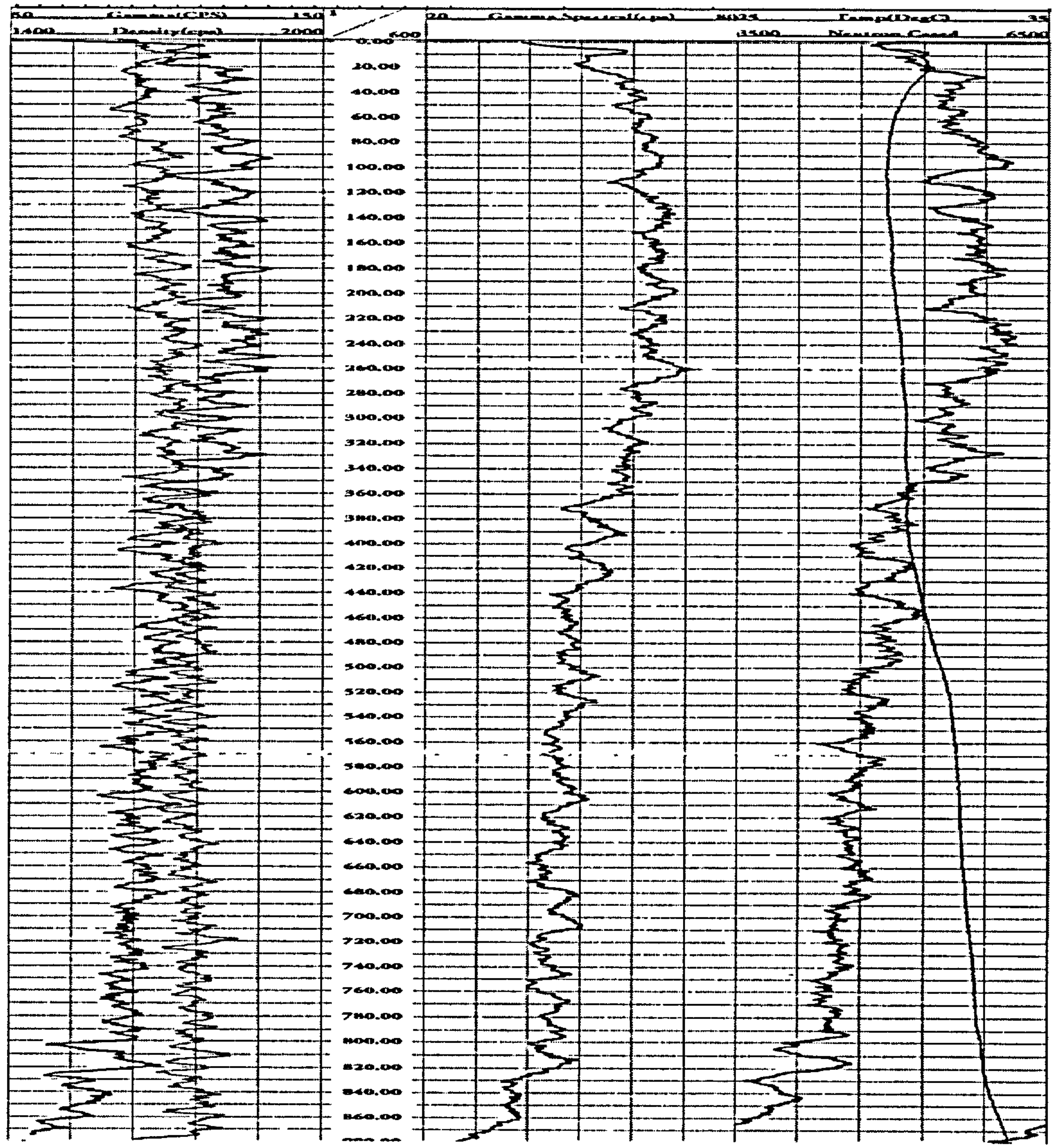


Figure 4.4-1b
Drill-String Geophysical Logs for Wells NC-EWDP-19IM1A (a) and NC-EWDP-19IM2A (b)

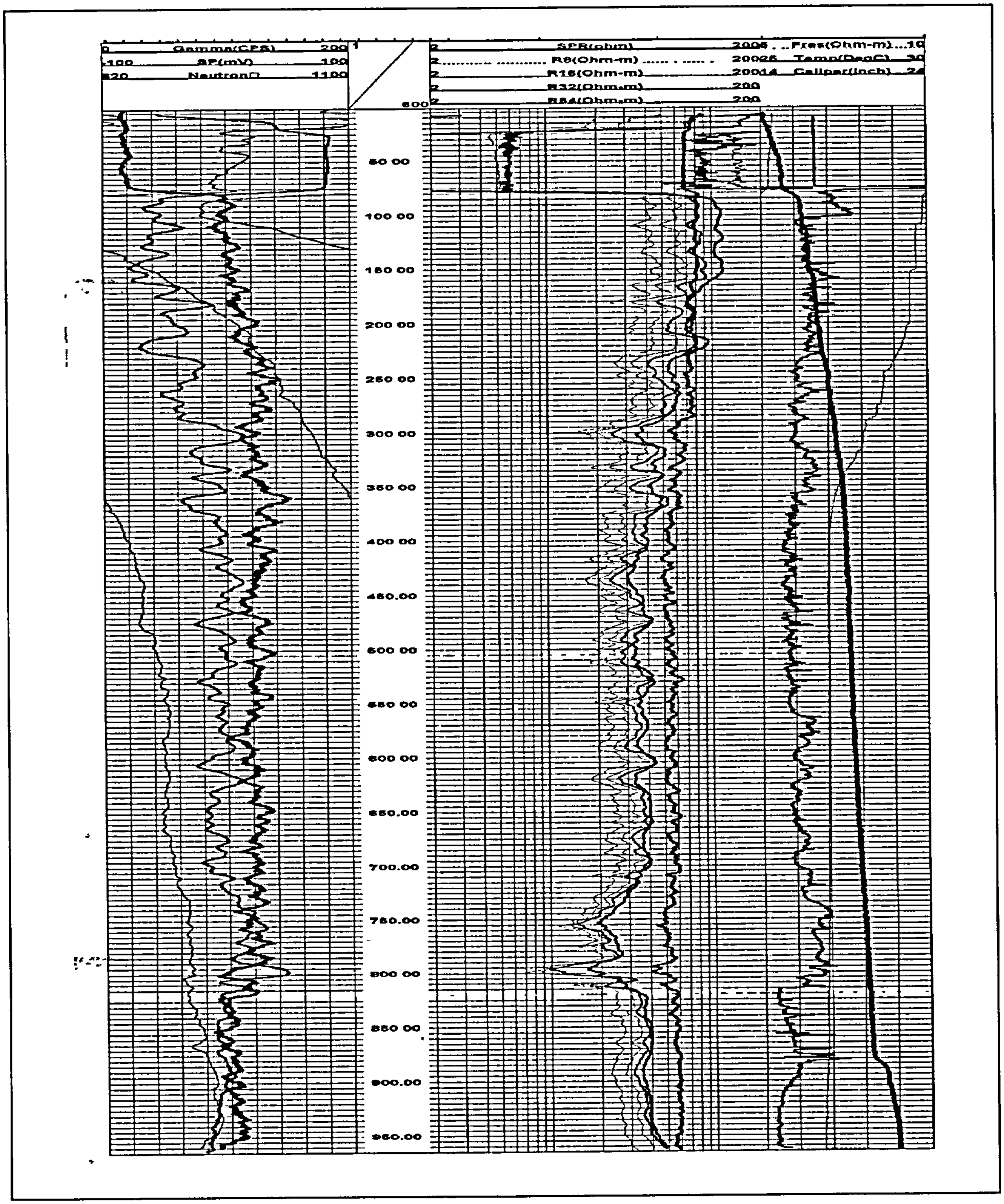


Figure 4.4-2a
Open-Hole Geophysical Logs for Wells NC-EWDP-19IM2 (a) and NC-EWDP-23P (b)

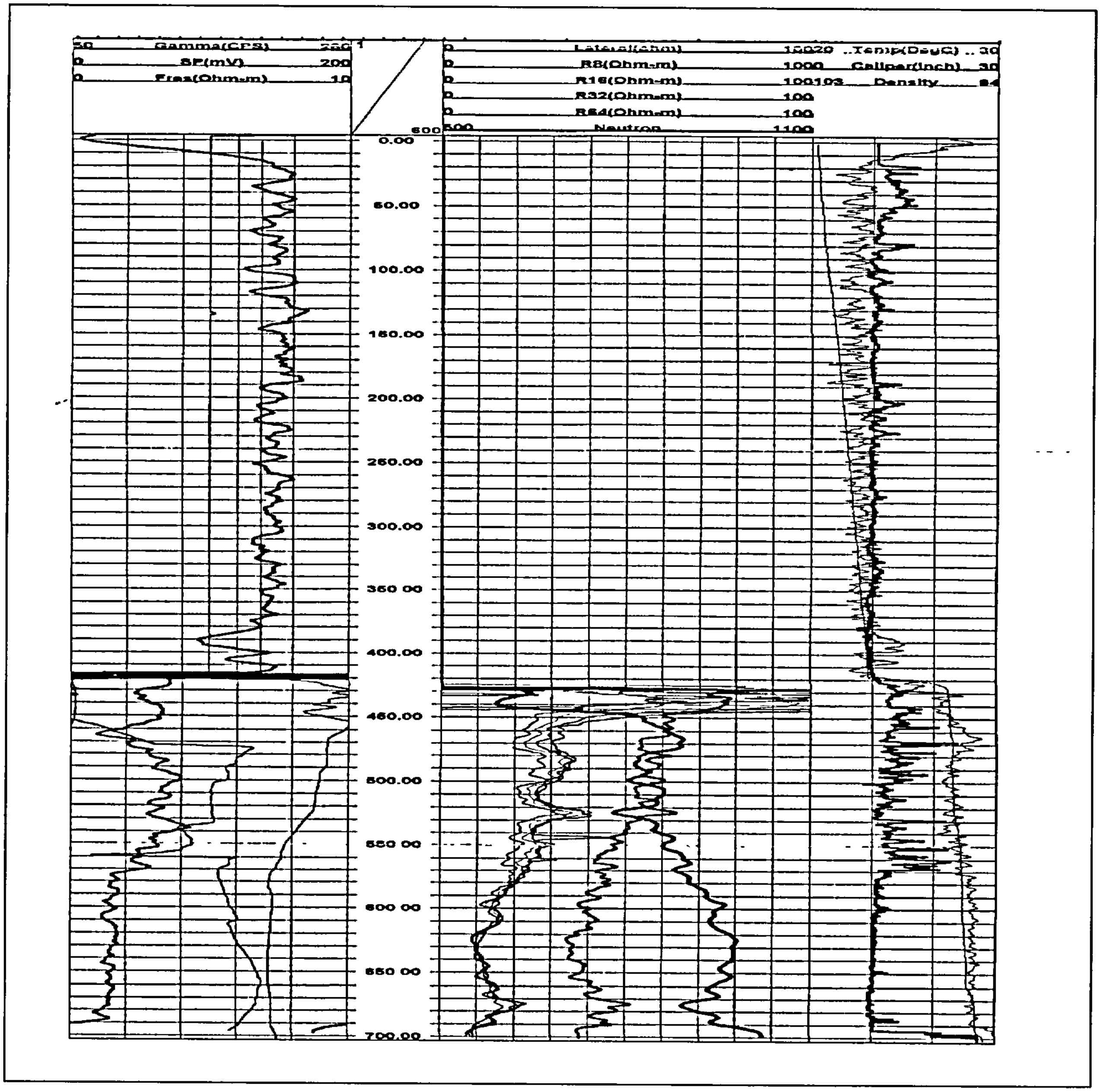
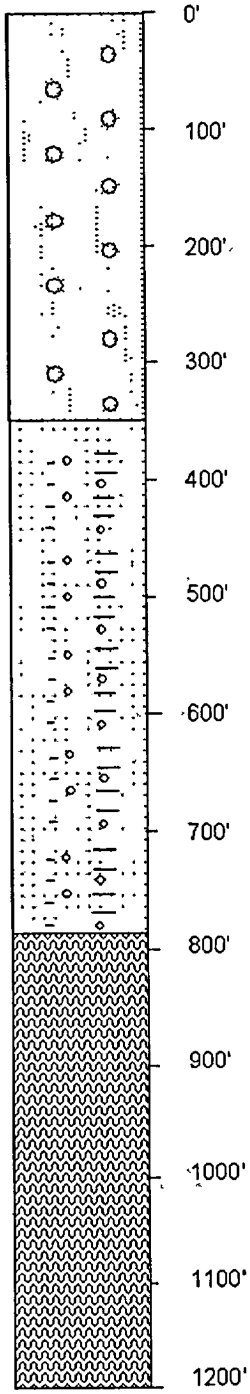


Figure 4.4-2b
Open-Hole Geophysical Logs for Wells NC-EWDP-19IM2 (a) and NC-EWDP-23P (b)



0 to 350 ft WELL-GRADED SAND with silt and gravel (SW-SM)

SW-SM layers generally less than 50 ft thick predominate Silty sand with gravel layers (SM) up to 20 ft thick are present throughout the interval. Several thin layers less than 15 ft thick of well-graded gravel with silt and sand (GW-GM) are present between 100 and 300 ft Fines in SM layers are predominantly non-plastic with some occurrences of low plasticity in the interval 310 to 345 ft Gravel clasts are volcanic in origin and subangular to subrounded Sediment color ranges from moderate yellowish brown (10YR 5/4) to moderate brown (5YR 5/4) and (5YR 4/4) Clasts exhibited weak cementation from 15 to 22 5 ft A weak reaction to 10% HCl is displayed in sediments from 15 to 22 5 ft, otherwise, the sediments show no reaction All samples were dry.

350 to 790 ft SILTY SAND with gravel (SM)*

A thick sequence of SM with gravel is present to 790 ft Several gravelly layers with silt (GM) are present from 460 to 655 ft Unit also contains several layers of well-graded sand with silt and gravel (SW-SM) and silty gravel (GM) less than 5 ft thick from 598 to 665 ft A 5 ft layer of sandy lean clay (CL) is present from 745 to 750 ft The plasticity of fines in SM and GM layers range from non-plastic to moderately plastic Gravel clasts are volcanic in origin and subrounded Sediment color ranges from moderate yellowish brown (10YR 5/4) to dark yellowish orange (10YR 6/6) to moderate brown (5YR 5/4) to light brown (5YR 5/6) The interval exhibited no cementation and no reaction to 10% HCl was observed. All samples were moist below 570 ft and wet below 665 ft

*USCS texture classification between 665 and 790 ft is based on drill cutting particle size distribution measurements from this borehole between 350 and 665 ft, and similar measurements on core samples from 4 core runs between 348 and 745 ft in NC-EWDP-10P

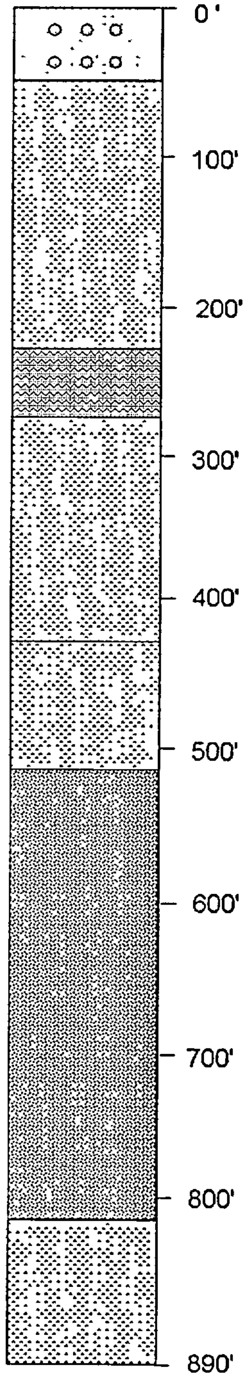
790 to 1200 ft (T.D.) VOLCANIC CONGLOMERATE

Clasts range in color from grayish brown (5YR 5/1) to dark yellowish brown (10YR 4/2) Clasts are well sorted, rounded to subrounded, and composed of welded ashflow tuff lithologies The matrix color is medium gray (N5) to light brown (5YR 6/4) and pale yellowish brown (10YR 6/2) and consists of clayey fine sand Clasts are well sorted and well rounded No reaction to HCl was observed

Nye County, Nevada Nuclear Waste Repository Project Office	
Early Warning Drilling Program Summary Lithology Log NC-EWDP-10SA	
Date. 12/18/02	Geologist JSW
Scale Not to scale	Drawn by RFD

NOTE: T.D. = total depth

Figure 4.5-1
Summary Lithologic Log for Well NC-EWDP-10SA



0 to 45 ft ALTERNATING WELL-GRADED SAND with silt and gravel (SW-SM) and WELL-GRADED GRAVEL with silt and sand (GW-GM)

Alternating layers SW-SM up to 10 ft of SW-SM thick and layers of GW-GM up to 5 ft thick predominate. Sediment color ranges from very pale orange (10YR 8/2) to grayish orange (10YR 7/4) Gravel clasts are moderate brown (5YR 4/4) to pale brown (5YR 5/2), derived from underlying welded ashflow tuff (possibly Topopah Spring Tuff) and are typical of colluvium. Weak cementation and strong reaction to 10% HCl was observed thoughout the unit. All samples were dry.

45 to 230 ft ASHFLOW TUFF

Pale brown (5YR 5/2) to moderate brown (5YR 4/4), moderate to densely welded, devitrified, 5 to 10% pumice, pinkish gray (5YR 8/1), 2% lithic fragments, olive gray (5Y 4/1); 1 to 5% quartz phenocrysts, 1 to 3% mafic phenocrysts, rare feldspar phenocrysts. Contains zones of lithophysal mineralization. Vitrophyre occurs from 215 to 230 ft Sharp contact with underlying non-welded tuff. Possibly Topopah Spring Tuff

230 to 275 ft ASHFALL TUFF

Grayish orange pink (5YR 7/2) to light brown (5YR 6/4) and moderate brown (5YR 3/4), non-welded, devitrified, 10 to 15% pumice, very light gray (N8) to medium dark gray (N4); 5 to 10% lithic fragments, medium dark gray (N4 to grayish black N2), 5% quartz phenocrysts and rare mafics are present. Displays bedded tuff characteristics from 235 to 255 ft Sharp contact with underlying welded tuff. Possibly Calico Hills Formation.

275 to 425 ft ASHFLOW TUFF

Pale brown (5YR 5/2) to moderate brown (5YR 5/4), moderately welded, vitric alteration; 5% pumice, medium gray (N3), 5% lithics, grayish orange (10YR 7/4); 10 to 15% quartz phenocrysts, 2% mafics, rare feldspar Local occurrence of chalcedony and carbonate coatings of fracture surfaces. Possibly Prow Pass Tuff

425 to 515 ft ASHFLOW TUFF

Light brown (5YR 5/6) to moderate brown (5YR 4/6) and pale red (10R 6/2), partially welded, vitric alteration; 2% pumice, white (N9); lithic poor, 5% quartz phenocrysts, rare feldspars and mafics. Local occurrences of chalcedony. Possibly Bullfrog Tuff.

515 to 810 ft VOLCANIC SANDSTONE with weakly welded tuff horizons

Moderate orange pink (5YR 8/4) to grayish orange pink (5YR 7/2) sandstone with medium light gray (N6) tuff horizons (5 to 15 ft thick). Unit is soft and samples were ground by the drill bit. Sandstone grains are well rounded and oxidized. Sharp contact with underlying welded tuff Possibly pre-Bullfrog Tuff and sedimentary unit.

810 to 890 ft (T.D.) ASHFLOW TUFF*

Grayish orange (10YR 7/4) to moderate yellowish brown (10YR 5/4), partially welded, vitric alteration; 1 to 5% pumice, pale yellowish orange (10YR 8/6), moderate red (5R 4/6), very light gray (N8); 1 to 5% lithics, dusky red (5R 3/4), and pale yellowish orange (10YR 8/6), 1 to 4% quartz phenocrysts, absence of feldspars and mafics. Unit contains sandstone and siltstone horizons. Stongly oxidized with orange to red hematitic staining on tuffaceous clasts. Possibly Tram Tuff.

* Sample particle size is very small and difficult to describe due to drill bit grinding of the rock

Nye County, Nevada Nuclear Waste Repository Project Office	
Early Warning Drilling Program Summary Lithology Log NC-EWDP-18P	
Date: 5/23/02	Geologist: JSW
Scale: Not to Scale	Drawn by: RFD

NOTE: T.D. = total depth

Figure 4.5-2
Summary Lithologic Log for Well NC-EWDP-18P

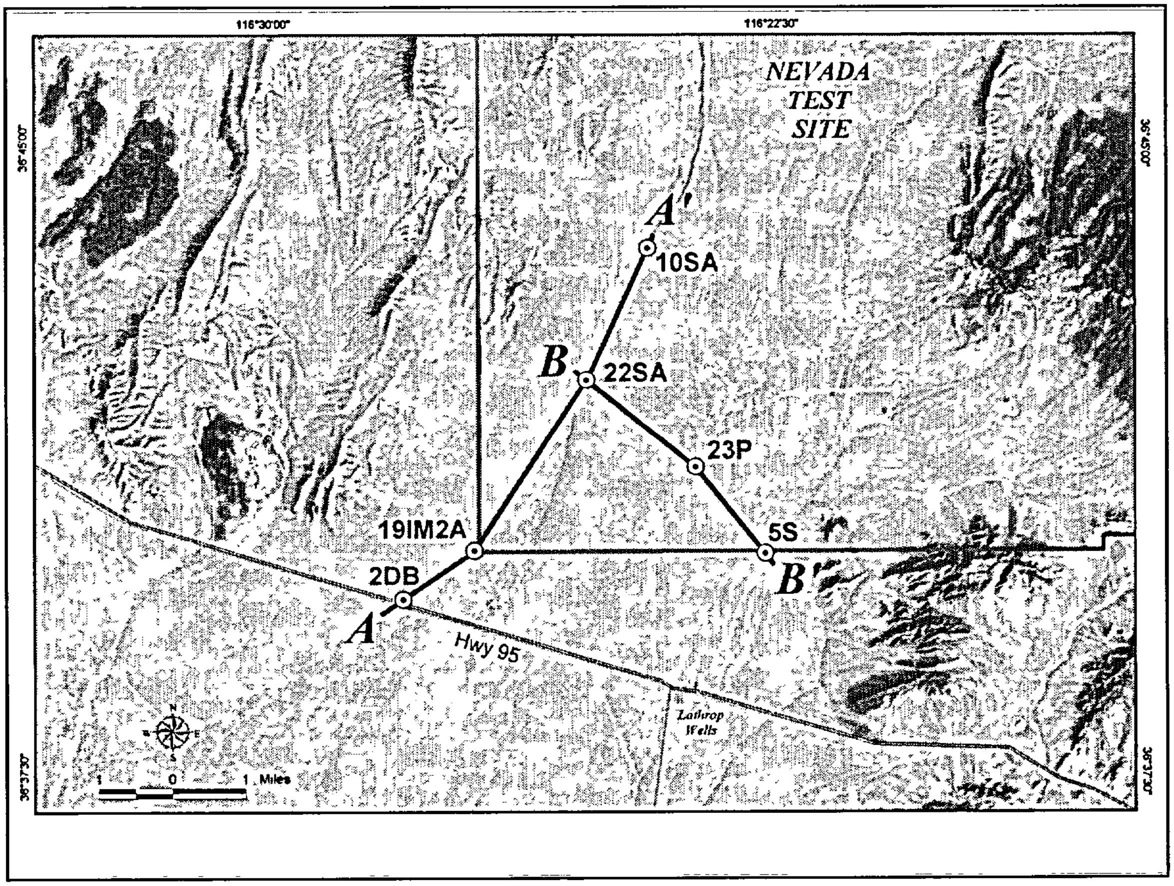


Figure 4.5-3
Alluvium Cross Section Construction Lines

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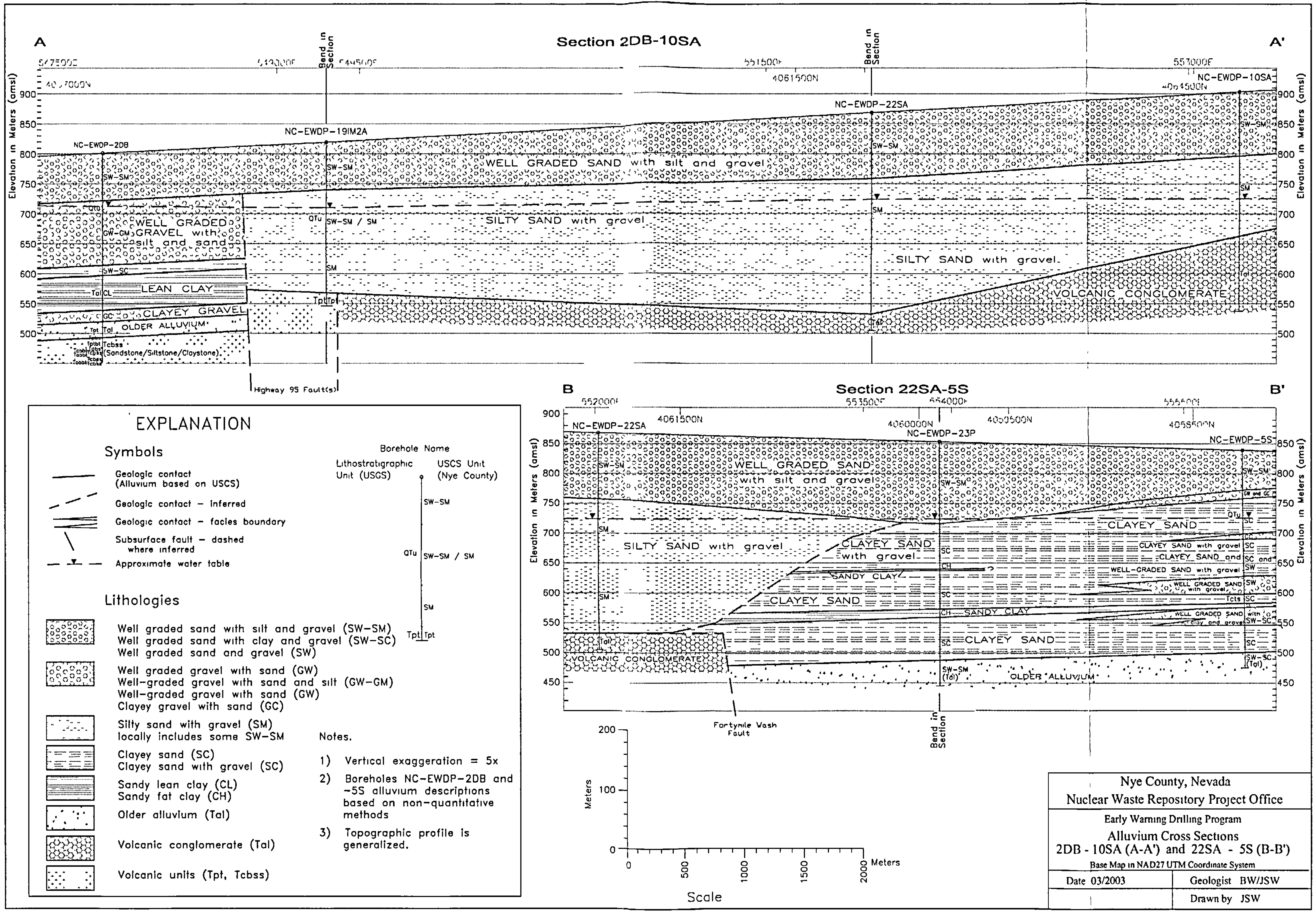

NOTES. USCS = Unified Soil Classification System, USGS = U.S. Geological Survey

Figure 4.5-4
Fortymile Wash Alluvium Cross Sections

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TABLES

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Table 1.3-1
Well Completion Summary for Early Warning Drilling Program Phase III

Well ID[a]	Well Type	Well Status	Start Drilling Date	Drilling Completion Date	Total Depth (feet, bgs)	Survey Coordinates		Ground Elevation (feet, amsl)	Approx Open Hole Water Level at End of Drilling (feet, bgs)	Screened Interval(s) (feet, bgs)	Sand Pack Interval(s) (feet, bgs)	Lithology at Sand Pack Intervals	Westbay Packer Interval(s) (feet, bgs)	Well Casing Type	Well Casing Depth (feet, bgs)	Well Casing Outside Diameter (in.)
						Latitude	Longitude									
19IM1A	Exploratory Borehole	Abandoned	7/10/01	7/13/01	900	36° 40' 14 615"	116° 26' 56 397"	2687 3	366	NA	NA	NA	NA	NA	NA	NA
19IM1	Monitor Well - Multiple Screen	Completed	8/13/01	8/28/01	1012 5	36° 40' 14 615"	116° 26' 56 397"	2687 3	358	410 0-430 0	394 1-440 6	Alluvium	404-436	Steel	949 3	7
										515 0-535 0	503 3-545 4	Alluvium	508-540			
										574 9-674 9	562 3-689 6	Alluvium	568-680			
										724 9-784 8	715 0-797 7	Alluvium	722-788			
										849 5-949 3	838 8-967 3	Tertiary Tuff	846-949 3			
											967 3-1012 5[b]	Tertiary Tuff				
19IM2A	Exploratory Borehole	Abandoned	7/13/01	7/17/01	900	36° 40' 14 614"	116° 26' 55 597"	2688 1	369	NA	NA	NA	NA	NA	NA	NA
19IM2	Monitor Well - Multiple Screen	Completed	8/14/01	9/13/01	965 6	36° 40' 14 614"	116° 26' 55 597"	2688 1	358	410 2-430 2	382 7-443 4	Alluvium	NA	Steel	950 1	7
										515 0-534 9	500 5-550 4	Alluvium				
										574 9-674 9	561 2-684 6	Alluvium				
										724 9-784 9	715 8-797 6	Alluvium				
										849 9-950 1	840 1-965 8	Tertiary Tuff				
10SA	Exploratory Borehole	Abandoned	7/18/01	7/28/01	1200	36° 43' 48 339"	116° 24' 20 725"	2963 5	383	NA	NA	NA	NA	NA	NA	NA
10S	Monitor Well - Multiple Screen	Completed	9/20/01	10/3/01	900	36° 43' 48 339"	116° 24' 20 725"	2963 5	579	660 0-700 0	650 5-710 8	Alluvium	652-702	Steel	880	6 5/8
										800 0-860 0	787 2-900 0	Tertiary Volcanic Conglomerate	796-870			
10P	Piezometer	Completed	9/20/01	1/13/02	910 5	36° 43' 48 874"	116° 24' 20 362"	2964 6	580	660 1-699 3 801 2-860 0	145 6-154 4[c]	Alluvium	NA	PVC	879 9	2 3/8
											247 2-256 8[c]	Alluvium				
											347 0-350 0[c]	Alluvium				
											444 7-464 4[c]	Alluvium				
											530 0-583 8[c]	Alluvium				
											650 9-706 1	Alluvium				
											776 - 910 5	Tertiary Volcanic Conglomerate				
18P	Piezometer	Completed	9/20/01	10/21/01	890 4	36° 45' 04 797"	116° 25' 50 340"	3164 5	777	835 8-885	830 2-890 4	Tertiary Tuff	NA	PVC	885	2 3/8
22SA	Exploratory Borehole	Abandoned	7/28/01	8/2/01	1200	36° 42' 15 132"	116° 25' 06 636"	2849 0	474	NA	NA	NA	NA	NA	NA	NA
22S	Monitor Well - Multiple Screen	Completed	9/21/01	10/25/01	1196 5	36° 42' 15 132"	116° 25' 06 636"	2849 0	473	521 5-581 3	510 4-590 1	Alluvium	514-582	Steel	1190 1	6 5/8
										661 2-760 6	648 8-770 6	Alluvium	650-766			
										880 2-980 0	866 5-991 0	Alluvium	874-982			
										1140 0-1180 0	1127 5-1196 5	Tertiary Volcanic Conglomerate	1134-1188			
22PA	Piezometer	Completed	1/13/02	2/5/02	779 8	36° 42' 15 712"	116° 25' 06 581"	2849 9	471	520 7-579 7 661 5-759 8	47 3-53 3[c]	Alluvium	NA	PVC	770	2 3/8
											147 4-153 6[c]	Alluvium				
											244 2-253 0[c]	Alluvium				
											346 7-353 9[c]	Alluvium				
											445 7-455 0[c]	Alluvium				
											508 7-587 0	Alluvium				
											649 7-779 8	Alluvium				
22PB	Piezometer	Completed	2/21/02	2/27/02	1199 7	36° 42' 15 665"	116° 25' 05 863"	2849 3	474	881 3-979 7	868 7-989 7	Alluvium	NA	PVC	1189 9	2 3/8
										1140 3-1179 7	1125 2-1199 7	Tertiary Volcanic Conglomerate				
23P	Piezometer	Completed	3/9/02	3/20/02	1339 9	36° 41' 05 317"	116° 23' 50 412"	2800 2	426	460 9-519 9	449 1-531 0	Alluvium	NA	PVC	700	2 3/8
										650 5-689 8	635 9-700 0	Alluvium				

NOTES bgs = below ground surface, amsl = above mean sea level, NA = not applicable, all depth data have not been corrected for borehole deviation
[a] The official prefix for all new Nye County wells is "NC-EWDP- "
[b] Caved interval of the borehole
[c] Air piezometers

Table 1.4-1
List of Relevant Early Warning Drilling Program Phase III Work Plan and Technical Procedure Quality Assurance Documents

Document	Title	Date
Work Plan 5	Early Warning Drilling Program Phase III Drilling and Well Construction Work Plan	5/17/01, Revision 2
Work Plan 6	Early Warning Drilling Program Geophysical Logging Work Plan	5/31/01, Revision 1
Work Plan 8	Sample Management Plan	5/31/01, Revision 2
Technical Procedure TP-7.0	Drill Site Management	9/21/01, Revision 2
Technical Procedure TP-8.0	Field Logging and Handling of Borehole Samples	9/25/01, Revision 3

Table 2.3-1
Drill Cuttings Sampling, Splitting, and Testing Summary

Borehole ID (NC-EWDP-)[a]	Geologic Material Description	Drilling Method[b]	Drill Cuttings Sample Interval (feet)	Total Number of Drill Cuttings Samples	Density-Related Field Measurements[c]	Number of Drill Cuttings Samples						Hydrometer
						Splits (5-lb. bags)			NWRPO Lab Analyses			
						NWRPO SMF split	DOE/YMP SMF Split	NWRPO Lab Split	Gravimetric Water Content[d]	Soil Water Extract EC[d]	Wet Sieve	
19IM1A	Alluvium[e]	RC	2.5	276	Selected samples	276	276	154	105	86	154	8
	Non-alluvium	RC	5	16	Selected samples	16	16	0	0	0	0	0
19IM2A	Alluvium	RC	2.5	277	Selected samples	277	277	165	79	84	165	9
	Non-alluvium	RC	5	15	Selected samples	15	15	0	0	0	0	0
10SA	Alluvium	RC	2.5	283	Selected samples	283	283	150	133	133	150	15
	Non-alluvium	RC	5	90	Selected samples	90	90	0	0	0	0	0
10P	Alluvium	CA	2.5	314	Selected samples	314	314	156	131	131	156	2
	Non-alluvium	CA	5	25	Selected samples	25	25	0	0	0	0	0
22SA	Alluvium	RC	2.5	334	Selected samples	334	334	222	93	93	222	11
	Non-alluvium	RC	5	18	Selected samples	18	18	0	0	0	0	0
22PA	Alluvium	CA	2.5	275	Selected samples	275	275	156	98	98	156	4
	Non-alluvium	CA	5	0	Selected samples	0	0	0	0	0	0	0
22PB	Alluvium	RC	2.5	340	Selected samples	340	340	240	103	103	240	6
	Non-alluvium	RC	5	16	Selected samples	16	16	0	0	0	0	0
23P	Alluvium	RC	2.5	358	Selected samples	358	358	240	88	88	240	11
	Non-alluvium	RC	5	0	Selected samples	0	0	0	0	0	0	0
18P	Alluvium	CA	2.5	17	Selected samples	17	17	10	10	10	10	0
	Non-alluvium	CA	5	170	Selected samples	170	170	0	0	0	0	0
TOTALS				2,824	NA	2,824	2,824	1,493	840	826	1,493	66

NOTES: DOE = U.S Department of Energy; EC = electrical conductivity; NA = not applicable; NWRPO = Nuclear Waste Repository Project Office; SMF = Sample Management Facility; YMP = Yucca Mountain Project

[a]Official prefix of all Nye County wells.

[b]RC = air-rotary dual-wall reverse circulation; CA = casing advance

[c]Measurements not made on samples below the water table, or where water was being used as a drilling fluid.

[d]Analyses not conducted on samples below the water table.

[e]Alluvium is defined as all unconsolidated sediments.

Table 2.3-2
Drive Core Sampling, Splitting, and Testing Summary

Borehole ID[a]	Geologic Material Description	Drilling Method	Number of Core Runs per Borehole	Density-Related Field Measurements	Number of Splits (6- and 3-in -long liners)			Number of NWRPO Lab Analyses				
					NWRPO SMF Subsamples	DOE/YMP SMF Subsamples	NWRPO Lab Subsamples	Volumetric Water Content	Grain and Bulk Density	Wet Sieve	Hydrometer	Saturated Hydraulic Conductivity
10P	Alluvium–Unsaturated Zone	CA	3	3	6	9	3	5	5	5	5	5
	Alluvium–Saturated Zone	CA	3	3	6	9	3	9	9	9	9	8
22PA	Alluvium–Unsaturated Zone	CA	1	1	2	3	1	3	3	3	3	3
	Alluvium–Saturated Zone	CA	6	6	11	13	6	12	12	12	12	12
TOTALS			13	13	25	34	13	29	29	29	29	28

NOTES: CA = casing advance drilling method; DOE = U.S. Department of Energy; NA = not applicable; NWRPO = Nuclear Waste Repository Project Office; SMF = Sample Management Facility; YMP = Yucca Mountain Project

[a]Official prefix of all Nye County wells is "NC-EWDP-".

Table 2.4-1
Laboratory Test Methods

Sample Type	Lab Test	Method
Core	Volumetric Water Content	ASTM D-2216-92. Method for laboratory determination of water (moisture content) of soil, rock, and soil-aggregate mixtures. In: *1996 Annual Book of ASTM Standards*, Vol. 04.08, American Society for Testing and Materials.
	Dry Bulk Density	Blake, G.R. and K.H. Hartge. 1986. "Bulk Density." In: Klute, A. (ed), *Methods of Soil Analysis*, Part 1, Physical and Mineralogical Methods (2nd ed.), American Society of Agronomy, Chapter 13, pp. 363-367.
	Specific Gravity (grain density)	ASTM D-854-92. Standard test method for specific gravity of soils. In: *1996 Annual Book of ASTM Standards*, Vol. 04 08, American Society for Testing and Materials.
	Saturated Hydraulic Conductivity (constant head method)	Klute, A. , and C. Dirksen, 1986. "Hydraulic Conductivity and Diffusivity: Laboratory Methods." In: Klute, A. (ed), *Methods of Soil Analysis*, Part 1, Physical and Mineralogical Methods (2nd ed.), American Society of Agronomy, Chapter 28, pp. 694-700.
Drill Cuttings	Gravimetric Water Content	ASTM D-2216-92. Method for laboratory determination of water (moisture content) of soil, rock, and soil-aggregate mixtures. In: *1996 Annual Book of ASTM Standards*, Vol. 04 08, American Society for Testing and Materials.
	Soil Extract Electrical Conductivity	Rhoades, J.D. 1986. Soluble salts—Electrical conductivity of saturation extract. In: Page, A.L. (ed), *Methods of Soil Analysis*, Part 2, Chemical and Microbiological Properties (2nd ed.), American Society of Agronomy, pp. 172-173.
Core and Drill Cuttings	Wet Sieve Analysis	ASTM D-1140-97. Standard test method for amount of material in soil finer than the No. 200 (75 um) sieve (Method B for wet sieve analysis). In: *1997 Annual Book of ASTM Standards*, Vol. 04 08, American Society for Testing and Materials.
	Hydrometer Analysis (silt/clay break starting with No. 4 sieve)	ASTM D-422. Standard method for Particle Size Analysis of Soils. In: *1996 Annual Book of ASTM Standards*, Vol. 04.08, American Society for Testing and Materials

Table 2.6-1
Summary of Types and Application of Geophysical Logs Used in Phase III Boreholes

Type of Log	Suites[a]	Properties Measured	Application
Caliper	2	Borehole diameter	Provides borehole correction (e.g., wash-out zones) for other logs, borehole volume for well completions, possible identification of fractures and contacts.
Density	1, 2, 3	Tool generated radiation altered by formation materials	Yields density information on adjacent borehole wall formation material; identifies wash-out zones.
Deviation	1, 2, 3	Deviation of borehole from vertical	Permits calculation of true elevations for lithologic contacts, well screens, water levels, and other borehole depth measurements.
Fluid Resistivity	2	Borehole fluid resistivity and conductivity	Estimates relative amount of dissolved salts in borehole fluid and may provide an indication of inflow in open borehole
Fluid Temperature (Temperature)	1, 2, 3	Borehole fluid temperature	Helps to identify locations of inflow/outflow in open borehole; geothermal gradient in cased borehole
Gamma (Natural Gamma)	1, 2, 3	Gamma radiation from natural sources in formation and borehole drilling fluids	Assists in identification of lithology and stratigraphic correlation of units; may respond to differences in clay content
Magnetic Susceptibility	2	Ferromagnetism in rocks	Assists in identification of lithology changes involving ferromagnetic rocks, including hydrothermal alteration
Moisture	1, 2, 3	Tool generated radiation altered by water in formation and borehole	Identifies moisture content changes in the unsaturated zone; possibly indicates porosity changes in the saturated zone.
Resistivity (R8, R16, R32, R64)	2	Apparent resistivity of formation at different distances from borehole	Assists in the identification of lithology and stratigraphic correlation; indicates relative changes in water quality.
Single-Point Resistivity (SPR)	2	Resistivity of borehole fluids and adjacent formation	Assists in identification of lithology and changes in borehole fluid composition.
Sonic (Acoustic Velocity)	2, 3	Compressional-wave velocity through fluids and formations	Helps define saturated zones and lithology; indicator of fractures.
Spectral Gamma	1, 2	Radiation emitted by U, Th, and K	Can help in identification of minerals containing U, Th, and K.
Spontaneous Potential (SP)	2	Electrical potential between fluids in borehole and adjacent formation	Assists in identification of lithology, clay, and shale content and relative changes in formation water quality.

Source: Modified from Keys (1990).

NOTES: [a]1 = logged inside drill pipe or casing (drill-string log); 2 = logged in open borehole (open-hole log); 3 = logged inside well casing (well-completion log)

Table 2.6-2
Geophysical Logging Summary

Borehole ID (NC-EWDP-)	Date	Log Suite Type[a]	Borehole/Well Depth at Time of Logging (feet)	Logged Interval (feet)	Log Type												Comments
					Gamma	Density	Spectral Gamma	Moisture	Fluid Temperature	Deviation	Resistivity (SPR, R8-R64)	Fluid Resistivity	Spontaneous Potential	Caliper	Acoustic Velocity (Sonic)	Magnetic Susceptibility	
10SA	7/27/01	1	1200	0-1180	x	x	x	x	x	x							Run inside 4 5-in. dual-wall drill pipe in 5 375-in. borehole with approximately 20 ft of 6 625-in. OD steel surface casing
10S	9/30/01	2	900	0-895	x	x	x	x	x	x	x	x	x	x	x	x	Run in 14 75-in flooded mud borehole with 62.5 ft of 18-in. OD steel conductor casing and drilling mud from approximately 5 ft to total depth
10S	2/18/02	3	880	0-880	x	x		x									Run inside 6 625-in OD steel well casing
10S	9/25/02	3	870	0-867						x						x	Run inside 4-in. Schedule 80 PVC riser pipe from 0 to 647 ft and 2 9-in. OD PVC Westbay® casing from 647 to 867 ft.
10P	12/27/01	1	910 5	0-900	x					x			x		x	x	Run in 6 625-in OD drill casing from 0 to 792 ft, telescoped inside of 9 625-in. drill casing from 0 to 304 ft, and in 5 875 in. open hole from 792 to 900 ft.
10P	12/27/01	2	910 5	790-907	x	x	x	x	x	x	x	x	x	x	x	x	Run inside 5 875-in. open hole beyond drill casing from 790 to 900 ft.
10P	2/19/02	3	880	0-880	x	x		x		x							Run inside 2-in Schedule 80 PVC well casing, unable to run deviation tool below 128 ft.
10P	9/25/02	3	880	0-879						x						x	Run inside 2-in. Schedule 80 PVC well casing
18P	2/20/02	3	885	0-885	x	x		x		x							Run inside 2-in. Schedule 80 PVC well casing
19IM1A	7/13/01	1	900	0-880	x	x	x	x	x	x							Run inside 4 5-in. dual-wall drill pipe in 5.375-in borehole with approximately 20 ft of 6 625-in OD steel surface casing
19IM1[b]	10/2/01	3	950	0-935	x	x			x	x							Run inside 7-in. OD steel well casing prior to pump testing
19IM2A	7/17/01	1	900	0-880	x	x	x	x	x	x							Run inside 4 5-in. dual-wall drill pipe in 5 375-in borehole with approximately 20 ft of 6 625-in. OD steel surface casing.
19IM2	9/8/02 - 9/9/02	2	965	0-965	x	x	x	x	x	x	x	x	x	x	x	x	Run in 14.75-in. flooded mud borehole with 75 ft of 18-in. OD steel conductor casing and drilling mud from approximately 12 ft to total depth.
19IM2	10/2/01	3	950	0-925	x	x			x	x		x					Run inside 7-in. OD steel well casing prior to pump testing
19IM2	9/26/02	3	950	0-917											x		Run inside 7-in. OD steel well casing.
22SA	8/1/01	1	1200	0-1180	x	x	x	x	x	x							Run inside 4.5-in. dual-wall drill pipe in 5 375-in. borehole with approximately 20 ft of 6 625-in. OD steel surface casing
22S	10/20/01	2	1197	0-1190	x	x	x	x	x	x	x	x	x	x	x	x	Run in 14 75-in. flooded mud borehole with 75 ft of 18-in. OD steel conductor casing and drilling mud from approximately 5 ft to total depth
22S	2/19/02	3	1190	0-1180	x	x		x									Run inside 6 625-in. OD steel well casing
22S	9/26/02	3	1183	0-1181						x						x	Run inside 4-in. Schedule 80 PVC riser pipe from 0 to 508 ft and 2 9-in OD PVC Westbay® casing from 508 to 1183 ft.
22PA	2/19/02	3	770	0-770	x	x		x		x							Run inside 2-in Schedule 80 PVC well casing, unable to run deviation tool below 229 ft.
22PA	9/25/02	3	770	0-767						x						x	Run inside 2-in Schedule 80 PVC well casing
22PB	3/3/02	1	1212	1212	x	x	x	x	x	x	x	x	x	x	x	x	Run inside 8 5-in. open hole with 15 1 ft of 10 75-in. OD steel surface casing
22PB	3/18/02	3	1212	0-987			x										Run inside 2-in. Schedule 80 PVC well casing to total depth in the shallow piezometer and to 271 ft in the deep piezometer.
22PB	9/25/02	3	1190	0-1188						x						x	Run inside 2-in Schedule 80 PVC well casing in the deep piezometer.
23P	3/26/02	2	702	0-702	x	x		x	x	x	x	x	x	x		x	Run inside 8 5-in. open hole with 16 9 ft of 10 75-in OD steel surface casing.
23P	9/26/02	3	700	0-691	x	x	x	x									Run inside 2-in Schedule 80 PVC well casing in the deep piezometer.

NOTES: NA = not applicable; OD = outer diameter; PVC = polyvinyl chloride

[a]1 = logged inside drill pipe or casing (drill-string log), 2 = logged in open borehole (open-hole log); 3 = logged inside well casing (well-completion log).

[b]No open-hole logging was conducted in well borehole NC-EWDP-19IM1 due to borehole instability problems at total depth.

Table 3.1-1
Well Elevation and Water Level Summary

Well Name (NC-EWDP-)	Casing	Top of Casing Elevation (ft amsl)[a]	Original Ground Surface Elevation (ft amsl)	Date of Water Level Measurement (mo./day/yr.)	Groundwater Elevation (ft amsl)	Depth to Water (ft)[b]
19IM1	7-in. OD steel	2,688.96[c]	2,687.29	10/15/01	2,329.3[d]	359.7[d, e]
19IM2	7-in. OD steel	2,690.00	2,688.06	9/24/02	2,333.6[d]	356.4[d]
10S	6.625-in OD steel	2,965 92[c]	2,963.62[f]	2/5/02	2,385.1[d]	580 8[d, e]
10P (deep)	2-in. SCH 80 PVC	2,966.65	2,964.60	9/25/02	2,385.0	581.67
10P (shallow)	2-in. SCH 80 PVC	2,966.65	2,964.60	9/25/02	2,385.1	581.52
22S	6.625-in. OD steel	2,851.37[c]	2,849.00	2/25/02	2,378 4[d]	473.0[d, e]
22PA (deep)	2-in. SCH 80 PVC	2,852.15	2,849.86	9/25/02	2,378.2	473.98
22PA (shallow)	2-in SCH 80 PVC	2,852.15	2,849 86	9/25/02	2,378.1	474.03
22PB (deep)	2-in. SCH 80 PVC	2,851.79	2,849.33	9/25/02	2,378 1	473.68
22PB (shallow)	2-in. SCH 80 PVC	2,851.79	2,849.33	8/28/02	2,377 9	473.90
23P (deep)	2-in. SCH 80 PVC	2,802.65	2,800.15	10/01/02	2,376 0	426.70
23P (shallow)	2-in. SCH 80 PVC	2,802.65	2,800.15	10/01/02	2,376.3	426.40
18P	2-in. SCH 80 PVC	3,166.56	3,163.19[f]	8/22/02	2,386.9	779 65

NOTES: OD = outer diameter; all subsurface elevation and depth data have not been corrected for borehole deviation

[a] ft amsl = feet above mean sea level

[b] Depth to water measurements are most recent available.

[c] A Westbay® packer system has been installed in NC-EWDP-19IM1, -10S, and -22S. The reference casing elevation (measuring point) for the new Westbay® casing has not been surveyed as of February 2003.

[d] Depth to water based on composite head in multiple screened well

[e] Further data on Westbay® packer zone interval water levels are available.

[f] Original ground surface elevation based on GPS survey elevation at top of casing less stick-up of casing. All other original ground surface elevations based on GPS survey of ground elevation

Table 4.0-1
Summary of Censored Geologic Sample Data from Phase III Boreholes

	Geologic Logging Data–Depth Interval Censored (ft, bgs)						Laboratory Test Data–Depth Interval Censored (ft, bgs)					Drilling Data–Depth Interval Censored (ft, bgs)
	Drill Cuttings Samples					Drive Core Samples	Alluvium Drill Cuttings Samples				Drive Core Samples	
Borehole No.[a]	Alluvium Field Estimated PSD and USCS Group Symbol Data[b]	Alluvium Sample Bulk Density Related Data[c]	Non-Alluvium Sample Bulk Density Related Data[c]	Alluvium Sample Recovery Data[d]	Non-Alluvium Sample Recovery Data[d]	Alluvium Field Estimated PSD and USCS Group Symbol Data[b]	Wet Sieve PSD Data	Electrical Conductivity Data[e]	Gravimetric Water Content Data[e]	Hydrometer PSD Data[f]	Dry Bulk Density, Volumetric Water Content, and Saturated Hydraulic Conductivity Data[g]	Water Production Data
10SA	0–750			665-750	750-1,200		665–750[h]	582 5–665	582 5–665	665–670 675–680 685–690 700–705 725–730 745–750		865-1,200[i]
10P	0–787 5		787 5-910	587 5-787 5	787 5-910	57 5-60[j] 58 35-58 85 168 22-168 72 667 47-667 72 703 16-703 66 704 16-704 41 743 11-743 61 744 11-744 36	2 5–790[k]	582 5–665	582 5–665	297 5–300 367 5–370	58 85-59 35 347 87-348 37 666 97-667 47	
18P	0–45		45–135		850-890		45–50	45–50				0-890[l]
19IM1A	0–820			522 5-820			522 5–820[h]	362 5–430	362 5–525	537 5–540 620–625 695–700		0-900[l]
19IM2A	0–825			392 5-825			372 5-380[m] 750-825[h]	362 5–395 542 5-545 547 5-550 552 5-555 560-565 575-580	362 5–395			825-900[l]
22SA	0–1,110			482 5-1,110			487 5-590[m] 665–1,110[h]	472 5–485	472 5–485	750–755 825–830 990–995		1,110-1,200[l]
22PA	2 5–780			500-780		392 25-392 75 393 25-393 5 553 24-553 74 572 64-573.14 670 11-670 61 710 33-710 58 740 85-741 35 741 85-742 10	0–780[k]	472 5–490	472 5–490	172 5–175 292 5–295 437 5–440 770–775	523 00–523 50	
22PB	0–1,120		1,120-1,200	517 5-1,120	1,120-1,200		2 5–1,120[k] 1,120-1,200[n]	472 5–515	472 5–515	302 5–305 352 5–355 507 5–510 765–770 935–940 1,100–1,105		
23P	0–1,340			450-1,340			555–1,200[h]	427 5–435	427 5–435	585–590 685–690 815-820 840–845 1,025–1,030 1,100–1,105 1,125–1,130		1,200-1,340[l]

NOTES [a] Prefix for all Nye County EWDP wells is "NC-EWDP-"

[b] Particle size distribution (PSD) and Unified Soil Classification Group Symbol data are censored because field estimates differ significantly from laboratory measurements

[c] Data (tare weight, sample plus tare weight, and sample weight) are censored because a significant amount of sample was not collected and weighed over 10- or 20-ft drill run intervals

[d] Data are censored because they were not accurately adjusted to account for splitting of samples when water production was greater than zero

[e] Electrical conductivity of soil-water extract and gravimetric water content data obtained from drill cuttings are applicable to regions above the water table only

f Data are censored for the same reasons given for the PSD wet sieve data

[g] Data are censored because core sample density and porosity were disturbed during coring and/or during lab sample preparation

[h] Data are censored because drilling reduced relatively soft rock clasts to smaller particle size fractions.

[i] Data are censored because 5-gal bucket measurements were not made and too few air lift measurements at the end of drill runs were made to provide a basis for estimating water production

[j] These data plus all other logging parameter data are censored for this depth interval because errors were made in recording data on the logging form

[k] Data are censored because of significant drilling and/or sample handling disturbance of PSDs

[l] Data are censored because air-lift production measurements were conducted in an open borehole with more than 750 ft of unsaturated zone where a significant amount of air-lift water was likely lost to the formation.

[m] Data are censored because bentonite drilling fluid contaminated samples

[n] Data are censored because PSDs are not applicable below alluvium and non-alluvium contact at 1,120 ft

Table 4.1-1
Example of an Alluvium Logging Form for Borehole NC-EWDP-22SA (Cuttings)

Borehole ID: NC-EWDP-22SA (Phase 3) Driller/Drilling Company B Mikelson/Eklund Drilling Method: Reverse Circulation - Air Alluvium Depth (ft bgs): 0 to 1110 Start Date 7/28/01 End Date 8/1/01 Page 1 of 13

Date Logged	Logged By (Initials)	Date Checked	Checked By (Initials)	Sample Number	Sample Type	Depth Interval (feet bgs) From	Depth Interval (feet bgs) To	Drilling/Coring Data: Liquid Drilling Fluid Injection Rate (gpm)	Drilling/Coring Rate (feet/min)	Water Production (gpm)	Sample Recovery (gallons)	Borehole/Core Diameter (inches)	Sample Density Measurements: Tare Weight (kg)	Sample Plus Tare Weight (kg)	Sample Weight (kg)	Munsell Color Symbol	Moisture Content: Dry	Moist	Wet	Particle Size Distribution (%): Gravel	Sand	Silt	Clay	Fines (Silt plus Clay)	Grading: Well Graded	Poorly Graded	Estimated Plasticity: None	Low	Moderate	High	USCS Group Symbol	Gravel/Sand GrainShape: Angular	Subangular	Subrounded	Rounded	Cementation: None	Weak	Moderate	Strong	HCL Reaction: None	Weak	Strong	Major Rock Type (%): Volcanics	Carbonates	Other
7/28/01	KDD	8/12/01	GH	BCS00010401-22SA-554	Cuttings	0 00	2 50	0 0	2 5	0 0	3 0	5 4	0.85	9.90	9.05	5YR 5/4	☑	☐	☐	13	77	10	0	10	☐	☑	☑	☐	☐	☐	SP-SM	☐	☐	☐	☑	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010402-22SA-555	Cuttings	2 50	5 00	0 0	2 5	0 0	3 2	5 4	0.85	21.50	20.65	5YR 5/4	☑	☐	☐	25	65	10	0	10	☐	☑	☑	☐	☐	☐	SP-SM	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010403-22SA-556	Cuttings	5 00	7 50	0 0	2 5	0 0	1 8	5 4	0.85	10.50	9.65	5YR 5/4	☑	☐	☐	19	71	10	0	10	☑	☐	☑	☐	☐	☐	SW-SM	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010404-22SA-557	Cuttings	7 50	10 00	0 0	2 5	0 0	2 0	5 4	0.85	12.10	11.25	5YR 5/4	☐	☑	☐	29	66	5	0	5	☑	☐	☑	☐	☐	☐	SW	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010405-22SA-558	Cuttings	10 00	12 50	0 0	2 5	0 0	1 8	5 4	0.85	7.50	6.65	10YR 5/4	☐	☑	☐	27	69	4	0	4	☑	☐	☑	☐	☐	☐	SW	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010406-22SA-559	Cuttings	12 50	15 00	0 0	2 5	0 0	2 0	5 4	0.85	11.80	10.95	5YR 4/4	☐	☑	☐	40	55	5	0	5	☑	☐	☑	☐	☐	☐	SW	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010407-22SA-560	Cuttings	15 00	17 50	0 0	5 0	0 0	1 8	5 4	0.85	8.10	7.25	5YR 4/4	☐	☑	☐	28	67	5	0	5	☑	☐	☑	☐	☐	☐	SW	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010408-22SA-561	Cuttings	17 50	20 00	0 0	5 0	0 0	1 8	5 4	0.85	10.70	9.85	5YR 4/4	☐	☑	☐	37	58	5	0	5	☑	☐	☑	☐	☐	☐	SW	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010409-22SA-562	Cuttings	20 00	22 50	0 0	5 0	0 0	2 2	5 4	0.85	13 80	12.95	5YR 4/4	☐	☑	☐	37	58	5	0	5	☑	☐	☑	☐	☐	☐	SW	☐	☐	☐	☑	☐	☐	☑	☐	☐	☐	☑	100		
[illegible]/01	KDD	8/12/01	GH	BCS00010410-22SA-563	Cuttings	22 50	25 00	0 0	2 5	0 0	1 0	5 4	0.85	7.80	6.95	5YR 4/4	☑	☐	☐	29	61	10	0	10	☑	☐	☑	☐	☐	☐	SW-SM	☐	☐	☑	☐	☐	☑	☐	☐	☐	☑	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010411-22SA-564	Cuttings	25 00	27 50	0 0	2 5	0 0	2 0	5 4	0.85	9 55	8.70	5YR 4/4	☑	☐	☐	38	54	8	0	8	☑	☐	☑	☐	☐	☐	SW-SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010412-22SA-565	Cuttings	27 50	30 00	0 0	1 3	0 0	1 9	5 4	0.85	10.55	9.70	5YR 4/4	☑	☐	☐	26	59	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010413-22SA-566	Cuttings	30 00	32 50	0 0	2 5	0 0	2 0	5 4	0.85	17.45	16.60	5YR 4/4	☑	☐	☐	17	63	20	0	20	■	■	☑	☐	☐	☐	SM	☐	☐	☑	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010414-22SA-567	Cuttings	32 50	35 00	0 0	3 8	0 0	1.7	5 4	0.85	8.10	7.25	5YR 4/4	☑	☐	☐	18	67	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010415-22SA-568	Cuttings	35 00	37 50	0 0	3 8	0 0	1 8	5 4	0.85	10.15	9.30	5YR 4/4	☑	☐	☐	22	63	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☐	☑	☐	☐	☑	☐	☐	☐	☑	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010416-22SA-569	Cuttings	37 50	40 00	0 0	3 8	0 0	2 0	5 4	0.85	12.40	11.55	5YR 4/4	☑	☐	☐	48	37	15	0	15	■	■	☑	☐	☐	☐	GM	☐	☐	☑	☐	☐	☐	☐	☑	☐	☐	☑	100		
7/29/01	KDD	8/12/01	GH	BCS00010417-22SA-570	Cuttings	40 00	42 50	0 0	2 2	0 0	1 4	5 4	0.85	9 20	8.35	5YR 4/4	☑	☐	☐	23	62	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☐	☑	☐	☐	☐	☑	☐	☑	☐	☐	100		
7/29/01	KDD	8/12/01	GH	BCS00010418-22SA-571	Cuttings	42 50	45 00	0 0	2 2	0 0	1 0	5 4	0.85	6.80	5.95	5YR 4/4	☑	☐	☐	36	49	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☐	☑	☐	☐	☐	☑	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010419-22SA-572	Cuttings	45 00	47.50	0 0	2.2	0 0	1 6	5 4	0.85	10.30	9.45	5YR 6/4	☑	☐	☐	38	47	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☐	☐	☑	100		
7/28/01	KDD	8/12/01	GH	BCS00010420-22SA-573	Cuttings	47 50	50 00	0 0	2 2	0 0	2 0	5 4	0.85	13.40	12.55	5YR 6/4	☑	☐	☐	21	64	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/28/01	KDD	8/12/01	GH	BCS00010421-22SA-574	Cuttings	50 00	52 50	0 0	2 2	0 0	2 3	5 4	0.85	16.45	15.60	5YR 6/4	☑	☐	☐	21	64	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/28/01	KDD	8/12/01	GH	BCS00010422-22SA-575	Cuttings	52 50	55 00	0 0	2 2	0 0	1.7	5 4	0.85	11.20	10.35	5YR 6/4	☑	☐	☐	28	57	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/28/01	KDD	8/12/01	GH	BCS00010423-22SA-576	Cuttings	55 00	57 50	0 0	2 2	0 0	1 6	5 4	0.85	13 00	12.15	5YR 6/4	☑	☐	☐	16	69	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/28/01	KDD	8/12/01	GH	BCS00010424-22SA-577	Cuttings	57 50	60 00	0 0	2 2	0 0	2 0	5 4	0.85	14.05	13.20	5YR 6/4	☑	☐	☐	11	69	20	0	20	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/28/01	KDD	8/12/01	GH	BCS00010425-22SA-578	Cuttings	60 00	62 50	0 0	1.7	0 0	1 4	5 4	0.85	9.55	8.70	5YR 6/4	☑	☐	☐	10	75	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		
7/28/01	KDD	8/12/01	GH	BCS00010426-22SA-579	Cuttings	62 50	65 00	0 0	1 7	0 0	1 7	5 4	0.85	10.55	9.70	5YR 6/4	☑	☐	☐	42	43	15	0	15	■	■	☑	☐	☐	☐	SM	☐	☑	☐	☐	☐	☑	☐	☐	☑	☐	☐	100		

NOTE: Shading indicates censored data

Table 4.1-2
Example of a Non-Alluvium Logging Form for Borehole NC-EWDP-22SA (Cuttings)

Borehole ID. NC-EWDP-22SA (Phase 3) Driller/Drilling Company: B Mikelson/Eklund Drilling Method: Reverse Circulation - Air Alluvium Depth (ft bgs) 1110 to 1200 Start Date 8/1/01 End Date: 8/1/01 Page 1 of 1

Logged		Checked			Depth Interval (feet/bgs)		Drilling/Coring Data				Sample Density Data				
Date	By	Date	By	Sample Number	From	To	Liquid Drilling Fluid Injection Rate (gpm)	Drilling/Coring Rate (feet/min)	Water Production (gpm)	Sample Recovery (gallons)	Borehole Diameter (inches)	Tare Weight (kg)	Sample Plus Tare Weight (kg)	Sample Weight (kg)	Munsell Color Symbol
08/01/01	KDD	09/07/01	jsw	BCS00010735	1110.00	1115.00	2.0	1.7			5.4				5YR 4/4
08/01/01	KDD	09/07/01	jsw	BCS00010736	1115.00	1120.00	2.0	1.7			5.4				5YR 4/4
08/01/01	KDD	09/07/01	jsw	BCS00010737	1120.00	1125.00	2.0	2.0			5.4				5YR 4/4
08/01/01	KDD	09/07/01	jsw	BCS00010738	1125.00	1130.00	2.0	2.0			5.4				5YR 4/4
08/01/01	KDD	09/07/01	jsw	BCS00010739	1130.00	1135.00	2.0	2.0			5.4				10R 4/2
08/01/01	KDD	09/07/01	jsw	BCS00010740	1135.00	1140.00	2.0	2.0			5.4				10R 4/2
08/01/01	KDD	09/07/01	jsw	BCS00010741	1140.00	1145.00	2.0	1.3			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010742	1145.00	1150.00	2.0	1.3			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010743	1150.00	1155.00	2.0	1.3			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010744	1155.00	1160.00	2.0	2.5			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010745	1160.00	1165.00	2.0	1.7			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010746	1165.00	1170.00	2.0	1.7			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010747	1170.00	1175.00	2.0	2.0			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010748	1175.00	1180.00	2.0	2.0			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010749	1180.00	1185.00	2.0	2.0			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010750	1185.00	1190.00	2.0	2.0			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010751	1190.00	1195.00	2.0	1.7			5.4				10YR 3/4
08/01/01	KDD	09/07/01	jsw	BCS00010752	1195.00	1200.00	2.0	1.7			5.4				10YR 3/4

	Moisture Content				HCL Reaction			Rock Unit – Tuff: Deposition			Welding				Alteration				
Sample Number	Not Applicable	Dry	Moist	Wet	None	Weak	Strong	Ash Fall	Ash Flow	Reworked	Dense	Moderate	Weak	None	Vitric	Devitrified	Matrix	Vapor Phase	Spherulitic
BCS00010735				✓		✓			✓		✓								
BCS00010736				✓		✓			✓		✓								
BCS00010737				✓		✓			✓		✓								
BCS00010738				✓		✓			✓		✓								
BCS00010739				✓		✓			✓		✓								
BCS00010740				✓			✓		✓		✓								
BCS00010741				✓			✓	✓			✓								
BCS00010742				✓			✓		✓		✓								
BCS00010743				✓		✓			✓		✓								
BCS00010744				✓		✓			✓		✓								
BCS00010745				✓		✓			✓		✓								
BCS00010746				✓		✓			✓		✓								
BCS00010747				✓		✓			✓		✓								
BCS00010748				✓		✓			✓		✓								
BCS00010749				✓		✓			✓		✓								
BCS00010750				✓		✓			✓		✓								
BCS00010751				✓		✓			✓		✓								
BCS00010752				✓		✓			✓		✓								

	Rock Unit – Sedimentary						Carbonate			Weathering					Structure					Matrix		
Sample Number	Claystone	Mudstone	Siltstone	Sandstone	Conglomerate	Chert	Limestone	Dolomite	Other	Fresh	Slight	Moderate	High	Decomposed	None Observed	Stratified	Laminated	Fractured	Other	Dense/Non-porous	Open/Porous	Other
BCS00010735					✓					✓					✓					✓		
BCS00010736					✓					✓					✓					✓		
BCS00010737					✓					✓					✓					✓		
BCS00010738					✓					✓					✓					✓		
BCS00010739					✓					✓					✓					✓		
BCS00010740					✓					✓					✓					✓		
BCS00010741					✓					✓					✓					✓		
BCS00010742					✓					✓					✓					✓		
BCS00010743					✓					✓					✓					✓		
BCS00010744					✓					✓					✓					✓		
BCS00010745					✓					✓					✓					✓		
BCS00010746					✓					✓					✓					✓		
BCS00010747					✓					✓					✓					✓		
BCS00010748					✓					✓					✓					✓		
BCS00010749					✓					✓					✓					✓		
BCS00010750					✓					✓					✓					✓		
BCS00010751					✓					✓					✓					✓		
BCS00010752					✓					✓					✓					✓		

	Phenocrysts – Mafics			Quartz			Feldspar			Clasts – Pumice			Lithics		
Sample Number	% by Vol	Munsell Color Symbol	Max. Size (mm)	% by Vol	Munsell Color Symbol	Max Size (mm)	% by Vol	Munsell Color Symbol	Max Size (mm)	% by Vol	Munsell Color Symbol	Max Size (mm)	% by Vol	Munsell Color Symbol	Max Size (mm)
BCS00010735	2	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	2	N2	2
BCS00010736	5	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	2	N2	2
BCS00010737	2	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010738	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010739	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010740	2	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010741	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010742	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010743	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010744	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	[illegible]
BCS00010745	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010746	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010747	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010748	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010749	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010750	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010751	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1
BCS00010752	1	N2	1	5	COLORLESS	2	0	N/A	0	0	N/A	0	1	N2	1

Table 4.1-3
Summary Statistics for Fines in Alluvium Drill Cuttings Samples

Borehole Number[a]	Measure-ment Type	Depth Interval (ft, bgs)	Number of Samples	Percent Fines in Samples				
				Minimum	Maximum	Average	Standard Deviation	Coefficient of Variation
10SA	Field[b]	0–750	276	1	51	9	7	122
	Lab[c]	2.5–750	150	4.9	54.0	20.6	9.6	213
19IM1A	Field	0–820	261	1	35	6	5	126
	Lab	2.5–820	154	5 0	33 0	14.0	5.4	257
19IM2A	Field	0–825	274	1	23	6	5	124
	Lab	2.5–825	165	2.5	34.9	16.1	8.1	198
22SA	Field	0–1,110	332	2	60	15	8	187
	Lab	7.5–1,110	222	4.4	48.9	23.6	10.2	232

NOTES: [a] Prefix for all Nye County EWDP wells is "NC-EWDP-".

[b] Field estimates were by geologic logging visual-manual method. Raw field estimate data have been censored.

[c] Laboratory measurements were by wet sieve method.

Table 4.1-4
Summary of Drilling Rates in Phase III Boreholes

Bore-hole No.[a]	Unsaturated Alluvium					Saturated Alluvium					Saturated Non-Alluvium				
	Depth Interval (ft, bgs)	Drill Method[b]	Drill Bit OD (in.)	Average Drilling Rate (ft/min.)	Standard Deviation	Depth Interval (ft, bgs)	Drill Method	Drill Bit OD (in.)	Average Drilling Rate (ft/min.)	Standard Deviation	Depth Interval (ft, bgs)	Drill Method	Drill Bit OD (in.)	Average Drilling Rate (ft/min.)	Standard Deviation
10SA	0–580	RC	5.375	1.2	0 5	580–750	RC	5.375	1.2	1.0	750–1,200	RC	5.375	2.1	0.8
19IM1A	0–360	RC	5.375	0.9	0 5	360–820	RC	5.375	1.0	0.5	820–900	RC	5.375	1.2	0.3
19IM2A	0–360	RC	5.375	1.2	0 8	360–825	RC	5.375	1.9	0 8	825–900	RC	5.375	1.2	0.3
22SA	0–472.5	RC	5 375	1.7	0.7	472.5–1,110	RC	5.375	2.0	1.0	1,110–1,200	RC	5.375	1.8	0.3
10P	0–304	CA Stradex	10.0	0.8	0.4	580–787.5	CA Tubex	6.625	0.7	0 2	792–910	Rotary	5.875	1.1	0.5
	304–580	CA Tubex	6 625	0 6	0 2										
22PA	0–356	CA Stradex	10	1.1	0.8	472.5–709	CA Tubex	6 625	0.9	0.4					
	356–472 5	CA Tubex	6.625	0.9	0 3	709–780	Rotary	5 875	0 8	0.2					
22PB	0–472.5	RC	8.5	0.4	0 3	472 5–1,120	RC	8.5	1.2	0.7	1,120–1,200	RC	8 5	0.8	0.1
23P	0–425	RC	8.5	0.5	0.3	425–1,340	RC	8.5	1.0	0.4					
18P	0–45	CA Stradex	10.0	1 3	1 2						45–770[c]	Rotary[c]	7.875[c]	0.5[c]	0.2[c]
											779–890	Rotary	7.875	0.3	0.1

NOTE: [a] Prefix for all Nye County EWDP wells is "NC-EWDP-".

[b] RC = air-rotary dual-wall reverse circulation; CA = casing advance.

[c] This interval is in unsaturated non-alluvium.

Table 4.2-1
Drive-Core Intervals and Recoveries

Borehole Number[a]	Core Run Number	Core Barrel Length (ft)[b]	Cored (Cut) Interval (ft, bgs)[c]		Total Cut[d] (ft)	Recovered Core Length[d] (ft)	Percent Recovery[d]
			From	To			
10P	1	2.69	57.35	59.85	2.50	2.00	80
	2	2.69	167.22	169.72	2.50	censored	censored
	3	2.69	347.95	349.06	1.11	censored	censored
	4	2.69	665 28	667.97	2.69	2.69	100
	5	2.69	702.46	704.85	2.39	2.39	100
	6	2.69	742.49	744.80	2.31	2.31	100
22PA	1	2 69	391.06	394.01	2.95	2.57	87
	2	2.26	522.14	524.26	2.12	2.12	100
	3	2.26	552.52	554.99	2.47	2.04	83
	4	2.26	572.33	574.40	2.07	2.07	100
	5	2.26	669.79	671.87	2.08	2.08	100
	6	2.26	709.22	711.09	1.87	censored	censored
	7	2.26	740.50	742 60	2.10	2.10	100

NOTES: [a] Prefix for all Nye County EWDP wells is "NC-EWDP-".

[b] 2.69-ft-long core barrels include 0 19-ft-long shoes. 2.26-ft-long core barrels include 0.26-ft-long shoes.

[c] Includes sediments in core barrel shoes.

[d] These measurements and calculations may contain errors.

Table 4.2-2
Estimated Major Rock and Mineral Percentages in Different Gravel and Sand Fractions

Borehole ID[a]	Depth Interval (ft, bgs)	% in Gravel Fraction Retained on #4 Sieve					% in Sand Fraction Retained on #10 Sieve				% in Sand Fraction Retained on #40 Sieve				% in Sand Fraction Retained on #100 Sieve				% in Sand Fraction Retained on #200 Sieve			
		Welded Tuffs	Non-Welded Tuffs	Felsic Flows	Porphyritic Intrusives	Basalt	Welded Tuffs	Non-Welded Tuffs	Pumice	Crystals	Welded Tuffs	Non-Welded Tuffs	Pumice	Crystals	Welded Tuffs	Non-Welded Tuffs	Pumice	Crystals	Welded Tuffs	Non-Welded Tuffs	Pumice	Crystals
10P	58.35–58 85	50	50	0	0	0	40	58	1	1	30	63	2	5	15	78	2	5	0	96	2	2
	168.22–168.72	75	24	0	0	1	50	48	2	0	47	50	1	2	35	53	2	10	25	70	0	5
	666.47—666.97	90	10	0	0	0	89	10	1	0	77	20	1	2	30	60	5	5	10	86	2	2
	667 47–667.72	50	50	0	0	0	25	72	1	2	15	70	10	5	10	65	15	10	0	85	10	5
	703.16–703.66	10	90	0	0	0	5	94	1	0	0	93	2	5	0	90	5	5	0	94	5	1
	704.16–704.41	40	60	0	0	0	30	68	1	1	19	75	1	5	5	88	2	5	0	97	2	1
	743.11–743.61	5	95	0	0	0	5	84	1	10	0	83	2	15	0	80	5	15	0	93	2	5
	744.11–744.36	5	95	0	0	0	5	89	5	1	2	80	8	10	0	80	10	10	0	87	8	5
22PA	392.25–392.75	50	50	0	0	0	59	40	1	0	25	73	2	0	10	80	5	5	0	94	5	1
	393.25–393.50	25	75	0	0	0	15	85	0	0	5	93	1	1	3	90	2	5	0	98	1	1
	553.24–553.74	50	50	0	0	0	25	73	1	1	25	71	2	2	5	90	1	4	0	99	0	1
	572.64–573.14	95	5	0	0	0	67	30	2	1	20	72	3	5	15	75	5	5	5	90	5	0
	670.11–670.61	10	10	50	30	0	25	74	1	0	20	70	5	5	19	75	1	5	0	98	1	1
	710.33–710.58	90	10	0	0	0	68	30	2	0	45	45	5	5	25	60	10	5	4	90	5	1
	740.85–741.35	80	20	0	0	0	63	30	5	2	45	47	3	5	25	60	10	5	4	90	5	1
	741.85–742.10	40	59	0	0	1	30	69	1	0	20	73	2	5	10	77	5	8	0	94	5	1

NOTE: [a] Prefix for all Nye County EWDP wells is "NC-EWDP-".

Table 4.2-3
Summary of Laboratory Hydraulic Parameter Test Results on Selected Core Segments

Borehole No.[a]	Core Interval: Depth From (ft)	Core Interval: Depth To (ft)	Initial Water Content: Gravimetric Water Content (g/g)	Initial Water Content: Volumetric Water Content (cm³/cm³)	Sat. Water Content: Volumetric Water Content (cm³/cm³)	Density: Grain Density (g/cm³)	Density: Dry Bulk Density (g/cm³)	Calculated Porosity (cm³/cm³)	Wet Sieve: Gravel (%)	Wet Sieve: Sand (%)	Wet Sieve: Fines (%)	Hydrometer: Silt (%)	Hydrometer: Clay (%)	Hydrometer: Sand (%)	Saturated Hydraulic Conductivity (cm/sec)
Initial Testing on 6-in.-Long Core Samples															
10P	58.85	59.35	0.062	censored	NM	2.51	censored	censored	18	75	7	2	4	NM	censored
	168.72	169.22	0.169	0.272	NM	2.55	1.60	0.369	14	78	8	2	5	NM	1.0E-02
	347.87	348.37	0.168	censored	NM	2.50	censored	censored	23	62	15	6	9	61	censored
	666.97	667.47	0.267	censored	NM	2.53	censored	censored	41	35	24	13	15	34	censored
	703.66	704.16	0.301	0 461	NM	2.53	1.54	0.393	22	43	35	19	17	41	NM
	743.61	744.11	0.315	0.490	NM	2.52	1.56	0 382	22	45	33	16	18	44	6.0E-03
22PA	392.59	393 09	0.142	0.251	NM	2.50	1.76	0.296	32	59	9	5	9	58	1.0E-03
	523.00	523.50	0.215	censored	NM	2.55	censored	censored	38	45	17	9	14	45	censored
	553.74	554.24	0.210	0 367	NM	2.58	1.75	0.321	31	53	16	10	10	52	3.0E-03
	573.14	573.64	0.233	0.384	NM	2.57	1.65	0.360	38	44	18	12	11	43	3 0E-03
	670.61	671.11	0.221	0.377	NM	2.55	1.71	0 380	47	42	11	6	6	40	4.0E-03
	710.02	710.33	0.128	0.217	NM	2.52	1.69	0.329	19	69	12	7	7	68	4.0E-03
	741.35	741.85	0.141	0.271	NM	2 53	1.92	0.216	41	54	5	5	7	53	1.0E-03
Additional Testing on 6-in.- and 3-in.-Long Core Samples															
10P	58.35	58.85	0.062	0.116	0.270	2.51	1.88	0.250	56	34	10	5	4	35	1.7E-03
	168 22	168.72	0.111	0.180	0.365	2.52	1.62	0.357	46	44	10	6	3	45	3.7E-03
	666.47	666.97	0.143	0.261	0.301	2.50	1.82	0.272	64	26	10	6	4	25	6.3E-06
	667.47	667.72	0.247	0.411	0.443	2.55	1.67	0.347	44	28	28	15	13	33	2.1E-05
	703.16	703.66	0 261	0.400	0.467	2.53	1.53	0.394	57	29	14	6	8	28	5 0E-05
	704.16	704.41	0.235	0.364	0 425	2.51	1.55	0.382	33	43	24	11	13	44	3.0E-05
	743.11	743.61	0.240	0 373	0.403	2.52	1.55	0.383	21	50	29	14	15	47	2.5E-05
	744.11	744.36	0 232	0.355	0.420	2.51	1.53	0.390	35	42	23	10	12	42	5 1E-04
22PA	392.25	392.75	0.161	0 284	NM	2.50	1.77	0 292	31	49	20	8	12	47	1.2E-04
	393.25	393.50	0.147	0.266	NM	2.51	1.81	0.279	52	32	16	6	9	32	7.0E-05
	553.24	553.74	0.198	0.342	0.364	2.58	1.73	0.331	18	67	15	6	9	64	1.2E-03
	572.64	573.14	0.201	0.343	0.367	2.57	1.71	0.335	20	60	20	8	12	58	1.2E-04
	670.11	670.61	0.185	0.325	0.361	2.55	1.76	0.310	57	28	15	7	8	29	7.6E-04
	710.33	710.58	0.184	0.319	NM	2.52	1.74	0.311	39	39	22	10	12	40	5.2E-04
	740.85	741.35	0.165	0.304	0.318	2.53	1.84	0 272	45	38	17	6	9	38	3.7E-05
	741.82	742.10	0.194	0.372	0 385	2.55	1.92	0.246	40	46	14	7	9	47	9.2E-07

NOTES: NM = not measured; [a] Prefix for all Nye County Early Warning Drilling Program wells is "NC-EWDP-."

Table 4.2-4
Saturated Hydraulic Conductivity Results from Laboratory Core Tests and Aquifer Pump Tests

Borehole ID[a]	Core Sample Laboratory Test Results					Aquifer Pump Test Results		
	Test Intervals (ft, bgs)		Test Results (cm/sec)			Test Intervals (ft, bgs)		Interval Result (cm/sec)
	From	To	Core Result	Arithmetic Mean	Geometric Mean	From	To	
10P	168.72	169.22	1.0E-02	2.1E-03	1.4E-04	653.4	707.6	3.2E-03
	666.47	666.97	6.3E-06					
	667.47	667.72	2.1E-05					
	703.16	703.66	5.0E-05					
	704.16	704.41	3.0E-05					
	743.11	743.61	2.5E-05					
	743.61	744.11	6.0E-03					
	744.11	744.36	5.1E-04					
22PA	392.59	393.09	1.0E-03	1.6E-03	5.1E-04	508.5	587.0	1.5E-02
	553.24	553.74	1.2E-03					
	553.74	554.24	3.0E-03					
	572.64	573.14	1.2E-04					
	573.14	573.64	3.0E-03					
	670.11	670.61	7.6E-04			649.7	779.8	1.7E-02
	670.61	671.11	4.0E-03					
	710.02[b]	710.33	4.0E-03					
	710.33	710.58	5.2E-04					
	740.85	741.35	3.7E-05					
	741.35	741.85	1.0E-03					
	741.85	742.10	9.2E-07					

NOTE: [a]The official prefix of all Nye County wells is "NC-EWDP-".

[b]6-in.-long sample liner filled approximately two-thirds full.

APPENDIX A
SUMMARY OF DRILLING FLUID AND ADDITIVE USE IN PHASE III BOREHOLES

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APPENDIX A
SUMMARY OF DRILLING FLUID AND ADDITIVE USE IN PHASE III BOREHOLES

This appendix is a detailed description and justification of the use of drilling fluids and drilling fluid additives in Phase III boreholes. Quantities of these materials (excluding compressed air and injection water) used over specific depth intervals are summarized in Tables A1 to A4. These tables also summarize quantities of materials used in the abandonment of the exploratory boreholes.

Exploratory Reverse-Circulation Boreholes

Exploratory boreholes were drilled using air-rotary dual-wall reverse-circulation (RC) drilling methods. The use of drilling fluids (other than compressed air) and additives was limited as much as possible to provide uncontaminated samples for further study. Conditioning of borehole walls was primarily needed in unconsolidated alluvium above the water table. Where practicable, drilling and sampling were conducted in the unsaturated zone using only air circulation over approximately 50- to 100-ft depth intervals. Borehole advancement was then stopped, and a small volume of bentonite slurry (approximately 50 lb. MAX GEL®, a polymer-coated bentonite, in approximately 100 gal. of water) was either pumped through the center tube of the drill string to the drill bit and up the annular space between the drill casing and the borehole wall or directly flooded down the annular space from the ground surface. The bentonite slurry was dried by circulating compressed air for about 1 hr. up the annular space. The borehole was then advanced and sampled using only air circulation for the next 50 to 100 ft. This method of borehole conditioning provided a stable borehole in unsaturated unconsolidated alluvium and minimized the potential for bentonite contamination of drill cuttings samples.

Use of injection water during RC drilling was restricted to the upper 20 to 50 ft of the saturated zone, where the drill hole would produce minimal water, and injection water was required to lift the moist or wet sample. Injection water was also used during the conventional circulation drilling from surface to 20 to 22.5 ft in the pilot holes used for setting a surface casing.

Drilling in the saturated zone presented very few borehole stability problems. Conditioning of borehole walls was accomplished as needed following methods similar to those used in the unsaturated zone, except for the drying-out phase. Bentonite was used sparingly to avoid sample contamination. Borehole NC-EWDP-19IM1A, where this conditioning technique was developed, had the greatest number of impacted samples. Samples from the interval from 557.5 to 605 ft. (10 samples) were not processed due to bentonite contamination. Borehole NC-EWDP-19IM2A had bentonite-contaminated samples in the interval from 370 to 380 ft (four samples), due to excessive use of bentonite when the borehole "tightened up" on the drill string. In this case, bentonite slurry was pumped down to the bit and up the annular space to loosen the drill string. Borehole NC-EWDP-22SA had a single bentonite-contaminated sample in the interval from 487.5 to 490 ft. No contaminated samples were noted in borehole NC-EWDP-10SA.

Flooded-Mud Monitoring Wells

Flooded-mud (FM) monitoring wells were drilled subsequent to exploratory RC boreholes at all four exploratory borehole locations. The FM boreholes were not sampled (except the lower portion of NC-EWDP-22S) because the RC exploratory holes provided good quality samples without contamination from drilling fluids. The FM drilling technique provides for large-diameter, stable, and plumb boreholes ideally suited for open-hole geophysical logging and completion of multiple-screen monitor wells. FM wells were drilled using reverse FM circulation, whereby conventional single-wall drill pipe and collars are used in a borehole that is flooded with bentonite drilling fluid (mud) in the annular space. Mud is maintained and allowed to flood down the annular space from tanks or pits on the surface, and cuttings are returned through the center tube of the drill pipe. This flow direction is opposite to conventional mud drilling and is sometime called reverse drilling. Mud flow and return is initiated and controlled by injection of air into the center tube of the drill string, thereby "air-lifting" the drilling mud to the surface. The mud system provides a stable positive pressure on the borehole walls that maintains borehole integrity during borehole advancement, logging, and completion. The drilling fluid level in the annular space must be maintained to surface level to circulate the cuttings from the drill bit effectively. If lost circulation zones are encountered, usually additional additives and lost circulation materials (LCMs) are added to the drilling fluid to control the loss. In difficult lost circulation zones, the zone is usually grouted with cement grout to plug off fluid-loss zones. Drilling with FM methods develops a mud cake on the borehole walls that provides stability to the open borehole during logging and completion. After well completion, the mud cake is developed out of the sand pack and screen zones by a combination of airlift-swab and pump-swab development techniques.

Drilling fluids used for FM drilling included: AQUA GEL GOLD SEAL®, an untreated bentonite, and QUIK-GEL®, a treated (polymerized) bentonite together with soda ash (sodium carbonate) to control pH. Lesser amounts of drilling fluid additives, including DrisPac®, a polyanionic cellulose polymer, and EZ-MUD®, a liquid polyacrylamide, were used for viscosity and fluid loss control. Finally, Magma Fiber®, a mineral-based extruded "wool", BENSEAL®, granular 8-mesh untreated bentonite, and Portland cement were variously used either alone or in combination to control lost circulation.

The boreholes NC-EWDP-19IM1 and -19IM2 were drilled using drilling fluid containing only an untreated ground bentonite product, AQUA GEL GOLD SEAL®, because of concerns about adding any organic chemicals, such as polymers. A lost circulation zone encountered at total depth in -19IM1 (1,012.5 ft) required the use of 90 lb. of Magma Fiber® in an attempt to seal the rapid fluid loss in this zone. Circulation was never re-established, and the Magma Fiber® is not likely to have coated the borehole walls and was probably lost to the encountered fracture or pore void space. Borehole sounding prior to well completion indicated the hole caved above the fracture to about 980.3 ft. No lost circulation problems were encountered during drilling of -19IM2.

The boreholes NC-EWDP-10S and -22S were drilled using both AQUA GEL GOLD SEAL® and QUIK-GEL® drilling mud. In NC-EWDP-10S, AQUA GEL GOLD SEAL® was used together with QUIK-GEL® in approximately the upper 300 ft, and QUIK-GEL® was used in the remainder. In NC-EWDP-22S, QUIK-GEL® was used primarily in the unsaturated zone and AQUA GEL GOLD SEAL® in the saturated zone.

Lost circulation was encountered in the unsaturated alluvial sediments in both boreholes. At NC-EWDP-10S, several additives were used to control the fluid loss in the borehole. Drilling through the interval from 75 ft to approximately 440 ft, DrisPac®, EZ-MUD®, Magma Fiber®, and native soil were added to the drilling fluid. Approximately 90,000 gal. of drilling fluid were lost in the interval from 75 to 440 ft. Drilling beyond 440 ft and into the water table at approximately 590 ft, the rate of drilling fluid loss decreased, and no additives were added to the drilling fluid.

Similar lost circulation zones were encountered drilling NC-EWDP-22S in the unsaturated alluvium as at -10S. Drilling in the interval from 120 to 176 ft, lost circulation zones required addition of Magma Fiber® to the drilling fluid and adding BENSEAL® (ground 8-mesh bentonite) directly down the borehole. Drilling was stopped at 176 ft and the borehole was grouted with cement from 176 ft up to approximately 70 ft. The grout was drilled out and lost circulation zones were again encountered beyond 181 ft. Drilling continued to 290 ft with the addition of Magma Fiber® and DrisPac® to the drilling fluid. Drilling was stopped at 290 ft and the borehole was again grouted with cement from 290 ft up to approximately 100 ft. A total of approximately 90,000 gal. of drilling fluid were lost in the unsaturated zone from 120 to 290 ft. Drilling beyond 290 ft and into the saturated zone at approximately 480 ft, the rate of drilling fluid loss decreased and 50 lb. of DrisPac® was added to the drilling fluid. Continued loss of drilling fluids for the remainder of the borehole indicates that approximately 200,000 gal. total of drilling fluid was lost, most likely to the unsaturated zone. The use of drilling fluid additives DrisPac®, EZ-MUD®, and Magma Fiber® were limited to the unsaturated zone and the uppermost portion of the saturated zone of -10S and -22S.

Following completion of the FM wells, extensive well development was conducted to remove excess drilling fluids and excess drilling fluid additives.

Casing Advance Piezometer Wells

Boreholes NC-EWDP-10P and -22PA were drilled using air circulation and did not require the use of drilling fluid additives. Water was injected during drilling of NC-EWDP-10P from 252.5 to 295 ft. Fugitive water from lost circulation zones in NC-EWDP-10S (120 to 290 ft) was encountered through this interval. Water production from this zone caused sample return problems. Injection water was required to flush the sample out of the drill string and sample return hoses.

No injection water was required during drilling of borehole NC-EWDP-22PA.

Open-Hole Sections of NC-EWDP-18P

Borehole NC-EWDP-18P was drilled with casing advance methods in alluvium to 45 ft. Beyond this depth, the borehole was advanced using open-hole conventional rotary methods with a 7.875-in. drill bit and compressed air as the primary drilling fluid in consolidated rock. Due to the high air permeability and/or instability of some formation intervals, it was necessary to use other drilling fluids and additives to restore circulation in several depth intervals. Small quantities of WYO-Foam®, an anionic detergent, were used to improve circulation at a depth of 135 ft. EZ-MUD® and QUIK-GEL® were used from about 140 to 145 ft. At about 145 ft, some water was injected. At about 490 ft, circulation was lost again and more EZ-MUD®, QUIK-GEL®, and WYO-Foam® were added. At 505 ft, lost circulation was encountered and some Magma Fiber® was added. At about 515 ft, more Magma Fiber® and Portland cement were added to condition the problem zone and plug the lost circulation zone up to about 480 ft depth. The plug was drilled out, and drilling proceeded while occasionally circulating QUIK-GEL® with EZ-MUD® to thinly cake the borehole walls and help prevent sloughing. At about 730 ft, there was another major loss of air circulation, the drill rods began sticking, and it was necessary to again add Magma Fiber®, EZ-MUD®, and BENSEAL®.

First water was observed at a depth of about 811 ft at NC-EWDP-18P, although the water table subsequently was measured at a shallower level (see Table 3.1-1). Drill cuttings return problems continued, and it was necessary to inject water to lift the 810 to 815 ft interval of drill cuttings to ground surface. Since there was still no (or very poor) cuttings return, WYO-Foam® was again added from about 815 ft to about 845 ft. The cuttings from 850 to 855 ft continued to show evidence of the detergent foam. Caving continued to be a problem from about 888 ft to a total depth of 890.4 ft.

After reaching total depth and prior to completion of NC-EWDP-18P, foam and other liquid and solid drilling fluids and additives, including LCMs, were flushed out of the hole by air lifting. As a result of this air lifting and because these substances were mostly used above the water table, these additives are unlikely to impact water production or water quality at this site.

Piezometer Boreholes Drilled by Reverse-Circulation Methods

Injection water was used in NC-EWDP-22PB and -23P during the conventional circulation drilling from surface to 22.5 ft in the pilot holes used for setting a surface casing. Following the cementing of surface casing with Portland cement and Cal Seal (cement hardening accelerator), the remaining portions of these boreholes were drilled similarly to the exploratory RC boreholes. Air was used as the primary drilling fluid in each borehole with the following exceptions: Water was injected in both boreholes in the upper 20 to 50 ft of the saturated zone, where the drill hole would produce minimal water, and injection water was required to lift the moist or wet sample. In addition, at NC-EWDP-22PB, injection water was needed to lift samples between 387.5 to 400 ft where moisture was encountered from fugitive water lost during the drilling of -22S.

In the unsaturated zone, small volumes of water and MAX GEL® were used to stabilize borehole walls in a manner similar to that used in exploratory RC boreholes. This method of borehole conditioning provided a stable borehole in unsaturated unconsolidated alluvium and minimized the potential for bentonite contamination of drill cuttings samples.

Drilling in the saturated zone presented more difficulties and required the use of significantly more MAX GEL® to condition borehole walls than in the smaller RC exploratory boreholes. A total of approximately 2,000 gal. of MAX GEL® slurry was intermittently added from the surface down the annular space while drilling the saturated zone of NC-EWDP-22PB. No drill cuttings samples were identified as being contaminated by bentonite.

Difficulties with borehole stability below approximately 490 ft in borehole NC-EWDP-23P required more aggressive use of drilling additives. Borehole conditioning from 490 to 1,340 ft (total depth) required the use of 130 bags (6,500 lb.) of MAX GEL® mixed with approximately 14,000 gal. of water to be flooded down the annular space during the advancement of the borehole. Alluvial drill cuttings samples from the interval from 945 to 990 ft (10 samples) were contaminated by drilling mud (MAX GEL®). Another six scattered samples below 900 ft were also identified as being contaminated.

Even with the aggressive use of bentonite to condition NC-EWDP-23P, after reaching total depth, loose sandy material collapsed below 700 ft and formed a sand collar at approximately 1,050 ft. The drill string became stuck in the hole and ultimately was separated with an explosive charge, and the bottom hole assembly was lost. Another approximately 5,000 gal. of MAX GEL® were flooded down the annular space in an effort to loosen the drill string.

Table A1
Drilling Additives Used in Boreholes NC-EWDP- 19IM1A, -19IM2A, -10SA, and -22SA

Bore-hole ID	Borehole Activity	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
19IM1A	Seal Surface/ Conductor Casing	7/10/01	0–22	KWIK PLUG®	<1 bag	Used in annular space of 22 ft - 8 5/8 in hole and 6 5/8 in. surface casing
	Borehole Advancement	7/12/01	22–470	MAX GEL®	3 bags (300 gal.)	Flooded down annular space of 5 3/8 in borehole to control caving
	Borehole Advancement	7/12/01	22–540	MAX GEL®	2 bags (300 gal.)	Flooded down annular space of 5 3/8 in borehole to control caving.
	Abandonment	7/13/01	900–0	SUPER PLUG®	48 bags (<2400 gal.)	Used to plug-back borehole in stages from 900 ft to surface.
19IM2A	Seal Surface/ Conductor Casing	7/13/01	0—22	KWIK PLUG®	<1 bag	Used in annular space of 22 ft - 8 5/8 in. hole and 6 5/8 in surface casing.
	Borehole Advancement	7/15/02	22–370	MAX GEL®	1 2/3 bags (235 gal)	Pumped down drill string through bit to condition caving hole. Hole drilled without additives through 370 ft.
	Borehole Advancement	7/16/02	370–720	MAX GEL®	4 bags (1,000 gal.)	Flooded down annular space of 5 3/8 in. borehole to control caving.
	Borehole Advancement	7/17/02	720–900	MAX GEL®	1 bag (100 gal.)	Flooded down annular space of 5 3/8 in. borehole to control caving
	Abandonment	7/17/01	900–0	SUPER PLUG®	78 bags (<3,900 gal.)	Used to plug-back borehole in stages from 900 ft to surface.
10SA	Seal Surface/ Conductor Casing	7/18/02	0–22	KWIK PLUG®	12 bags	Used in annular space of 22 ft - 8 5/8 in. hole and 6 5/8 in. surface casing.
	Borehole Advancement	7/19/01	200–260	MAX GEL®	4 bags (400 gal.)	Flooded down annular space of 5 3/8 in. borehole and pumped down through bit to control caving
	Borehole Advancement	7/24/01	260–590	MAX GEL®	2 bags (300 gal.)	Pumped down drill string through bit to condition caving hole.
	Borehole Advancement	7/25/01	590–665	MAX GEL®	2 bags (300 gal.)	Pumped down drill string through bit to condition caving hole.
	Borehole Advancement	7/26/01	665–1,150	MAX GEL®	6 bags (400 gal.)	Flooded down annular space of 5 3/8 in borehole to control caving.
	Borehole Advancement	7/27/01	1,150–1,200	MAX GEL®	6 bags (400 gal.)	Flooded down annular space of 5 3/8 in. borehole to control caving.
	Abandonment	7/27/01	1,200–0	SUPER PLUG®	71 bags (<3,600 gal,)	Used to plug-back borehole in stages from 1,200 ft to surface.
	Abandonment	7/28/01	1,200—0	SUPER PLUG®	70 bags (<3,600 gal.)	Used to plug-back hole in stages from 1,200 ft to surface
22SA	Seal Surface/ Conductor Casing	7/28/01	0–22	KWIK PLUG®	10 bags	Used in annular space of 22 ft - 8 5/8 in. hole and 6 5/8 in. surface casing.

Bore-hole ID	Borehole Activity	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
22SA	Borehole Advancement	7/29/01	100–360	MAX GEL®	2 bags (300 gal.)	Pumped down drill string through bit to condition caving hole
	Borehole Advancement	7/30/01	360–705	MAX GEL®	4 bags (600 gal.)	Flooded down annular space of 5 3/8 in. borehole and pumped down to bit to control caving.
	Borehole Advancement	8/1/01	705–940	MAX GEL®	4 bags (600 gal.)	Flooded down annular space of 5 3/8 in. borehole to control caving.
	Abandonment	8/2/01	940–1,200	SUPER PLUG®	126 bags (<6,400 gal.)	Used to plug-back hole from 1200 ft to the surface in stages.

NOTES: Exploratory and sampling boreholes drilled with reverse-circulation air rotary.

KWIK PLUG® is untreated ground sodium bentonite chips used to seal between borehole walls and casings. It produces dense bentonite when hydrated.

MAX GEL® is a sodium bentonite coated with polymer used for circulation and hole conditioning.

SUPER PLUG® is a high solids bentonite grout (>30% solids) used to plug/abandon boreholes and seal annular space on wells.

Table A2
Drilling Additives Used in Boreholes NC-EWDP-19IM1, -19IM2, -10S, and -22S

Borehole ID	Borehole Activity	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
19IM1	Seal Conductor Casing	8/13/01	0–78	Concrete	10 yards	Used to cement annular space between 30 in. auger hole and 18 in conductor casing
	Borehole Advancement	8/17/01	78–155	AQUA GEL GOLD SEAL®	12 bags (1,500 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving
	Borehole Advancement	8/18/01	155–404	AQUA GEL GOLD SEAL®	128 bags (10,000 gal.)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving
	Borehole Advancement	8/19/01	404–471	AQUA GEL GOLD SEAL®	110 bags (14,000 gal.)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving
	Borehole Advancement	8/20/01	471–661	AQUA GEL GOLD SEAL®	144 bags (14,500 gal.)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving
	Borehole Advancement	8/21/01	661–854	AQUA GEL GOLD SEAL®	139 bags (13,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving.
	Borehole Advancement	8/22/01	854–975	AQUA GEL GOLD SEAL®	50 bags (1,000 gal)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving
	Borehole Advancement	8/23/01	975–1,012.5	AQUA GEL GOLD SEAL®	70 bags (7,000 gal.)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving.
	Borehole Advancement	8/23/01	1,012 5	Magma Fiber®	3 bags	Lost circulation materials used in attempt to plug lost circulation zone at 1012.5 ft.
19IM2	Seal Conductor Casing	8/14/04	0–77	Concrete	17 yards	Used to cement annular space between 30 in. auger hole and 18 in conductor casing.
	Borehole Advancement	9/4/01	77–105	AQUA GEL GOLD SEAL®	64 bags (4,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving
	Borehole Advancement	9/5/01	105–409	AQUA GEL GOLD SEAL®	194 bags (10,000 gal)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving
	Borehole Advancement	9/6/01	409–580	AQUA GEL GOLD SEAL®	68 bags (4,000 gal.)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving
	Borehole Advancement	9/7/01	580–835	AQUA GEL GOLD SEAL®	142 bags (14,500 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving
	Borehole Advancement	9/8/01	835–965 6	AQUA GEL GOLD SEAL®	25 bags (2,000 gal.)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving.
10S	Seal Conductor Casing	9/20, 21/01	0–62	Concrete	25 yards	Used to cement annular space between 30 in auger hole and 18 in. conductor casing
	Borehole Advancement	9/24/01	62–156	QUIK-GEL®/ AQUA GEL GOLD SEAL®	74 bags (2,000 gal.)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving Hauled 24,000 gal water. pH adjusted with 3 bags soda ash
	Borehole Advancement	9/24/01	125	DrisPac®	1 bag	Added to mud to increase viscosity and control loss.
	Borehole Advancement	9/24/01	62–156	Magma Fiber®	3 bags	Attempt to slow lost circulation.

Borehole ID	Borehole Activity	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
10S	Borehole Advancement	9/25/01	156–313	QUIK-GEL®/ AQUA GEL GOLD SEAL®	286 bags (28,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving. Two bags soda ash added to adjust pH.
	Borehole Advancement	9/25/01	156–313	DrisPac®	3 bags	Added to mud to increase viscosity and control loss.
	Borehole Advancement	9/25/01	156–313	Magma Fiber®	4 bags	Attempt to slow lost circulation.
	Borehole Advancement	9/25/01	156	EZ-MUD®	5 gal.	Added to mud to increase viscosity and control loss.
	Borehole Advancement	9/26/01	313–377	QUIK-GEL®	100 bags (32,000 gal.)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving Two bags soda ash added to adjust pH.
	Borehole Advancement	9/26/01	377	BENSEAL®	6 bags	Added down open borehole in attempt to seal lost circulation zone.
	Borehole Advancement	9/26/01	377	DrisPac®	2 bags	Added to mud to increase viscosity and control loss.
	Borehole Advancement	9/26/01	377	Magma Fiber®	47 bags	Attempt to slow lost circulation.
	Borehole Advancement	9/26/01	377	EZ-MUD®	5 gal.	Added to mud to increase viscosity and control loss.
	Borehole Advancement	9/26/01	377	Native soil	125 gal.	Added to slow loss of drilling fluid.
	Borehole Advancement	9/27/01	377–440	QUIK-GEL®	85 bags (34,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving.
	Borehole Advancement	9/27/01	377–440	DrisPac®	1/4 bag	Added to mud to increase viscosity and control loss.
	Borehole Advancement	9/28/01	440–691	QUIK-GEL®	72 bags (12,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving. Loss under control.
	Borehole Advancement	9/29/01	691–900	QUIK-GEL®	20 bags (4,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving.
22S	Seal Conductor Casing	9/21/01, 9/22/01, and 10/4/01	0–66	Concrete	27 yards	Used to cement annular space between 30 in. auger hole and 18 in. conductor casing.
	Borehole Advancement	10/10/01	66–181	QUIK-GEL®	267 bags (20,000 gal.)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving.
	Borehole Advancement	10/10/01	120	Magma Fiber®	1 bag	Attempt to slow lost circulation.
	Borehole Advancement	10/11/01	181	QUIK-GEL®	131 bags (13,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving.
	Borehole Advancement	10/11/01	181	Magma Fiber®	49 bags	Attempt to plug lost circulation zones.

Borehole ID	Borehole Activity	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
22S	Borehole Advancement	10/11/01	181	BENSEAL®	51 bags	Attempt to plug lost circulation zones.
	Borehole Advancement	10/12/01	176	Concrete	8 yards (3 sack mix)	Sealed lost circulation zone
	Borehole Advancement	10/13/01	181–282	QUIK-GEL®	242 bags (24,000 gal)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving
	Borehole Advancement	10/13/01	181–282	Magma Fiber®	28 bags	Attempt to control lost circulation.
	Borehole Advancement	10/14/01	282–290	QUIK-GEL®	68 bags (34,000 gal.)	Attempt to regain circulation; refill baker tanks.
	Borehole Advancement	10/14/01	282–290	Magma Fiber®	5 bags	Attempt to control lost circulation
	Borehole Advancement	10/14/01	282–290	DrisPac®	3 bags	Added to mud to increase viscosity and control loss.
	Borehole Advancement	10/15/01	236	Concrete	10 yards (3 sack mix)	Sealed lost circulation zone.
	Borehole Advancement	10/16/01	290–345	QUIK-GEL®	115 bags (12,500 gal.)	Flood hole start drilling plug; used one bag soda ash added to adjust pH.
	Borehole Advancement	10/16/01	290	DrisPac®	1 bag	Added to mud to increase viscosity and control loss.
	Borehole Advancement	10/17/01	345–624	QUIK-GEL® / AQUA GEL GOLD SEAL®	381 bags (42,500 gal.)	Flooded down annular space of 14 3/4 in. borehole for circulation fluid and to control caving. Began using AQUA GEL GOLD SEAL® below 528 ft
	Borehole Advancement	10/18/01	624–912	QUIK-GEL® / AQUA GEL GOLD SEAL®	224 bags (71,000 gal)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving.
	Borehole Advancement	10/19/01	912–1,198	QUIK-GEL® / AQUA GEL GOLD SEAL®	192 bags (57,000 gal)	Flooded down annular space of 14 3/4 in borehole for circulation fluid and to control caving.

NOTES: Flooded-mud reverse-circulation boreholes for installation of multiple screen wells.

AQUA GEL GOLD SEAL® is an untreated sodium bentonite used for circulation fluid

QUIK-GEL® is a sodium bentonite coated with polymer used for circulation and hole conditioning.

Magma Fiber® is inert mineral wool used for sealing lost circulation zones.

DrisPac® is polyanionic cellulosic polymer used to increase mud viscosity and for fluid loss control.

EZ-MUD® is a water soluble polymer designed to prevent clay disintegration, stabilize boreholes, and lubricate drill tools.

BENSEAL® is 8-mesh untreated ground sodium bentonite used to seal zones in boreholes and wells.

Table A3
Drilling Additives Used in Boreholes NC-EWDP- 10P, -22PA, and -18P

Bore-hole ID	Borehole Advancement	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
10P	Borehole Advancement	9/10/01 to 12/19/01	0–910.5	NA	NA	No additives were used during borehole advancement.
22PA	Borehole Advancement	1/15/01 to 1/27/02	0–779 8	NA	NA	No additives were used during borehole advancement.
18P	Borehole Advancement	9/21/01	85	QUIK-GEL®	2 bags (300 gal.)	Pumped down center of 3-1/2 in. drill pipe to control caving in 7-7/8 in. borehole.
	Borehole Advancement	9/22/01	135	Wyo-Foam®	2 cups foam (175 gal)	Pumped down tube of 3-1/2 in. drill pipe to clean out borehole cuttings.
	Borehole Advancement	9/22/01	135	EZ-MUD®	1 cup	Pumped down tube of 3-1/2 in. drill pipe to stabilize borehole
	Borehole Advancement	9/22/01	140	QUIK-GEL®	1/2 bag (175 gal.)	Used to lift cuttings and condition borehole.
	Borehole Advancement	9/24/01	490	QUIK-GEL®	2 bags (175 gal.)	Used to lift cuttings and condition borehole.
	Borehole Advancement	9/24/01	490	EZ-MUD®	1-quart (175 gal)	Mixed with QUIK-GEL® to stabilize borehole.
	Borehole Advancement	9/26/01	515	Magma Fiber®	1 bag (380 gal.)	Tremmie down 7-7/8 in hole to seal up lost circulation zone.
	Borehole Advancement	9/26/01	515–489	Portland Cement	35 bags (380 gal.)	Tremmie down 7-7/8 in. hole to seal up lost circulation zone.
	Borehole Advancement	10/4/01	515	Magma Fiber®	1 bag (380 gal.)	Tremmie down 7-7/8 in. hole to seal up lost circulation zone.
	Borehole Advancement	10/4/01	440	EZ-MUD®	1/2 cup (175 gal.)	Pumped down center of 3-1/2 in. drill pipe to stabilize borehole.
	Borehole Advancement	10/4/01	440	WYO-Foam®	2 cups foam (175 gal.)	Pumped down center of 3-1/2 in. drill pipe to clean out borehole cuttings. Subsequently flushed from hole by air lifting.
	Borehole Advancement	10/7/01	730	Magma Fiber®	1-1/2 bags (310 gal.)	Pumped down center of 3-1/2 in drill pipe to clean out borehole cuttings. Subsequently flushed from hole by air lifting.
	Borehole Advancement	10/7/01	730	EZ-MUD®	1/4 cup (175 gal)	Pumped down center of 3-1/2 in. drill pipe to stabilize borehole.
	Borehole Advancement	10/7/01	735	Enviro-Plug®	1 bag (135 gal)	Pumped down center of 3-1/2 in. drill pipe to seal lost circulation zone.
	Borehole Advancement	10/8/01	820	WYO-Foam®	2 gal. (175 gal.)	Pumped down center of 3-1/2 in. drill pipe to clean out borehole cuttings. Subsequently flushed from hole by air lifting

Bore-hole ID	Borehole Advancement	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
18P	Borehole Advancement	10/9/01	845	WYO-Foam®	2 gal. (400 gal.)	Pumped down center of 3-1/2 in. drill pipe to clean out borehole cuttings Subsequently flushed from hole by air lifting

NOTES: Casing advance boreholes for sampling, drive-core sampling, and installation of piezometer wells.

QUIK-GEL® is sodium bentonite coated with polymer used for circulation and hole conditioning.

Enviro-Plug® is a high solids bentonite grout (>30% solids) used to plug/abandon boreholes and seal annular space on wells.

EZ-MUD® is a water soluble polymer designed to prevent clay disintegration, stabilize boreholes, and lubricate drill tools.

WYO-Foam® is an anionic detergent used to clean cuttings from borehole.

Magma Fiber® is inert mineral wool used for sealing lost circulation zones

Table A4
Drilling Additives Used in Boreholes NC-EWDP-22PB and -23P

Bore-hole ID	Borehole Activity	Date	Depth or Depth Interval (ft bgs)	Material	Quantity	Comments
22PB	Seal Conductor Casing	2/21/02	0–22.5	Cal Seal / Portland Cement	8–50 lb. bags 12–94 lb. bags	Used to cement 10 3/4-in. conductor casing in 14 1/2-in. borehole.
	Borehole Advancement	2/22/02	60–180	MAX GEL®	2 bags (150 gal.)	Injected down center of 4 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	2/23/02	180–320	MAX GEL®	2 bags (150 gal.)	Injected down center of 4 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	2/24/02	320–420	MAX GEL®	2 bags (150 gal.)	Injected down center of 4 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	2/25/02	420–520	MAX GEL®	2 bags (150 gal.)	Injected down center of 4 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	2/26/02	520–840	MAX GEL®	6 bags (750 gal.)	Flooded down annular space of borehole to control caving in 8 1/2 in. hole.
	Borehole Advancement	2/27/02	840–1200	MAX GEL®	16 bags (1,200 gal.)	Flooded down annular space of borehole to control caving in 8 1/2 in. hole.
23P	Seal Conductor Casing	3/9/02	0–22.5	Cal Seal / Portland Cement	10–50 lb. bags 20–94 lb. bags	Used to cement 10 3/4-in. conductor casing in 14 1/2-in. borehole.
	Borehole Advancement	3/9/02	0–63	MAX GEL®	2 bags (150 gal.)	Injected down center of 5 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/10/02	63–190	MAX GEL®	3 bags (200 gal.)	Injected down center of 5 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/11/02	190–320	MAX GEL®	5 bags (200 gal.)	Injected down center of 5 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/12/02	320–490	MAX GEL®	<1 bag (<200 gal.)	Injected down center of 5 1/2 in. drill pipe to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/13/02	540–940	MAX GEL®	40 bags (6,000 gal.)	Flooded down annular space of borehole to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/14/02	940–1,140	MAX GEL®	60 bags (6,000 gal.)	Flooded down annular space of borehole to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/19/02	1,140–1,340	MAX GEL®	20 bags (4,000 gal.)	Flooded down annular space of borehole to control caving in 8 1/2 in. hole.
	Borehole Advancement	3/20/02	1,150	MAX GEL®	27 bags (4,500 gal.)	Pumped down annular space of borehole to stabilize top of hole while trying to loosen drill pipe from sand boot at 1,150 ft.
	Borehole Advancement	3/21/02	1,150	MAX GEL®	6 bags (600 gal.)	Pumped down annular space of borehole to stabilize top of hole while trying to loosen drill pipe from sand boot at 1,150 ft.

NOTES: Reverse-circulation air rotary boreholes for sampling and installation of piezometer wells.

MAX GEL® is a sodium bentonite coated with polymer used for circulation and hole conditioning.

APPENDIX B
WELL COMPLETION AND WELLHEAD PROTECTION DIAGRAMS

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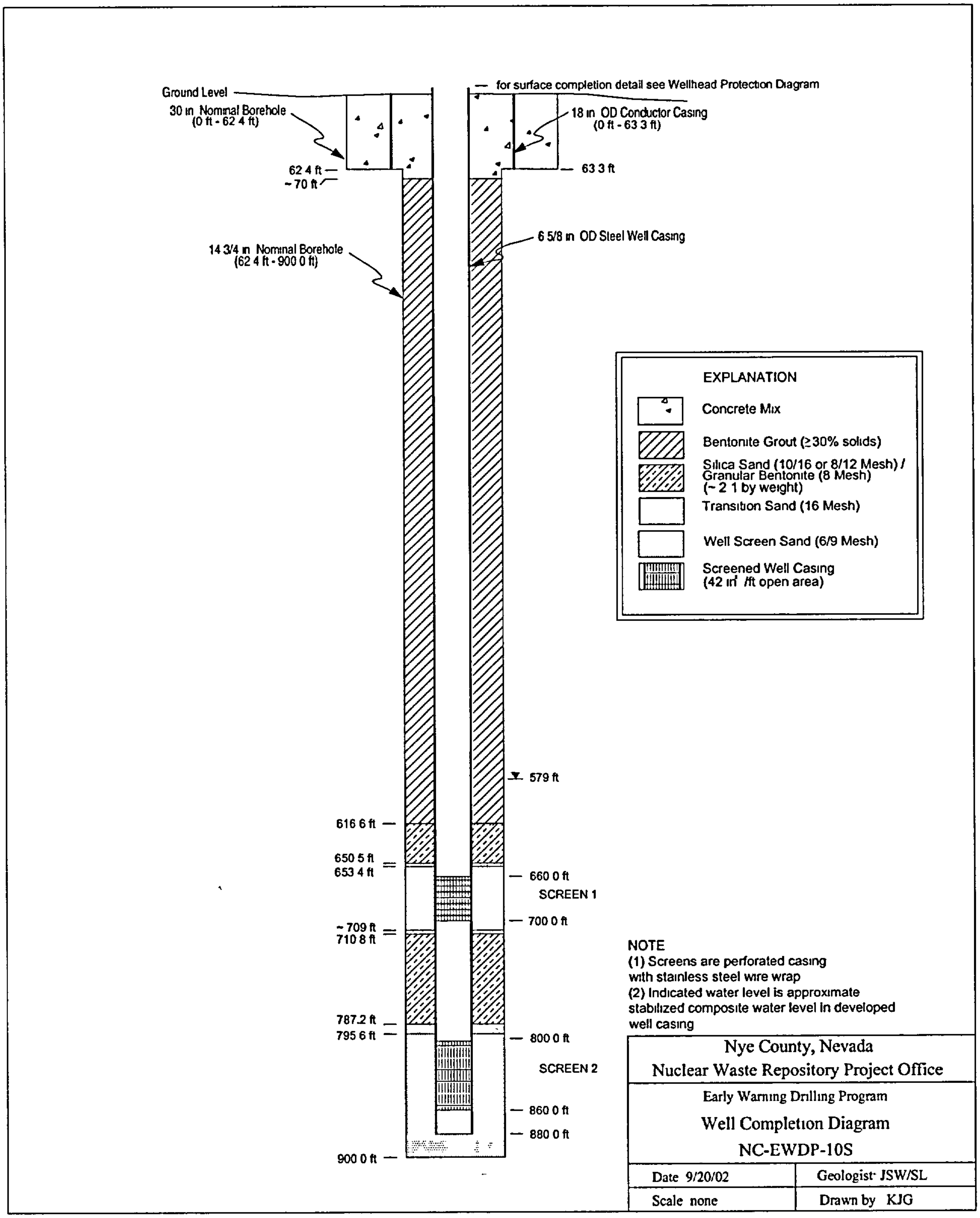
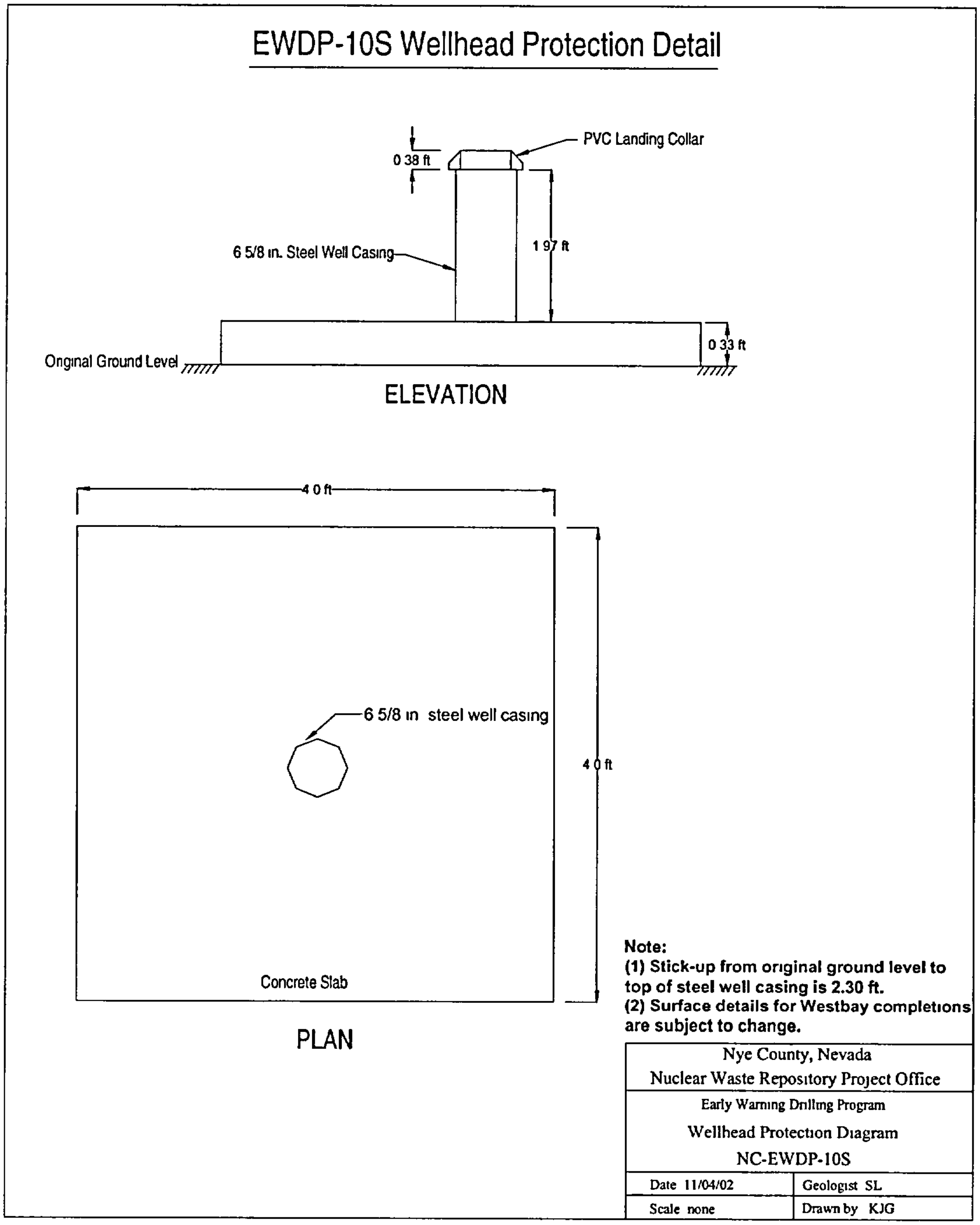


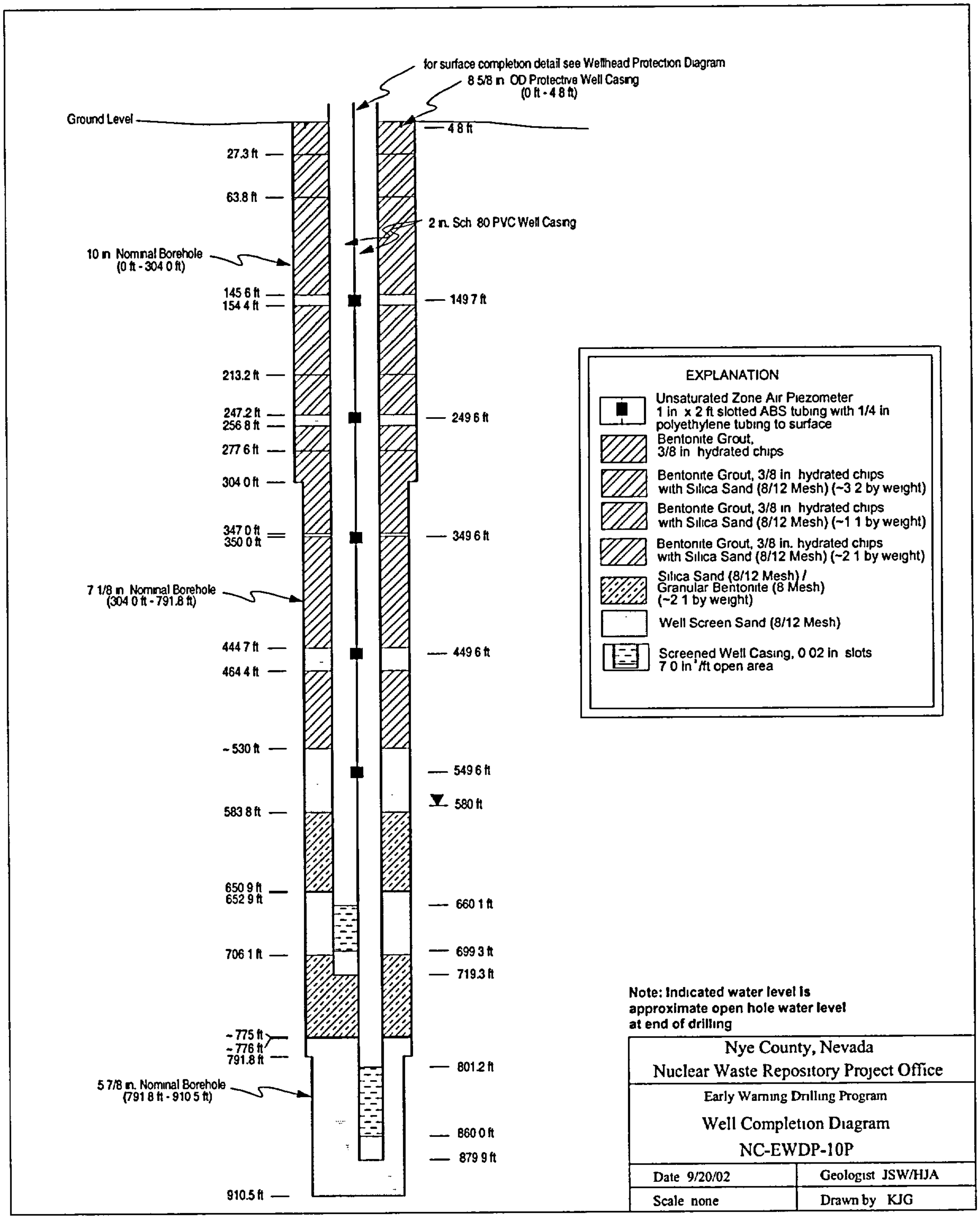
NOTE: OD = outside diameter

Figure B1
Well Completion Diagram for Well NC-EWDP-10S



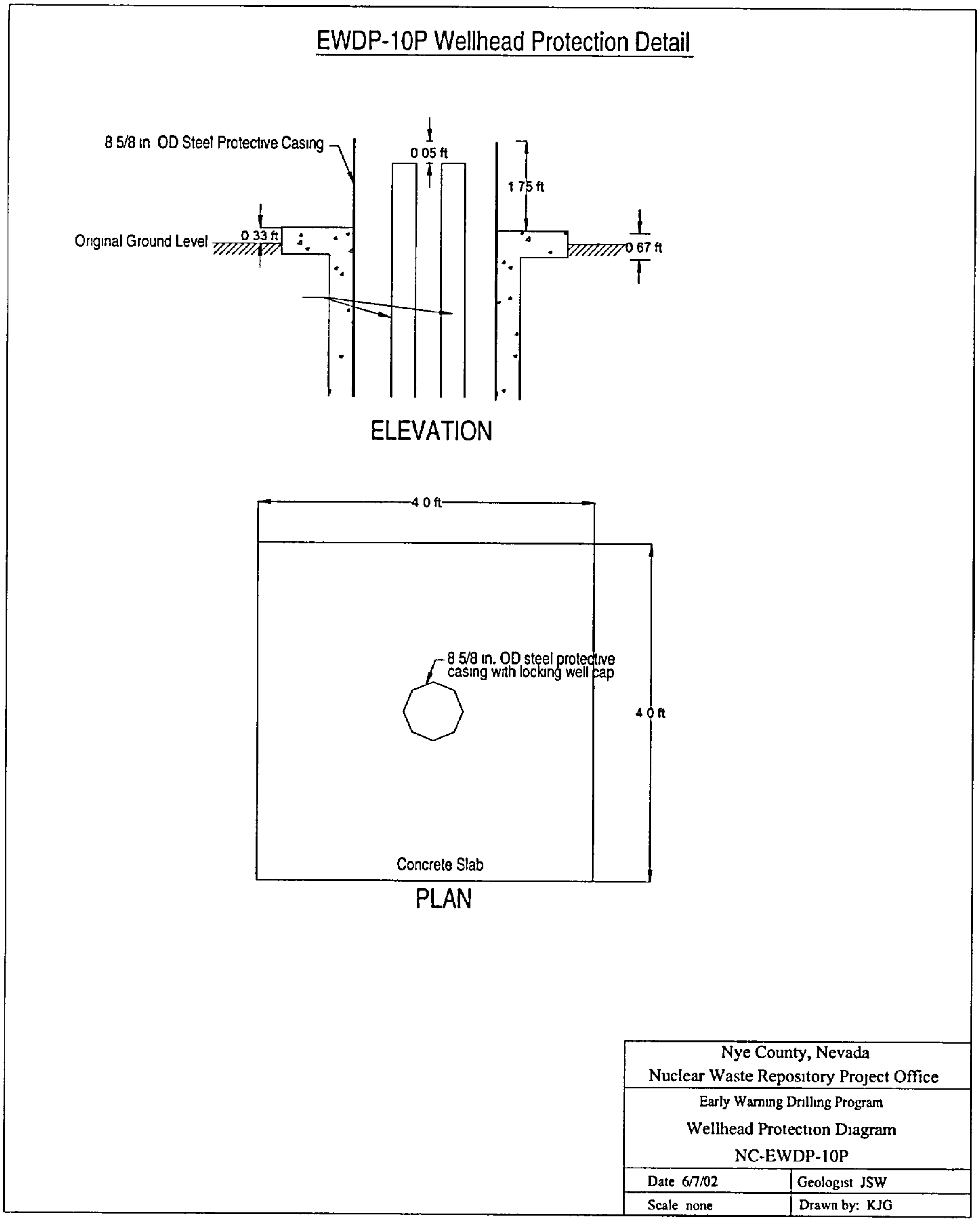
NOTE: PVC = polyvinyl chloride

Figure B2
Wellhead Protection Diagram for Well NC-EWDP-10S



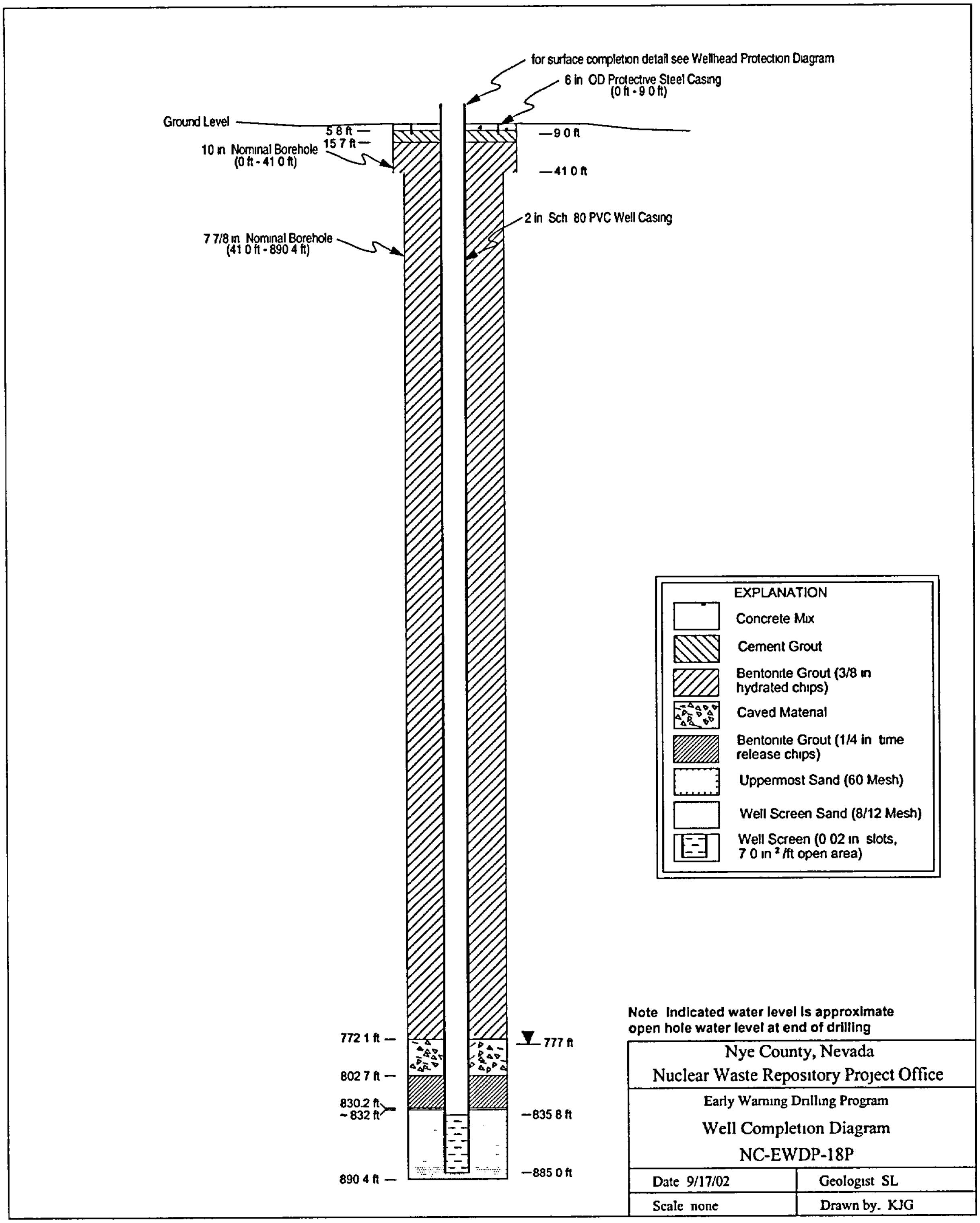
NOTES: OD = outside diameter; ABS = acrylonitrile butadiene styrene

Figure B3
Well Completion Diagram for Well NC-EWDP-10P



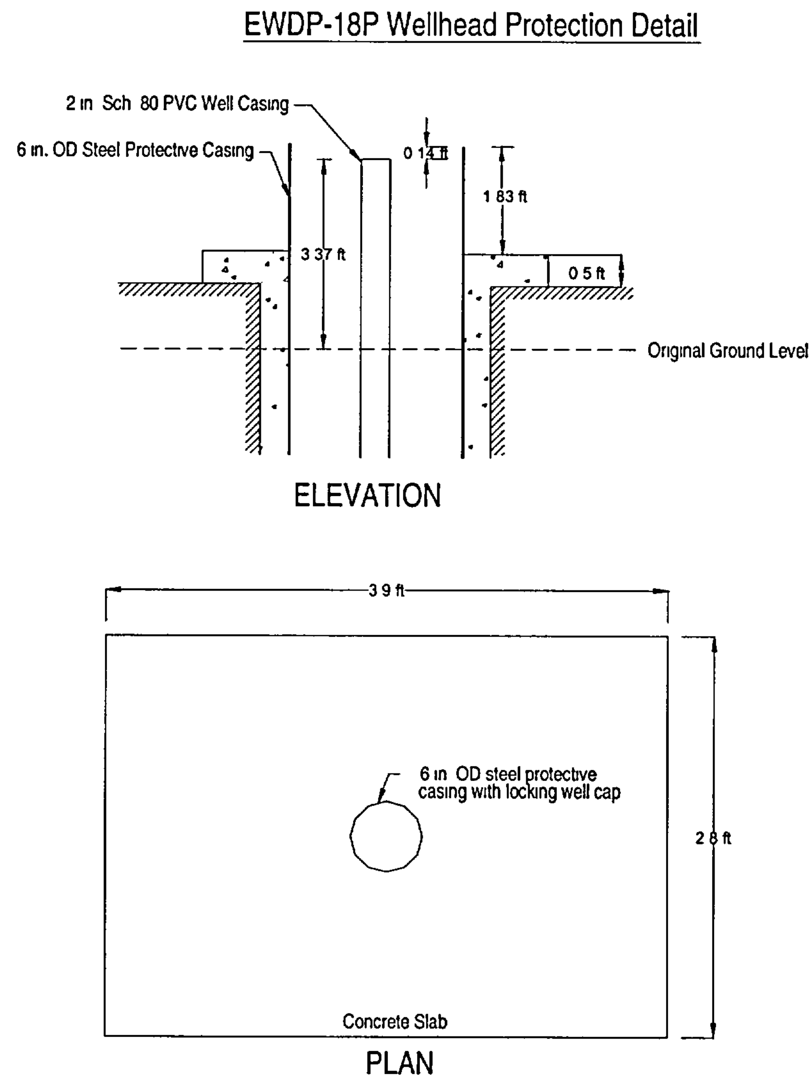
NOTE: OD = outside diameter

Figure B4
Wellhead Protection Diagram for Well NC-EWDP-10P



NOTES: OD = outside diameter; PVC = polyvinyl chloride

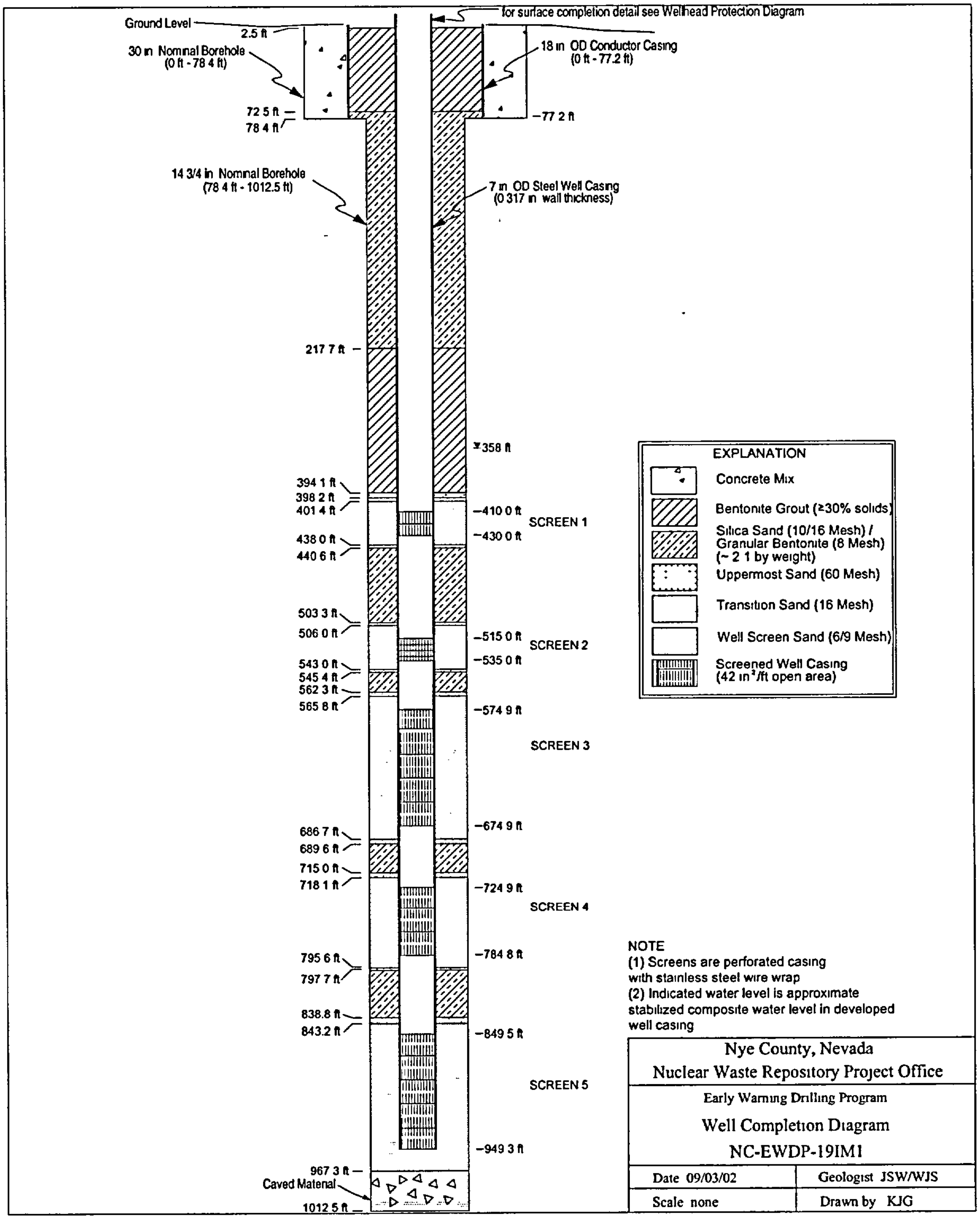
Figure B5
Well Completion Diagram for Well NC-EWDP-18P



Nye County, Nevada Nuclear Waste Repository Project Office	
Early Warning Drilling Program Wellhead Protection Diagram NC-EWDP-18P	
Date 3/22/02	Geologist SL
Scale none	Drawn by KJG

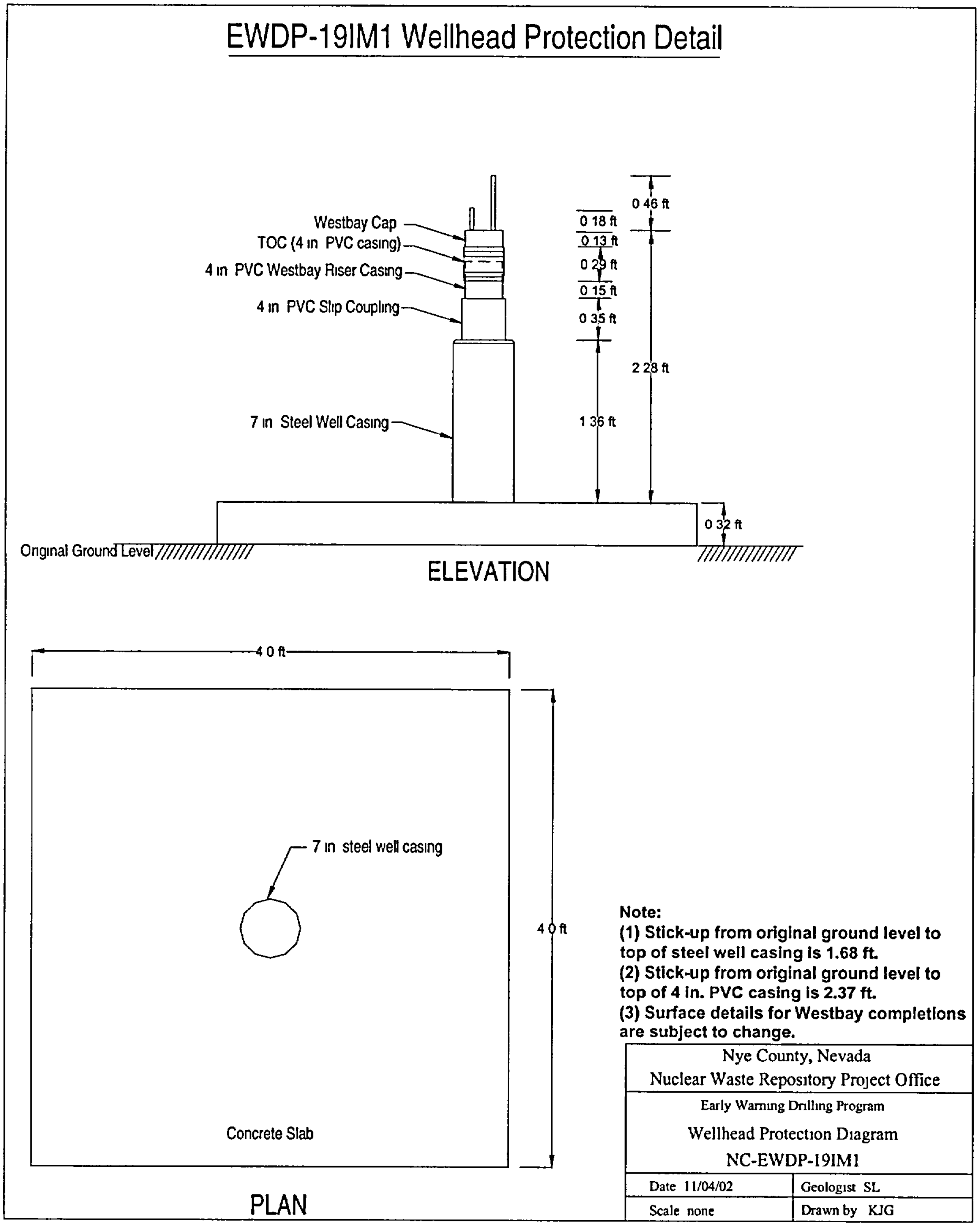
NOTES: OD = outside diameter; PVC = polyvinyl chloride

Figure B6
Wellhead Protection Diagram for Well NC-EWDP-18P



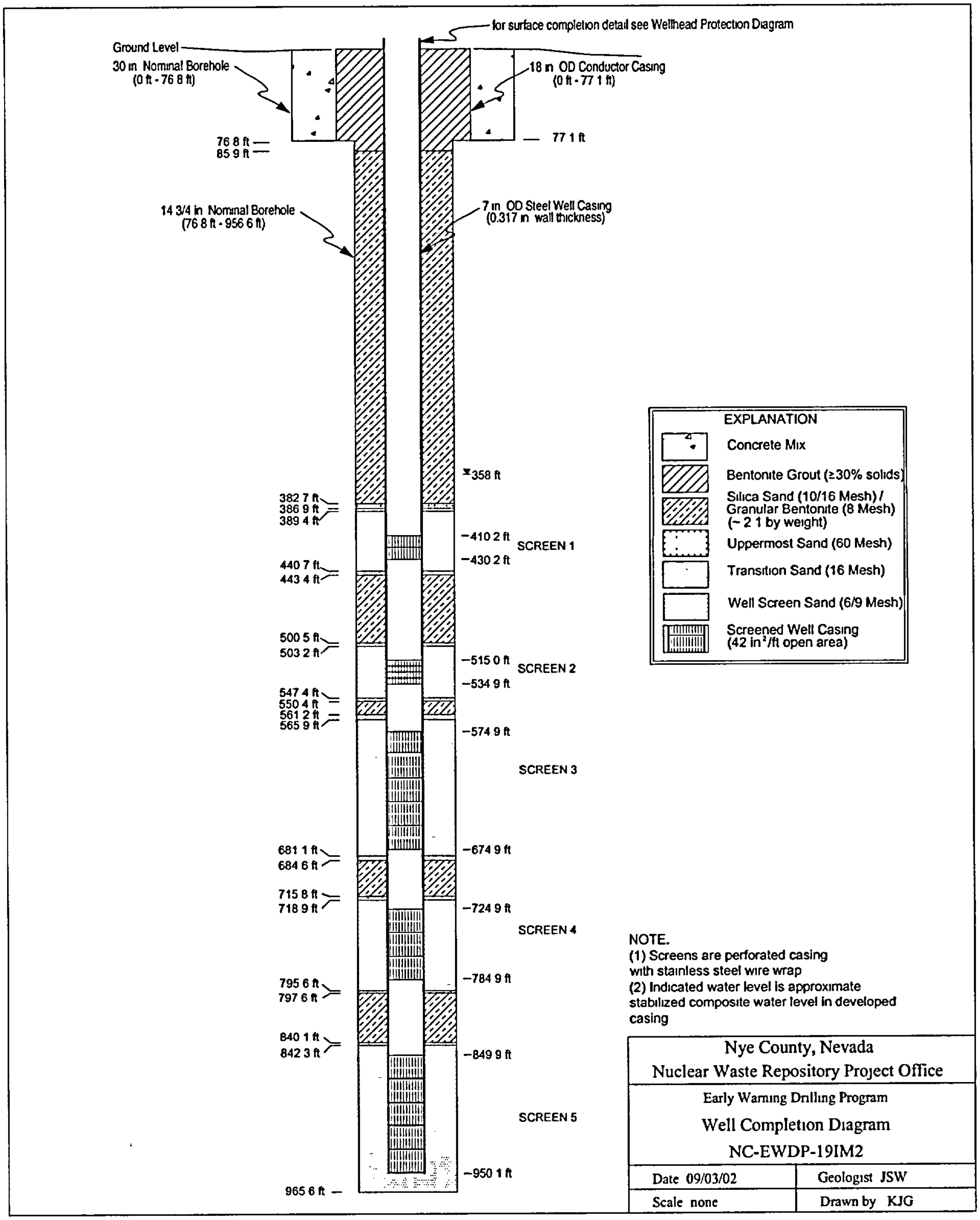
NOTE: OD = outside diameter

Figure B7
Well Completion Diagram for Well NC-EWDP-19IM1



NOTE: TOC = top of casing; PVC = polyvinyl chloride

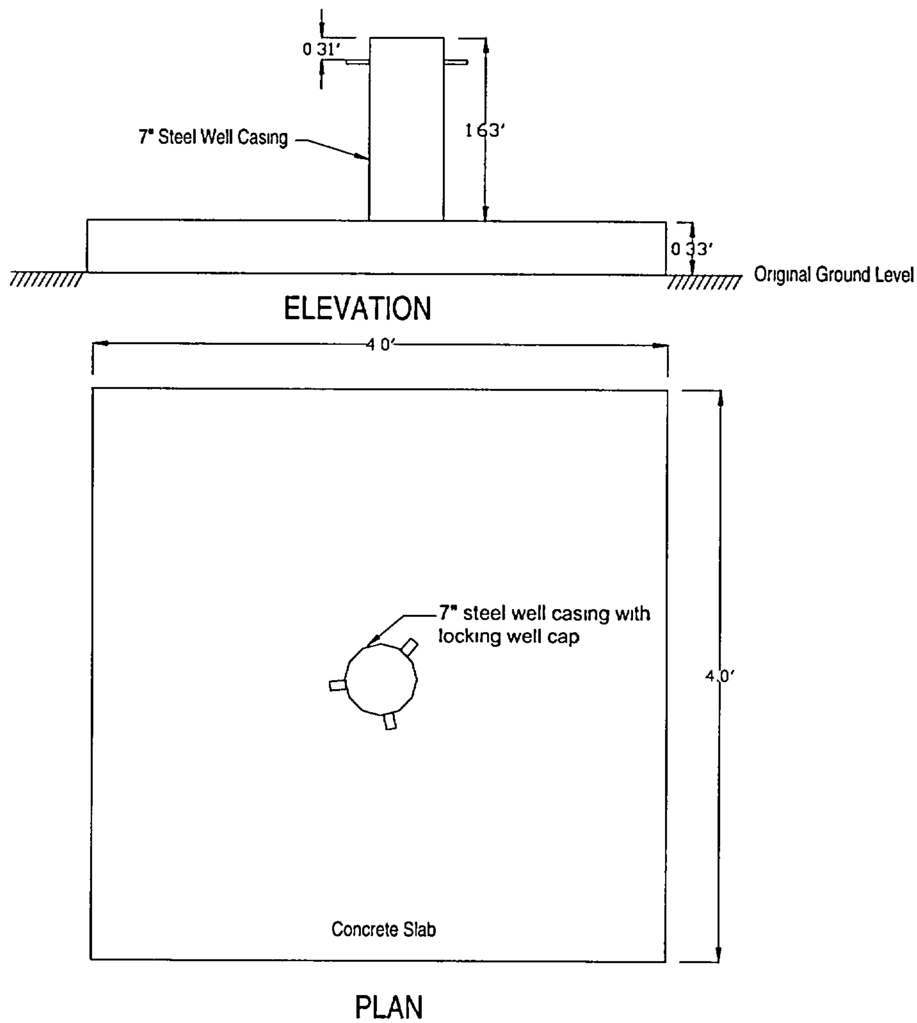
Figure B8
Wellhead Protection Diagram for Well NC-EWDP-19IM1



NOTE: OD = outside diameter

Figure B9
Well Completion Diagram for Well NC-EWDP-19IM2

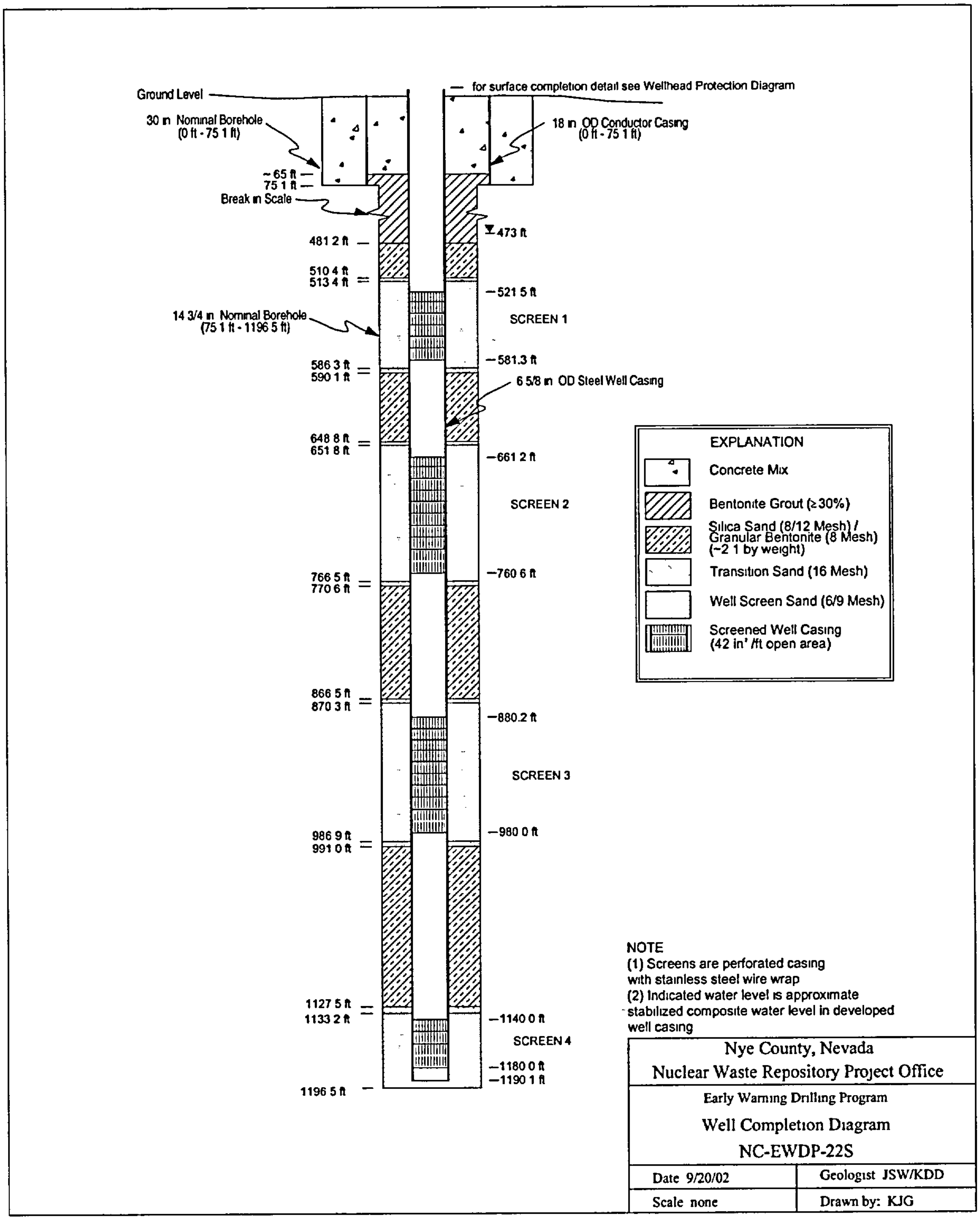
EWDP-19IM2 Wellhead Protection Detail



Nye County, Nevada Nuclear Waste Repository Project Office	
Early Warning Drilling Program Wellhead Protection Diagram NC-EWDP-19IM2	
Date 12/17/01	Geologist SL
Scale none	Drawn by KJG

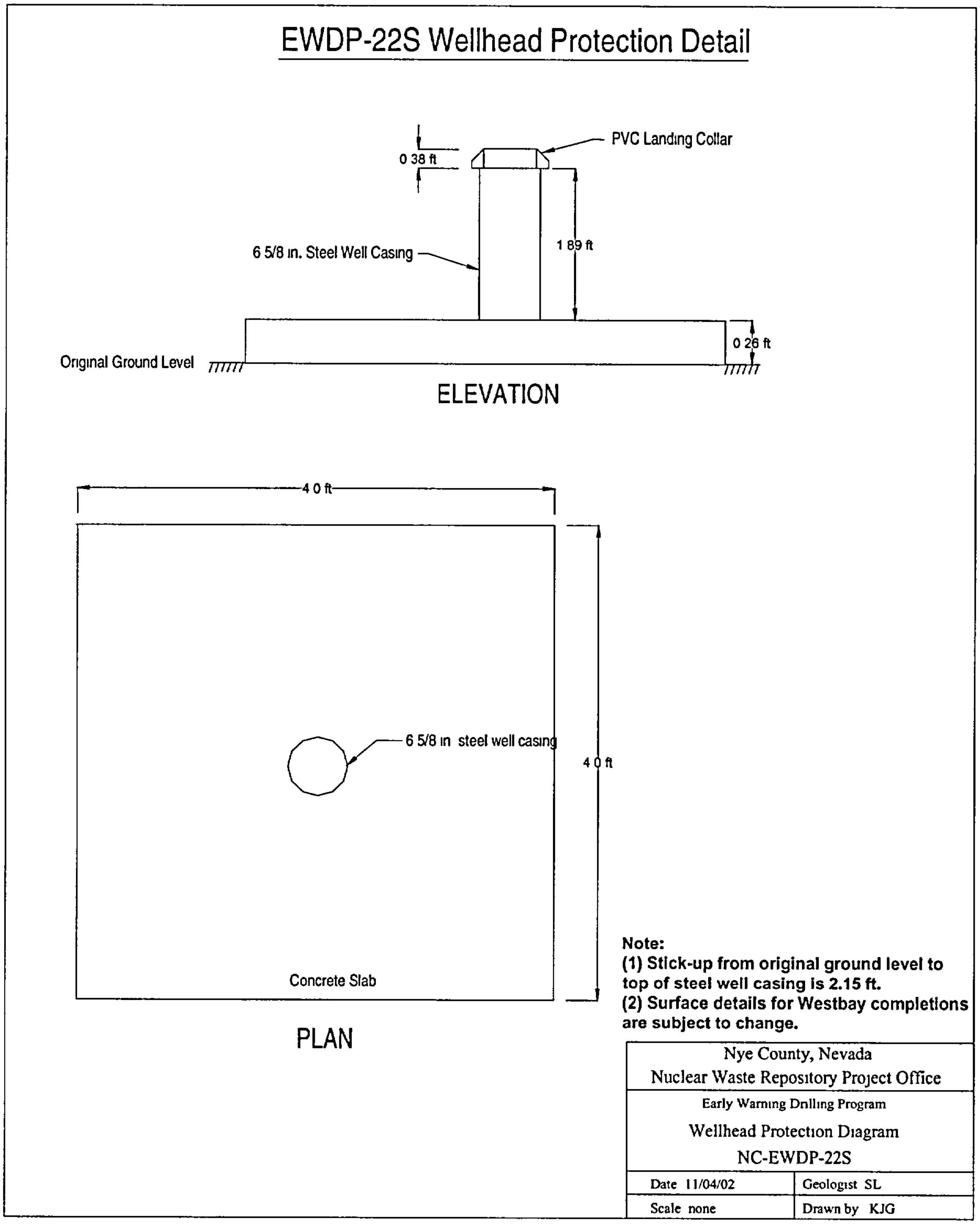
Note: Stick-up from original ground level to top of steel well casing= 1.96'

Figure B10
Wellhead Protection Diagram for Well NC-EWDP-19IM2



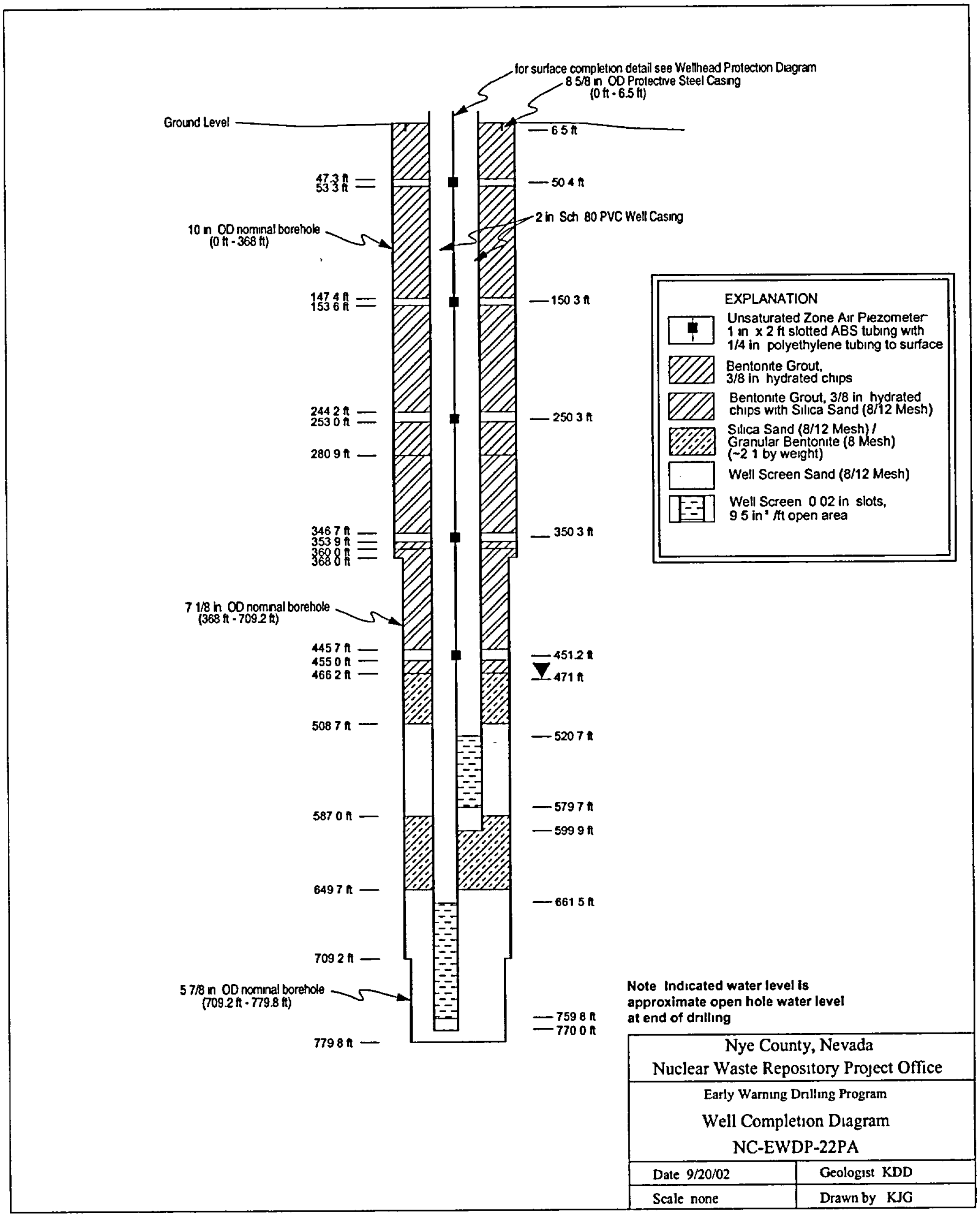
NOTE: OD = outside diameter

Figure B11
Well Completion Diagram for Well NC-EWDP-22S



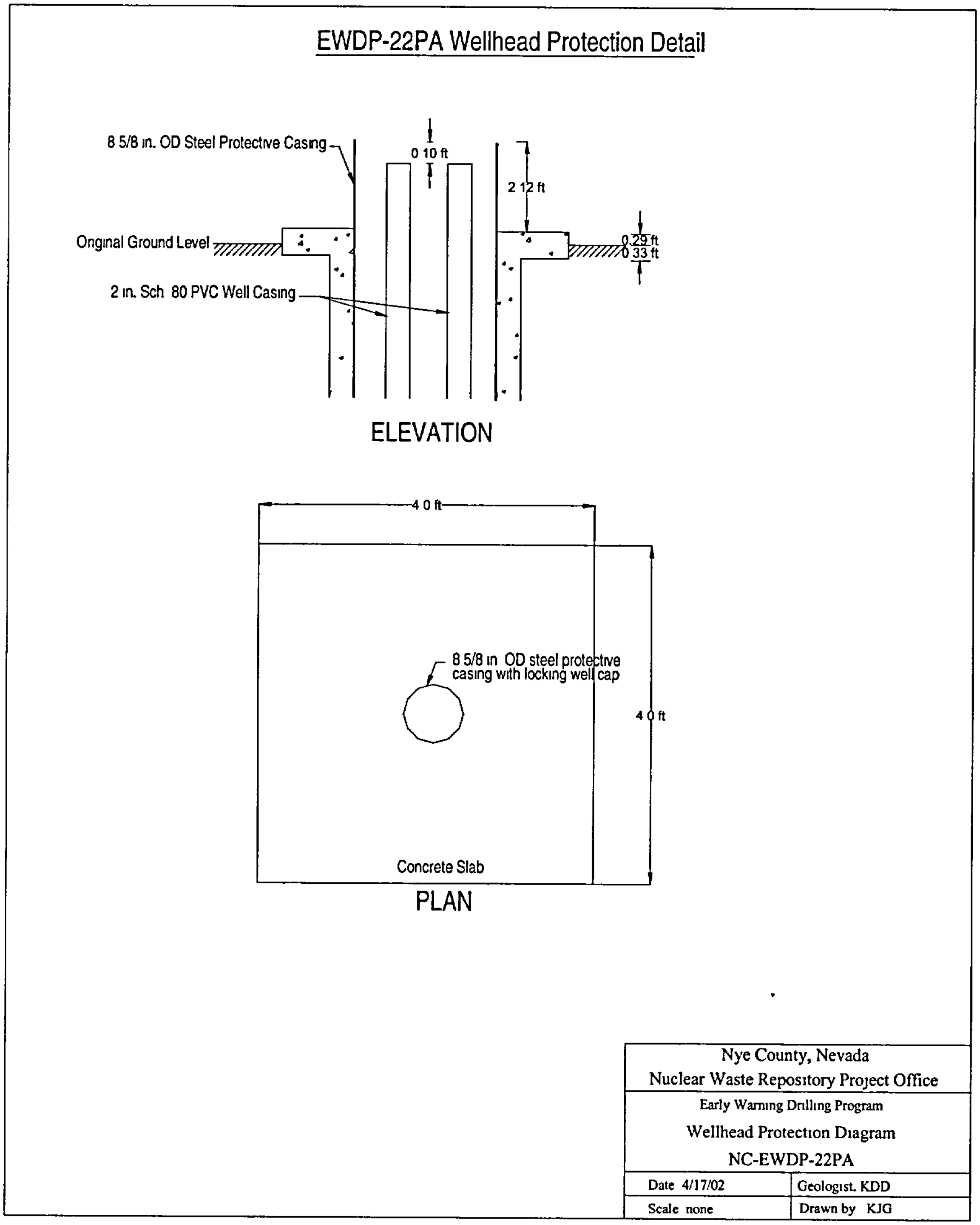
NOTE: PVC = polyvinyl chloride

Figure B12
Wellhead Protection Diagram for Well NC-EWDP-22S



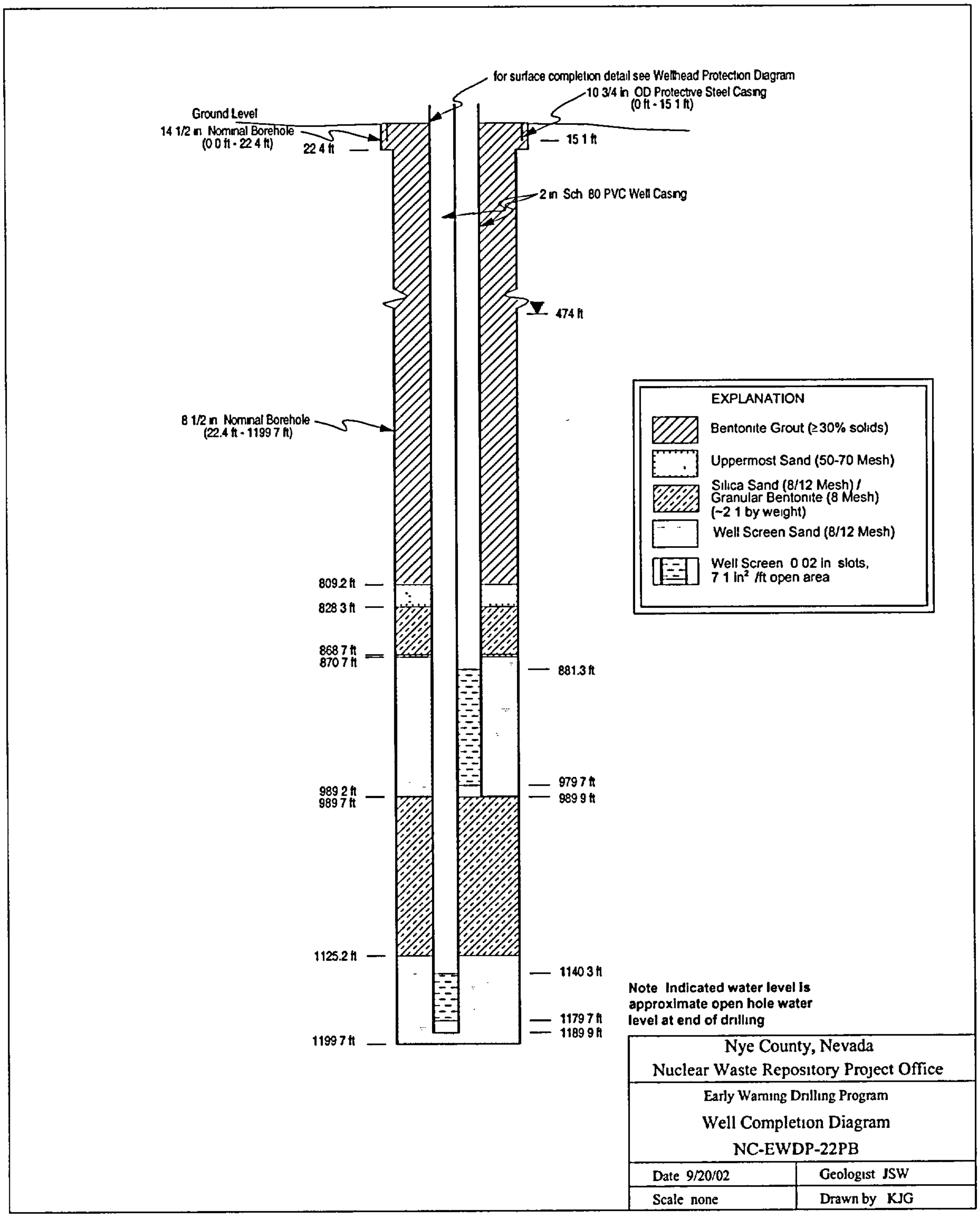
NOTES: OD = outside diameter; ABS = acrylonitrile butadiene styrene; PVC = polyvinyl chloride

Figure B13
Well Completion Diagram for Well NC-EWDP-22PA



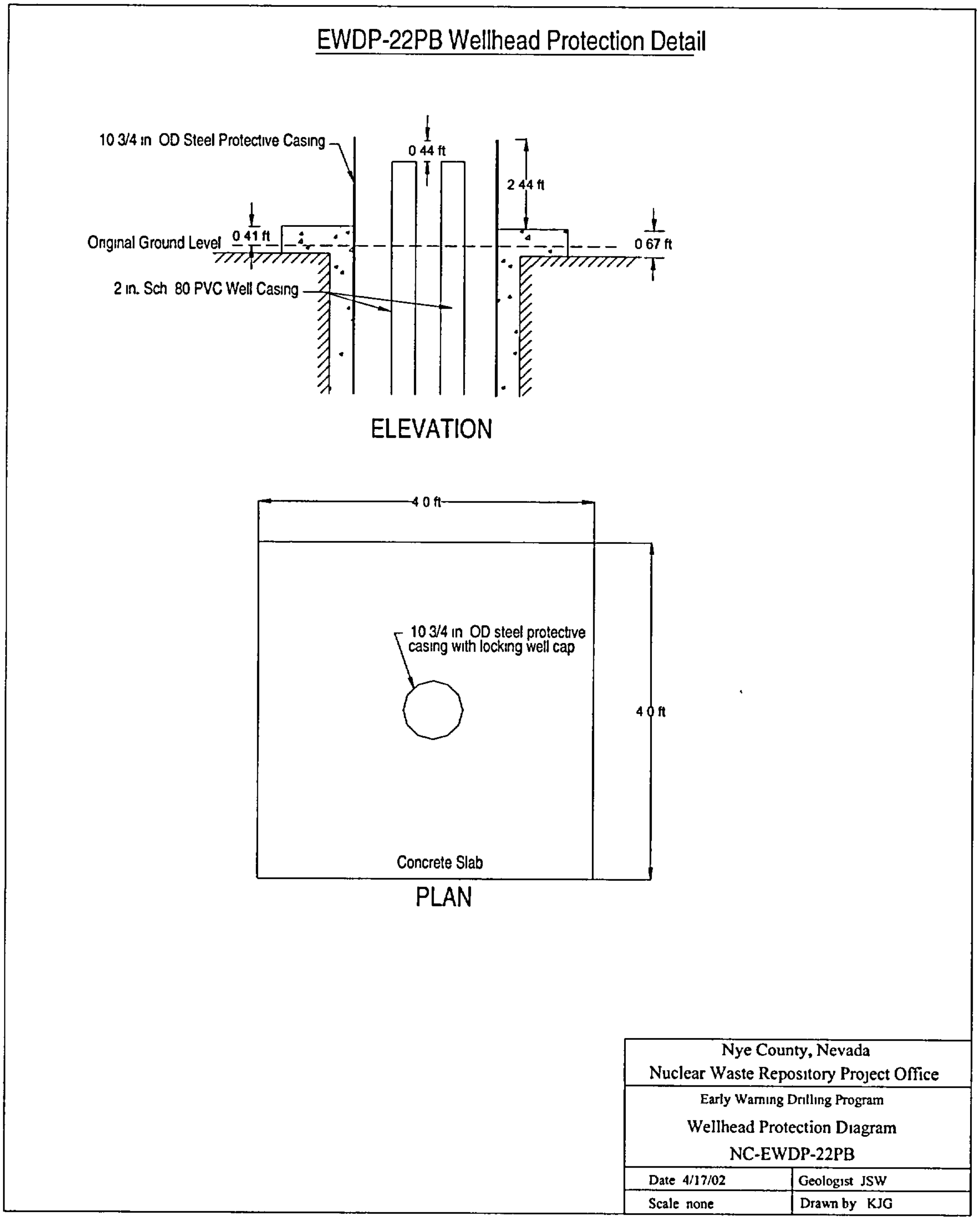
NOTES. OD = outside diameter; PVC = polyvinyl chloride

Figure B14
Wellhead Protection Diagram for Well NC-EWDP-22PA



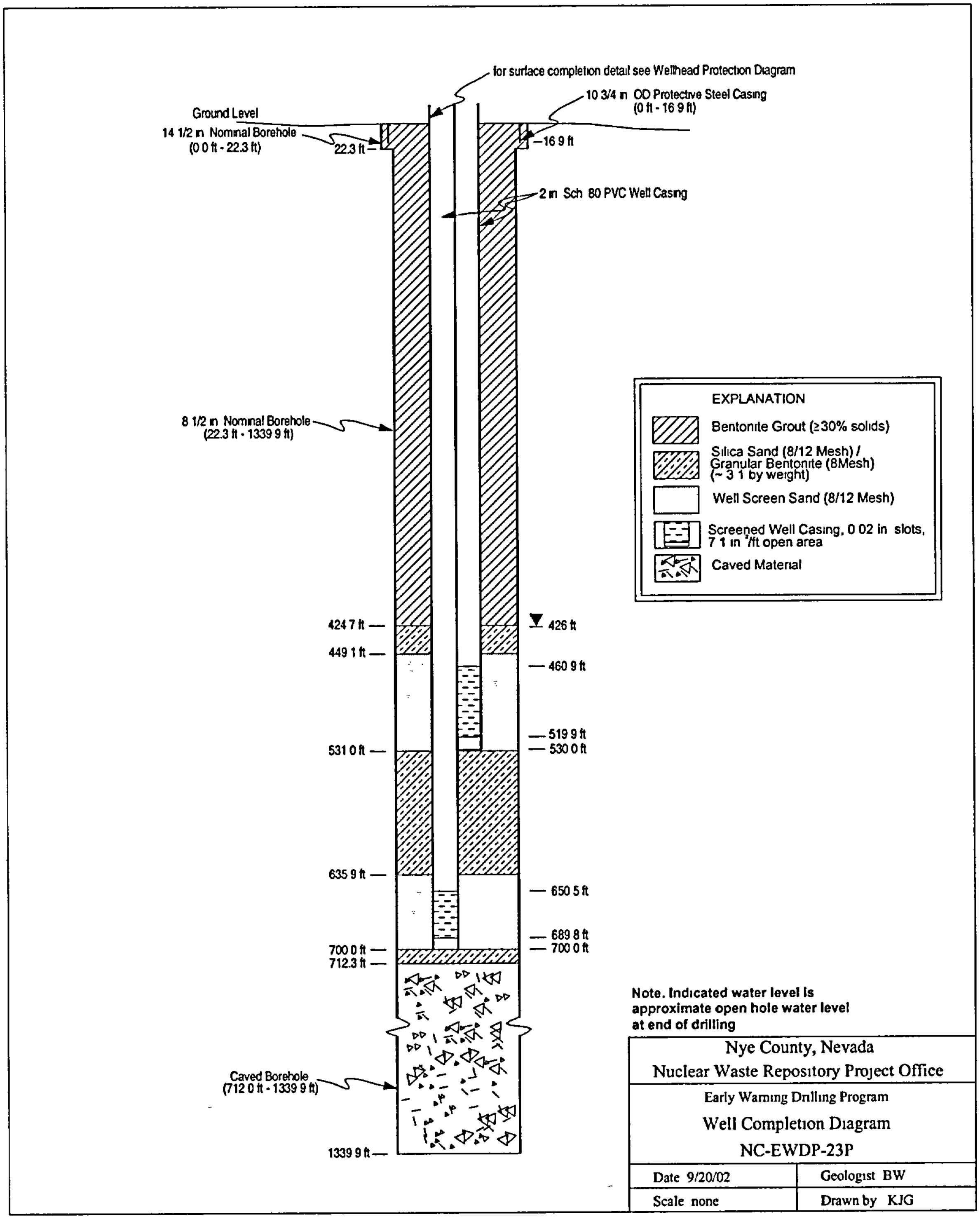
NOTE: OD = outside diameter

Figure B15
Well Completion Diagram for Well NC-EWDP-22PB



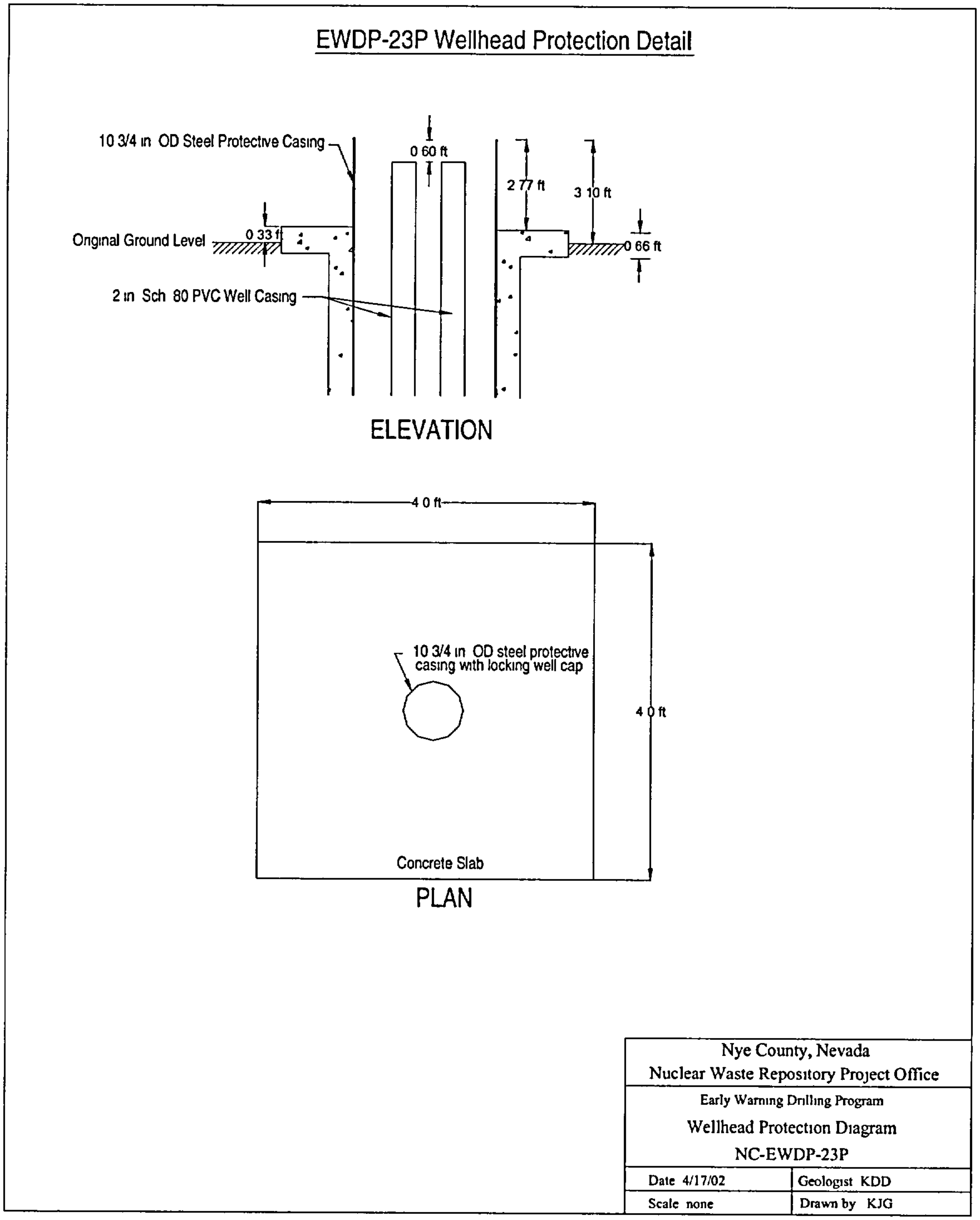
NOTES: OD = outside diameter; PVC = polyvinyl chloride

Figure B16
Wellhead Protection Diagram for Well NC-EWDP-22PB



NOTES: OD = outside diameter, PVC = polyvinyl chloride

Figure B17
Well Completion Diagram for Well NC-EWDP-23P



NOTES: OD = outside diameter; PVC = polyvinyl chloride

Figure B18
Wellhead Protection Diagram for Well NC-EWDP-23P