0074654

DOE/RL-2007-13
Revision 0

Sampling and Analysis Plan for Electrical Resistivity Correlation for the BC Cribs and Trenches Area Waste Site

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States Department of Energy
P.O. Box 550
Richland, Washington 99352

RECEIVED
DEC 03 2007
EDMC

Approved for Public Release;
Further Dissemination Unlimited

DOE/RL-2007-13
Revision 0

Sampling and Analysis Plan for Electrical Resistivity Correlation for the BC Cribs and Trenches Area Waste Site

Date Published
October 2007

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States Department of Energy
P.O. Box 550
Richland, Washington 99352

J. D. Aardal 10/11/2007
Release Approval Date

Approved for Public Release;
Further Dissemination Unlimited

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy. Available in paper copy.

Printed in the United States of America

APPROVAL PAGE

Title: Sampling and Analysis Plan for Electrical Resistivity Correlation for the BC Cribs and Trenches Area Waste Site

Approvals:

L. R. Fitch
Remedial Investigation Projects, Soil & Groundwater Remediation Project

Signature _____ Date 10/10/07

R. W. Oldham
Environmental Compliance Officer, Soil & Groundwater Remediation Project

Signature _____ Date 10.9.07

W. R. Thackaberry, Quality Assurance, Soil & Groundwater Remediation Project

Signature _____ Date 10/02/2007

M. W. Benecke, Task Lead, Soil & Groundwater Remediation Project

Signature _____ Date 10/02/07

CONCURRENCE PAGE

Title: Sampling and Analysis Plan for Electrical Resistivity Correlation for the BC Cribs and Trenches Area Waste Site

Concurrence: D. A. Brockman
U.S. Department of Energy, Richland Operations Office

Doug A. Shoop for — 11/8/07
Signature — Date

R. A. Lobos
U.S. Environmental Protection Agency

11-28-07
Signature — Date

EXECUTIVE SUMMARY

This sampling and analysis plan (SAP) describes the ongoing evaluation of potential applications of the electrical resistivity characterization (ERC) geophysical method to the vadose zone in the BC Cribs and Trenches Area. The ERC geophysical method detects changes in electrical resistivity in the vadose zone where sufficient moisture exists. The distribution of anions and cations, such as nitrate, that are associated with the resistivity changes may be inferred from the ERC scans. The distribution of contaminants of potential concern (COPC) that are associated with the detected anions or cations, such as technetium-99, also may be inferred from the ERC scans. Technetium-99 and nitrate are both COPCs in the BC Cribs and Trenches Area vadose zone and are expected to be co-located because they have similar partition coefficients (i.e., distribution coefficient values). A detailed explanation of the ERC geophysical method is attached in Appendix A.

If the ERC geophysical method adequately identifies the lateral and/or vertical distribution of targeted COPCs in the vadose zone, such as nitrate and technetium-99, then it would be useful in cost-effectively focusing characterization activities. For example, ERC could indicate where future boreholes should be drilled for obtaining soil/sediment samples to confirm the lateral boundary of a targeted COPC vadose-zone plume. The ERC geophysical method is not expected to be a standalone method for delineating COPCs, but rather another tool for characterizing the distribution of targeted COPCs in the vadose zone. The successful application of ERC scans and other surface geophysical methods could significantly reduce the cost and safety risks of characterizing the vadose zone through extensive direct soil/sediment sampling.

Three electrical resistivity surface surveys were completed in the BC Cribs and Trenches Area in fiscal years 2004, 2005, and 2006. The results are summarized in Step 1 of SGW-32480, *Data Quality Objectives Summary Report for the BC Cribs and Trenches Area – High-Resolution Resistivity Correlation* (DQO).[1] Borehole C4191 was drilled in Trench 216-B-26 in the BC Cribs and Trenches Area during fiscal year 2005 to collect soil/sediment-sample analytical

---

[1] SGW-32480, 2007, *Data Quality Objectives Summary Report for the BC Cribs and Trenches Area – High-Resolution Resistivity Correlation*, Draft A, Fluor Hanford, Inc., Richland, Washington.

data. The laboratory analytical data from Borehole C4191 were compared to the co-located electrical resistivity data. Significant qualitative levels of correlation were observed between the ERC data and concentrations of specific COPCs, anions, and cations, including nitrate and technetium-99. The correlation results are summarized in Step 1 of the preceding DQO (SGW-32480) and Appendix A of this SAP.

The activities included in this SAP are directed at continuing electrical resistivity and analytical data correlation activities by drilling and sampling up to five additional boreholes in the BC Cribs and Trenches Area. Laboratory analytical data from the borehole soil/sediment samples will be compared to co-located electrical resistivity data as described in the preceding DQO (SGW-32480). Each borehole location is planned to test different aspects of the capabilities of the electrical resistivity geophysical method. For example, Borehole A is intended to examine the correlation of electrical resistivity and analytical data in the vicinity of the crib waste sites where COPCs are expected relatively deeper in the vadose zone. The five selected borehole locations are shown in Figure 1-1 and described in Table 3-1.

CONTENTS

1.0 INTRODUCTION 1-1
1.1 DATA QUALITY OBJECTIVES 1-2
1.1.1 Statement of the Problem 1-2
1.1.2 Decision Statements and Decision Rules 1-3
1.1.3 Error Tolerance and Decision Consequences 1-3
1.2 PROPOSED BOREHOLE LOCATIONS 1-3
1.3 SUMMARY OF DATA QUALITY OBJECTIVES (SAMPLING DESIGN) 1-24
1.4 TARGETED PARAMETERS 1-30

2.0 QUALITY ASSURANCE PROJECT PLAN 2-1
2.1 PROJECT MANAGEMENT 2-1
2.1.1 Project/Task Organization 2-1
2.1.2 Problem Definition/Background 2-4
2.1.3 Project/Task Description 2-4
2.1.4 Quality Objectives and Criteria 2-4
2.1.5 Special Training Certification 2-5
2.1.6 Documentation and Records 2-6
2.2 DATA GENERATION AND ACQUISITION 2-6
2.2.1 Sampling-Process Design 2-6
2.2.2 Sampling Methods 2-7
2.2.3 Sample Handling, Shipping, and Custody Requirements 2-7
2.2.4 Laboratory Sample Custody 2-8
2.2.5 Analytical Methods 2-9
2.2.6 Quality Control Requirements 2-9
2.2.7 Instrument/Equipment Testing, Inspection, and Maintenance 2-11
2.2.8 Instrument/Equipment Calibration and Frequency 2-11
2.2.9 Inspection/Acceptance of Supplies and Consumables 2-12
2.2.10 Nondirect Measurements 2-12
2.2.11 Data Management 2-12
2.3 ASSESSMENT/OVERSIGHT 2-13
2.3.1 Assessments and Response Action 2-14
2.3.2 Reports to Management 2-14
2.4 DATA VALIDATION AND USABILITY 2-14
2.4.1 Data Review, Verification, and Validation 2-14
2.4.2 Verification and Validation Methods 2-15
2.4.3 Reconciliation with User Requirements 2-16

3.0 FIELD-SAMPLING PLAN 3-1
3.1 SAMPLING OBJECTIVES 3-1
3.2 SAMPLING LOCATIONS AND FREQUENCY 3-2
3.2.1 Sampling Methodology for Groundwater 3-3
3.2.2 Sampling Methodology for Soil/Sediment 3-3
3.2.3 Geophysical Logging 3-28

3.2.4 Vertical-Electrode Arrays 3-28
3.3 MANAGEMENT OF WASTE 3-29

4.0 HEALTH AND SAFETY 4-1

5.0 REFERENCES 5-1

APPENDIX

A EXPLANATION OF ELECTRICAL RESISTIVITY SURFACE GEOPHYSICAL TECHNIQUE ..... A-i

FIGURES

Figure 1-1. Proposed Borehole Locations in the BC Cribs and Trenches Area. 1-4

Figure 1-2. Three-Dimensional Inverted Electrical Resistivity Map for Borehole A in BC Cribs and Trenches Area. 1-5

Figure 1-3. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole A in BC Cribs and Trenches Area. 1-6

Figure 1-4. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking West) for Borehole A in BC Cribs and Trenches Area. 1-7

Figure 1-5. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole A in BC Cribs and Trenches Area. 1-8

Figure 1-6. Three-Dimensional Inverted Electrical Resistivity Map for Borehole B in BC Cribs and Trenches Area. 1-9

Figure 1-7. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole B in BC Cribs and Trenches Area. 1-10

Figure 1-8. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking East) for Borehole B in BC Cribs and Trenches Area. 1-11

Figure 1-9. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole B in BC Cribs and Trenches Area. 1-12

Figure 1-10. Three-Dimensional Inverted Electrical Resistivity Map for Borehole C in BC Cribs and Trenches Area. 1-13

Figure 1-11. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole C in BC Cribs and Trenches Area. 1-14

Figure 1-12. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking West) for Borehole C in BC Cribs and Trenches Area. 1-15

Figure 1-13. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole C in BC Cribs and Trenches Area. 1-16

Figure 1-14. Three-Dimensional Inverted Electrical Resistivity Map for Borehole D in BC Cribs and Trenches Area. 1-17

Figure 1-15. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole D in BC Cribs and Trenches Area. 1-18

Figure 1-16. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking East) for Borehole D in BC Cribs and Trenches Area. 1-19

Figure 1-17. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole D in BC Cribs and Trenches Area. 1-20

Figure 1-18. Three-Dimensional Inverted Electrical Resistivity Map for Borehole E in BC Cribs and Trenches Area. 1-21

Figure 1-19. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole E in BC Cribs and Trenches Area. 1-22

Figure 1-20. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking West) for Borehole E in BC Cribs and Trenches Area. 1-23

Figure 1-21. Generalized Stratigraphy of the BC Cribs and Trenches Area. 1-29

Figure 2-1. Project Organization Chart. 2-2

TABLES

Table 1-1. Summary of Decision Rules. 1-2

Table 1-2. Physical and Geochemical Analyses of Borehole Soil/Sediment Samples for Electrical Resistivity Evaluation in the Vadose Zone of the BC Cribs and Trenches Area. 1-25

Table 1-3. Additional Physical and Geochemical Analyses of Borehole Soil/Sediment Samples for Supplementing the Vadose-Zone Conceptual Site Model. 1-26

Table 1-4. Analytical Performance Requirements. 1-27

Table 1-5. Quick-Turnaround Laboratory Analytical Methods. 1-28

Table 1-6. Contaminants of Potential Concern Screened as Possible Targeted Parameters. 1-31

Table 1-7. Targeted Parameters for Electrical Resistivity Evaluation. 1-35

Table 2-1. Field Quality-Control Requirements. 2-10

Table 3-1. Rationale for Proposed New Borehole Locations. 3-1

Table 3-2. Sediment Samples in Borehole A Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. 3-4

Table 3-3. Sediment Samples in Borehole B Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. 3-9

Table 3-4. Sediment Samples in Borehole C Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. 3-12

Table 3-5. Sediment Samples in Borehole D Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. 3-15

Table 3-6. Sediment Samples in Borehole E Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. 3-18

Table 3-7. Soil/Sediment Sampling and Analytical Methods for Electrical Resistivity Evaluation Samples. 3-22

Table 3-8. Sample Preservation, Container, and Holding Times for Soil/Sediment Samples 3-23

TERMS

3-D inversion	three-dimensional inversion
ALARA	as low as reasonably achievable
bgs	below ground surface
CFR	*Code of Federal Regulations*
COPC	contaminant of potential concern
CSM	conceptual site model
DOE	U.S. Department of Energy
DQO	data quality objective
DR	decision rule
DS	decision statement
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
ERC	electrical resistivity characterization
FFS	focused feasibility study
HEIS	*Hanford Environmental Information System*
HRR	high-resolution resistivity
IC	ion chromatography
ICP	inductively coupled plasma
ICP/MS	inductively coupled plasma/mass spectrometry
K_d	distribution coefficient
LSC	liquid scintillation counter
MDC	minimum detectable concentration
MS	mass spectrometry
N/A	not applicable
QA	quality assurance
QAPjP	quality assurance project plan
QC	quality control
RL	DOE, Richland Operations Office
SAP	sampling and analysis plan
VEA	vertical-electrode array
WIDS	*Waste Information Data System* database

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If you know	*Multiply by*	*To get*	*If you know*	*Multiply by*	*To get*
Length			**Length**		
inches	25.40	millimeters	millimeters	0.0394	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles (statute)	1.609	kilometers	kilometers	0.621	miles (statute)
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.0929	sq. meters	sq. meters	10.764	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.591	sq. kilometers	sq. kilometers	0.386	sq. miles
acres	0.405	hectares	hectares	2.471	acres
Mass (weight)			**Mass (weight)**		
ounces (avoir)	28.349	grams	grams	0.0353	ounces (avoir)
pounds	0.454	kilograms	kilograms	2.205	pounds (avoir)
tons (short)	0.907	ton (metric)	ton (metric)	1.102	tons (short)
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.034	ounces (U.S., liquid)
tablespoons	15	milliliters	liters	2.113	pints
ounces (U.S., liquid)	29.573	milliliters	liters	1.057	quarts (U.S., liquid)
cups	0.24	liters	liters	0.264	gallons (U.S., liquid)
pints	0.473	liters	cubic meters	35.315	cubic feet
quarts (U.S., liquid)	0.946	liters	cubic meters	1.308	cubic yards
gallons (U.S., liquid)	3.785	liters			
cubic feet	0.0283	cubic meters			
cubic yards	0.764	cubic meters			
Temperature			**Temperature**		
Fahrenheit	(°F-32)*5/9	Centigrade	Centigrade	(°C*9/5)+32	Fahrenheit
Radioactivity			**Radioactivity**		
picocurie	37	millibecquerel	millibecquerel	0.027	picocurie

1.0 INTRODUCTION

This sampling and analysis plan (SAP) specifies vadose-zone data to be collected in association with drilling five boreholes (Boreholes A through E) in the BC Cribs and Trenches Area of the Hanford Site. Data-collection requirements were identified during the data quality objectives (DQO) process (SGW-32480, *Data Quality Objectives Summary Report for the BC Cribs and Trenches Area – High-Resolution Resistivity Correlation*). The data requirements primarily are directed at evaluating a ground surface electrical resistivity geophysical method. Secondary data requirements are included for refining and updating the conceptual site model (CSM). The primary focus of this SAP is the development of correlations between electrical resistivity and contaminant concentration data in the vadose zone.

The electrical resistivity characterization (ERC) geophysical method to be evaluated in this SAP is based on three-dimensional inversion (3-D inversion) processing of electrical resistivity data. The data are processed with EarthImager 3DCL,[2] Version 1.0.1, a 3-D inversion computer program. Another ERC method, high-resolution resistivity (HRR), was described in the preceding DQO. HRR is a term developed by hydroGEOPHYSICS, Inc., Tucson, Arizona, a geophysical and consulting firm that is assisting the U.S. Department of Energy (DOE) in the application of electrical resistivity geophysical methods at the Hanford Site. HRR is based on interpretations of apparent electrical resistivity data as described in the DQO and Appendix A of this SAP. The 3-D inversion and HRR methods both use the same electrical resistivity data. One advantage of the 3-D inversion method is that it reduces horizontal smearing, or a "pantleg effect," which occurs in HRR data interpretations. A possible disadvantage of the 3-D inversion method is that the results are subject to a vertical smearing effect, especially near the lower boundary of low-resistivity zones.

The soil/sediment sample analytical data described in this SAP will be compared to ERC data that are processed by a 3-D inversion computer program. The primary objective is to correlate sampling data with 3-D inverted data. The sampling analytical results also may be correlated to HRR data where the 3-D inverted data indicate vertical smearing. Both correlations are considered, because the primary objective of this SAP is to evaluate the capabilities of electrical resistivity surveys for investigating vadose-zone contamination.

This SAP contains five chapters:

- Chapter 1.0 – Summarizes the recent DQO process and required data for electrical resistivity evaluation
- Chapter 2.0 – Describes the quality assurance project plan (QAPjP)
- Chapter 3.0 – Describes the field-sampling plan

[2] EarthImager is a trademark of AGI Advanced Geosciences, Inc., Austin, Texas.

- Chapter 4.0 – Describes the health and safety plan.
- Chapter 5.0 – Provides a list of the references cited.

1.1 DATA QUALITY OBJECTIVES

This SAP is based on EPA/600/R-96/055, *Guidance for the Data Quality Objectives Process*, EPA QA/G-4. The DQO process is a strategic planning approach for defining the criteria that a data collection design should satisfy. The DQO process is used to ensure that the type, quantity, and quality of environmental data used in decision making is appropriate for the intended application. Note that EPA/600/R-96/055 was replaced by EPA/240/B-06/001, *Guidance on Systematic Planning Using the Data Quality Objectives Process*, EPA QA/G-4.

This section presents a summary of the key outputs resulting from the DQO process. The decision statements and decision rules in Table 1-1 were developed during the preceding DQO process. For additional details, refer to the DQO (SGW-32480).

Table 1-1. Summary of Decision Rules.

Decision Statement	Decision Rule
DS #1 – Estimate the degree of correlation between electrical resistivity data and the distribution (i.e., concentration and location) of vadose-zone targeted parameters that are listed in Table 1-7.	**DR #1** – If electrical resistivity data generally correlate with soil/sediment analytical results at various locations of the electrical resistivity region, then electrical resistivity data may sufficiently identify areas of elevated COPC concentrations in the vadose zone of the BC Cribs and Trenches Area.
DS #2 – Determine whether electrical resistivity and analytical data correlate sufficiently to use electrical resistivity to assist in updating the existing CSM and evaluating remedial alternatives.	**DR #2** – If electrical resistivity and soil/sediment analytical data correlate laterally and vertically in areas of relatively high and low COPC concentrations, then electrical resistivity data may support CSM development and the evaluation of remedial decisions.
DS #3 – Determine whether electrical resistivity data interpretations are useful for guiding vadose-zone soil/sediment sampling for targeted COPCs.	**DR #3** – If electrical resistivity and soil/sediment analytical data correlate laterally and vertically in areas of relatively high and low COPC concentrations, then electrical resistivity data may support characterization of targeted COPCs in the vadose zone.

COPC = contaminant of potential concern.
CSM = conceptual site model.
DR = decision rule.
DS = decision statement.

1.1.1 Statement of the Problem

The purpose of this SAP is to ascertain the degree to which electrical resistivity data for the BC Cribs and Trenches Area correlate with the distribution of targeted parameters in the vadose zone. If electrical resistivity data interpretations identify selected contaminant of potential concern (COPC) distributions, then electrical resistivity scans may assist in characterizing the vadose zone and evaluating remedial alternatives.

The successful application of electrical resistivity scans could significantly reduce the costs and safety risks for characterizing the vadose zone. Direct soil/sediment sampling could be focused by identifying important borehole locations, such as the lateral boundary of a targeted COPC plume.

1.1.2 Decision Statements and Decision Rules

Decision statements are presented in the DQO to consolidate potential questions and alternative actions. Decision rules are generated from the decision statements. A decision rule is an "IF…THEN…" statement that incorporates the parameter of interest, unit of decision making, action level, and action(s) that would result from resolution of the decision. Table 1-1 presents the decision statements and decision rules that were identified in the DQO (SGW-32480).

The decision rules are not explicitly quantitative, because the purpose of the HRR evaluation is to assess whether any correlation exists between electrical resistivity and soil/sediment analytical data. No correlation between the two data sets would indicate that the electrical resistivity geophysical method is not applicable to the purposes described in the decision statements. Data generated for this SAP will be appropriately applied to the decision rules in Table 1-1.

1.1.3 Error Tolerance and Decision Consequences

As explained for the decision statements and rules, the electrical resistivity evaluation is based on qualitative criteria rather than quantitative statistical analyses. The borehole locations and the soil/sediment sampling and analyses plans are based on professional judgment for acquiring information that will resolve the decision rules. Professional judgment included an evaluation of electrical resistivity data and soil/sediment-sample analytical results from Borehole C4191, which previously was drilled through Trench 216-B-26. Significant correlations were found in Borehole C4191 between vadose-zone regions of low apparent electrical resistivity, as measured by the electrical resistivity geophysical method, and soil/sediment concentrations of nitrate, Tc-99, sodium, and other anions and cations.

1.2 PROPOSED BOREHOLE LOCATIONS

Five boreholes in the BC Cribs and Trenches Area are proposed in the DQO (SGW-32480) for collecting vadose-zone soil/sediment samples. The selected borehole locations are shown in Figure 1-1. The 3-D inverted electrical resistivity for each borehole is shown in a plan view map, two vertical profiles, and a vertical electrical resistivity plot (except for Borehole E) in Figures 1-2 through 1-20. The 3-D inverted electrical resistivity maps, vertical profiles, and plots are the results of computer inversion modeling of electrical resistivity data that were obtained from lines of electrode arrays placed on the ground surface in the BC Cribs and Trenches Area. The electrical resistivity data were collected during three series of geophysical surface surveys in fiscal years 2004, 2005, and 2006 (D&D-31659, *Geophysical Investigations by High-Resolution Resistivity for the BC Cribs and Trenches Area, 2004-2006*).

Figure 1-1. Proposed Borehole Locations in the BC Cribs and Trenches Area.

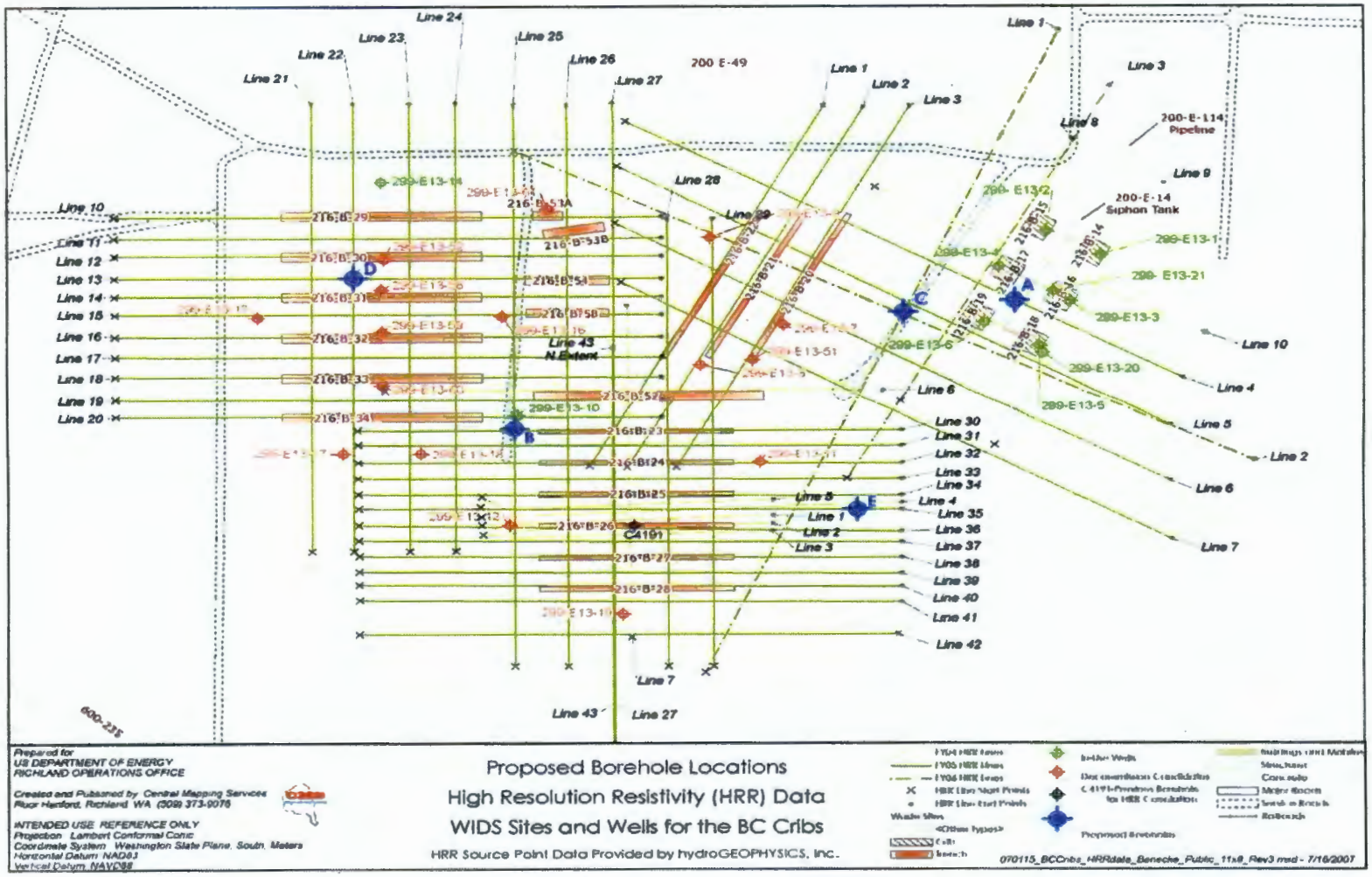


Figure 1-2. Three-Dimensional Inverted Electrical Resistivity Map for Borehole A in BC Cribs and Trenches Area.

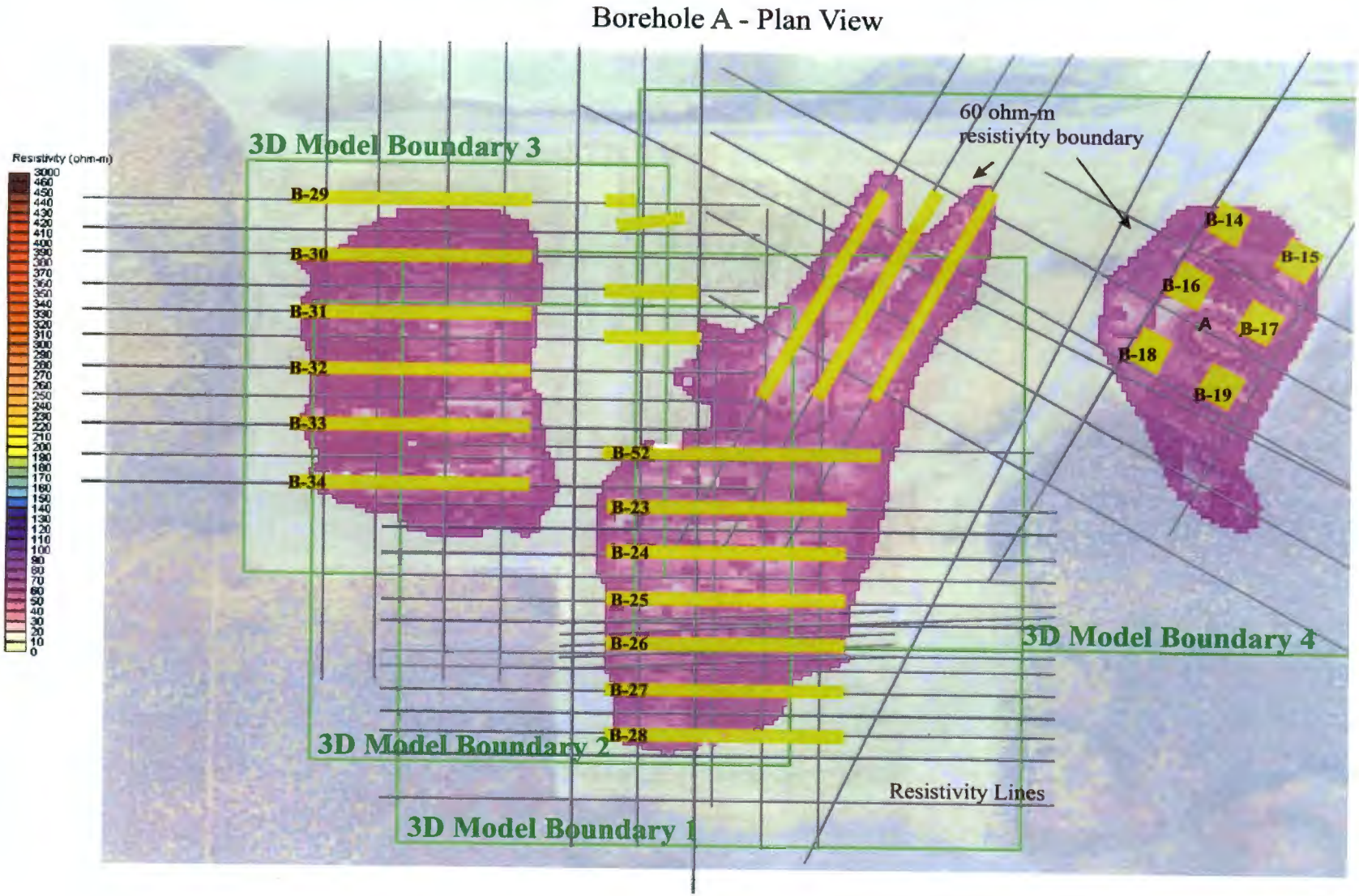


Figure 1-3. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole A in BC Cribs and Trenches Area.

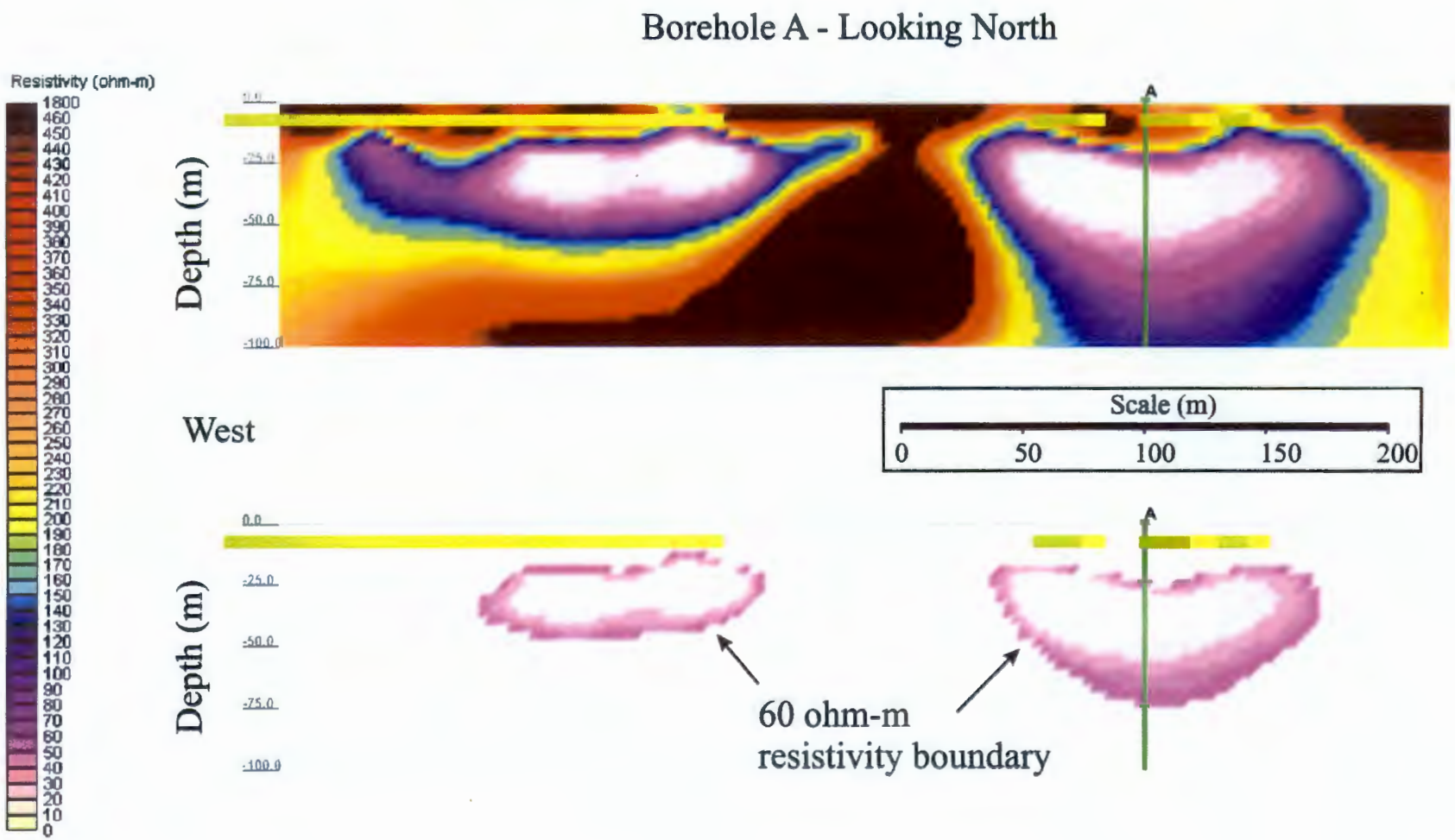


Figure 1-4. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking West) for Borehole A in BC Cribs and Trenches Area.

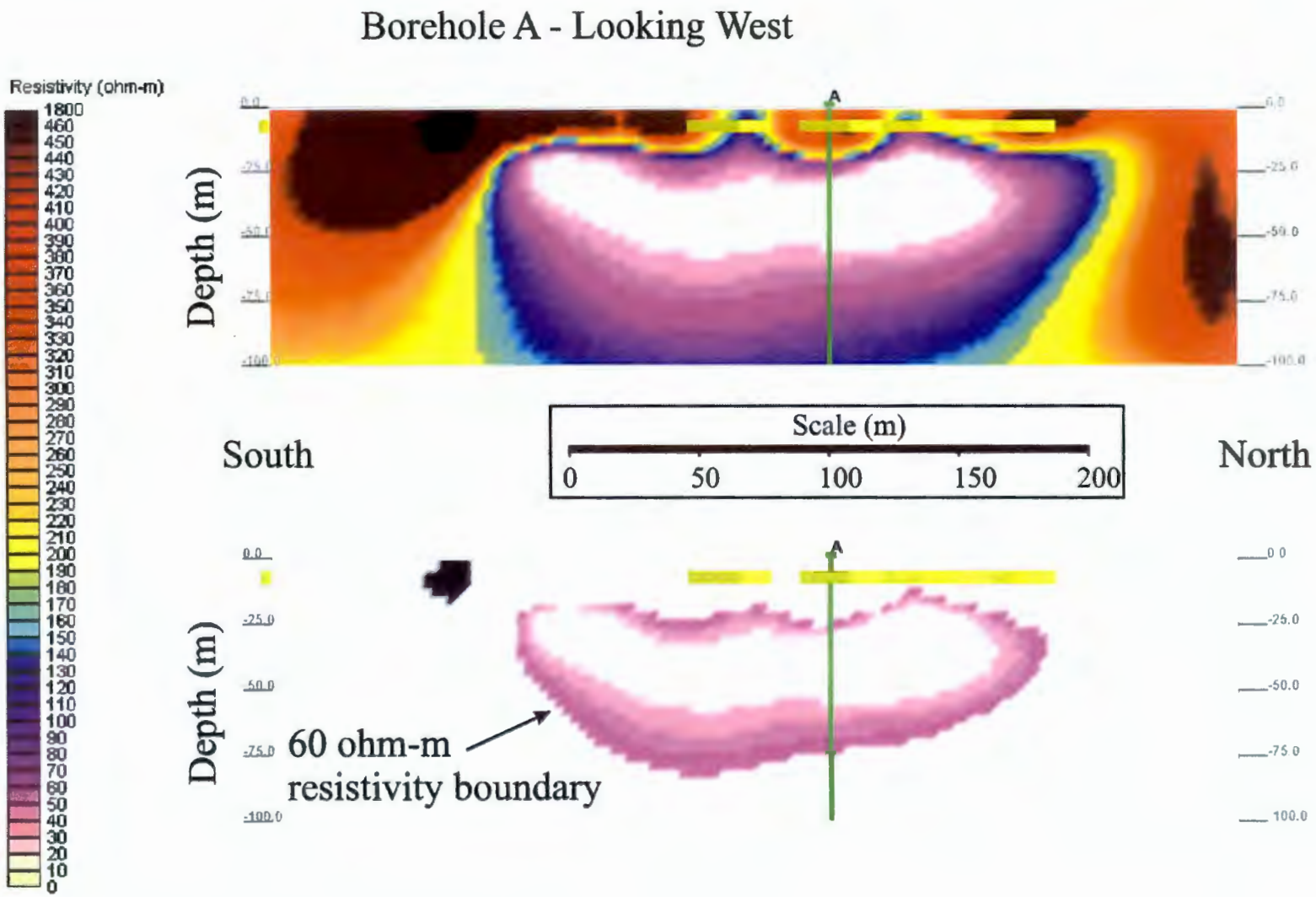


Figure 1-5. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole A in BC Cribs and Trenches Area.

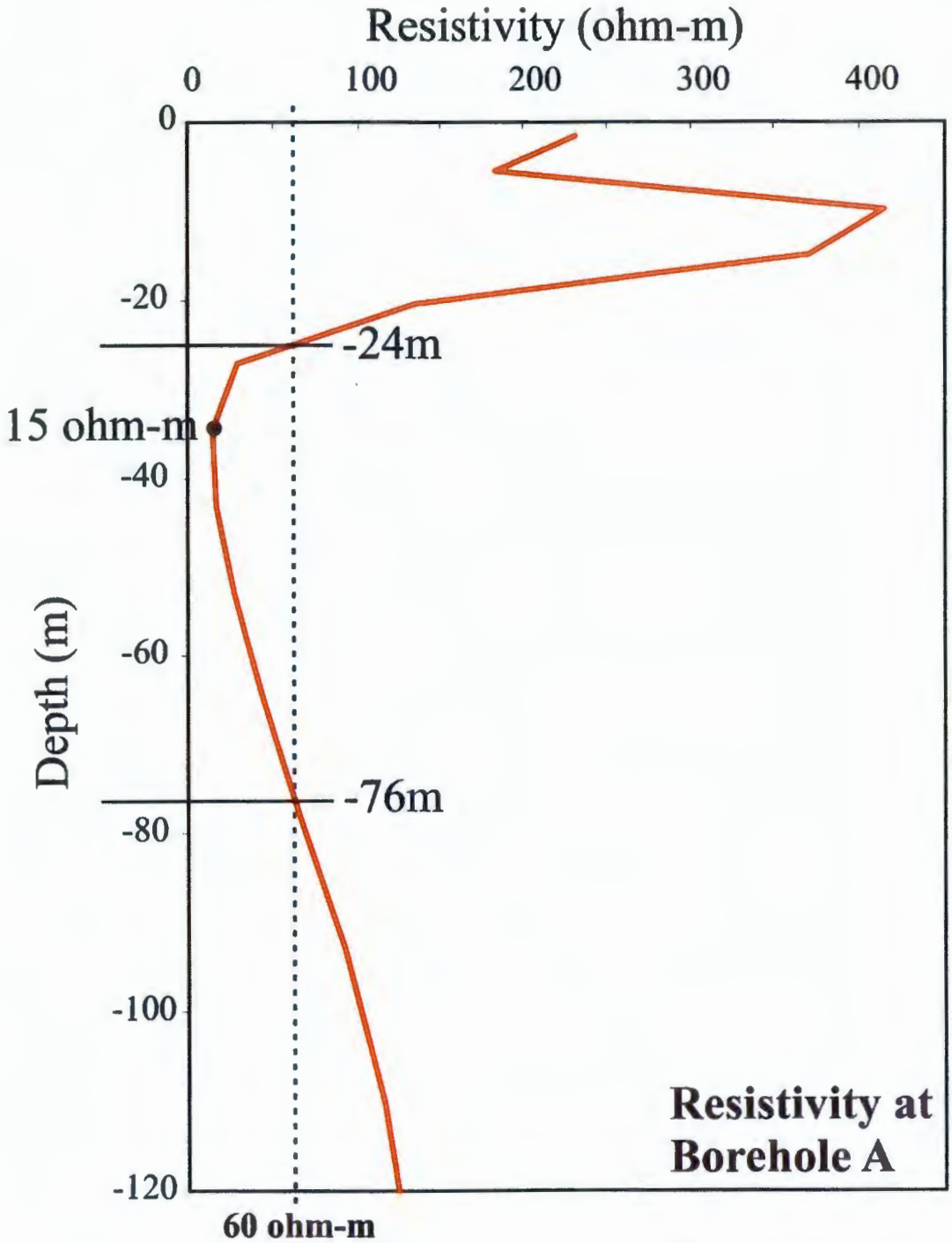


Figure 1-6. Three-Dimensional Inverted Electrical Resistivity Map for Borehole B in BC Cribs and Trenches Area.

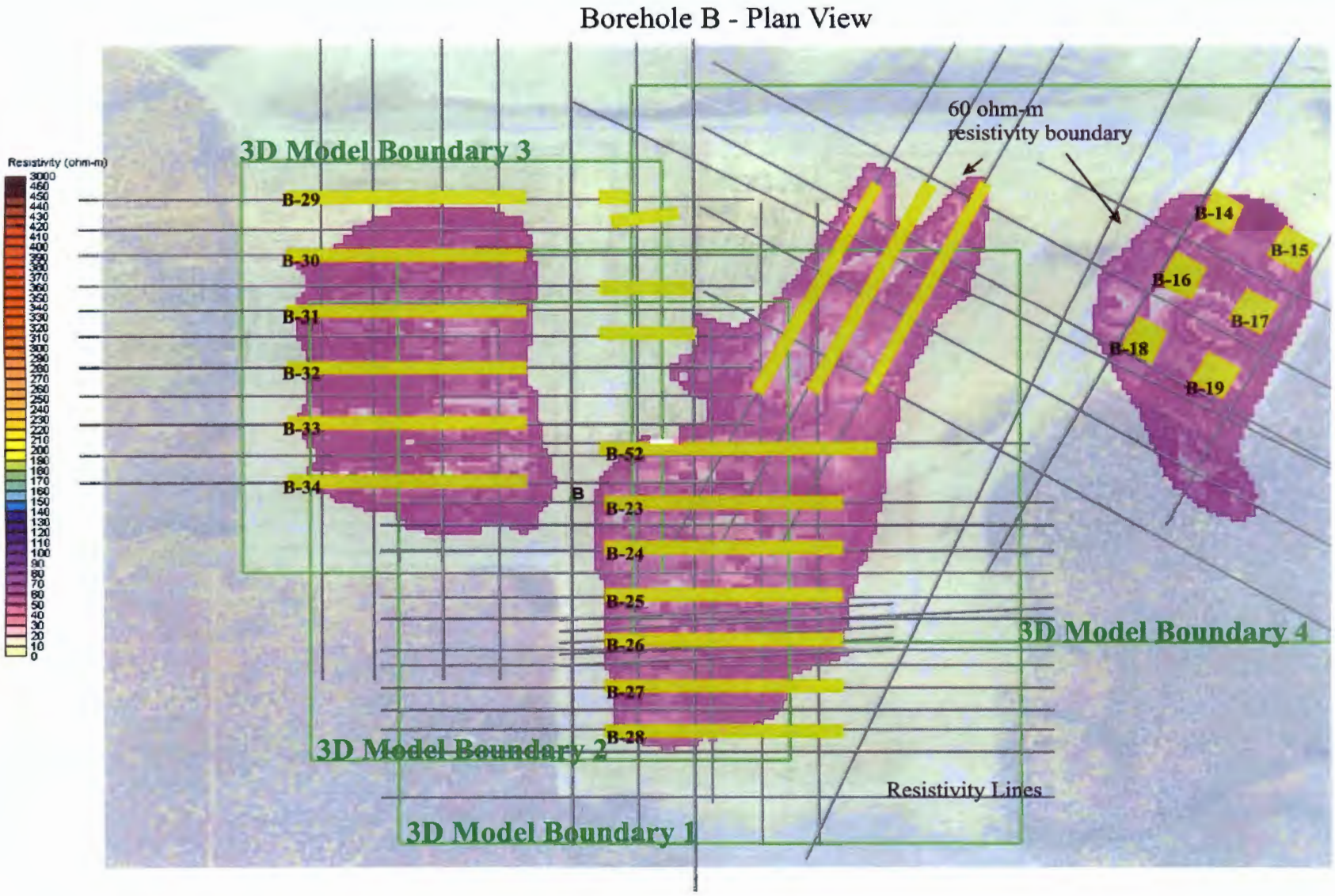


Figure 1-7. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole B in BC Cribs and Trenches Area.

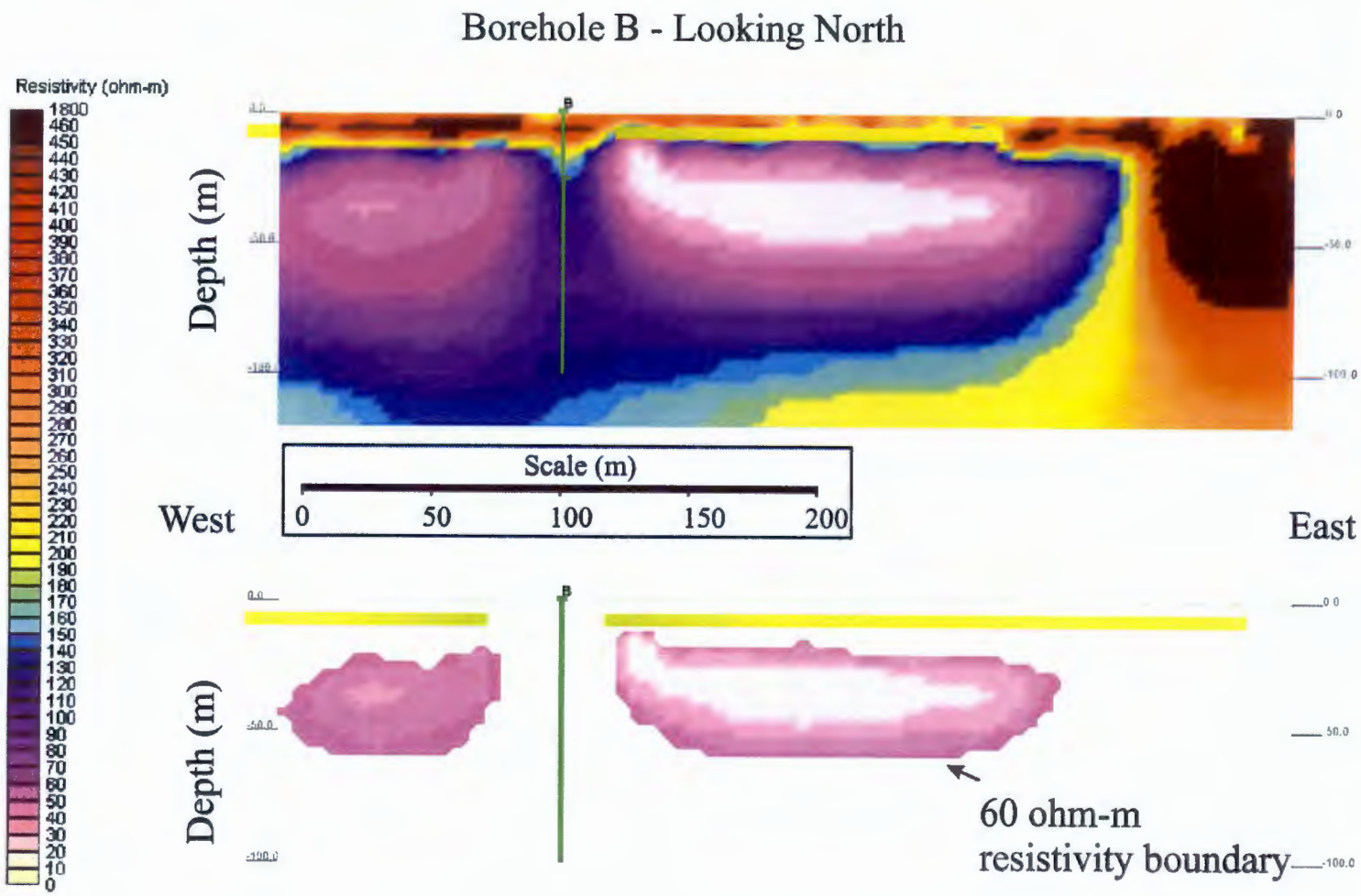


Figure 1-8. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking East) for Borehole B in BC Cribs and Trenches Area.

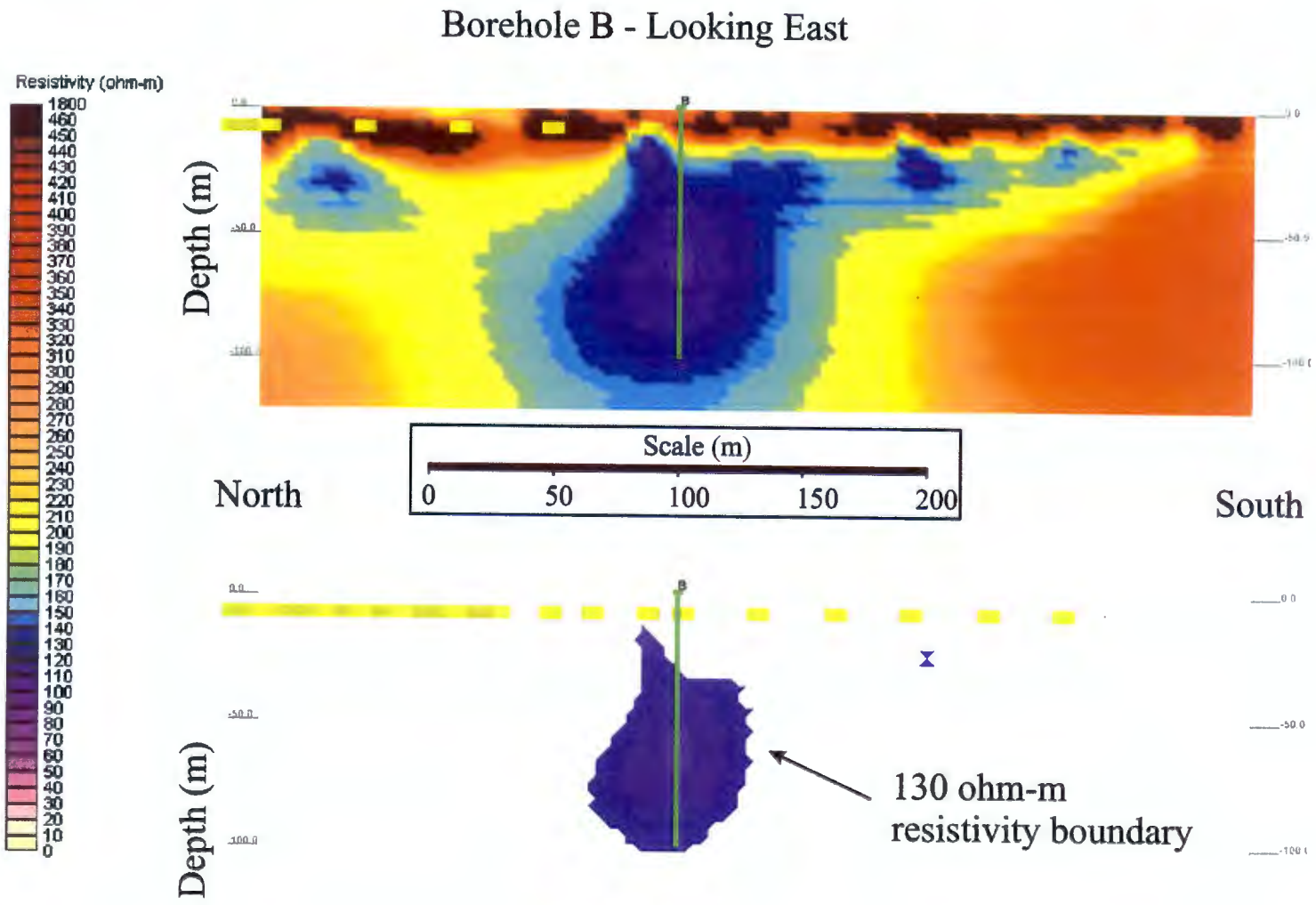


Figure 1-9. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole B in BC Cribs and Trenches Area.

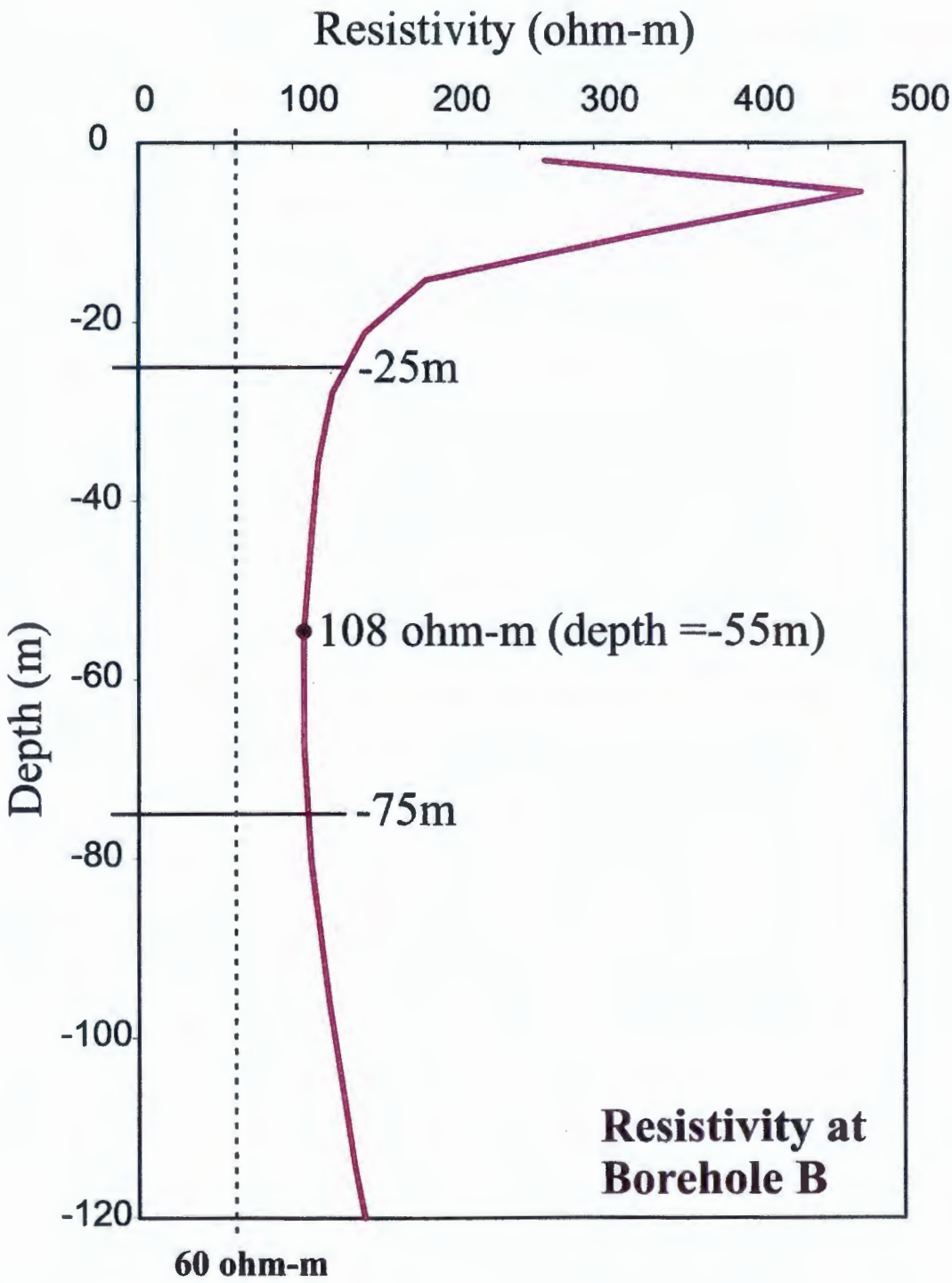


Figure 1-10. Three-Dimensional Inverted Electrical Resistivity Map for Borehole C in BC Cribs and Trenches Area.

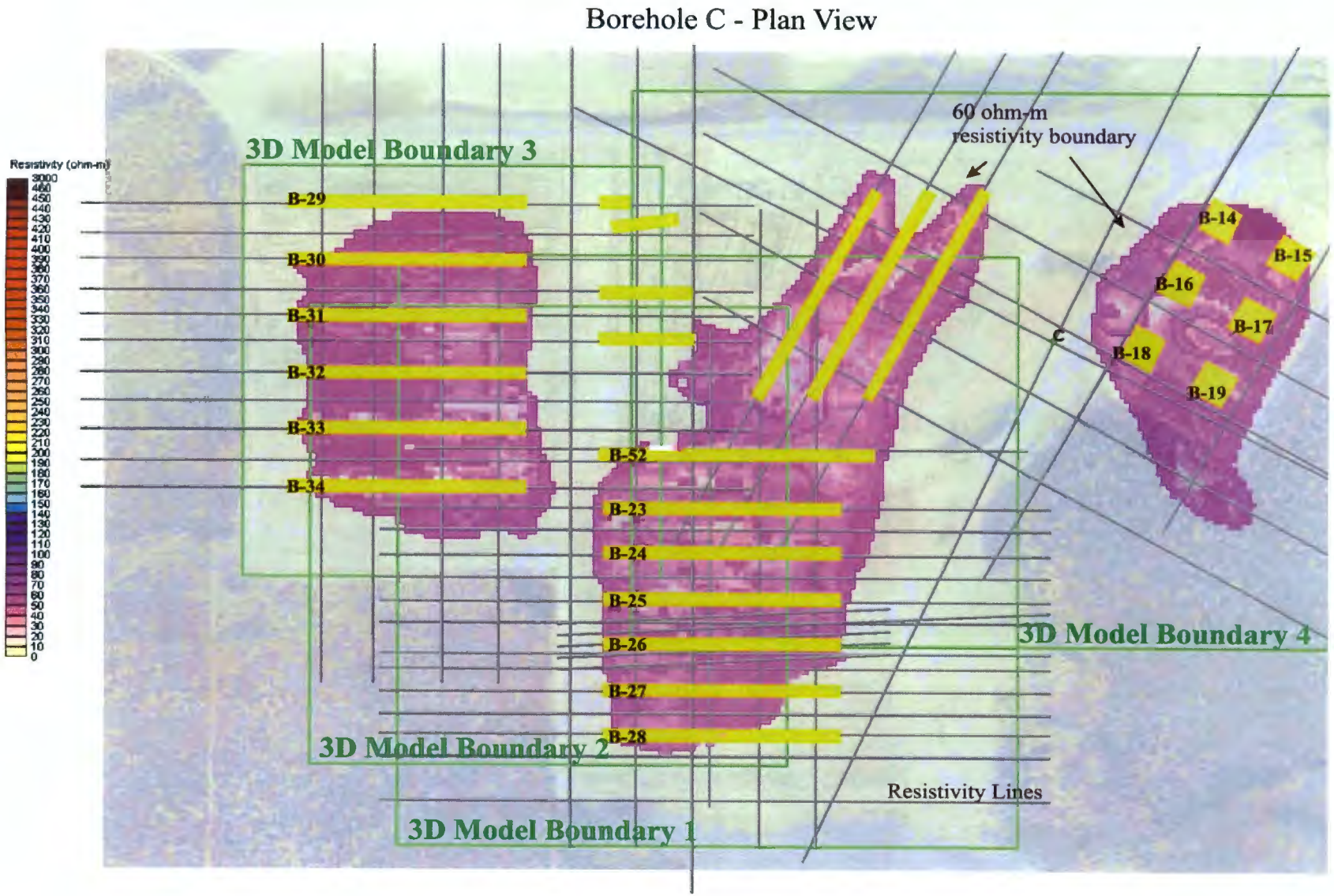


Figure 1-11. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole C in BC Cribs and Trenches Area.

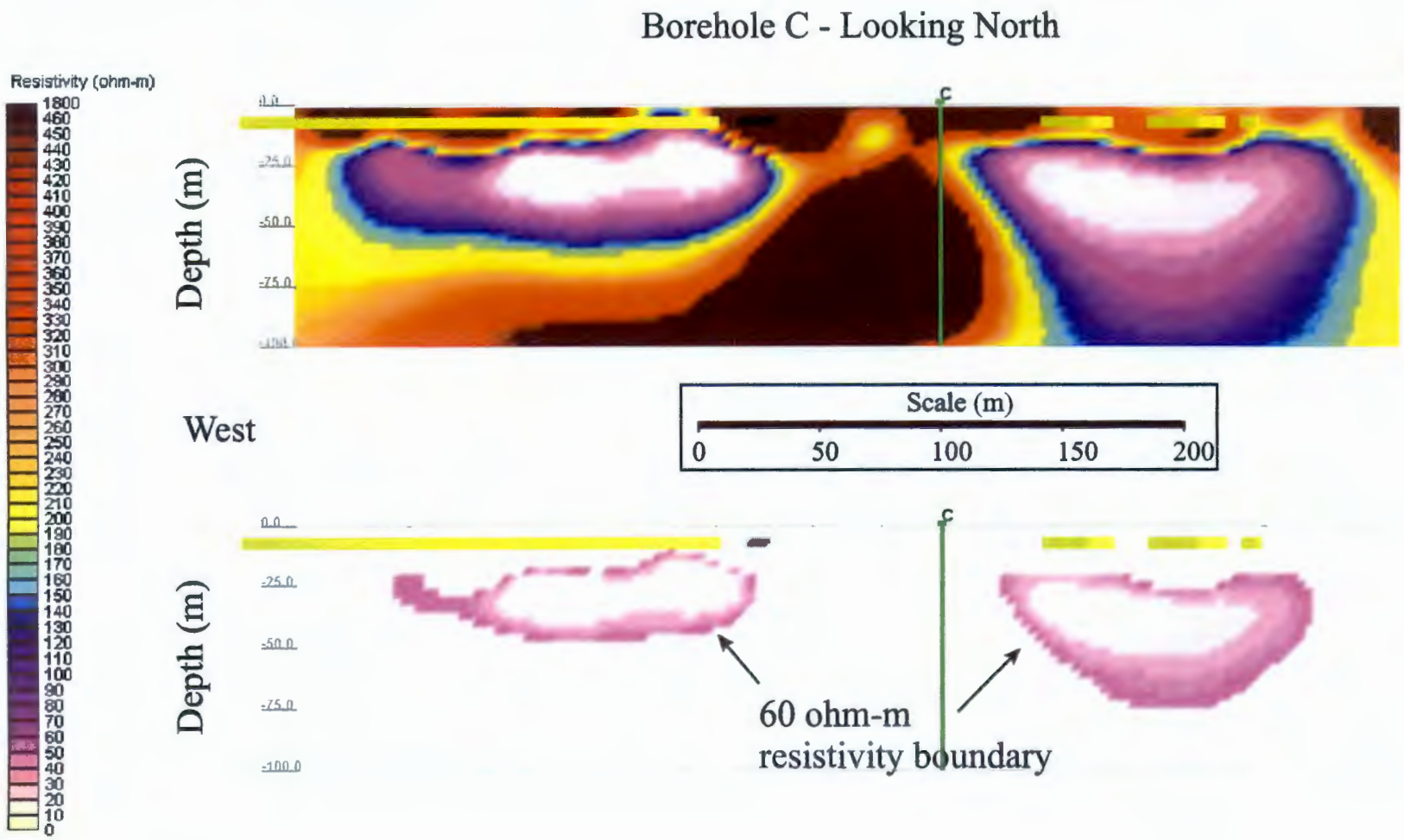


Figure 1-12. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking West) for Borehole C in BC Cribs and Trenches Area.

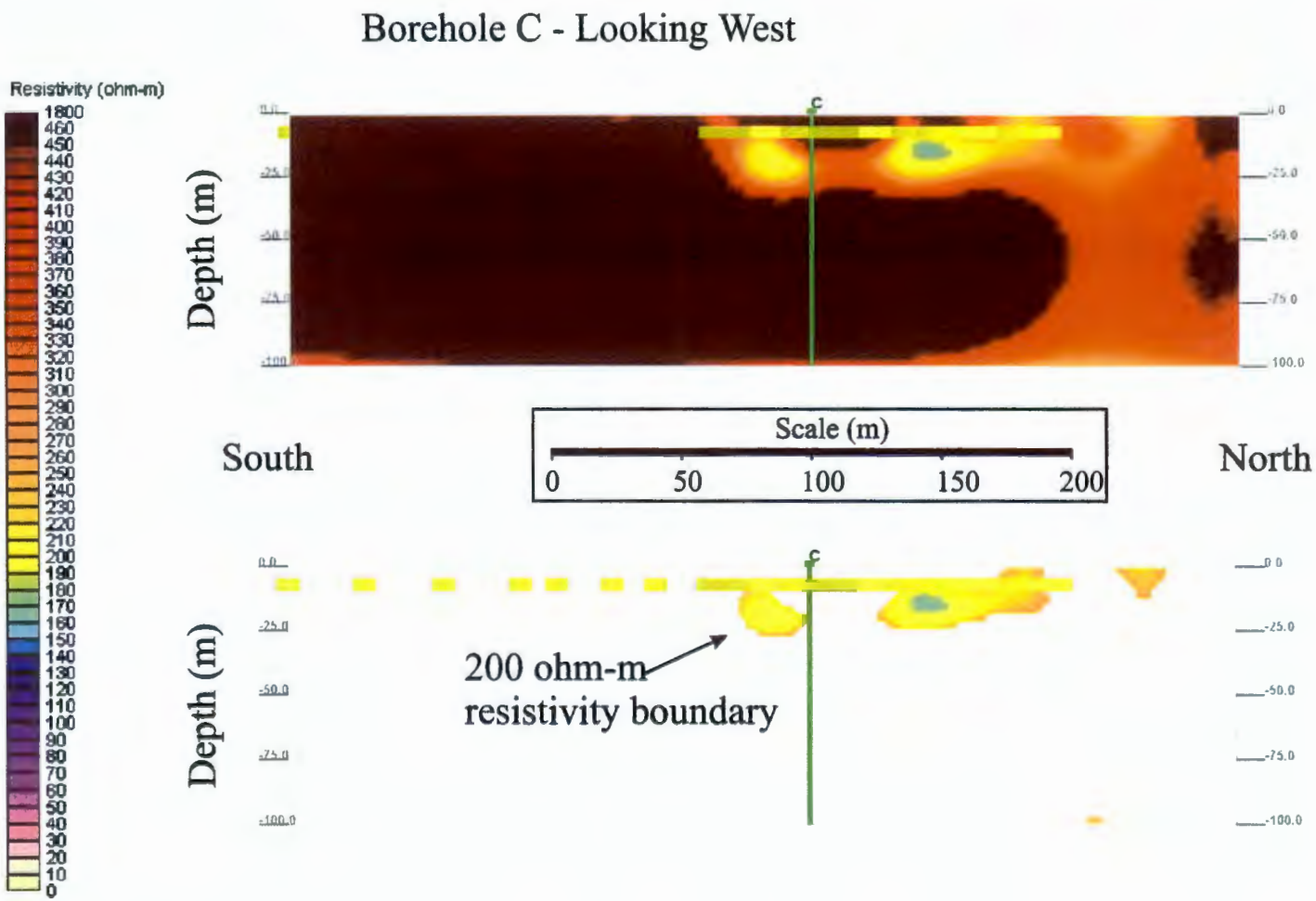


Figure 1-13. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole C in BC Cribs and Trenches Area.

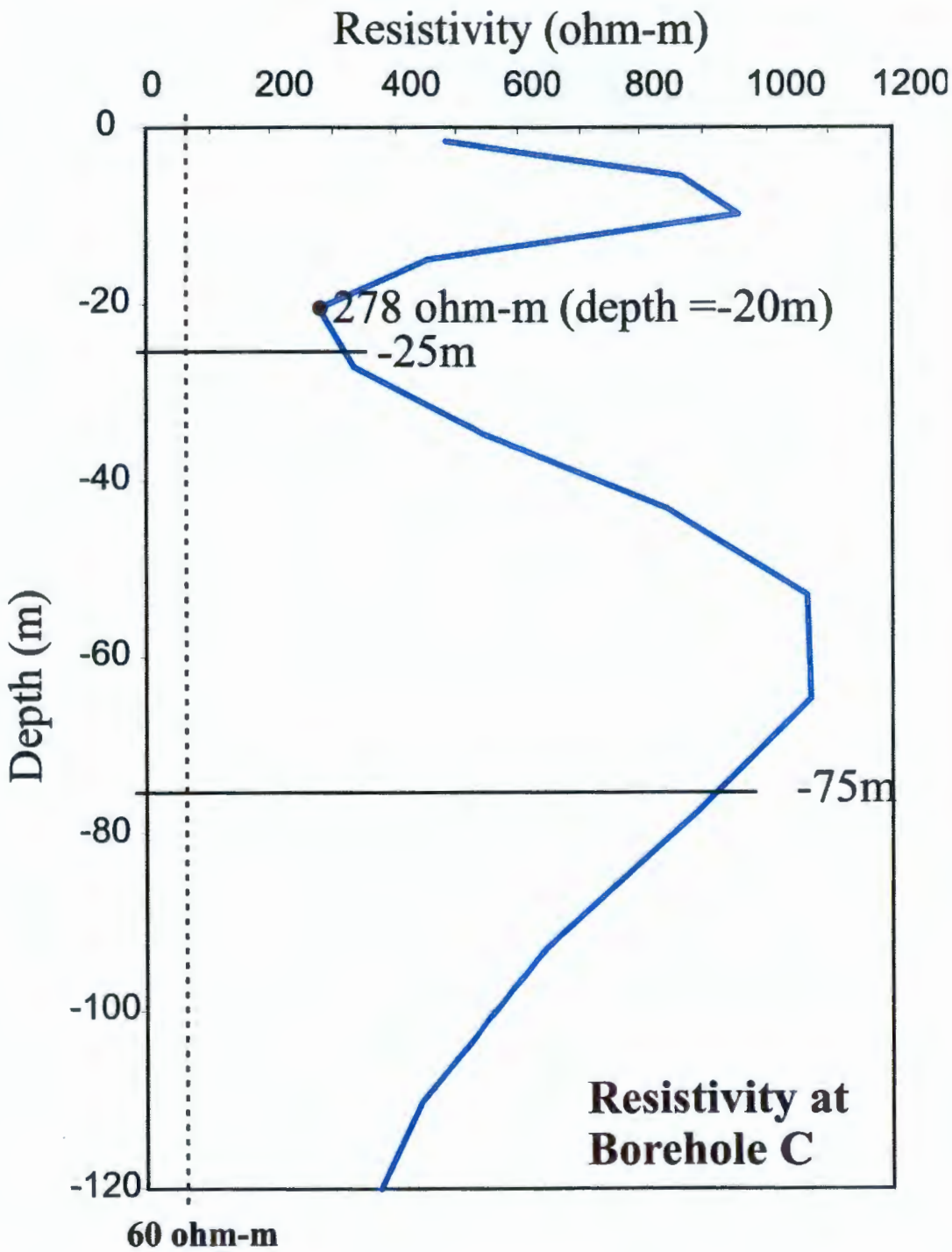


Figure 1-14. Three-Dimensional Inverted Electrical Resistivity Map for Borehole D in BC Cribs and Trenches Area.

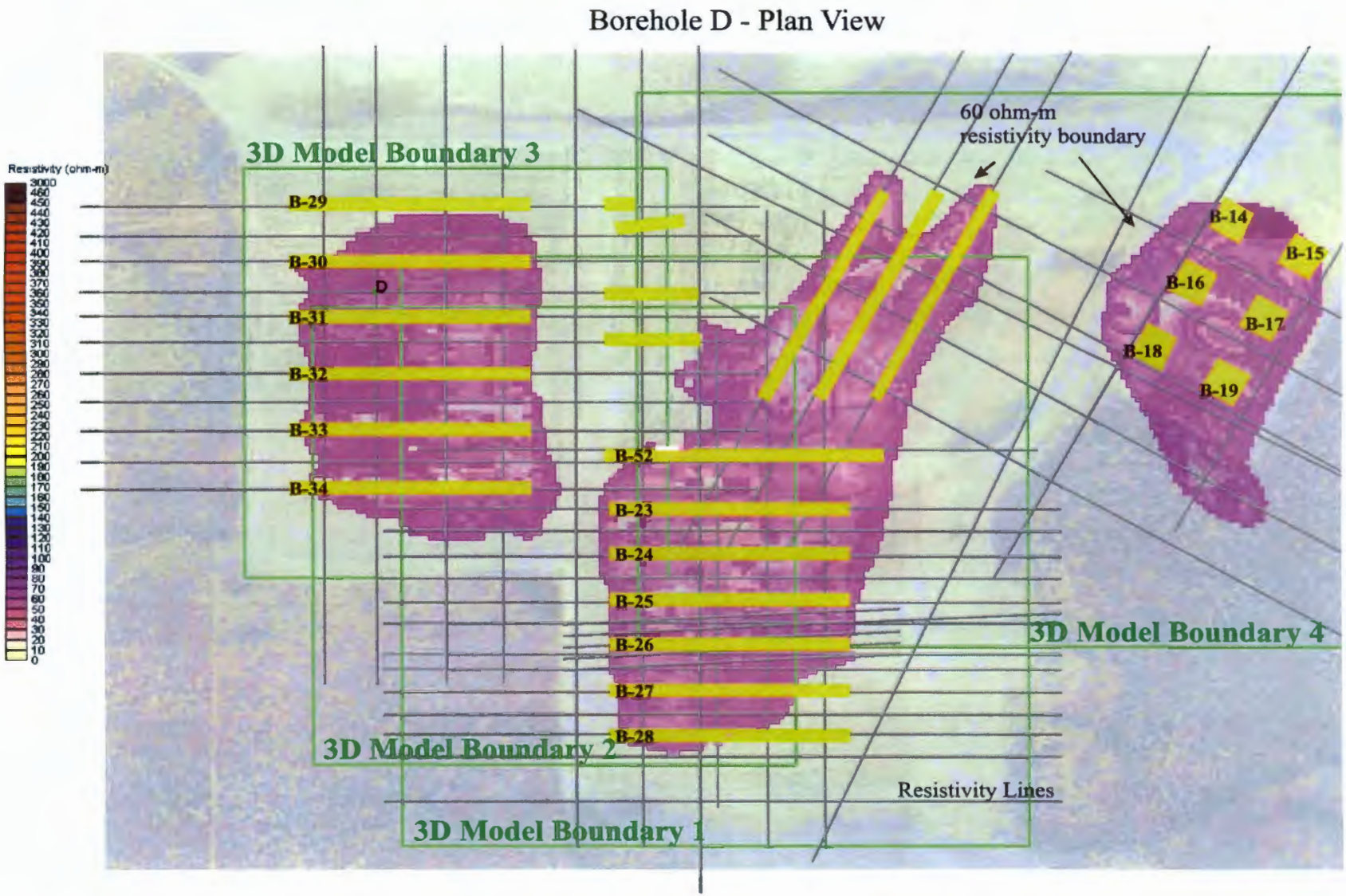


Figure 1-15. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole D in BC Cribs and Trenches Area.

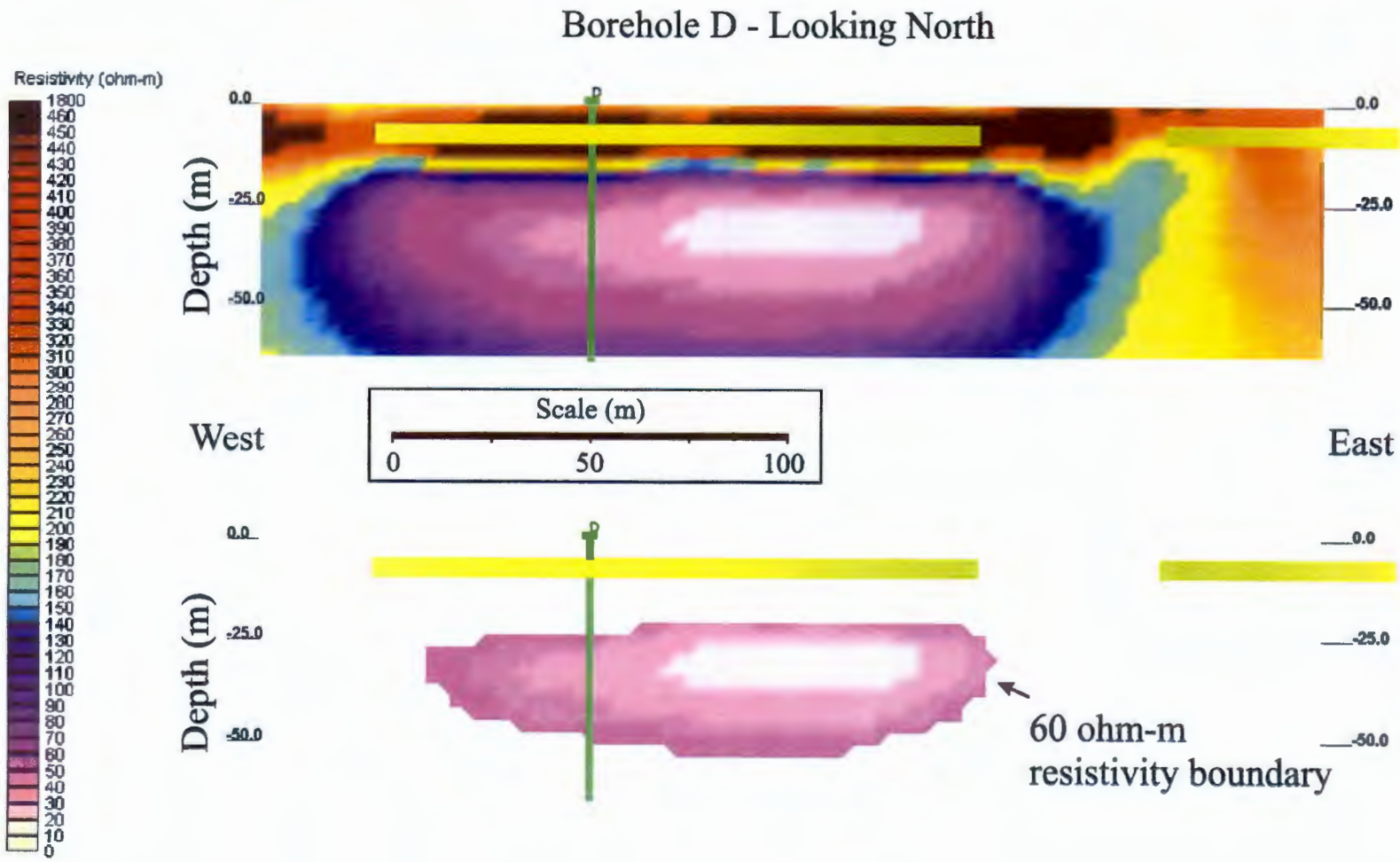


Figure 1-16. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking East) for Borehole D in BC Cribs and Trenches Area.

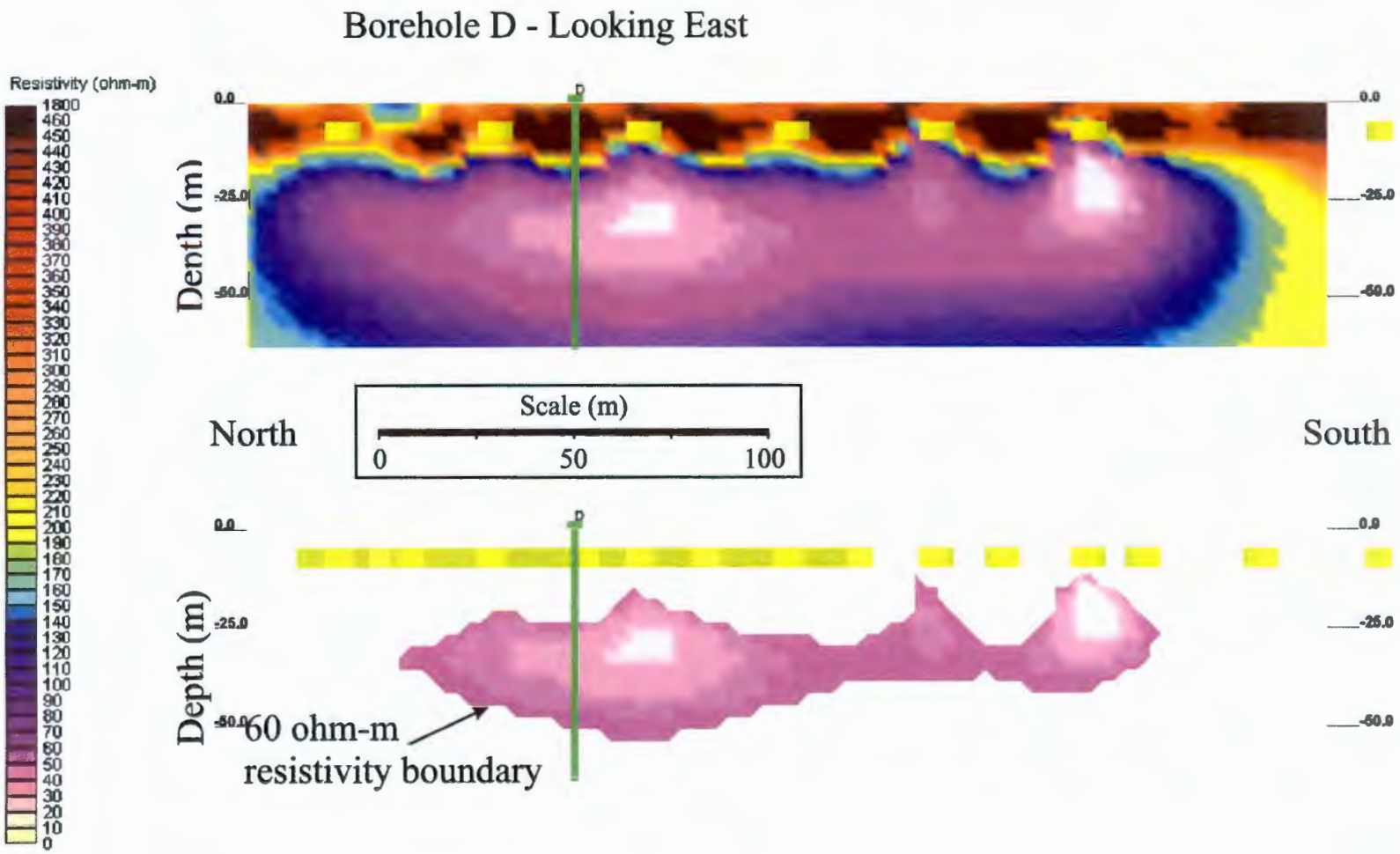


Figure 1-17. Three-Dimensional Inverted Electrical Resistivity Plot for Borehole D in BC Cribs and Trenches Area.

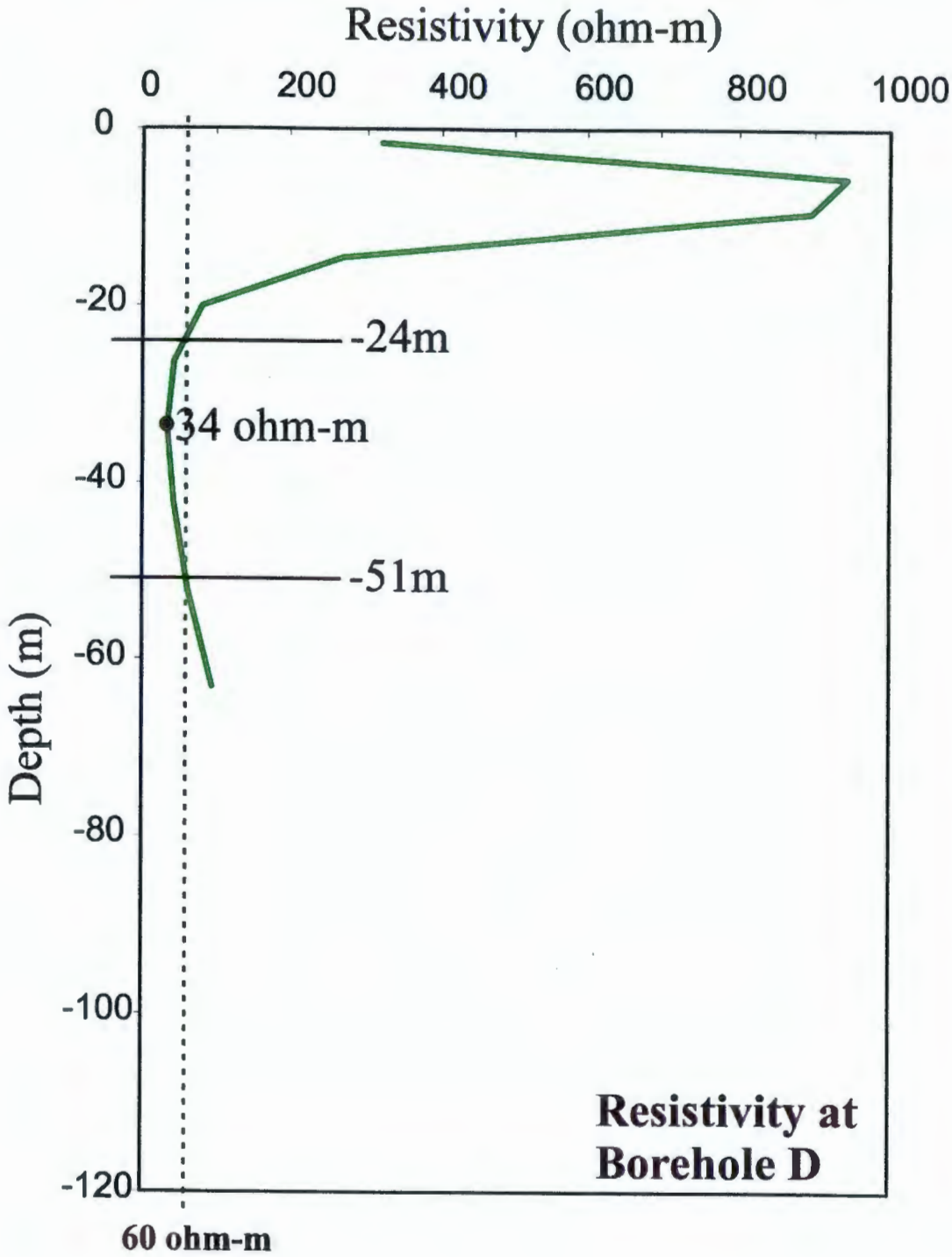


Figure 1-18. Three-Dimensional Inverted Electrical Resistivity Map for Borehole E in BC Cribs and Trenches Area.

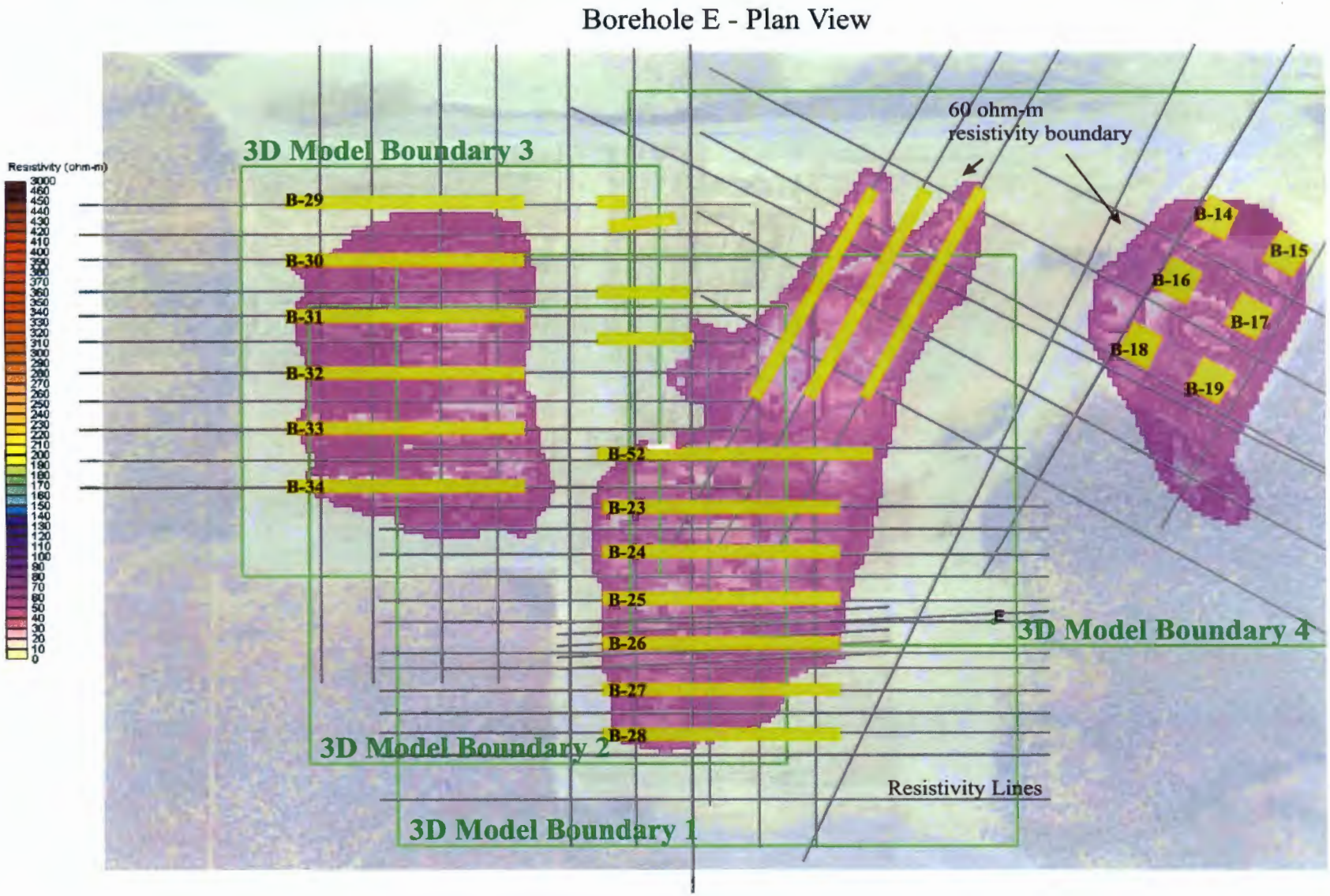


Figure 1-19. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking North) for Borehole E in BC Cribs and Trenches Area.

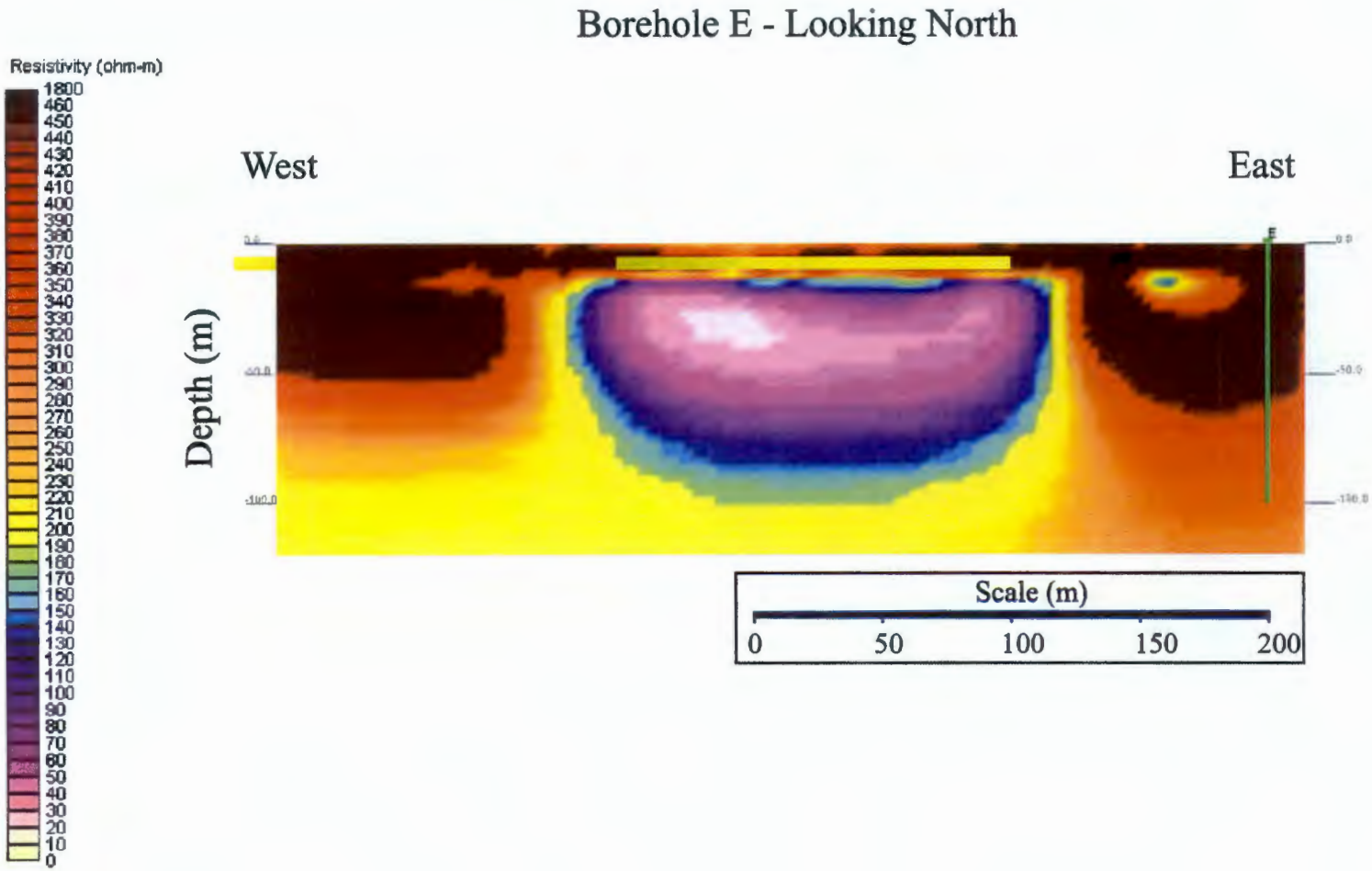
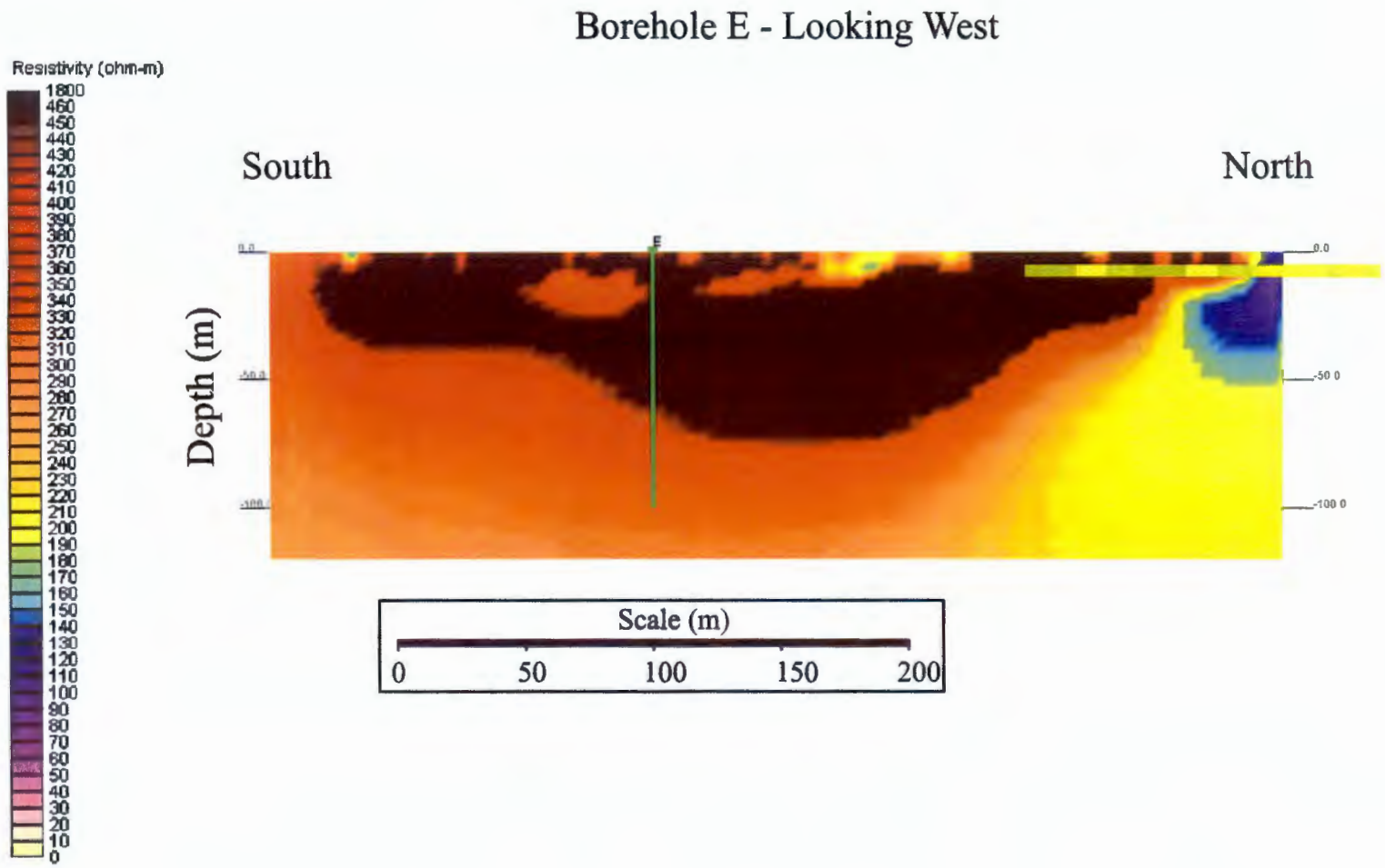


Figure 1-20. Three-Dimensional Inverted Electrical Resistivity Vertical Profile (Looking West) for Borehole E in BC Cribs and Trenches Area.



The 3-D inversion models identified regions of low electrical resistivity in the vadose zone that are the basis for selecting the five borehole locations (Boreholes A through E). The electrical resistivity geophysical method is described in Appendix A. Each borehole location is intended to test electrical resistivity data interpretations under differing conditions, such as the lateral edges and deeper extent of low electrical resistivity zones. Professional judgment was applied to the 3-D inverted data to select the number and locations of the boreholes.

Soil/sediment sampling is planned at closely spaced depth intervals in each borehole. Analytical data from the borehole soil/sediment samples will be compared to existing corresponding (i.e., co-located) electrical resistivity data to address the principal study questions identified in the DQO (SGW-32480), and the decision statements and decision rules in Table 1-1. The planned analyses of the soil/sediment samples are described in Chapter 3.0 of this SAP. Samples that are not analyzed will be stored for future use.

1.3 SUMMARY OF DATA QUALITY OBJECTIVES (SAMPLING DESIGN)

This section presents a summary of data required to evaluate the electrical resistivity geophysical method and to address the decision statements as presented in the DQO (SGW-32480). The data will be obtained by analyzing vadose-zone soil/sediment samples from five proposed boreholes to be drilled in the BC Cribs and Trenches Area during calendar year 2007. Selected soil/sediment samples from each borehole will be analyzed for the parameters that are required to evaluate the electrical resistivity data. The required soil/sediment-sample analytical results will be compared to existing co-located electrical resistivity data to address the decision rules in Table 1-1. The soil/sediment-sample analyses for electrical resistivity evaluation and the reasons for the analyses are summarized in Table 1-2. A detailed sampling design is presented in Chapter 3.0 of this SAP.

Additional analyses may be applied to selected soil/sediment samples to acquire data for purposes other than electrical resistivity evaluation, such as refinement and updating of the vadose-zone CSM. This SAP primarily addresses the sampling and analytical requirements for evaluating electrical resistivity data. Table 1-3 summarizes additional analyses for vadose-zone characterization and CSM enhancement.

Table 1-4 presents the selected analytical methods that will meet the analytical performance requirements. The analyses identified in Table 1-4 will be completed by an analytical laboratory and will include the laboratory quality control (QC) requirements specified in Section 2.2.6 of this SAP. Table 1-5 lists the quick-turnaround laboratory methods that will be used to aid in selecting soil/sediment samples for analyses and determining the total depth of each borehole.

Figure 1-1 shows the location of the five proposed boreholes (Boreholes A through E) that are the subject of this SAP. The general stratigraphy underlying the 200 Areas of the Hanford Site is presented in Figure 1-21.

Table 1-2. Physical and Geochemical Analyses of Borehole Soil/Sediment Samples for Electrical Resistivity Evaluation in the Vadose Zone of the BC Cribs and Trenches Area. (2 Pages)

Property	Parameter	Reason for Measuring	Method	Reporting Limit	Precision Required	Accuracy Required
Physical	Borehole geophysics (neutron probe, natural gamma)	Electrical resistivity data interpretation, CSM update. Neutron probe yields soil/sediment moisture information. Natural gamma information helps determine geologic lithology.	Hanford Site-specific versions of the following methods are available from field loggers: ASTM D5753-05 (general logging guidelines), D6274-98 (gamma logging), and D6727-01 (neutron logging) [a]	N/A	N/A	N/A
	Moisture content	Electrical resistivity data interpretation, CSM update.	ASTM D2216-05	N/A	±5%	±1%
	Electrical resistivity of soil/sediments	Compare and correlate to electrical resistivity data.	Rucker, draft laboratory method [b]	N/A	±20%	±20%
	Specific electrical conductivity of soil/sediment pore water	Compare and correlate to electrical resistivity data, CSM update.	ASTM D1125-95 or SW-846, EPA Method 9050A [c]	10 µS/cm	±20%	±20%
	Ionic strength of soil/sediment pore water or dilution-corrected water extract	Compare and correlate to electrical resistivity data.	Calculate from major anion, cation, alkalinity measurements	$1x10^{-4}$ Molar	±30%	±30%
Geochemical	Major cation concentrations in soil/sediment pore water (i.e., sodium, potassium, magnesium, and calcium)	Compare and correlate to electrical resistivity data	ASTM C1111-04 or SW-846, EPA Method 6010B [c]	For calcium, magnesium: 0.25 mg/L For sodium, potassium: 2.5 mg/L	±20%	±20%
	Major anion concentrations in soil/sediment pore water (i.e., nitrate, sulfate, chloride, fluoride, and phosphate)	Compare and correlate to electrical resistivity data	Equivalent ion-chromatography methods: ASTM D4327 or SW-846, EPA Method 9056 [c]	0.1 mg/L	25%	25%
	Alkalinity of soil/sediment pore water	Compare and correlate to electrical resistivity data	Titration for alkalinity; ASTM D1067-06 for bicarbonate; may be estimated from total inorganic carbon results	10 mg/L as CO_3	20%	25%
	Targeted COPCs	Compare and correlate to electrical resistivity data	Refer to Table 1-3	Table 1-3	Table 1-3	Table 1-3

[a] Method will be defined by technical support before implementation.
[b] See SGW-32737, *Field Petrophysics Test Method*, for description of Rucker draft laboratory analytical method for apparent resistivity of soils and sediments.
[c] Method from SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update III-B.*
ASTM C1111-04, *Standard Test Method for Determining Elements in Waste Streams by Inductively Coupled Plasma-Atomic Emission Spectroscopy.*
ASTM D1067-06, *Standard Test Methods for Acidity or Alkalinity of Water.*
ASTM D1125-95, *Standard Test Methods for Electrical Conductivity and Resistivity of Water.*
ASTM D2216-05, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.*
ASTM D4327-03, *Standard Test Method for Anions in Water by Chemically Suppressed Ion Chromography.*
ASTM D5753-05, *Standard Guide for Planning and Conducting Borehole Geophysical Logging.*

Table 1-2. Physical and Geochemical Analyses of Borehole Soil/Sediment Samples for Electrical Resistivity Evaluation in the Vadose Zone of the BC Cribs and Trenches Area. (2 Pages)

Property	Parameter	Reason for Measuring	Method	Reporting Limit	Precision Required	Accuracy Required

ASTM D6274-98, *Standard Guide for Conducting Borehole Geophysical Logging-Gamma.*
ASTM D6727-01, *Standard Guide for Conducting Borehole Geophysical Logging-Neutron.*
COPC = contaminant of potential concern.
CSM = conceptual site model.
EPA = U.S. Environmental Protection Agency.
N/A = not applicable.

Table 1-3. Additional Physical and Geochemical Analyses of Borehole Soil/Sediment Samples for Supplementing the Vadose-Zone Conceptual Site Model.

Property	Parameter	Reason for Measuring	Method	Reporting Limit	Precision Required	Accuracy Required
Physical	Hydraulic conductivity as a function of saturation [a]	CSM update	ASTM D6836-02 ASTM D2325-68	N/A	N/A	N/A
	Air permeability as a function of saturation [a]	CSM update	ASTM D4525-04	N/A	N/A	N/A
	Lithology	CSM update	Soil/sediment types and depths by ASTM D2488-06	N/A	N/A	N/A
	Particle-size distribution [a]	CSM update	ASTM D422-63	N/A	N/A	N/A
Geochemical	Cation exchange capacity [a] of soil/sediments	CSM update	Routson et al., 1973	N/A	N/A	N/A
	pH	CSM update	EPA SW-846 Method 9045[b]	0.1	+0.1 pH unit	+0.1 pH unit
	Specific surface area	CSM update	ASTM C1251-95	N/A	N/A	N/A

[a] Particle-size distribution measured after moisture content, hydraulic conductivity, and air permeability analyses.
[b] Method from SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update III-B.*
ASTM C1251-95, *Standard Guide for Determination of Specific Surface Area of Advanced Ceramic Materials by Gas Adsorption,* (Withdrawn 2000).
ASTM D422-63, *Standard Test Method for Particle-Size Analysis of Soils.*
ASTM D2325-68, *Standard Test Method for Capillary-Moisture Relationships for Coarse- and Medium-Textured Soils by Porous-Plate Apparatus.*
ASTM D2488-06, *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).*
ASTM D4525-04, *Standard Test Method for Permeability of Rocks by Flowing Air.*
ASTM D6836-02, *Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge.*
Routson et al., 1973, "A Column Cation-Exchange-Capacity Procedure for Low-Exchange Capacity Sands."
CSM = conceptual site model.
EPA = U.S. Environmental Protection Agency.
N/A = not applicable.

Table 1-4. Analytical Performance Requirements. (2 Pages)

Nonradiological Analytes						
Type of Analyte	**COPCS, Anions, Cations**	**Survey or Analytical Method [a]**	**Soil/Sediment Target Quantitation Limit [b] (mg/kg)**	**Pore Water Target Quantitation Limit [b] (mg/l)**	**Precision**	**Accuracy**
COPC	Aluminum	6010-B	2.5	0.05	±30%	70-130 %
	Manganese	6010-B	0.7	0.015	±30%	70-130 %
	Mercury	6020-B	2	0.05	±30%	70-130 %
	Selenium [c]	6010-B, 6020, or EPA Method 200.8 [d]	1.0	0.01	±30%	70-130 %
Cations [e]	Calcium	6010-B, 6020, or EPA Method 200.8 [d]	100.0	1.0	±30%	70-130 %
	Potassium	6010-B, 6020, or EPA Method 200.8 [d]	625	2.5	±30%	70-130 %
	Magnesium	6010-B, 6020, or EPA Method 200.8 [d]	75.0	0.005	±30%	70-130 %
	Sodium	6010-B, 6020, or EPA Method 200.8 [d]	250	1	±30%	70-130 %
Anions [e]	Chloride	EPA Method 300.0 [f]	2.0	0.4	±30%	70-130 %
	Fluoride	EPA Method 300.0 [f]	5.0	0.2	±30%	70-130 %
	Nitrite	EPA Method 300.0 [f]	2.5	0.6	±30%	70-130 %
	Nitrate	EPA Method 300.0 [f]	2.5	0.7	±30%	70-130 %
	Phosphate	EPA Method 300.0 [f]	1.1	1.1	±30%	70-130 %
	Sulfate	EPA Method 300.0 [f]	5.0	1.05	±30%	70-130 %
Radiological Contaminants of Potential Concern						
Type of Risk-Based COPC	**Isotope**	**Analytical Method [g]**	**Soil/Sediment Target Quantitation Limit [b] (ρCi/g, except as noted)**	**Pore Water Target Quantitation Limit [b] (pCi/L)**	**Precision**	**Accuracy**
Alpha	Plutonium-239/240 [c]	ICP/MS by 6020	400	8000 [h]	±35%	65-135 %
	Uranium (total)	Kinetic phosphorescence or ICP/MS by 6020 or EPA Method 200.8 [d]	0.005 mg/kg	0.1 µg/L	±35%	65-135 %
Beta	Nickel-63	Wet chemical separation and LSC	30	500	±35%	65-135 %
	Radium-226	Gamma energy analysis	2	1000	±35%	65-135 %
	Strontium-90	Wet chemical separation and LSC	1.5	150 [g]	±35%	65-135 %

Table 1-4. Analytical Performance Requirements. (2 Pages)

	Technetium-99	ICP/MS 6020, EPA Method 200.8, [d] or wet chemical separation and LSC	40 for ICP/MS 1.0 for LSC	17 for ICP/MS[g]	±35%	65-135 %
Gamma	Cesium-137 [c]	Gamma energy analysis	0.1	30 [g]	±35%	65-135 %
	Cobalt-60	Gamma energy analysis	0.05	50 [g]	±35%	65-135 %

[a]Analytical method selection is based on available methods by laboratories currently contracted to the Hanford Site. Four-digit methods are from SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update III-B.*

[b]Typical Target Quantitation Limits are based on current Hanford Site laboratory contracts or are adjusted based on the project requirements.

[c]Cesium-137, plutonium-239/240, and selenium are considered immobile, but are included as analytes, because they were risk-based COPCs in DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites.*

[d]EPA/600/R-94/111, *Methods for the Determination of Metals in Environmental Samples, Supplement 1.*

[e]Soil/sediment anion analyses performed on 1:1 solid to water leach, followed by EPA Method 300.0 ion chromatograph analysis (EPA/600/R-93/100, *Methods for the Determination of Inorganic Substances in Environmental Samples*). Soil/sediment cation analyses performed after concentrated hot-acid extract (SW-846, EPA Method 3050b) or total microwave digestion.

[f]EPA/600/R-93/100.

[g]Specific methods vary depending on laboratory.

[h]Based on assumption that vadose-zone pore-water volume is less than 10 mL.

COPC = contaminant of potential concern.
EPA = U.S. Environmental Protection Agency.
ICP/MS = inductively coupled plasma/mass spectrometer.
LSC = liquid scintillation counter.
MDC = minimum detectable concentration.

Table 1-5. Quick-Turnaround Laboratory Analytical Methods.

Parameter	Matrix	Laboratory Method
Moisture content	Soil/sediment	ASTM D2216-05 [a]
Electrical resistivity	Soil/sediment	Rucker [b]
Technetium-99	Soil/sediment	ICP/MS 6020, EPA Method 200.8, or wet chemical separation with LSC
Nitrate	Soil/sediment	EPA Method 300.0
pH	Soil/sediment	SW-846, EPA Method 9045 [c]
Other analytes	Soil/sediment	Refer to Table 1-4

[a]ASTM D2216-05, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass.*

[b]Draft laboratory method described in SGW-32737, *Field Petrophysics Test Method.*

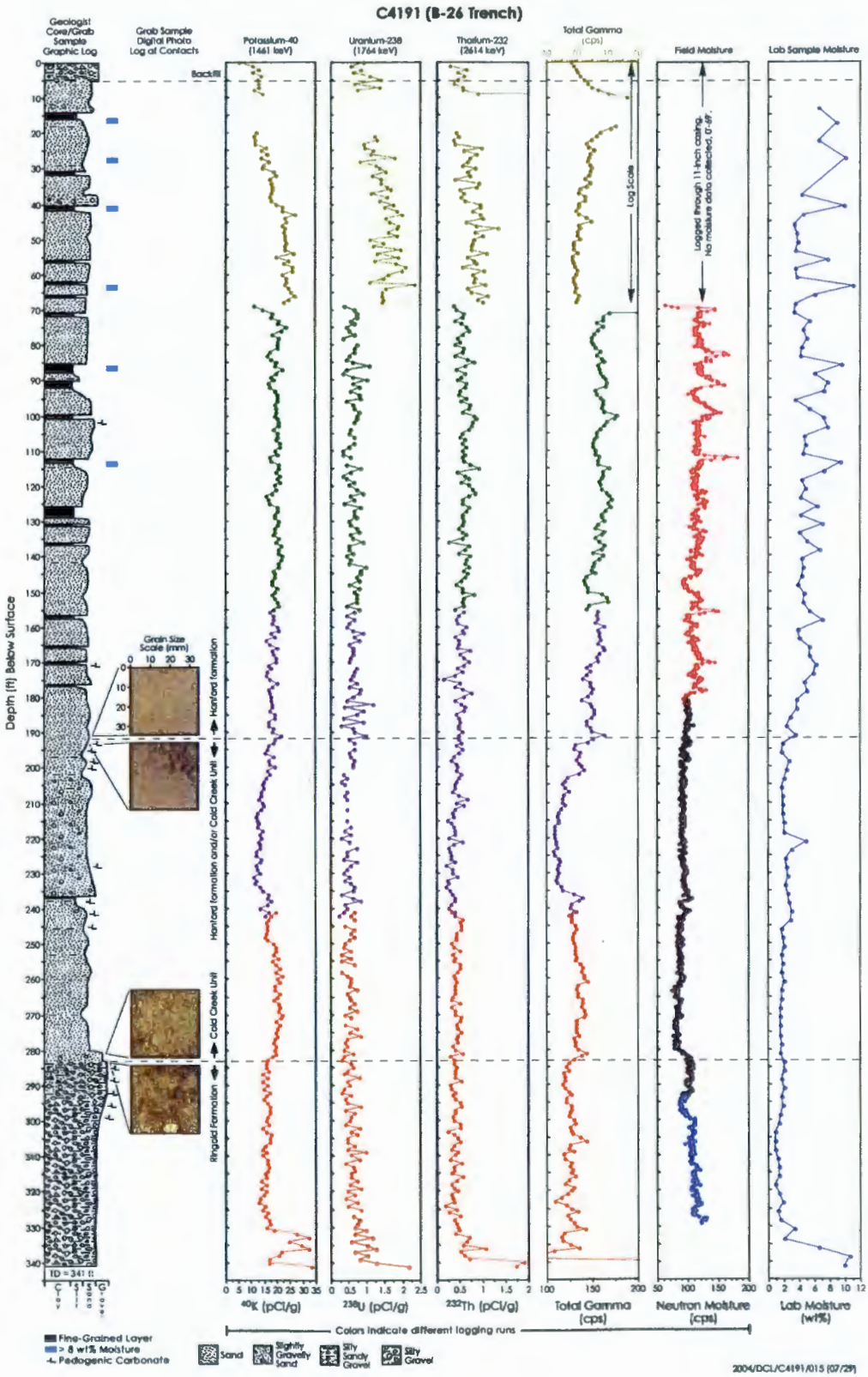
[c]SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update III-B.*

For EPA Method 300.0, see EPA/600/R-93/100, *Methods for the Determination of Inorganic Substances in Environmental Samples.*

For EPA Method 200.8, see EPA/600/R-94/111, *Methods for the Determination of Metals in Environmental Samples, Supplement* 1.

EPA = U.S. Environmental Protection Agency.
ICP/MS = inductively coupled plasma/mass spectrometer.
LSC = liquid scintillation counter.

Figure 1-21. Generalized Stratigraphy of the BC Cribs and Trenches Area.



1.4 TARGETED PARAMETERS

The targeted parameters for evaluating electrical resistivity as a vadose-zone characterization tool include risk-based and other COPCs, anions and cations, and geochemical and physical soil/sediment properties. Nonradionuclide and radionuclide lists of COPCs for the BC Cribs and Trenches Area are shown in Tables 3-1 and 3-2, respectively, of DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*. Additional COPCS are included in DOE/RL-2004-66 in Figures 2-4, 2-10a, 2-10b, and 2-11.

The risk-based COPCs in Tables 3-1 and 3-2 of DOE/RL-2004-66 (i.e., nitrate, selenium, uranium, Cs-137, Co-60, Pu-239/240, Sr-90, and Tc-99) were retained as targeted parameters. The remaining COPCs in Tables 3-1 and 3-2 and Figures 2-4, 2-10a, 2-10b, and 2-11 of DOE/RL-2004-66 were screened for those that are either detectable by electrical resistivity surveys or associated with analytes that are detectable by electrical resistivity (i.e., COPCs with a low partition coefficient). The resulting COPCs then were screened for those that are found in the BC Cribs and Trenches Area at relatively high concentrations or activity levels, and are thereby capable of significantly contributing to the measured electrical resistivity signal. The screening information and rationale for including or excluding each COPC as a targeted parameter are shown in Table 1-6.

Table 1-7 summarizes the final set of targeted parameters for analyses of borehole soil/sediment samples to evaluate the electrical resistivity geophysical method. The targeted parameters are identified in the DQO (SGW-32480). The reason for measuring each targeted parameter for electrical resistivity evaluation is included in Table 1-2. Additional analyses for further characterization of the vadose zone are shown in Table 1-3. Further explanation of the electrical resistivity evaluation and vadose-zone characterization parameters is provided in Section 3.2.2 of this SAP.

Table 1-6. Contaminants of Potential Concern Screened as Possible Targeted Parameters. (4 Pages)

Analytes	Representative Waste Sites[a]			FFS Tables 3-1 & 3-2	K_d[b]	Detectable by Electrical Resistivity[c]	Concentration/ Activity Level[d]	Inclusion or Exclusion Rationale
	216-B-26	216-B-46	216-B-58					
Acetone	--	--	Yes	Yes	--	No	low	no ionic strength
Aluminum	Yes	Yes	--	Yes	--	Yes	high	high concentration
Americium-241	Yes	--	Yes	Yes	500	No	--	high K_d
Antimony	--	Yes	--	Yes	--	Yes	low	low concentration; not detected at site in BC Cribs and Trenches Area
Aroclor-1254	--	--	Yes	Yes	--	No	low	no ionic strength
Barium	--	Yes	Yes	Yes	--	Yes	low	low concentration
Benzoic Acid	--	Yes	--	Yes	--	No	low	no ionic strength
bis(2-ethylhexyl)phthalate	--	Yes	--	Yes	--	No	low	no ionic strength
Bismuth	Yes	--	Yes	--	--	Yes	low	low concentration
2-Butanone	--	--	--	Yes	--	No	low	no ionic strength
Butylbenzylphthalate	--	--	--	Yes	--	No	low	no ionic strength
Cadmium	--	Yes	--	Yes	--	Yes	low	low concentration; not detected at site in BC Cribs and Trenches Area
Calcium	Yes	Yes	--	--	--	Yes, cation	--	detectable cation
Cesium-137	Yes	Yes	Yes	Yes	2000	No	high	risk-based COPC
Chloride	Yes	--	Yes	--	--	Yes, anion	--	detectable anion
Chromium	Yes	Yes	Yes	Yes	--	Yes	low	low concentration
Cobalt-60	Yes	Yes	Yes	Yes	50	Yes	--	risk-based COPC; low K_d
Copper	Yes	Yes	Yes	Yes	--	Yes	low	low concentration
Cyanide	Yes	Yes	Yes	Yes	--	Yes	low	low concentration
Di-n-butylphthalate	--	Yes	--	Yes	--	No	low	no ionic strength

Table 1-6. Contaminants of Potential Concern Screened as Possible Targeted Parameters. (4 Pages)

Analytes	Representative Waste Sites[a]			FFS Tables 3-1 & 3-2	K_d[b]	Detectable by Electrical Resistivity[c]	Concentration/ Activity Level[d]	Inclusion or Exclusion Rationale
	216-B-26	216-B-46	216-B-58					
Di-n-octylphthalate	--	--	--	Yes	--	No	low	no ionic strength
Dichlorodiphenyltrichloro-ethane	--	--	--	Yes	--	No	low	no ionic strength
Diethylphthalate	Yes	--	Yes	Yes	--	No	low	no ionic strength
Europium-154	--	--	Yes	--	400	unknown	low	moderate K_d, low-activity level
Europium-155	Yes	--	Yes	--	400	unknown	low	moderate K_d, low-activity level
Fluoride	Yes	--	Yes	Yes	0	Yes, anion	--	detectable anion
2-Hexanone	--	--	--	Yes	--	No	low	no ionic strength
Isophorone	--	--	--	Yes	--	No	low	no ionic strength
Lead	Yes	Yes	--	Yes	--	Yes	low	low concentration
Magnesium	Yes	Yes	--	--	--	Yes, cation	--	detectable cation
Manganese	Yes	Yes	--	Yes	--	Yes	--	detectable metal
Mercury	Yes	Yes	--	Yes	0	Yes	--	detectable metal, low K_d
Methylene chloride	--	Yes	Yes	Yes	--	No	low	no ionic strength
Neptunium-237	Yes	--	Yes	Yes	--	unknown	low	low-activity level
Nickel	Yes	Yes	Yes	Yes	--	Yes	low	low concentration
Nickel-63	Yes	--	Yes	Yes	200	Yes	moderate	low K_d
Nitrate (as nitrogen)	Yes	--	Yes	Yes	0.5	Yes, anion	high	risk-based COPC; detectable anion
Nitrite (as nitrogen)	Yes	--	Yes	Yes	--	Yes, anion	--	detectable anion
Pentachlorophenol	--	--	--	Yes	--	No	low	no ionic strength
Phenol	--	--	--	Yes	--	No	low	no ionic strength
Phosphate	Yes	--	--	--	--	Yes, anion	--	detectable anion

Table 1-6. Contaminants of Potential Concern Screened as Possible Targeted Parameters. (4 Pages)

Analytes	Representative Waste Sites[a]			FFS Tables 3-1 & 3-2	K_d[b]	Detectable by Electrical Resistivity[c]	Concentration/ Activity Level[d]	Inclusion or Exclusion Rationale
	216-B-26	216-B-46	216-B-58					
Plutonium-238	Yes	Yes	Yes	Yes	600	unknown	--	high K_d
Plutonium-239/240	Yes	Yes	Yes	Yes	600	unknown	--	risk-based COPC
Potassium	Yes	Yes	--	--	--	Yes, cation	--	detectable cation
Radium-226	Yes	Yes	Yes	Yes	20	Yes	--	moderate K_d
Radium-228	Yes	--	Yes	Yes	--	Yes	low	low-activity level
Selenium	--	--	Yes	Yes	0	Yes	--	risk-based COPC; low K_d value
Silver	Yes	--	--	Yes	--	Yes	low	low concentration
Sodium	Yes	Yes	--	--	--	Yes, cation	--	detectable cation
Styrene	--	--	--	Yes	--	No	low	no ionic strength
Strontium-90	Yes	Yes	Yes	Yes	50	Yes	high	risk-based COPC; moderate K_d value
Sulfate	Yes	--	Yes	Yes	--	Yes, anion	--	detectable anion
Technetium-99	Yes	Yes	--	Yes	0.5	No	--	risk-based COPC; low K_d value
Thallium	--	Yes	--	Yes	--	Yes	low	low concentration; not detected at site in BC Cribs and Trenches Area
Thorium-228	Yes	Yes	Yes	Yes	--	unknown	low	low-activity level
Thorium-232	Yes	--	Yes	Yes	--	unknown	low	low-activity level
Toluene	--	--	--	Yes	--	No	low	no ionic strength
1,1,1-Trichloroethane	--	--	--	Yes	--	No	low	no ionic strength
Tritium	Yes	Yes	Yes	Yes	0.2	No	--	non-detectable
Uranium	Yes	Yes	--	Yes	5	Yes	--	risk-based COPC; low K_d value
Uranium-233/234	Yes	--	Yes	Yes	--	Yes	--	included in total uranium analysis

Table 1-6. Contaminants of Potential Concern Screened as Possible Targeted Parameters. (4 Pages)

Analytes	Representative Waste Sites[a]			FFS Tables 3-1 & 3-2	K_d[b]	Detectable by Electrical Resistivity[c]	Concentration/ Activity Level[d]	Inclusion or Exclusion Rationale
	216-B-26	216-B-46	216-B-58					
Uranium-235	Yes	--	Yes	Yes	--	Yes	--	included in total uranium analysis
Uranium-238	Yes	--	Yes	Yes	--	Yes	--	included in total uranium analysis
Vanadium	Yes	Yes	--	Yes	--	Yes	low	low concentration
Zinc	Yes	Yes	--	Yes	--	Yes	low	low concentration

[a]COPCs detected in representative waste sites for BC Cribs and Trenches Area, as identified in Appendix C of DOE/RL-2004-66. The 216-B-46 Crib is not located in BC Cribs and Trenches Area.

[b]K_d partition coefficients obtained from PNNL-16531, *K_d Values for Agricultural and Surface Soils for use in Hanford Site Farm, Residential, and River Shoreline Scenarios*, "Best Values."

[c]Analytes that are potentially detectable by electrical resistivity geophysical method.

[d]Concentrations or activity levels found in representative waste sites, as reported in Appendix C of DOE/RL-2004-66. "Low" concentration is defined as < 200 ppm.

Aroclor is an expired trademark.

COPC = contaminant of potential concern.

FFS = focused feasibility study (DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*).

K_d = distribution coefficient.

Table 1-7. Targeted Parameters for Electrical Resistivity Evaluation.

Risk-Based COPCs [a]	Other COPCs [b]	Anions and Cations	Geochemical and Physical Properties
Nitrate (as nitrogen) [c,d]	Aluminum	Calcium	Moisture content
Selenium [e]	Manganese	Chloride	Electrical resistivity of soil/sediment
Uranium [c,d]	Mercury	Fluoride [b]	Specific electrical conductivity of pore water
Cesium-137 [c,d,e]	Nickel-63	Magnesium	Ionic strength of pore water
Cobalt-60 [e]	Nitrite	Nitrite (as nitrogen) [b]	Alkalinity (bicarbonate) of pore water
Plutonium-239/240 [d]	Radium-226	Potassium	Borehole neutron and natural gamma logs
Strontium-90 [c,d,e]	--	Phosphate	--
Technetium-99 [c,d]	--	Sodium	--
--	--	Sulfate [b]	--

[a] Risk-based COPCs that were identified in Table 3-1 of DOE/RL-2004-66.
[b] Included as an evaluated constituent in Table 3-1 of DOE/RL-2004-66. Cyanide could correlate with electrical resistivity data based on results for Borehole C4191.
[c] Applies to Trench 216-B-26 representative waste site and analogous sites as presented in DOE/RL-2004-66.
[d] Applies to the 216-B-46 Crib (representative waste site in BY Tank Farm) and analogous sites as presented in DOE/RL-2004-66.
[e] Applies to Trench 216-B-58 representative waste site and analogous sites as presented in DOE/RL-2004-66.
DOE/RL-2004-66, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*.
COPC = contaminant of potential concern.

This page intentionally left blank.

2.0 QUALITY ASSURANCE PROJECT PLAN

The QAPjP establishes the quality requirements for environmental data collection, including sampling, field measurements, and laboratory analysis. This QAPjP complies with the requirements of the following:

- DOE O 414.1C, *Quality Assurance*
- 10 CFR 830, "Nuclear Safety Management," Subpart A, "Quality Assurance Requirements"
- EPA/240/B-01/003, *EPA Requirements for Quality Assurance Project Plans*, EPA QA/R-5.

The following sections describe the quality requirements and controls applicable to this investigation.

2.1 PROJECT MANAGEMENT

This section addresses the basic areas of project management and ensures that the project has a defined goal, that the participants understand the goal and the approach to be used, and that the planned outputs have been appropriately documented.

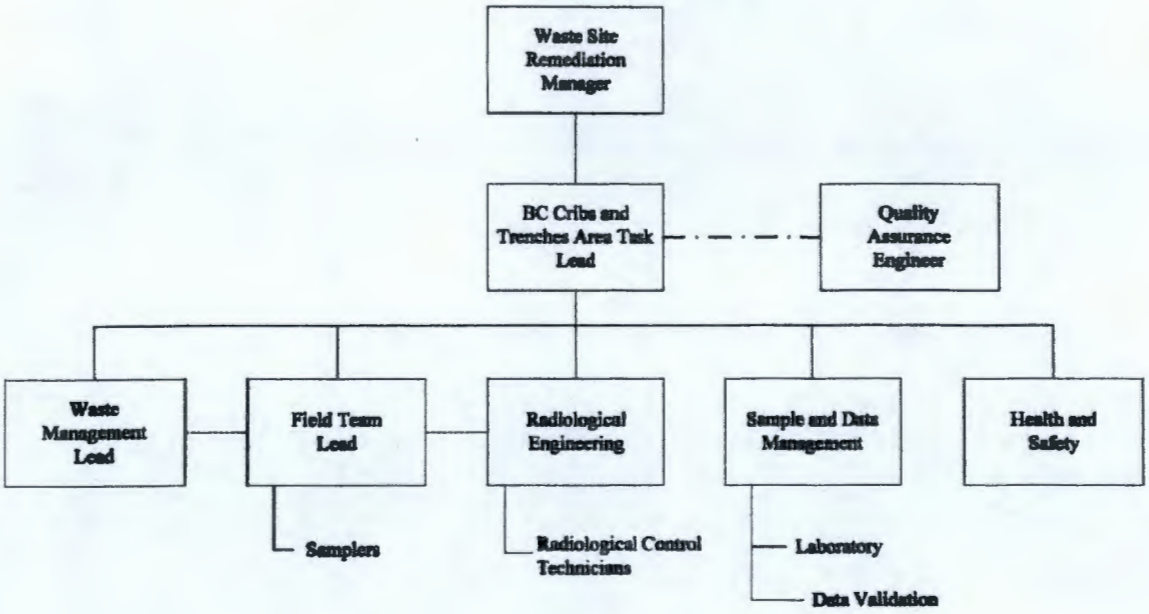
2.1.1 Project/Task Organization

Fluor Hanford, or its approved subcontractor, is responsible for collecting, packaging, and shipping samples to the laboratory. Fluor Hanford will select a laboratory to perform the analyses; the selected laboratory must conform to Hanford Site laboratory procedures (or equivalent), as approved by the DOE, Richland Operations Office (RL), and the U.S. Environmental Protection Agency (EPA). Fluor Hanford is responsible for managing all interfaces among subcontractors involved in executing the work described in this SAP. The project organization is described in the subsections that follow and is shown in Figure 2-1.

2.1.1.1 Waste Site Remediation Manager

The Waste Site Remediation Manager provides oversight for all activities and coordinates with RL, the regulators, and Fluor Hanford management in support of sampling activities. In addition, the Waste Site Remediation Manager provides support to the BC Cribs and Trenches Area Task Lead to ensure that work is performed safely and cost effectively. The Waste Site Remediation Manager maintains the approved QAPjP.

Figure 2-1. Project Organization Chart.



2.1.1.2 BC Cribs and Trenches Area Task Lead

The BC Cribs and Trenches Area Task Lead is responsible for direct management of sampling documents and requirements, field activities, and subcontracted tasks. The Task Lead ensures that the Field Team Lead, samplers, and others responsible for implementation of the SAP and QAPjP are provided with current copies of this document and any revisions thereto. The Task Lead works closely with the Quality Assurance (QA) and Health and Safety organizations and the Field Team Lead to integrate these and the other lead disciplines in planning and implementing the scope of work. The Task Lead coordinates with and reports to RL and Fluor Hanford management on all sampling activities. The Task Lead supports RL in coordinating sampling activities with the regulators.

2.1.1.3 Quality Assurance Engineer

The QA Engineer is matrixed to the BC Cribs and Trenches Area Task Lead and is responsible for QA on the project. Responsibilities include oversight of implementation of the project QA requirements; review of project documents including DQO summary reports, SAPs, and the QAPjP; and participation in QA assessments on sample collection and analysis activities, as appropriate.

2.1.1.4 Environmental Compliance Officer

The Environmental Compliance Officer also is matrixed to the BC Cribs and Trenches Area Task Lead and provides technical oversight, direction, and acceptance of project and subcontracted environmental work and develops appropriate mitigation measures with a goal of

minimizing adverse environmental impacts. The Environmental Compliance Officer also reviews plans, procedures, and technical documents to ensure that all environmental requirements have been addressed, identifies environmental issues that affect operations and develops cost-effective solutions, and responds to environmental and regulatory issues or concerns raised by the DOE and/or regulatory agency staff.

2.1.1.5 Waste Management Lead

The Waste Management Lead communicates policies and procedures and ensures project compliance for storage, transportation, disposal, and waste tracking in a safe and cost-effective manner. Other responsibilities include identifying waste management sampling/characterization requirements to ensure regulatory compliance and interpreting the characterization data to generate waste designations, profiles, and other documents that confirm compliance with waste-acceptance criteria.

2.1.1.6 Field Team Lead

The Field Team Lead has overall responsibility for the planning, coordination, and execution of field characterization activities. Specific responsibilities include converting the sampling design requirements into field task instructions that provide specific direction for field activities. Responsibilities also include directing training, mock-ups, and practice sessions with field personnel to ensure that the sampling design is understood and can be performed as specified. The Field Team Lead communicates with the BC Cribs and Trenches Area Task Lead to identify field constraints that could affect the sampling design. In addition, the Field Team Lead directs the procurement and installation of materials and equipment needed to support field work.

The Field Team Lead oversees field-sampling activities including sample collection and packaging; provision of certified clean sampling bottles/containers; documentation of sampling activities in controlled logbooks, chain-of-custody documentation, and packaging; and transportation of samples to the laboratory or shipping center.

2.1.1.7 Radiological Engineering

The Radiological Engineering organization is responsible for the radiological engineering and health physics support for the project. Specific responsibilities include conducting as low as reasonably achievable (ALARA) reviews, exposure and release modeling, and radiological controls optimization for all work planning. In addition, radiological hazards are identified and appropriate controls are implemented to maintain worker exposures to hazards at ALARA levels. Radiological Engineering interfaces with the project Health and Safety Representative and plans and directs radiological control technician support for all activities.

2.1.1.8 Sample and Data Management

The Sample and Data Management organization ensures that laboratories providing analytical services for this SAP conform to Hanford Site internal laboratory QA requirements (or their equivalent), as approved by RL, the EPA, and the Washington State Department of Ecology (Ecology). Sample and Data Management receives the analytical data from the laboratories,

performs data entry into the *Hanford Environmental Information System* (HEIS) database, and arranges for data validation.

2.1.1.9 Health and Safety

The Health and Safety organization's responsibilities include coordination of industrial safety and health support within the project as carried out through health and safety plans, job hazard analyses, and other pertinent safety documents required by Federal regulations or by internal Fluor Hanford work requirements. In addition, assistance is provided to project personnel in complying with applicable health and safety standards and requirements. Personal protective equipment requirements are coordinated with Radiological Engineering.

2.1.2 Problem Definition/Background

The definition of the problem is provided in Section 1.1.1 of this SAP.

2.1.3 Project/Task Description

Sampling and analysis activities will be performed to characterize soil/sediment samples that are collected during the drilling of five boreholes in the BC Cribs and Trenches Area (Boreholes A through E). Geophysical and geologic logs will be prepared for each borehole. The sampling and analysis activities are described in further detail in Section 3.2.2 of this SAP.

One or more of the boreholes might be completed as groundwater monitoring wells. As described in the DQO (SGW-32480), Borehole E is optional pending the results for Borehole C. If Borehole E is drilled, it currently is expected to be completed to a groundwater monitoring well.

2.1.4 Quality Objectives and Criteria

Quality objectives and criteria (including analytical methods, detection limits, and precision and accuracy requirements for each analysis to be performed) are summarized in Table 1-4.

The QA objective of this plan is to develop implementation guidance that will provide data of known and appropriate quality. Data quality is assessed by accuracy and precision, by evaluation against the identified DQOs, and by evaluation against the work activities identified in this SAP. The applicable QC guidelines, quantitative target limits, and levels of effort for assessing data quality are dictated by the intended use of the data and the nature of the analytical method, which are addressed in the following subsections.

2.1.4.1 Accuracy

Accuracy is an assessment of the closeness of the measured value to the true value. Accuracy of chemical test results is assessed by spiking samples with known standards and establishing the average recovery. A matrix spike is the addition to a sample of a known amount of a standard compound similar to the compounds being measured. Radionuclide measurements that require

chemical separations use this technique to measure method performance. For radionuclide measurements that are analyzed by gamma spectroscopy, laboratories typically compare the results of blind audit samples against known standards to establish accuracy. Validity of calibrations is evaluated by comparing results from the measurement of a standard to known values and/or by generating in-house statistical limits based on three standard deviations (i.e., 3 SD). Table 1-4 lists the accuracy requirements for fixed laboratory analyses for the project.

2.1.4.2 Precision

Precision is a measure of the data spread when more than one measurement has been taken on the same sample. Precision can be expressed as the relative percent difference for duplicate measurements. Analytical precision requirements for fixed laboratory analyses are listed in Table 1-4.

2.1.4.3 Detection Limits

Detection limits are functions of the analytical method used to provide the data and the quantity of the sample available for analyses. Detection limits identified for analyses for this project are listed in Table 1-4.

2.1.5 Special Training Certification

Typical training or certification requirements have been instituted by the Fluor Hanford team to meet the training requirements imposed by such documents as the Fluor Hanford contract, regulations, DOE orders, contractor requirements documents, American National Standards Institute/American Society of Mechanical Engineers standards, and the *Washington Administrative Code*. The Environmental Health and Safety Training Program provides workers with the knowledge and skills necessary to safely execute assigned duties. Field personnel typically will have completed the following training before starting work:

- Occupational Safety and Health Administration 40-Hour Hazardous Waste Worker Training
- 8-Hour Hazardous Waste Worker Refresher Training (as required)
- Radiological Worker Training
- Hanford General Employee Training.

A graded approach is used to ensure that workers receive a level of training that is commensurate with their responsibilities and that complies with applicable DOE orders and government regulations. Specialized employee training includes pre-job briefings, on-the-job training, emergency preparedness, plan-of-the-day activities, and facility/worksite orientations. Field-personnel training records will be documented and kept on file by the training organization. Training requirements for specific tasks are determined by personnel with

expertise in the relevant subject area. The BC Cribs and Trenches Area Task Lead is responsible for ensuring that training requirements are appropriately established.

2.1.6 Documentation and Records

The BC Cribs and Trenches Area Task Lead ensures that the Field Team Lead, samplers, and others responsible for implementation of this SAP and QAPjP are provided with current copies of this document and any revisions thereto. Documentation and records, regardless of medium or format, are controlled in accordance with internal work requirements and processes that comprise a collection of document control systems and processes that use a graded approach for the preparation, review, approval, distribution, use, revision, storage/retention, retrieval, disposition, and protection of documents and records generated or received in support of Fluor Hanford work.

All information pertinent to field sampling and analysis will be recorded in bound logbooks or other forms of media as required by applicable protocols. The sampling team will be responsible for recording all relevant sampling information in the logbooks. Entries made in the logbook will be dated and signed by the individual making the entry.

Borehole soil/sediment-sample data will support the development and evaluation of remedial alternatives through the feasibility study process. A contractor-level document (i.e., a borehole summary report) will be produced to summarize field activities and to capture field-screening and geophysical data that are collected during drilling activities. The borehole summary report will be consistent with similar documents that are prepared for other boreholes at the Hanford Site. Project documentation and records will be prepared, approved, and maintained according to RL and contractor requirements.

2.2 DATA GENERATION AND ACQUISITION

This section presents the requirements for sampling methods, sample handling and custody, analytical methods, and field and laboratory QC. The requirements for instrument calibration and maintenance, supply inspections, and data management also are addressed.

2.2.1 Sampling-Process Design

Professional judgment was applied to the 3-D inverted electrical resistivity maps and vertical profiles to select five new borehole locations, soil/sediment sampling intervals, and soil/sediment samples that are planned for field-screening and/or laboratory analyses. Locations of the resulting soil/sediment samples are identified in Section 3.2.2 of this SAP. These represent proposed locations and may be influenced by site-specific conditions (e.g., limited sample volume, inability to obtain a sample). The field team will note in the daily field-sampling logbook any instance when samples cannot be collected because of field conditions, and these events will be discussed in the follow-up borehole summary report. Sample locations may be adjusted based on visual or field-screening methods that may indicate a better sampling location to meet the DQOs (e.g., higher concentrations at a different depth). Additional depth locations

may be sampled, based on the judgment of field personnel and the BC Cribs and Trenches Area Task Lead, and based on real-time field conditions.

The borehole location will be staked before the field engineer begins drilling. Minor changes in sample locations can be made and documented in the field. More significant changes in sample locations that do not impact the DQOs will require notification and approval of the BC Cribs and Trenches Area Task Lead. Changes to sample locations that could result in impacts to meeting the DQOs will require RL and EPA concurrence.

2.2.2 Sampling Methods

The planned borehole grab and split-spoon sampling for this SAP will be performed in accordance with established sampling practices and requirements pertaining to sample collection, collection equipment, and sample handling. The Field Team Lead and the BC Cribs and Trenches Area Task Lead are responsible for ensuring that all field procedures are followed completely and that field personnel are trained adequately. The Field Team Lead and the BC Cribs and Trenches Area Task Lead must document situations that may impair the usability of the samples and/or data in the field logbook or on nonconformance report forms in accordance with internal corrective-action procedures, as appropriate. The Field Team Lead will note any deviations from the standard procedures for sample collection, COPCs, sample transport, or monitoring that occurs. The Field Team Lead also will be responsible for coordinating all activities relating to the use of field monitoring equipment (e.g., dosimeters and industrial-hygiene equipment). Field personnel will document in the logbook all noncompliant measurements taken during field sampling. Ultimately, the BC Cribs and Trenches Area Task Lead, or the Field Team Lead (at the discretion of the BC Cribs and Trenches Area Task Lead), will be responsible for developing, implementing, and communicating corrective-action procedures, for documenting all deviations from procedure, and for ensuring that immediate corrective actions are applied to field activities. Problems with sample collection, custody, or data acquisition that adversely impact the quality of data, or impair the ability to acquire data, or failure to follow procedure, will be documented in accordance with internal corrective-action procedures, as appropriate.

Sample preservation, containers, holding times, and sampling-method details for chemical and radiological analytes of interest and physical property analyses are presented in Section 3.2.2. Final sample-collection requirements will be identified on the Sampling Authorization Form.

2.2.3 Sample Handling, Shipping, and Custody Requirements

Level I EPA precleaned sample containers will be used for samples collected for chemical and radiological analysis. Container sizes may vary depending on laboratory-specific volumes/ requirements for meeting analytical detection limits. Planned container types and volumes are identified in Section 3.2.2. The final types and volumes will be indicated on the Sampling Authorization Form.

The Fluor Hanford sample and data-tracking database will be used to track the samples from the point of collection through the laboratory analysis process. The HEIS database is the repository for laboratory analytical results. The HEIS sample numbers will be issued to the sampling organization for this project in accordance with onsite organization procedures. Each chemical/radiological and physical properties sample will be identified and labeled with a unique HEIS sample number. The sample location, depth, and corresponding HEIS numbers will be documented in the sampler's field logbook.

Each sample container will be labeled with the following information using a waterproof marker on firmly affixed, water-resistant labels:

- Sampling Authorization Form
- HEIS number
- Sample collection date/time
- Name of person collecting the sample
- Analysis required
- Preservation method (if applicable).

A custody seal (i.e., evidence tape) will be affixed to the lid of each sample jar in a manner that will indicate potential tampering with the sample. The container seal will be inscribed with the sampler's initials and the date.

2.2.4 Laboratory Sample Custody

Sample custody during laboratory analysis will be addressed in the applicable laboratory standard operating procedures. Laboratory custody procedures will ensure the maintenance of sample integrity and identification throughout the analytical process.

All information pertinent to field sampling and analysis will be recorded in field checklists and bound logbooks in accordance with existing sample-collection protocols. The sampling team will be responsible for recording all relevant sampling information. Entries made in the logbook will be dated and signed by the individual making the entry. Program requirements for managing the generation, identification, transfer, protection, storage, retention, retrieval, and disposition of records by Fluor Hanford also will be followed.

Sample custody will be maintained in accordance with existing Hanford Site protocols. The custody of samples will be maintained from the time that the samples are collected until the ultimate disposal of the samples, as appropriate. A chain-of-custody record will be initiated in the field at the time of sampling and will accompany each set of samples shipped to any laboratory. Wire or laminated waterproof tape will be used to seal the coolers. Chain-of-custody procedures will be followed throughout sample collection, transfer, analysis, and disposal to ensure that sample integrity is maintained. Each time the responsibility changes for the custody of the sample, the new and previous custodians will sign the record and note the date and time. The sampler will make a copy of the signed record before the sample is shipped and will transmit the copy to Fluor Hanford Sample and Data Management within 48 hours of shipping.

It is not necessary to indicate the planned analyses on the chain-of-custody form for every soil/sediment sample, because not all samples will be analyzed. Grab and/or split-spoon

soil/sediment samples are planned at 0.76 m (2.5-ft) intervals in each borehole. The soil/sediment samples that are planned for analyses, and the targeted analyses for each borehole, are described in Section 3.2.2 and Tables 3-2 through 3-6 in Chapter 3.0 of this SAP. All samples will be transported to the laboratory that is selected to perform the analyses. The BC Cribs and Trenches Area Task Lead, in consultation with the laboratory, may modify the samples selected for analyses and the specific targeted analyses that are performed on each sample. The chain-of-custody forms for sample intervals that are planned for analyses in each borehole will indicate the selected analyses shown on Tables 3-2 through 3-6 in Chapter 3.0. The analyzing laboratory will screen samples with electrical-resistivity measurements and then select samples for a complete set of analyses, in consultation with the BC Cribs and Trenches Area Task Lead.

The radiological control technician will measure both the contamination levels on the outside of each sample jar and the dose rates on each sample jar. The radiological control technician also will measure the radiological activity on the outside of the sample container (through the container) and will document the highest contact radiological reading in millirem per hour. This information, along with other data, will be used to select proper packaging, marking, labeling, and shipping paperwork in accordance with U.S. Department of Transportation regulations (49 CFR, "Transportation") and to verify that the sample can be received by the analytical laboratory in accordance with the laboratory's acceptance criteria. The sampler will send copies of the shipping documentation to Fluor Hanford Sample and Data Management within 48 hours of shipping.

2.2.5 Analytical Methods

Analytical parameters and methods are listed in Tables 1-2 and 1-3. These analytical methods are controlled in accordance with the laboratory's QA plan and the requirements of this SAP.

Laboratories providing analytical services in support of this SAP will report errors to the Fluor Hanford Sample Management Project Coordinator who will then initiate a Sample Disposition Record. The error reporting process is intended to document analytical errors and the resolution of those errors with the BC Crib and Trenches Area Task Lead. The corrective-action program addresses the following:

- Evaluation of impacts of laboratory QC failures on data quality
- Root-cause analysis of QC failures
- Evaluation of recurring conditions that are adverse to quality
- Trend analysis of quality-affecting problems
- Implementation of a quality-improvement process
- Control of nonconforming materials that may affect data quality.

2.2.6 Quality Control Requirements

The QC procedures must be followed in the field and laboratory to ensure that reliable data are obtained. When field sampling is performed, care should be taken to prevent the cross-contamination of sampling equipment, sample bottles, and other equipment that could compromise sample integrity.

Field QC samples will be collected to evaluate the potential for cross-contamination and laboratory performance. Field QC for sampling under this SAP will require the collection of field duplicates and equipment rinsate blanks. The QC samples and the required frequency for collection are described in this section. The field geologist may request that additional equipment blanks be taken. The QC samples will be collected as part of the verification and confirmatory sampling activities.

The collection of QC samples for onsite measurements is not applicable to the field-screening techniques described in this SAP. Field-screening instrumentation will be calibrated and controlled as discussed in Sections 2.2.7 and 2.2.8, as applicable.

The laboratory method blank, laboratory-control sample/blank spike, and matrix spike are defined in Chapter 1 of SW-846, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update III-B*, and will be run at the frequency specified in that reference.

Table 2-1 lists the field QC requirements for sampling. If only disposable equipment is used, or equipment is dedicated to a particular well, then an equipment rinsate blank is not required. If no volatile organic compound samples are collected, then a field transfer blank is not required. Field transfer blanks are not required when simply transferring samples to the field gas chromatograph for analysis.

Table 2-1. Field Quality-Control Requirements.

Sample Type	Frequency	Purpose
Duplicate	5% (1 sample in 20)	Check the precision of the laboratory analyses
Equipment rinsate	One per 30 samples in each borehole	Check the effectiveness of the decontamination process
Field transfer blank	NOT required	NOT required

2.2.6.1 Field Duplicates

Field duplicates are independent samples collected as close as possible to the same point in space and time, taken from the same source, stored in separate containers, and analyzed independently. These samples are not to be homogenized together. One field duplicate will be collected for every 20 samples collected from each borehole. The duplicate generally should be collected from an interval that is expected to have some contamination, so that valid comparisons between the samples can be made (i.e., at least some of the COPCs will be above detection limit). When sampling with a split spoon, the duplicate sample likely will be from a separate split spoon, either above or below the main sample, because of sample-volume requirements.

2.2.6.2 Equipment Rinsate Blanks

Equipment blanks will consist of pure deionized water that is washed through decontaminated sampling equipment and placed in containers, as identified on the project Sampling Authorization Form. One equipment blank will be collected for every 30 sample retrieval trips

in each borehole. The field geologist may request that additional equipment blanks be taken. Equipment rinsate blanks will be analyzed for the following:

- When characterization analysis is for radionuclides only:
  - Gamma emitters
  - Gross alpha
  - Gross beta
- When characterization analysis is for radionuclides and chemical constituents:
  - Gamma emitters
  - Gross alpha
  - Gross beta
  - Metals (excluding hexavalent chromium and mercury)
  - Anions.

2.2.6.3 Field Transfer Blanks

No field transfer blanks (i.e., trip blanks) are required, because no sampling for volatile organic analyses is planned.

2.2.7 Instrument/Equipment Testing, Inspection, and Maintenance

All onsite environmental instruments will be tested, inspected, and maintained in accordance with the manufacturers' operating instructions and in accordance with approved work packages. Results from testing, inspection, and maintenance activities are documented in logbooks and/or work packages.

Measurement and testing equipment used in the field or in the laboratory that directly affect the quality of analytical data will be subject to preventive-maintenance measures to minimize the downtime of the measurement system. Laboratories and onsite measurement organizations must maintain and calibrate their equipment. Maintenance requirements (e.g., parts lists, documentation of routine maintenance) will be included in the individual laboratories' and the onsite organization's QA plans or operating procedures (as appropriate). Analytical laboratory instruments and measuring equipment are tested, inspected, and maintained in accordance with the laboratories' QA plans. Daily response checks for radiological field-survey instruments are performed in accordance with approved work packages.

2.2.8 Instrument/Equipment Calibration and Frequency

All onsite environmental instruments are calibrated in accordance with the manufacturers' operating instructions, internal work requirements and processes, and/or work packages that provide direction for equipment calibration or verification of accuracy by analytical methods. Calibration of laboratory instruments will be performed in a manner consistent with SW-846 or

with auditable DOE Hanford Site-wide and contractual requirements. The results from all instrument calibration activities are recorded in logbooks and/or work packages.

Analytical-laboratory instruments and measuring equipment are calibrated in accordance with laboratories' QA plans. Calibration of radiological field-survey instruments on the Hanford Site is performed under contract by Pacific Northwest National Laboratory on an annual basis, as specified in their program documentation. Field instrumentation, calibration, and QA checks will be performed in accordance with the following.

- Calibration of radiological field instruments on the Hanford Site is performed under contract by Pacific Northwest National Laboratory, as specified in their program documentation.
- Daily calibration checks will be performed and documented for each instrument used to characterize areas that are under investigation. These checks will be made on standard materials that are sufficiently similar to the matrix under consideration, so that direct comparison of data can be made. Analysis times will be sufficient to establish detection efficiency and resolution.

2.2.9 Inspection/Acceptance of Supplies and Consumables

Supplies and consumables for sampling and analysis activities will be acquired according to applicable procurement specifications. Supplies and consumables will be checked and accepted by users before they are used. Supplies and consumables procured by the analytical laboratories are procured, checked, and used in accordance with the laboratories' QA plans.

Consumables, supplies, and reagents will be reviewed in accordance with SW-846 requirements and will be appropriate for their use. Note that contamination is monitored using the QC sample process discussed in Section 2.2.

2.2.10 Nondirect Measurements

Nondirect measurements include data obtained from sources such as computer databases, programs, literature files, and historical databases. Nondirect measurements will not be evaluated as part of this activity.

2.2.11 Data Management

Data resulting from the implementation of this SAP will be managed and stored in accordance with applicable programmatic requirements governing data-management procedures. At the direction of the BC Cribs and Trenches Area Task Lead, all analytical data packages will be subject to final technical review by qualified personnel (as determined by the BC Cribs and Trenches Area Task Lead) before the results are submitted to the regulatory agencies or before they are included in reports. Electronic data access, when appropriate, will be via a database

(e.g., HEIS or a project-specific database). Where electronic data are not available, hard copies will be provided in accordance with the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al., 1989), Section 9.6.

Planning for sample collection and analysis will be in accordance with the programmatic requirements governing fixed laboratory sample-collection activities, as discussed in the sampling teams' procedures. In the event that specific procedures do not exist for a particular work evolution, or if additional guidance to complete certain tasks is needed, a work package will be developed to adequately control the activities, as appropriate. Examples of the sample teams' requirements include activities associated with the following:

- Chain-of-custody/sample analysis requests
- Project and sample identification for sampling services
- Control of certificates of analysis
- Logbooks and checklists
- Sample packaging and shipping.

Approved work-control packages and procedures will be used to document radiological measurements when this SAP is being implemented. Examples of the types of documentation for field radiological data include the following:

- Instructions regarding the minimum requirements for documenting radiological controls information in accordance with 10 CFR 835, "Occupational Radiation Protection"

- Instructions for managing the identification, creation, review, approval, storage, transfer, and retrieval of Hanford Site radiological records

- Minimum standards and practices necessary for preparing, performing, and retaining radiological-related records

- Indoctrination of personnel on the development and implementation of survey/sample plans

- Requirements associated with preparing and transporting regulated material.

The sampling team and the laboratory that is selected to analyze soil/sediment samples will cross-reference analytical data and radiation measurements to facilitate interpretation of the investigation results. Errors reported by the laboratories are reported to the Sample Management Project Coordinator, who initiates a Sample Disposition Record. This process is used to document analytical errors and to establish resolution with the Project Task Lead.

2.3 ASSESSMENT/OVERSIGHT

Assessment and oversight activities evaluate the effectiveness of project implementation and associated QA and QC activities. The purpose of assessment is to ensure that the QAPjP is implemented as prescribed.

2.3.1 Assessments and Response Action

The Fluor Hanford QA group may conduct random surveillances and assessments to verify compliance with the requirements outlined in this SAP, project work packages, the project quality management plan, procedures, and regulatory requirements.

Deficiencies identified during these assessments will be reported in accordance with existing programmatic requirements. The Fluor Hanford QA group coordinates deficiency reporting according to Fluor Hanford's QA Program. When appropriate, corrective actions will be taken by the Project Engineer and/or Task Lead.

Oversight activities in the analytical laboratories, including corrective-action management, are conducted in accordance with the laboratories' QA plans. Fluor Hanford conducts oversight of offsite analytical laboratories to qualify them for performing Hanford Site analytical work. No laboratory assessments currently are planned for this SAP.

2.3.2 Reports to Management

Reports to management on data-quality issues will be made if and when these issues are identified. These issues will be reported by laboratory personnel to the Sample Management group, who then will communicate the issues to the BC Cribs and Trenches Area Task Lead and Manager. Subsequently, standard reporting protocols (e.g., project status reports) will be used to communicate these issues to management. Because performance or system assessments are not planned as part of this activity, the BC Cribs and Trenches Area Task Lead will not be providing audit or assessment reports to management for this activity, unless an unanticipated request is made for such an assessment to be conducted. At the end of the project, a data-quality-assessment report will be prepared to evaluate whether the type, quality, and quantity of data that were collected meet the intent of the DQOs and SAP.

2.4 DATA VALIDATION AND USABILITY

Data validation and usability activities occur after the data collection phase of the project is completed. Implementation of these elements determines whether the data conform to the specified criteria, thus satisfying project objectives. The steps in the process are as follows:

- Data review
- Data verification
- Data validation
- Data quality assessment.

2.4.1 Data Review, Verification, and Validation

Data review is completed by the laboratory. The laboratories under contract to Fluor Hanford review the data and provide case narratives that describe the QC evaluation of the data set. The data review is used in the subsequent data verification and validation activities, described below.

2.4.2 Verification and Validation Methods

Completed data packages will be verified by qualified Fluor Hanford Sample and Data Management personnel or by a qualified independent contractor. Verification consists of confirming that sampling and chain-of-custody documentation is complete and that sample numbers can be tied to the specific sampling locations, checking required deliverables, comparing requested versus reported analyses, and identifying transcription errors. Once the deliverables are verified, the data are validated.

Validation as defined in SW-846, Chapter 1, indicates that data validation is the process of evaluating the available data against project DQOs. Data validation may be performed by Sample and Data Management, or by a party independent of both the data collector and the data user. Specifically, the process of validation includes the following:

- Documenting any errors found in the data for subsequent project resolution
- Verifying compliance with the QA requirements
- Checking QC values against defined limits
- Applying qualifiers to analytical results for the purpose of defining the limitations in the use of the data.

Validation will include evaluating and qualifying the results based on holding times, method blanks, laboratory control samples, laboratory duplicates, and chemical and tracer recoveries, as appropriate. No other validation or calculation checks will be performed.

Level C data validation, as defined in the contractor's validation procedures that are based on the EPA's functional guidelines (Bleyler 1988a, *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses*; Bleyler 1988b, *Laboratory Data Validation Functional Guidelines for Evaluating Organics Analyses*), will be performed for a minimum of 5 percent of the laboratory-generated chemical and radiochemical data by matrix and analyte group. When outliers or questionable results are identified, additional data validation will be performed. The additional validation will be performed for up to 5 percent of the statistical outliers and/or questionable data. The additional validation will begin with Level C and may increase to Levels D and E as needed to ensure that the data are usable. Note that Level C validation is a review of the QC data, while Levels D and E include review of calibration data and calculations of representative samples from the data set. Data validation will be documented in data validation reports, which will be provided to the Sample and Data Management organization and in the data-quality assessment report (see Section 2.4.3). At least one data validation package will be generated for each waste site. The Sample and Data Management organization is responsible for distributing the data validation report to the 200-BC-1 Operable Unit Task Lead and to others as necessary.

2.4.3 Reconciliation with User Requirements

The determination of data usability will be documented in the data-quality assessment report. The data-quality-assessment process is defined in EPA/240/B-06/002, *Data Quality Assessment: A Reviewers Guide*, EPA QA/G-9R. The EPA data-quality-assessment process will be used for laboratory data. The analytical data will be reviewed to determine whether DQOs are met for precision, accuracy, and completeness. The quality and quantity of the borehole analytical data also will be reviewed to determine whether conclusions may be formed regarding correlation of the analytical data and co-located electrical resistivity data. Verified and/or validated data will be reviewed to assess their usability. The BC Cribs and Trenches Area Task Lead is responsible for ensuring that the data-quality assessment is performed. The data-quality assessment results will be reported to the BC Cribs and Trenches Area Task Lead.

3.0 FIELD-SAMPLING PLAN

3.1 SAMPLING OBJECTIVES

The objective of the field-sampling plan is to clearly identify project sampling and analysis activities. The field-sampling plan is based on the sampling design identified during the DQO process (SGW-32480). Five borehole locations in the BC Cribs and Trenches Area (Boreholes A through E) were identified in the DQO (SGW-32480) and are listed in order of priority in Table 3-1. The boreholes will be drilled and sampled as described in Section 3.2.2. Borehole E is optional and currently is planned to be completed as a monitoring well if it is drilled.

Table 3-1. Rationale for Proposed New Borehole Locations. (2 Pages)

Borehole Designation and Total Depth [a]	Borehole Location [a,b]	Primary Purpose or Rationale [b]
A, water table at 104 m (342 ft) below ground surface	Between Cribs 216-B-17 and 216-B-19 along fiscal year 2005 Survey Line 4 near 340 m position. Avoid pipeline from siphon tank to cribs. Global Positioning System coordinates [c]: 573588.2, 134361.5	Correlation test where electrical resistivity is low and COPC concentrations are expected to be high (possibly deeper in vadose zone below cribs than trenches). Evaluate extent of vertical smearing in 3-D inverted electrical resistivity data in the vicinity of the cribs, especially near water table. Also, compare correlation of electrical resistivity and COPC concentrations under cribs and trenches.
B, 75 m (248.5 ft) below ground surface	Directly west of Trench 216-B-52, and east of Trenches 216-B-33 and 216-B-34, at intersection of fiscal year 2005 Survey Lines 19 (~315 m position) and 25 (~240 m position). Global Positioning System coordinates [c]: 573192.6, 134239.7	Correlation test where electrical resistivity data indicate low to mid-range COPC concentrations at lateral edges of low electrical resistivity regions. Investigate whether COPC plumes merge in deeper vadose zone under road between Trenches 216-B-23 and 216-B-34. Also, evaluate extent of horizontal smearing in non-inverted electrical resistivity data.
C, 62 m (203.5) ft below ground surface	Between Trench 216-B-20 and 216-B-17 Crib at intersection of fiscal year 2006 Survey Lines1 (~385 m position) and 2 (~345 m position). Global Positioning System coordinates [c]: 573500.6, 134350.9	Correlation test where higher electrical resistivity indicates lower or no COPC concentrations in vadose zone (i.e., a false-negative hypothesis). Investigate whether COPC plumes from trenches and cribs merge in vadose zone. Also, evaluate influence of moisture content on measured electrical resistivity where nitrate concentration is expected to be low or not present above background values.
D, 62 m (203.5 ft) below ground surface	Between Trenches 216-B-30 and 216-B-31 at the intersection of fiscal year 2005 Survey Lines 13 (~180 m position) and 22 (~265 m position). Global Positioning System coordinates [c]: 573066.0, 134383.1	Correlation test of low to mid-range electrical resistivity data in western trenches. Evaluate extent of vertical smearing in 3-D inverted electric resistivity data near trenches.

Table 3-1. Rationale for Proposed New Borehole Locations. (2 Pages)

Borehole Designation and Total Depth [a]	Borehole Location [a,b]	Primary Purpose or Rationale [b]
E, below water table	East of Trenches 216-B-25 and 216-B-26 along fiscal year 2005 Survey Line 35 at 360 m position. Although not required for electrical resistivity evaluation, the borehole would be extended below the water table to install a monitoring well for record of decision compliance. Global Positioning System coordinates [c]: 573463.7, 134161.0	Optional location pending outcome of drilling Borehole C. If targeted analyte concentrations in Borehole C are low or near background values, then it might not be necessary to drill Borehole E to test false-negative hypothesis. Correlation test at lateral edge of low electrical resistivity region. Electrical resistivity data indicate that closest lateral plume edge is approximately 50 m (164 ft) below ground surface.

[a] Borehole total depths that are above the water table are estimated and subject to modification based on soil/sediment-sample quick laboratory turnaround data.
[b] Electrical resistivity survey lines and associated vertical profile images are described in Step 1 and Appendix A of SGW-32480, *Data Quality Objectives Summary Report for the BC Cribs and Trenches Area – High-Resolution Resistivity Correlation*, and in D&D-31659, *Geophysical Investigations by High-Resolution Resistivity for the BC Cribs and Trenches Area, 2004-2006.*
[c] Global Positioning System coordinates reference: Washington State Plane (south); meters; NAD83, *North American Datum of 1983*, as revised, datum.
3-D = three dimensional.
COPC = contaminant of potential concern.

Data-Collection Activities

The data-collection activities associated with drilling the new boreholes include the following:

- Geologic description of soil/sediment encountered during drilling
- Collection and analysis of soil/sediment samples
- Geophysical logging.

3.2 SAMPLING LOCATIONS AND FREQUENCY

The purpose of this section is to identify the location of the new boreholes to be drilled and to define the sampling and analysis requirements for media samples and measurements to be collected from each of the boreholes during drilling. Figure 1-1 shows the five borehole locations that were identified in the DQO (SGW-32480). The 3-D inverted electrical resistivity for each borehole is shown in plan view maps, two vertical profiles, and a vertical electrical resistivity plot (except for Borehole E) in Figures 1-2 through 1-20. The sampling objectives for each borehole location vary according to the requirements for electrical resistivity evaluation and vadose-zone characterization/CSM enhancement. The sampling objectives and combinations of split-spoon and soil/sediment grab samples that are planned for each borehole are described in Section 3.2.2. The soil/sediment analyses and performance requirements are summarized in Tables 1-2, 1-3, and 1-4.

3.2.1 Sampling Methodology for Groundwater

A groundwater sample will be collected from boreholes that are drilled to the water table and from boreholes that are completed as monitoring wells. Groundwater samples are not required for electrical resistivity evaluation, but are useful for groundwater-monitoring purposes. Groundwater samples will be collected and analyzed according to other SAPs for the 200-PO-1 Groundwater Operable Unit.

3.2.2 Sampling Methodology for Soil/Sediment

The sampling instructions are different for the five boreholes because of the requirements of two different sampling objectives. The primary objective is to collect soil/sediment samples for evaluating the electrical resisitivity geophysical characterization method. The secondary objective is to collect soil/sediment samples for further vadose-zone characterization and enhancement of the CSM. The combination of the two sampling objectives results in both grab and split-spoon samples in Borehole A, as shown in Table 3-2. No split-spoons are planned in the other four boreholes (refer to Tables 3-3 through 3-6). The total number of planned samples for each borehole is shown in Table 3-7. The number and type of containers, sample volume, preservation methods, packing requirements, and holding time for grab samples are summarized in Table 3-8. Laboratory analyses for (1) electrical resistivity evaluation (i.e., the primary objective) and (2) vadose-zone characterization and CSM enhancement (i.e., the secondary objective) are summarized in Tables 1-2 and 1-3, respectively. The analytical-performance requirements are shown in Table 1-5. All split spoons will be 0.76 m (2.5 ft) long.

All soil/sediment samples from the five boreholes will be delivered to the laboratory that is selected to perform the electrical resistivity evaluation analyses (electrical resistivity laboratory). The electrical resistivity laboratory, in consultation with the BC Cribs and Trenches Area Task Lead or designee, will determine, first, the final set of samples required for electrical resistivity evaluation, and then the samples to be designated for vadose-zone characterization (i.e., the secondary sampling objective). If a specific soil/sediment sample is required for both electrical resistivity evaluation and vadose-zone characterization, then the primary objective of electrical resistivity evaluation will take precedence over the secondary objective. The BC Cribs and Trenches Area Task Lead will have the discretionary authority to make the final sampling-objective determination for all soil/sediment samples.

The sampling plan for each borehole is described below. Targeted laboratory analytical parameters will be correlated to electrical resistivity that is calculated through 3-D inversion computer modeling, and to non-inverted apparent resistivity data. Both HRR apparent electrical resistivity and 3-D inverted electrical resistivity are based on the same geophysical electrical resistivity survey data. The sampling and analysis plans for Boreholes A through E are based on the 3-D inverted electrical resistivity model results that are illustrated in Chapter 1.0 of this SAP, and laboratory analytical data from Borehole C4191, which was drilled in Trench 216-B-26.

Table 3-2. Sediment Samples in Borehole A Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Upper vadose zone	Collect samples at 0.76 m (2.5-ft) intervals. Grab samples from ~1.5 m (~5 ft) to ~10.7 m (~35 ft) bgs, split-spoons from ~10.7 m (~35 ft) to ~13.7 m (~45 ft) bgs.	5.0	6.0	1	Grab	–	–	–	–
		7.5	8.5	2	Grab	–	–	–	–
		10.0	11.0	3	Grab	–	–	–	–
		12.5	13.5	4	Grab	–	–	–	–
		15.0	16.0	5	Grab	–	–	–	–
		17.5	18.5	6	Grab	–	–	–	–
		20.0	21.0	7	Grab	–	–	–	–
		22.5	23.5	8	Grab	–	–	–	–
		25.0	26.0	9	Grab	–	–	–	–
		27.5	28.5	10	Grab	–	–	–	–
		30.0	31.0	11	Grab	–	–	–	–
		32.5	33.5	12	Grab	–	–	–	–
		35.0	37.5	13	SS	–	–	1	SS
		37.5	40.0	14	SS	–	–	1	SS
		40.0	42.5	15	SS	–	–	1	SS
		42.5	45.0	16	SS	–	–	1	SS
Immediately above low electrical resistivity region [d]	Collect grab samples at 0.76 m (2.5-ft) intervals; analyze samples at ~3 m (~10-ft) intervals from electrical resistivity upper boundary to 10.7 m (~35 ft) above electrical resistivity upper boundary.	45.0	46.0	17	Grab	1	Quart	1	Pint
		47.5	48.5	18	Grab	–	–	–	–
		50.0	51.0	19	Grab	–	–	–	–
		52.5	53.5	20	Grab	–	–	–	–
		55.0	56.0	21	Grab	1	Quart	1	Pint
		57.5	58.5	22	Grab	–	–	–	–
		60.0	61.0	23	Grab	–	–	–	–
		62.5	63.5	24	Grab	–	–	–	–
		65.0	66.0	25	Grab	1	Quart	1	Pint
		67.5	68.5	26	Grab	–	–	–	–
		70.0	71.0	27	Grab	–	–	–	–
		72.5	73.5	28	Grab	–	–	–	–
		75.0	76.0	29	Grab	–	–	–	–
		77.5	78.5	30	Grab	1	Quart	1	Pint

Table 3-2. Sediment Samples in Borehole A Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Within low electrical resistivity region [d]	Upper boundary	80.0	81.0	31	Grab	1	Quart	1	Pint
	Collect samples at 0.76 m (2.5-ft) intervals. Grab and split-spoon samples where indicated. Analyze samples as shown.	82.5	83.5	32	Grab	--	-- [e]	--	--
		85.0	87.5	33	SS	--	--	1	SS
		87.5	90.0	34	SS	--	--	1	SS
		90.0	91.0	35	Grab	1	Quart	1	Pint
		92.5	93.5	36	Grab	--	--	--	--
		95.0	96.0	37	Grab	--	--	--	--
		97.5	98.5	38	Grab	--	--	--	--
		100.0	101.0	39	Grab	--	--	--	--
		102.5	103.5	40	Grab	1	Quart	1	Pint
		105.0	107.5	41	SS	--	--	1	SS
		107.5	110.0	42	SS	--	--	1	SS
		110.0	112.5	43	SS	--	--	1	SS
		112.5	115.0	44	SS	--	--	1	SS
		115.0	116.0	45	Grab	1	Quart	1	Pint
		117.5	118.5	46	Grab	--	--	--	--
		120.0	121.0	47	Grab	--	--	--	--
		122.5	123.5	48	Grab	1	Quart	1	Pint
		125.0	127.5	49	SS	--	--	1	SS
		127.5	130.0	50	SS	--	--	1	SS
		130.0	132.5	51	SS	--	--	1	SS
		132.5	135.0	52	SS	--	--	1	SS
		135.0	136.0	53	Grab	1	Quart	1	Pint
		137.5	138.5	54	Grab	--	--	--	--
		140.0	141.0	55	Grab	--	--	--	--
		142.5	143.5	56	Grab	--	--	--	--
		145.0	146.0	57	Grab	1	Quart	1	Pint
		147.5	148.5	58	Grab	--	--	--	--
		150.0	151.0	59	Grab	--	--	--	--
		152.5	153.5	60	Grab	--	--	--	--
		155.0	156.0	61	Grab	1	Quart	1	Pint
		157.5	158.5	62	Grab	--	--	--	--
		160.0	161.0	63	Grab	--	--	--	--
		162.5	163.5	64	Grab	--	--	--	--
		165.0	166.0	65	Grab	1	Quart	1	Pint
		167.5	168.5	66	Grab	--	--	--	--

Table 3-2. Sediment Samples in Borehole A Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Within low electrical resistivity region [d] (cont.)	Collect samples at 0.76 m (2.5-ft) intervals. Grab and split-spoon samples where indicated. Analyze samples as shown. (cont.)	170.0	171.0	67	Grab	--	--	--	--
		172.5	173.5	68	Grab	1	Quart	1	Pint
		175.0	177.5	69	SS	--	--	1	SS
		177.5	180.0	70	SS	--	--	1	SS
		180.0	182.5	71	SS	--	--	1	SS
		182.5	185.0	72	SS	--	--	1	SS
		185.0	186.0	73	Grab	1	Quart	1	Pint
		187.5	188.5	74	Grab	--	--	--	--
		190.0	191.0	75	Grab	--	--	--	--
		192.5	193.5	76	Grab	--	--	--	--
		195.0	196.0	77	Grab	1	Quart	1	Pint
		197.5	198.5	78	Grab	--	--	--	--
		200.0	201.0	79	Grab	--	--	--	--
		202.5	203.5	80	Grab	--	--	--	--
		205.0	206.0	81	Grab	1	Quart	1	Pint
		207.5	208.5	82	Grab	--	--	--	--
		210.0	211.0	83	Grab	--	--	--	--
		212.5	213.5	84	Grab	--	--	--	--
		215.0	216.0	85	Grab	1	Quart	1	Pint
		217.5	218.5	86	Grab	--	--	--	--
		220.0	221.0	87	Grab	--	--	--	--
		222.5	223.5	88	Grab	--	--	--	--
		225.0	226.0	89	Grab	1	Quart	1	Pint
		227.5	228.5	90	Grab	--	--	--	--
		230.0	231.0	91	Grab	--	--	--	--
		232.5	233.5	92	Grab	1	Quart	1	Pint
		235.0	237.5	93	SS	--	--	1	SS
		237.5	240.0	94	SS	--	--	1	SS
		240.0	242.5	95	SS	--	--	1	SS
		242.5	245.0	96	SS	--	--	1	SS
		245.0	246.0	97	Grab	1	Quart	1	Pint
		247.5	248.5	98	Grab	--	--	--	--

Table 3-2. Sediment Samples in Borehole A Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
	Lower Boundary	250.0	251.0	99	Grab	1	Quart	1	Pint
Immediately below low electrical resistivity region [d]	Collect grab samples at 0.76 m (2.5-ft) intervals. No analyses planned.	252.5	253.5	100	Grab	--	--	--	--
		255.0	256.0	101	Grab	--	--	--	--
		257.5	258.5	102	Grab	--	--	--	--
		260.0	261.0	103	Grab	--	--	--	--
		262.5	263.5	104	Grab	--	--	--	--
		265.0	266.0	105	Grab	--	--	--	--
		267.5	268.5	106	Grab	--	--	--	--
		270.0	271.0	107	Grab	--	--	--	--
		272.5	273.5	108	Grab	--	--	--	--
		275.0	276.0	109	Grab	--	--	--	--
		277.5	278.5	110	Grab	--	--	--	--
		280.0	281.0	111	Grab	--	--	--	--
		282.5	283.5	112	Grab	--	--	--	--
		285.0	286.0	113	Grab	--	--	--	--
Lower vadose zone	Collect grab samples at 0.76 m (2.5-ft) intervals. No analyses planned until water table.	287.5	288.5	114	Grab	--	--	--	--
		290.0	291.0	115	Grab	--	--	--	--
		292.5	293.5	116	Grab	--	--	--	--
		295.0	296.0	117	Grab	--	--	--	--
		297.5	298.5	118	Grab	--	--	--	--
		300.0	301.0	119	Grab	--	--	--	--
		302.5	303.5	120	Grab	--	--	--	--
		305.0	306.0	121	Grab	--	--	--	--
		307.5	308.5	122	Grab	--	--	--	--
		310.0	311.0	123	Grab	--	--	--	--
		312.5	313.5	124	Grab	--	--	--	--
		315.0	316.0	125	Grab	--	--	--	--
		317.5	318.5	126	Grab	--	--	--	--
		320.0	321.0	127	Grab	--	--	--	--
		322.5	323.5	128	Grab	--	--	--	--
		325.0	326.0	129	Grab	--	--	--	--
		327.5	328.5	130	Grab	--	--	--	--
		330.0	331.0	131	Grab	--	--	--	--
		332.5	333.5	132	Grab	--	--	--	--
		335.0	336.0	133	Grab	--	--	--	--
		337.5	338.5	134	Grab	--	--	--	--
		340.0	341.0	135	Grab	--	--	--	--

Table 3-2. Sediment Samples in Borehole A Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Water table	Total depth	341.0	342.0	136	Grab	1	Quart	1	Pint
TOTAL Containers				22	SS	0	SS	22	SS
				114	Grab	23	Quart	23	Pint

[a]All split-spoons shall be 0.76 m (2.5 ft) long. Each grab sample shall consist of 1 quart-size container. If sufficient sample material is available, a pint-size container also shall be collected for each grab sample that is planned for geochemical analyses.

[b]Geochemical analyses are specified in a sampling and analysis plan for evaluation of electrical resistivity characterization.

[c]Geotechnical analyses are specified in associated data quality objectives and a sampling and analysis plan for vadose-zone characterization. The BC Cribs and Trenches Area Task Lead and laboratory may select specific geotechnical analyses for samples that are analyzed for geochemical parameters.

[d]Low electrical resistivity <=60 ohm-m.

bgs = below ground surface.

SS = split-spoon.

quart or pint: refer to Table 3-8 for sample handling and container information.

Table 3-3. Sediment Samples in Borehole B Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Upper vadose zone	Collect grab samples at 0.76 m (2.5-ft) intervals, but no analyses planned.	5.0	6.0	1	Grab	--	--	--	--
		7.5	8.5	2	Grab	--	--	--	--
		10.0	11.0	3	Grab	--	--	--	--
		12.5	13.5	4	Grab	--	--	--	--
		15.0	16.0	5	Grab	--	--	--	--
		17.5	18.5	6	Grab	--	--	--	--
		20.0	21.0	7	Grab	--	--	--	--
		22.5	23.5	8	Grab	--	--	--	--
		25.0	26.0	9	Grab	--	--	--	--
		27.5	28.5	10	Grab	--	--	--	--
		30.0	31.0	11	Grab	--	--	--	--
		32.5	33.5	12	Grab	--	--	--	--
		35.0	36.0	13	Grab	--	--	--	--
		37.5	38.5	14	Grab	--	--	--	--
		40.0	41.0	15	Grab	--	--	--	--
		42.5	43.5	16	Grab	--	--	--	--
		45.0	46.0	17	Grab	--	--	--	--
		47.5	48.5	18	Grab	--	--	--	--
Immediately above lowest electrical resistivity zone. Highest nitrate and technetium-99 concentrations in this zone.	Collect grab samples at 0.76 m (2.5-ft) intervals. Analyze as shown at ~3 m (~10-ft) intervals.	50.0	51.0	19	Grab	1	Quart	--	--
		52.5	53.5	20	Grab	--	--	--	--
		55.0	56.0	21	Grab	--	--	--	--
		57.5	58.5	22	Grab	--	--	--	--
		60.0	61.0	23	Grab	1	Quart	--	--
		62.5	63.5	24	Grab	--	--	--	--
		65.0	66.0	25	Grab	--	--	--	--
		67.5	68.5	26	Grab	--	--	--	--
		70.0	71.0	27	Grab	1	Quart	--	--
		72.5	73.5	28	Grab	--	--	--	--
		75.0	76.0	29	Grab	--	--	--	--
		77.5	78.5	30	Grab	--	--	--	--
		80.0	81.0	31	Grab	1	Quart	--	--
		82.5	83.5	32	Grab	--	--	--	--
		85.0	86.0	33	Grab	--	--	--	--
		87.5	88.5	34	Grab	--	--	--	--

Table 3-3. Sediment Samples in Borehole B Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Immediately above lowest electrical resistivity zone. Highest nitrate and technetium-99 concentrations in this zone. (cont.)	Collect grab samples at 0.76 m (2.5-ft) intervals. Analyze as shown at ~3 m (~10-ft) intervals. (cont.)	90.0	91.0	35	Grab	1	Quart	--	--
		92.5	93.5	36	Grab	--	--	--	--
		95.0	96.0	37	Grab	--	--	--	--
		97.5	98.5	38	Grab	--	--	--	--
		100.0	101.0	39	Grab	1	Quart	--	--
		102.5	103.5	40	Grab	--	--	--	--
		105.0	106.0	41	Grab	--	--	--	--
		107.5	108.5	42	Grab	--	--	--	--
		110.0	111.0	43	Grab	1	Quart	--	--
		112.5	113.5	44	Grab	--	--	--	--
		115.0	116.0	45	Grab	--	--	--	--
		117.5	118.5	46	Grab	--	--	--	--
		120.0	121.0	47	Grab	1	Quart	--	--
		122.5	123.5	48	Grab	--	--	--	--
		125.0	126.0	49	Grab	--	--	--	--
		127.5	128.5	50	Grab	--	--	--	--
		130.0	131.0	51	Grab	1	Quart	--	--
		132.5	133.5	52	Grab	--	--	--	--
		135.0	136.0	53	Grab	--	--	--	--
		137.5	138.5	54	Grab	--	--	--	--
		140.0	141.0	55	Grab	1	Quart	--	--
		142.5	143.5	56	Grab	--	--	--	--
		145.0	146.0	57	Grab	--	--	--	--
		147.5	148.5	58	Grab	--	--	--	--
Expected zone of lowest electrical resistivity based on 3-D inversion data. [d]	Collect and analyze grab samples as shown.	150.0	151.0	59	Grab	1	Quart	--	--
		152.5	153.5	60	Grab	--	--	--	--
		155.0	156.0	61	Grab	--	--	--	--
		157.5	158.5	62	Grab	--	--	--	--
		160.0	161.0	63	Grab	1	Quart	--	--
		162.5	163.5	64	Grab	--	--	--	--
		165.0	166.0	65	Grab	--	--	--	--
		167.5	168.5	66	Grab	--	--	--	--
		170.0	171.0	67	Grab	1	Quart	--	--
		172.5	173.5	68	Grab	--	--	--	--
		175.0	176.0	69	Grab	--	--	--	--
		177.5	178.5	70	Grab	--	--	--	--

Table 3-3. Sediment Samples in Borehole B Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Expected zone of lowest electrical resistivity [d] (cont.)	Collect and analyze grab samples as shown. (cont.)	180.0	181.0	71	Grab	1	Quart	--	--
		182.5	183.5	72	Grab	--	--	--	--
		185.0	186.0	73	Grab	--	--	--	--
		187.5	188.5	74	Grab	--	--	--	--
		190.0	191.0	75	Grab	1	Quart	--	--
		192.5	193.5	76	Grab	--	--	--	--
		195.0	196.0	77	Grab	--	--	--	--
		197.5	198.5	78	Grab	--	--	--	--
		200.0	201.0	79	Grab	1	Quart	--	--
		202.5	203.5	80	Grab	--	--	--	--
		205.0	206.0	81	Grab	--	--	--	--
		207.5	208.5	82	Grab	--	--	--	--
		210.0	211.0	83	Grab	--	--	--	--
		212.5	213.5	84	Grab	1	Quart	--	--
Lower vadose zone	Collect grab samples at 0.76 m (2.5-ft) intervals, but no analyses planned.	215.0	216.0	85	Grab	--	--	--	--
		217.5	218.5	86	Grab	--	--	--	--
		220.0	221.0	87	Grab	--	--	--	--
		222.5	223.5	88	Grab	--	--	--	--
		225.0	226.0	89	Grab	--	--	--	--
		227.5	228.5	90	Grab	--	--	--	--
		230.0	231.0	91	Grab	--	--	--	--
		232.5	233.5	92	Grab	--	--	--	--
		235.0	236.0	93	Grab	--	--	--	--
		237.5	238.5	94	Grab	--	--	--	--
		240.0	241.0	95	Grab	--	--	--	--
		242.5	243.5	96	Grab	--	--	--	--
		245.0	246.0	97	Grab	--	--	--	--
	Total depth	247.5	248.5	98	Grab	1	Quart	--	--
TOTAL Containers				0	SS	0	SS	0	SS
				98	Grab	18	Quart	0	Pint

[a]Each grab sample shall consist of 1 quart-size container.
[b]Geochemical analyses are specified in a sampling and analysis plan for evaluation of electrical resistivity characterization.
[c]Geotechnical analyses are specified in associated data quality objectives and a sampling and analysis plan for vadose-zone characterization. The BC Cribs and Trenches Area Task Lead and laboratory may select specific geotechnical analyses for samples that are analyzed for geochemical parameters.
[d]Lowest electrical resistivity (as calculated by 3-D inversion) is 108 ohm-m at a depth of ~55 m (~180.5 ft) bgs.
3-D = three dimensional.
bgs = below ground surface.
SS = split-spoon.
quart or pint: refer to Table 3-8 for sample handling and container information.

Table 3-4. Sediment Samples in Borehole C Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Upper vadose zone	Collect grab samples at 0.76 m (2.5-ft) intervals, but no analyses planned.	5.0	6.0	1	Grab	--	--	--	--
		7.5	8.5	2	Grab	--	--	--	--
		10.0	11.0	3	Grab	--	--	--	--
		12.5	13.5	4	Grab	--	--	--	--
		15.0	16.0	5	Grab	--	--	--	--
		17.5	18.5	6	Grab	--	--	--	--
		20.0	21.0	7	Grab	--	--	--	--
		22.5	23.5	8	Grab	--	--	--	--
		25.0	26.0	9	Grab	--	--	--	--
		27.5	28.5	10	Grab	--	--	--	--
		30.0	31.0	11	Grab	--	--	--	--
		32.5	33.5	12	Grab	--	--	--	--
Expected zone of lowest electrical resistivity based on 3-D inversion data. [d]	Collect and analyze grab samples as shown.	35.0	36.0	13	Grab	1	Quart	--	--
		37.5	38.5	14	Grab	--	--	--	--
		40.0	41.0	15	Grab	--	--	--	--
		42.5	43.5	16	Grab	--	--	--	--
		45.0	46.0	17	Grab	1	Quart	--	--
		47.5	48.5	18	Grab	--	--	--	--
		50.0	51.0	19	Grab	--	--	--	--
		52.5	53.5	20	Grab	--	--	--	--
		55.0	56.0	21	Grab	1	Quart	--	--
		57.5	58.5	22	Grab	--	--	--	--
		60.0	61.0	23	Grab	--	--	--	--
		62.5	63.5	24	Grab	--	--	--	--
		65.0	66.0	25	Grab	1	Quart	--	--
		67.5	68.5	26	Grab	--	--	--	--
		70.0	71.0	27	Grab	--	--	--	--
		72.5	73.5	28	Grab	--	--	--	--
		75.0	76.0	29	Grab	1	Quart	--	--
		77.5	78.5	30	Grab	--	--	--	--
		80.0	81.0	31	Grab	--	--	--	--
		82.5	83.5	32	Grab	--	--	--	--

Table 3-4. Sediment Samples in Borehole C Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Expected zone of lowest electrical resistivity based on 3-D inversion data. [d] (cont.)	Collect and analyze grab samples as shown. (cont.)	85.0	86.0	33	Grab	1	Quart	--	--
		87.5	88.5	34	Grab	--	--	--	--
		90.0	91.0	35	Grab	--	--	--	--
		92.5	93.5	36	Grab	--	--	--	--
		95.0	96.0	37	Grab	1	Quart	--	--
Lower vadose zone	Collect grab samples at 0.76 m (2.5-ft) intervals, but no analyses planned.	97.5	98.5	38	Grab	--	--	--	--
		100.0	101.0	39	Grab	--	--	--	--
		102.5	103.5	40	Grab	--	--	--	--
		105.0	106.0	41	Grab	--	--	--	--
		107.5	108.5	42	Grab	--	--	--	--
		110.0	111.0	43	Grab	--	--	--	--
		112.5	113.5	44	Grab	--	--	--	--
		115.0	116.0	45	Grab	--	--	--	--
		117.5	118.5	46	Grab	--	--	--	--
		120.0	121.0	47	Grab	--	--	--	--
		122.5	123.5	48	Grab	--	--	--	--
		125.0	126.0	49	Grab	--	--	--	--
		127.5	128.5	50	Grab	--	--	--	--
		130.0	131.0	51	Grab	--	--	--	--
		132.5	133.5	52	Grab	--	--	--	--
		135.0	136.0	53	Grab	--	--	--	--
		137.5	138.5	54	Grab	--	--	--	--
		140.0	141.0	55	Grab	--	--	--	--
		142.5	143.5	56	Grab	--	--	--	--
		145.0	146.0	57	Grab	--	--	--	--
		147.5	148.5	58	Grab	--	--	--	--
		150.0	151.0	59	Grab	--	--	--	--
		137.5	138.5	54	Grab	--	--	--	--
		152.5	153.5	60	Grab	--	--	--	--
		155.0	156.0	61	Grab	--	--	--	--
		157.5	158.5	62	Grab	--	--	--	--
		160.0	161.0	63	Grab	--	--	--	--
		162.5	163.5	64	Grab	--	--	--	--
		165.0	166.0	65	Grab	--	--	--	--
		167.5	168.5	66	Grab	--	--	--	--
		170.0	171.0	67	Grab	--	--	--	--

Table 3-4. Sediment Samples in Borehole C Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Lower vadose zone (cont.)	Collect grab samples at 0.76 m (2.5-ft) intervals, but no analyses planned. (cont.)	172.5	173.5	68	Grab	--	--	--	--
		175.0	176.0	69	Grab	--	--	--	--
		177.5	178.5	70	Grab	--	--	--	--
		180.0	181.0	71	Grab	--	--	--	--
		182.5	183.5	72	Grab	--	--	--	--
		185.0	186.0	73	Grab	--	--	--	--
		187.5	188.5	74	Grab	--	--	--	--
		190.0	191.0	75	Grab	--	--	--	--
		192.5	193.5	76	Grab	--	--	--	--
		195.0	196.0	77	Grab	--	--	--	--
		197.5	198.5	78	Grab	--	--	--	--
		200.0	201.0	79	Grab	--	--	--	--
	Total depth	202.5	203.5	80	Grab	--	--	--	--
TOTAL Containers				0	SS	0	SS	0	SS
				80	Grab	7	Quart	0	Pint

[a]Each grab sample shall consist of 1 quart-size container.
[b]Geochemical analyses are specified in a sampling and analysis plan for evaluation of electrical resistivity characterization.
[c]Geotechnical analyses are specified in associated data quality objectives and a sampling and analysis plan for vadose-zone characterization. The BC Cribs and Trenches Area Task Lead and laboratory may select specific geotechnical analyses for samples that are analyzed for geochemical parameters.
[d]Lowest electrical resistivity (as calculated by 3-D inversion) is 278 ohm-m at a depth of 20 m (65.6 ft) bgs.
3-D = three dimensional.
bgs = below ground surface.
SS = split-spoon.
quart or pint: refer to Table 3-8 for sample handling and container information.

Table 3-5. Sediment Samples in Borehole D Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Upper vadose zone	Collect grab samples at 0.76 m (2.5-ft) intervals, but no analyses planned.	5.0	6.0	1	Grab	--	--	--	--
		7.5	8.5	2	Grab	--	--	--	--
		10.0	11.0	3	Grab	--	--	--	--
		12.5	13.5	4	Grab	--	--	--	--
		15.0	16.0	5	Grab	--	--	--	--
		17.5	18.5	6	Grab	--	--	--	--
		20.0	21.0	7	Grab	--	--	--	--
		22.5	23.5	8	Grab	--	--	--	--
		25.0	26.0	9	Grab	--	--	--	--
		27.5	28.5	10	Grab	--	--	--	--
		30.0	31.0	11	Grab	--	--	--	--
		32.5	33.5	12	Grab	--	--	--	--
		35.0	36.0	13	Grab	--	--	--	--
		37.5	38.5	14	Grab	--	--	--	--
		40.0	41.0	15	Grab	--	--	--	--
Immediately above region of low electrical resistivity [d]	Collect grab samples at 0.76 m (2.5-ft) intervals; analyze samples at ~3 m (~10 ft) intervals from upper boundary to ~10.7 m (~35 ft) above upper boundary.	42.5	43.5	16	Grab	1	Quart	--	--
		45.0	46.0	17	Grab	--	--	--	--
		47.5	48.5	18	Grab	--	--	--	--
		50.0	51.0	19	Grab	--	--	--	--
		52.5	53.5	20	Grab	1	Quart	--	--
		55.0	56.0	21	Grab	--	--	--	--
		57.5	58.5	22	Grab	--	--	--	--
		60.0	61.0	23	Grab	--	--	--	--
		62.5	63.5	24	Grab	1	Quart	--	--
		65.0	66.0	25	Grab	--	--	--	--
		67.5	68.5	26	Grab	--	--	--	--
		70.0	71.0	27	Grab	--	--	--	--
		72.5	73.5	28	Grab	--	--	--	--
		75.0	76.0	29	Grab	1	Quart	--	--

Table 3-5. Sediment Samples in Borehole D Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Within region of low electrical resistivity [d]	Upper boundary	77.5	78.5	30	Grab	1	Quart	--	--
	Collect grab samples at 0.76 m (2.5-ft) intervals. Analyze samples as shown.	80.0	81.0	31	Grab	--	--	--	--
		82.5	83.5	32	Grab	--	--	--	--
		85.0	86.0	33	Grab	--	--	--	--
		87.5	88.5	34	Grab	1	Quart	--	--
		90.0	91.0	35	Grab	--	--	--	--
		92.5	93.5	36	Grab	--	--	--	--
		95.0	96.0	37	Grab	--	--	--	--
		97.5	98.5	38	Grab	1	Quart	--	--
		100.0	101.0	39	Grab	--	--	--	--
		102.5	103.5	40	Grab	--	--	--	--
		105.0	106.0	41	Grab	--	--	--	--
		107.5	108.5	42	Grab	1	Quart	--	--
		110.0	111.0	43	Grab	--	--	--	--
		112.5	113.5	44	Grab	--	--	--	--
		115.0	116.0	45	Grab	--	--	--	--
		117.5	118.5	46	Grab	1	Quart	--	--
		120.0	121.0	47	Grab	--	--	--	--
		122.5	123.5	48	Grab	--	--	--	--
		125.0	126.0	49	Grab	--	--	--	--
		127.5	128.5	50	Grab	1	Quart	--	--
		130.0	131.0	51	Grab	--	--	--	--
		132.5	133.5	52	Grab	--	--	--	--
		135.0	136.0	53	Grab	--	--	--	--
		137.5	138.5	54	Grab	1	Quart	--	--
		140.0	141.0	55	Grab	--	--	--	--
		142.5	143.5	56	Grab	--	--	--	--
		145.0	146.0	57	Grab	--	--	--	--
		147.5	148.5	58	Grab	1	Quart	--	--
		150.0	151.0	59	Grab	--	--	--	--
		152.5	153.5	60	Grab	--	--	--	--
		155.0	156.0	61	Grab	--	--	--	--
		157.5	158.5	62	Grab	1	Quart	--	--
		160.0	161.0	63	Grab	--	--	--	--
		162.5	163.5	64	Grab	--	--	--	--

Table 3-5. Sediment Samples in Borehole D Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (3 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
	Lower boundary	165.0	166.0	65	Grab	1	Quart	--	--
Immediately below region of low electrical resistivity [d]	Collect grab samples at 0.76 m (2.5-ft) intervals. Analyze samples as shown from lower boundary ~10.7 m (~35 ft) below lower boundary.	167.5	168.5	66	Grab	1	Quart	--	--
		170.0	171.0	67	Grab	--	--	--	--
		172.5	173.5	68	Grab	--	--	--	--
		175.0	176.0	69	Grab	--	--	--	--
		177.5	178.5	70	Grab	1	Quart	--	--
		180.0	181.0	71	Grab	--	--	--	--
		182.5	183.5	72	Grab	--	--	--	--
		185.0	186.0	73	Grab	--	--	--	--
		187.5	188.5	74	Grab	1	Quart	--	--
		190.0	191.0	75	Grab	--	--	--	--
		192.5	193.5	76	Grab	--	--	--	--
		195.0	196.0	77	Grab	--	--	--	--
		197.5	198.5	78	Grab	1	Quart	--	--
		200.0	201.0	79	Grab	--	--	--	--
	Total depth	202.5	203.5	80	Grab	1	Quart	--	--
TOTAL Containers				0	SS	0	SS	0	SS
				80	Grab	19	Quart	0	Pint

[a]Each grab sample shall consist of 1 quart-size container.
[b]Geochemical analyses are specified in a sampling and analysis plan for evaluation of electrical resistivity characterization.
[c]Geotechnical analyses are specified in associated data quality objectives and a sampling and analysis plan for vadose-zone characterization. The BC Cribs and Trenches Area Task Lead and laboratory may select specific geotechnical analyses for samples that are analyzed for geochemical parameters.
[d]Low electrical resistivity <=60 ohm-m.
bgs = below ground surface.
SS = split-spoon.
quart or pint: refer to Table 3-8 for sample handling and container information.

Table 3-6. Sediment Samples in Borehole E Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Vadose zone not segmented because no low electrical resistivity region expected [d]	Collect grab samples at 0.76 m (2.5-ft) intervals, samples to be selected for electrical resistivity evaluation analyses by BC Cribs and Trenches Area Task Lead and laboratory. No analyses planned for vadose-zone properties.	5.0	6.0	1	Grab	--	--	--	--
		7.5	8.5	2	Grab	--	--	--	--
		10.0	11.0	3	Grab	--	--	--	--
		12.5	13.5	4	Grab	--	--	--	--
		15.0	16.0	5	Grab	--	--	--	--
		17.5	18.5	6	Grab	--	--	--	--
		20.0	21.0	7	Grab	--	--	--	--
		22.5	23.5	8	Grab	--	--	--	--
		25.0	26.0	9	Grab	--	--	--	--
		27.5	28.5	10	Grab	--	--	--	--
		30.0	31.0	11	Grab	--	--	--	--
		32.5	33.5	12	Grab	--	--	--	--
		35.0	36.0	13	Grab	--	--	--	--
		37.5	38.5	14	Grab	--	--	--	--
		40.0	41.0	15	Grab	--	--	--	--
		42.5	43.5	16	Grab	--	--	--	--
		45.0	46.0	17	Grab	--	--	--	--
		47.5	48.5	18	Grab	--	--	--	--
		50.0	51.0	19	Grab	--	--	--	--
		52.5	53.5	20	Grab	--	--	--	--
		55.0	56.0	21	Grab	--	--	--	--
		57.5	58.5	22	Grab	--	--	--	--
		60.0	61.0	23	Grab	--	--	--	--
		62.5	63.5	24	Grab	--	--	--	--
		65.0	66.0	25	Grab	--	--	--	--
		67.5	68.5	26	Grab	--	--	--	--
		70.0	71.0	27	Grab	--	--	--	--
		72.5	73.5	28	Grab	--	--	--	--
		75.0	76.0	29	Grab	--	--	--	--
		77.5	78.5	30	Grab	--	--	--	--
		80.0	81.0	31	Grab	--	--	--	--
		82.5	83.5	32	Grab	--	--	--	--
		85.0	86.0	33	Grab	--	--	--	--
		87.5	88.5	34	Grab	--	--	--	--

Table 3-6. Sediment Samples in Borehole E Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Vadose zone not segmented because no low electrical resistivity region expected [d] (cont.)	Collect grab samples at 0.76 m (2.5-ft) intervals, samples to be selected for electrical resistivity evaluation analyses by BC Cribs and Trenches Area Task Lead and laboratory. No analyses planned for vadose-zone properties. (cont.)	90.0	91.0	35	Grab	--	--	--	--
		92.5	93.5	36	Grab	--	--	--	--
		95.0	96.0	37	Grab	--	--	--	--
		97.5	98.5	38	Grab	--	--	--	--
		100.0	101.0	39	Grab	--	--	--	--
		102.5	103.5	40	Grab	--	--	--	--
		105.0	106.0	41	Grab	--	--	--	--
		107.5	108.5	42	Grab	--	--	--	--
		110.0	111.0	43	Grab	--	--	--	--
		112.5	113.5	44	Grab	--	--	--	--
		115.0	116.0	45	Grab	--	--	--	--
		117.5	118.5	46	Grab	--	--	--	--
		120.0	121.0	47	Grab	--	--	--	--
		122.5	123.5	48	Grab	--	--	--	--
		125.0	126.0	49	Grab	--	--	--	--
		127.5	128.5	50	Grab	--	--	--	--
		130.0	131.0	51	Grab	--	--	--	--
		132.5	133.5	52	Grab	--	--	--	--
		135.0	136.0	53	Grab	--	--	--	--
		137.5	138.5	54	Grab	--	--	--	--
		140.0	141.0	55	Grab	--	--	--	--
		142.5	143.5	56	Grab	--	--	--	--
		145.0	146.0	57	Grab	--	--	--	--
		147.5	148.5	58	Grab	--	--	--	--
		150.0	151.0	59	Grab	--	--	--	--
		152.5	153.5	60	Grab	--	--	--	--
		155.0	156.0	61	Grab	--	--	--	--
		157.5	158.5	62	Grab	--	--	--	--
		160.0	161.0	63	Grab	--	--	--	--
		162.5	163.5	64	Grab	--	--	--	--
		165.0	166.0	65	Grab	--	--	--	--
		167.5	168.5	66	Grab	--	--	--	--
		170.0	171.0	67	Grab	--	--	--	--
		172.5	173.5	68	Grab	--	--	--	--
		175.0	176.0	69	Grab	--	--	--	--
		177.5	178.5	70	Grab	--	--	--	--

Table 3-6. Sediment Samples in Borehole E Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Vadose zone not segmented because no low electrical resistivity region expected [d] (cont.)	Collect grab samples at 0.76 m (2.5-ft) intervals, samples to be selected for electrical resistivity evaluation analyses by BC Cribs and Trenches Area Task Lead and laboratory. No analyses planned for vadose-zone properties. (cont.)	180.0	181.0	71	Grab	--	--	--	--
		182.5	183.5	72	Grab	--	--	--	--
		185.0	186.0	73	Grab	--	--	--	--
		187.5	188.5	74	Grab	--	--	--	--
		190.0	191.0	75	Grab	--	--	--	--
		192.5	193.5	76	Grab	--	--	--	--
		195.0	196.0	77	Grab	--	--	--	--
		197.5	198.5	78	Grab	--	--	--	--
		200.0	201.0	79	Grab	--	--	--	--
		202.5	203.5	80	Grab	--	--	--	--
		205.0	206.0	81	Grab	--	--	--	--
		207.5	208.5	82	Grab	--	--	--	--
		210.0	211.0	83	Grab	--	--	--	--
		212.5	213.5	84	Grab	--	--	--	--
		215.0	216.0	85	Grab	--	--	--	--
		217.5	218.5	86	Grab	--	--	--	--
		220.0	221.0	87	Grab	--	--	--	--
		222.5	223.5	88	Grab	--	--	--	--
		225.0	226.0	89	Grab	--	--	--	--
		227.5	228.5	90	Grab	--	--	--	--
		230.0	231.0	91	Grab	--	--	--	--
		232.5	233.5	92	Grab	--	--	--	--
		235.0	236.0	93	Grab	--	--	--	--
		237.5	238.5	94	Grab	--	--	--	--
		240.0	241.0	95	Grab	--	--	--	--
		242.5	243.5	96	Grab	--	--	--	--
		245.0	246.0	97	Grab	--	--	--	--
		247.5	248.5	98	Grab	--	--	--	--
		250.0	251.0	99	Grab	--	--	--	--
		252.5	253.5	100	Grab	--	--	--	--
		255.0	256.0	101	Grab	--	--	--	--
		257.5	258.5	102	Grab	--	--	--	--
		260.0	261.0	103	Grab	--	--	--	--
		262.5	263.5	104	Grab	--	--	--	--
		265.0	266.0	105	Grab	--	--	--	--
		267.5	268.5	106	Grab	--	--	--	--

Table 3-6. Sediment Samples in Borehole E Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size
Vadose zone not segmented because no low electrical resistivity region expected [d] (cont.)	Collect grab samples at 0.76 m (2.5-ft) intervals, samples to be selected for electrical resistivity evaluation analyses by BC Cribs and Trenches Area Task Lead and laboratory. No analyses planned for vadose-zone properties. (cont.)	270.0	271.0	107	Grab	--	--	--	--
		272.5	273.5	108	Grab	--	--	--	--
		275.0	276.0	109	Grab	--	--	--	--
		277.5	278.5	110	Grab	--	--	--	--
		280.0	281.0	111	Grab	--	--	--	--
		282.5	283.5	112	Grab	--	--	--	--
		285.0	286.0	113	Grab	--	--	--	--
		287.5	288.5	114	Grab	--	--	--	--
		290.0	291.0	115	Grab	--	--	--	--
		292.5	293.5	116	Grab	--	--	--	--
		295.0	296.0	117	Grab	--	--	--	--
		297.5	298.5	118	Grab	--	--	--	--
		300.0	301.0	119	Grab	--	--	--	--
		302.5	303.5	120	Grab	--	--	--	--
		305.0	306.0	121	Grab	--	--	--	--
		307.5	308.5	122	Grab	--	--	--	--
		310.0	311.0	123	Grab	--	--	--	--
		312.5	313.5	124	Grab	--	--	--	--
		315.0	316.0	125	Grab	--	--	--	--
		317.5	318.5	126	Grab	--	--	--	--
		320.0	321.0	127	Grab	--	--	--	--
		322.5	323.5	128	Grab	--	--	--	--
		325.0	326.0	129	Grab	--	--	--	--
		327.5	328.5	130	Grab	--	--	--	--
		330.0	331.0	131	Grab	--	--	--	--
		332.5	333.5	132	Grab	--	--	--	--
		335.0	336.0	133	Grab	--	--	--	--
		337.5	338.5	134	Grab	--	--	--	--
Water table	Total depth	340.0	341.0	135	Grab	--	--	--	--
TOTAL Containers				0	SS	0	SS	0	SS
				135	Grab	TBD	Quart	TBD	Pint

Table 3-6. Sediment Samples in Borehole E Selected for Analyses to Support Electrical Resistivity Evaluation and Vadose-Zone Characterization. (5 Pages)

Vertical Position (ft bgs)	Targeted Samples for Analyses	Sampling Information				Laboratory Information			
		Depth Interval (ft bgs)		All Samples [a]		Geochemical Analyses [b]		Geotechnical Analyses [c]	
		Top	Bottom	Number	Type	Number	Size	Number	Size

[a]Each grab sample shall consist of 1 quart-size container.
[b]Geochemical analyses are specified in a sampling and analysis plan for evaluation of electrical resistivity characterization.
[c]Geotechnical analyses are specified in associated data quality objectives and a sampling and analysis plan for vadose-zone characterization. The BC Cribs and Trenches Area Task Lead and laboratory may select specific geotechnical analyses for samples that are analyzed for geochemical parameters.
[d]Electrical resistivity is not expected to significantly vary from background levels.
bgs = below ground surface.
SS = split-spoon.
TBD = to be determined.
quart or pint: refer to Table 3-8 for sample handling and container information.

Table 3-7. Soil/Sediment Sampling and Analytical Methods for Electrical Resistivity Evaluation Samples.

Borehole Location	Approximate Sampling Depths (ft bgs)	Sampling Method	Estimated Number of Samples	Laboratory Analyses	
				Analytical Methods	Number and Type of Quality Control Samples
A	Every 0.76 m (2.5 ft) from (1.5 m) 5 ft bgs to total depth	Grab	114	Selected samples will be analyzed as shown in Tables 1-2, 1-3, and 1-5	5 duplicates 2 rinsates NO field transfer (i.e., trip) blanks
		Split-spoon	22		
B		Grab	98		
C		Grab	80		
D		Grab	80		
E*		Grab	135		

*Borehole E is optional pending results for Borehole C. If Borehole E is drilled, it currently is planned to extend below the water table, so that a monitoring well can be installed. The estimated number of samples is based on those required for high-resolution resistivity evaluation (i.e., from 1.5 to 59 m [5 to 194 ft bgs]).
bgs = below ground surface.

Table 3-8. Sample Preservation, Container, and Holding Times for Soil/Sediment Samples. (2 Pages)

Analytes	Priority	Holding Time	Container		Volume [a]	Preser-vation	Packing Require-ments
			No.	Type			
Geochemical Analytical Samples							
Cations and metals (Selenium, Uranium) [b]	1	6 months	1	Plastic, wide-mouth	500 g	None	None
Alkalinity	1	14 days from extraction to analysis					
Anions [c]	1	28 days from leach to analysis					
Aluminum	2	6 months					
Manganese	2						
Mercury	2						
Nickel-63	3						
Radium-226	3						
Plutonium 239/240	2						
Strontium-90	2						
Technetium-99	1						
Cation exchange capacity [d]	2	None					
pH	1	14 days from extraction to analysis					
Specific surface area [d]	2	None					
Gamma energy analysis (Cesium-137, Cobalt-60)	1	None	1		500 g		
Moisture content	1	As soon as possible after opening container	1	"moisture tin"	100 g	Moisture-sealed container	Moisture-sealed container
Geotechnical/Physical Analytical Samples							
Moisture content	1	As soon as possible after opening container	1	10.2 cm (4-in.) diameter Lexan liner for split-spoon core	100 g	Moisture-sealed container	Moisture-sealed container
Lab soil resistivity	1	Analyzed together			500 g, full intact core (15 cm [6 in.] long)	Keep core UPRIGHT; minimize disturbance	Keep core UPRIGHT; minimize disturbance
Hydraulic conductivity [d]	2						
Air permeability [d]	2	Analyzed after resistivity and hyd. conductivity					
Particle size distribution [d]	2						
Specific conductivity	1	14 days from extraction to analysis			100 g	None	None
Ionic strength	1	Calculated value based on moisture content and water extract cations, anions, alkalinity					

Table 3-8. Sample Preservation, Container, and Holding Times for Soil/Sediment Samples. (2 Pages)

Analytes	Priority	Holding Time	Container		Volume [a]	Preser-vation	Packing Require-ments
			No.	Type			

[a] Optimal volumes, which may be adjusted downward to accommodate the possibility of small sample recoveries. Minimum sample size will be defined on the Sampling Authorization Form.
[b] As listed in Table 1-4, cations are calcium, magnesium, potassium, and sodium. Cations will be analyzed with metals, including selenium and uranium.
[c] As listed in Table 1-4, anions are nitrate (as nitrogen), nitrite (as nitrogen), chloride, fluoride, phosphate, and sulfate. Anions are collected in one bottle and analyzed by ion chromatography.
[d] Analyses for supplementing the conceptual site model; not required for electrical resistivity evaluation.
LEXAN is a registered trademark of General Electric Company, New York, New York.

An initial threshold of 60 ohm-m is selected to identify vadose-zone regions of low electrical resistivity, or high conductivity, where targeted COPC concentrations (e.g., nitrate and Tc-99) are expected to be relatively high. The 60 ohm-m threshold is derived from a comparison of the 3-D inverted data and nitrate concentrations in Borehole C4191, which was drilled in Trench 216-B-26. The upper and lower boundaries of low electrical resistivity, or high conductivity, regions in the vadose zone could correspond to values greater or less than 60 ohm-m in each borehole. Sampling at 0.76 m (2.5-ft) intervals and laboratory sample screening are intended to allow for identification of low-resistivity zones in each borehole. If multiple regions of low electrical resistivity (i.e., where the 3-D inverted electrical resistivity is equal to or less than approximately 60 ohm-m, based on existing surveys) are identified in a borehole, then soil/sediment samples within, above, and below each low electrical resistivity region will be selected for analyses as described below.

Data from Borehole C4191 in the 216-B-26 Trench indicate that the 3-D inversion process spreads the region of low electrical resistivity to more than 30 m (100 ft) below the depth of significant nitrate or Tc-99 contamination. The BC Cribs and Trenches Area Task Lead and the electrical resistivity laboratory may adjust the soil/sediment samples that are selected for geochemical analyses within low electrical resistivity regions as described below. Additional soil/sediment samples may be selected for laboratory analyses of the geotechnical characterization parameters in Table 1-3 if approved by the BC Cribs and Trenches Area Task Lead. The following soil/sediment samples are targeted for electrical resistivity evaluation in each borehole:

- Upper and lower boundaries of the low electrical resistivity region (i.e., where the 3-D inverted electrical resistivity is equal to or less than approximately 60 ohm-m), unless near-background concentrations of either Tc-99 or nitrate indicate that the lower boundary depth is falsely indicated by the 3-D inverted electrical resistivity data. The electrical resistivity laboratory then may cease analyzing samples at a depth of approximately 6 m (20 ft) below the near-background Tc-99 and nitrate concentrations.

- Intervals of approximately 3 m (10 ft) within the low electrical resistivity region, as measured from the upper boundary, unless near-background concentrations of either

Tc-99 or nitrate show that the lower boundary depth is falsely indicated by the 3-D inverted electrical resistivity data.

- Intervals of approximately 3 m (10 ft) above and below the low electrical resistivity region to a distance of approximately 10.7 m (35 ft), unless near-background concentrations of either Tc-99 or nitrate show that the lower boundary depth is falsely indicated by the 3-D inverted electrical resistivity data.

- The bottom of the borehole.

3.2.2.1 Borehole A

For Borehole A, representative soil/sediment samples will be collected at an interval of 0.76 m (2.5 ft) from 1.5 m (5 ft) below ground surface (bgs) to the bottom of the borehole. Grab samples will be collected except where split-spoons are retrieved at the depth intervals shown in Table 3-2. The split-spoon intervals are depths where lithology changes are expected based on observations in Borehole C4191. The specific depths where split-spoons are retrieved may be adjusted based on field observations of significant lithology changes while drilling Borehole A. The spilt-spoon samples are intended for geotechnical characterization analyses. Geochemical analyses for electrical resistivity evaluation may be performed on grab samples. Grab-sample analyses are planned at the depth intervals shown in Table 3-2.

The upper boundary of a 3-D inverted low electrical resistivity region is expected to occur at a depth of approximately 24.4 m (80 ft) bgs, and the lower boundary is expected at a depth of approximately 76.5 m (251.0 ft) bgs, as indicated by 3-D inverted electrical resistivity data. The actual upper and lower boundaries of the low electrical resistivity region will be estimated by quick-turnaround laboratory analyses as described in Section 3.2.2.7. The BC Cribs and Trenches Area Task Lead and the electrical resistivity laboratory may adjust the soil/sediment samples that are selected for electrical resistivity evaluation (i.e., geochemical analyses) according to the quick-turnaround laboratory analytical results. The electrical resistivity laboratory may cease analyzing samples at a depth of approximately 6 m (20 ft) below where near-background Tc-99 and nitrate concentrations are detected.

Drilling for Borehole A is planned to continue to the water table at an expected depth of approximately 104 m (341.2 ft). All split spoons will be 0.76 m (2.5 ft) long. The electrical resistivity evaluation and the geotechnical vadose-zone characterization (e.g., CSM enhancement) analyses are summarized in Tables 1-2 and 1-3, respectively.

3.2.2.2 Borehole B

The minimum electrical resistivity, based on 3-D inverted data, expected in Borehole B is approximately 108 ohm-m at a depth of approximately 55 m (180 ft) bgs. For Borehole B, representative soil/sediment grab samples will be collected every 0.76 m (2.5 ft) from 1.5 m (5 ft) bgs to the bottom of the borehole. No split-spoon samples are planned in Borehole B. The grab samples that are planned for electrical resistivity evaluation are shown in Table 3-3.

The electrical resistivity laboratory may use quick-turnaround analyses to determine whether drilling has progressed below the depth at which Tc-99 is detected and/or nitrate concentrations

are approximately equal to background levels. The BC Cribs and Trenches Area Task Lead and the electrical resistivity laboratory may adjust the soil/sediment samples that are selected for electrical resistivity evaluation according to the quick-turnaround laboratory analytical results. The electrical resistivity laboratory may cease analyzing samples at a depth of approximately 6 m (20 ft) below where near-background Tc-99 and nitrate concentrations are detected.

The planned total depth for Borehole B is approximately 75.7 m (248.5 ft) bgs unless drilling is terminated based on quick-turnaround analyses as described above. The BC Cribs and Trenches Area Task Lead may terminate drilling before the planned total depth if significant Tc-99 activity levels and/or nitrate concentrations are not detected as described above. The highest Tc-99 activity levels and nitrate concentrations are expected between 15 m (50 ft) and 45.7 m (150 ft) bgs based on the contaminant distributions found in Borehole C4191, which was drilled in Trench 216-B-26. The electrical resistivity evaluation analyses are summarized in Table 1-2.

3.2.2.3 Borehole C

The minimum electrical resistivity, based on 3-D inverted data, expected in Borehole C is approximately 278 ohm-m at a depth of approximately 20 m (65.6 ft) bgs. For Borehole C, representative soil/sediment grab samples will be collected every 0.76 m (2.5 ft) from 1.5 m (5 ft) bgs to total depth. No split-spoon samples are planned.

The planned total depth of approximately 62 m (203.5 ft) bgs is intended to include a region of apparent low electrical resistivity, which is indicated by non-inverted data. The electrical resistivity laboratory may use quick-turnaround analyses to determine whether Tc-99 and/or nitrate concentrations are present in the depth interval where analyses are planned (refer to Table 3-4). The BC Cribs and Trenches Area Task Lead may terminate drilling before the planned total depth if Tc-99 and/or nitrate are not detected.

The electrical resistivity laboratory, in consultation with the BC Cribs and Trenches Area Task Lead, may select additional samples for electrical resistivity evaluation. No samples are required for vadose-zone characterization/CSM enhancement analyses. The sampling plan for Borehole C is shown in Table 3-4. The electrical resistivity evaluation analyses are summarized in Table 1-2.

3.2.2.4 Borehole D

For Borehole D, representative soil/sediment grab samples will be collected every 0.76 m (2.5 ft) from 1.5 m (5 ft) bgs to total depth. No split-spoon samples are planned.

The upper boundary of a 3-D inverted low electrical resistivity region is expected to occur at a depth of approximately 23.6 m (77.5 ft) bgs, and the lower boundary is expected at a depth of approximately 50.6 m (166 ft) bgs. The actual upper and lower boundaries of the low electrical resistivity region will be estimated by quick-turnaround laboratory analyses as described in Section 3.2.2.7. The BC Cribs and Trenches Area Task Lead and the electrical resistivity laboratory may adjust the soil/sediment samples that are selected for electrical resistivity evaluation (i.e., geochemical analyses) according to the quick-turnaround laboratory analytical results. The electrical resistivity laboratory may cease analyzing samples at a depth of

approximately 6 m (20 ft) below where near-background Tc-99 and nitrate concentrations are detected.

The planned total depth for Borehole D is approximately 62 m (203.5 ft) bgs. The BC Cribs and Trenches Area Task Lead may adjust the total depth based on the results of the quick-turnaround laboratory analyses described above. The sampling plan for Borehole D is shown in Table 3-5. The electrical resistivity evaluation analyses are summarized in Table 1-2.

3.2.2.5 Borehole E

Borehole E is considered an optional borehole that may be drilled depending on the results from drilling Borehole C. If no significant targeted-parameter concentrations are detected in the soil/sediment samples from Borehole C, then RL, in consultation with the EPA, may decide not to drill Borehole E. The location for Borehole E is intended to test the possibility of a false-negative outcome from interpreting electrical resistivity values. Electrical resistivity is expected in the range of background values at Borehole E. An implication is that concentrations of targeted anions, cations, and COPCs (e.g., nitrate and Tc-99) are insignificant.

If Borehole E is drilled, representative soil/sediment grab samples will be collected every 0.76 m (2.5 ft) from 1.5 m (5 ft) bgs to total depth. No split-spoon sampling is planned. The planned total depth is approximately 104 m (341.2 ft) bgs where the water table is expected.

No low electrical resistivity region is expected at this location, and no quick-turnaround laboratory analyses are planned. The electrical resistivity laboratory, in consultation with the BC Cribs and Trenches Task Lead, will select soil/sediment samples for analyzing electrical resistivity evaluation parameters. The sampling plan for Borehole E is shown in Table 3-6. As shown in Table 3-6, only electrical resistivity evaluation analyses (i.e., the primary objective) are planned for soil/sediment grab samples from Borehole E. The electrical resistivity evaluation analyses are summarized in Table 1-2.

3.2.2.6 Grab Samples

Grab samples for electrical resistivity evaluation will be collected in quart-size plastic wide-mouth containers that are capable of sealing existing moisture in the sample for a reasonable time period. If representative samples cannot be collected (e.g., if large particles do not fit in the container), notes describing the condition of the sample will be put in the geologist's log. The samples for moisture-content analysis will be contained in airtight containers. This process is used to maintain soil/sediment moisture as close to field condition as possible. The number and type of containers, sample volume, preservation methods, packing requirements, and holding time for grab samples are summarized in Table 3-8.

3.2.2.7 Quick-Turnaround Laboratory Analyses

For Boreholes A and D, quick-turnaround laboratory analyses (i.e., approximately 24 hours or less) are planned to verify the upper and lower boundaries of expected low electrical resistivity regions. For Boreholes B, C, and D, quick-turnaround laboratory analyses are planned to determine whether Tc-99 and/or nitrate concentrations are increasing, decreasing, non-detectable, or near-background levels. The BC Cribs and Trenches Task Lead and the

electrical resistivity laboratory may select additional analyses from Table 1-2 to perform on a quick-turnaround basis.

3.2.3 Geophysical Logging

Spectral-gamma geophysical logging is required for each borehole. The purpose of the logging is to determine the depth distribution of any gamma-emitting contaminants around the boreholes and to interpret subsurface lithology. The boreholes are to be logged throughout the entire drilled depth.

Neutron-moisture geophysical logging will be conducted in the boreholes to total depth to estimate the moisture profile. The neutron-moisture logging tool must be calibrated for the diameter of the borehole at the time that the logging is conducted.

Additional downhole electrical resistivity logging may be conducted in one or more of the five proposed boreholes. Downhole electrical logging would be performed to measure and evaluate changes in vadose-zone electrical resistivity as a function of depth in selected boreholes. At this time, the feasibility of such measurements is uncertain.

None of the five proposed boreholes will be decommissioned until a separate study is completed for evaluating the measurement of electrical resistivity in steel-cased boreholes. If such downhole measurements are successful, boreholes may be logged where contaminated intervals were intersected for which anomalous electrical resistivity was measured at ground surface.

3.2.4 Vertical-Electrode Arrays

Before borehole decommissioning, a vertical-electrode array (VEA) may be installed in Boreholes A, B, C, and D after sampling is completed and total depth is reached. Borehole E is optional (i.e., pending the results of drilling Borehole C) and currently is planned for completion as a monitoring well if it is drilled. There are two purposes for installing the VEAs. First, the vertical configuration of the electrical resistivity electrode arrays should allow for an improved definition of the low electrical resistivity region. Second, potential changes in the current low electrical resistivity region extent could be monitored over time. For boreholes where RL, in consultation with the EPA, approves a VEA installation, the VEA will be installed as described in WHC-SD-EN-TA-004, *Feasibility of CPT-Deployed Vertical Electrode Array in Single-Shell Tank Farms*, and in compliance with the requirements of WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells."

None of the five proposed boreholes will be decommissioned until a separate study is completed for evaluating their potential applicability for a deep vadose-zone treatability test that is being planned.

3.3 MANAGEMENT OF WASTE

Waste generated by sampling activities will be managed in accordance with an approved waste-control plan. The waste-control plan establishes the requirements for management and disposal of generated waste. Investigation-derived waste from these sampling activities will be handled as *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* waste. Unused samples and associated laboratory waste for analysis will be dispositioned in accordance with the laboratory contract and agreements concerning return to the Hanford Site. In accordance with 40 CFR 300.440, "National Oil and Hazardous Substances Pollution Contingency Plan," "Procedures for Planning and Implementing Off-Site Response Actions," Task Lead approval is required before unused samples or wastes are returned from offsite laboratories.

4.0 HEALTH AND SAFETY

- All field operations will be performed in accordance with Fluor Hanford's (or its approved subcontractor's) health and safety requirements and the appropriate Soil and Groundwater Remediation Project requirements. If necessary, a work-planning package will include an activity job-hazard analysis and/or site-specific health and safety plan and applicable radiological work permits. Work will be performed in accordance with site-specific health and safety plans and applicable radiological work permits.

This page intentionally left blank.

5.0 REFERENCES

10 CFR 830, "Nuclear Safety Management," Subpart A, "Quality Assurance Requirements," Title 10, *Code of Federal Regulations*, Part 830, Subpart A.

10 CFR 835, "Occupational Radiation Protection," Title 10, *Code of Federal Regulations*, Part 835.

40 CFR 300.440, "National Oil and Hazardous Substances Pollution Contingency Plan," "Procedures for Planning and Implementing Off-site Response Actions," Title 40, *Code of Federal Regulations*, Part 300.440.

49 CFR, "Transportation," Title 49, *Code of Federal Regulations*.

ASTM C1111-04, 2004, *Standard Test Method for Determining Elements in Waste Streams by Inductively Coupled Plasma-Atomic Emission Spectroscopy*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM C1251-95, 1995, *Standard Guide for Determination of Specific Surface Area of Advanced Ceramic Materials by Gas Adsorption*, (Withdrawn 2000), American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D422-63(2002), 2002, *Standard Test Method for Particle-Size Analysis of Soils*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D1067-06, 2006, *Standard Test Methods for Acidity or Alkalinity of Water*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D1125-95, 2005, *Standard Test Methods for Electrical Conductivity and Resistivity of Water*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D2216-05, 2005, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D2325-68(2000), 2000, *Standard Test Method for Capillary-Moisture Relationships for Coarse- and Medium-Textured Soils by Porous-Plate Apparatus*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D2488-06, 2006, *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D4327-03, 2003, *Standard Test Method for Anions in Water by Chemically Suppressed Ion Chromatography*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D4525-04, 2004, *Standard Test Method for Permeability of Rocks by Flowing Air*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D5753-05, 2005, *Standard Guide for Planning and Conducting Borehole Geophysical Logging*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D6274-98(2004), 2004, *Standard Guide for Conducting Borehole Geophysical Logging-Gamma*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D6727-01(2007), 2007, *Standard Guide for Conducting Borehole Geophysical Logging-Neutron*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM D6836-02, 2002, *Standard Test Methods for Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge*, American Society for Testing and Materials, West Conshohocken, Pennsylvania.

Bleyler, R., 1988a, *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analyses*, Hazardous Site Evaluation Division, U.S. Environmental Protection Agency, Washington, D.C.

Bleyler, R., 1988b, *Laboratory Data Validation Functional Guidelines for Evaluating Organics Analyses*, Hazardous Site Evaluation Division, U.S. Environmental Protection Agency, Washington, D.C.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9601, et seq.

D&D-31659, 2007, *Geophysical Investigations by High-Resolution Resistivity for the BC Cribs and Trenches Area, 2004-2006,* Rev. 0, Fluor Hanford, Inc., Richland, Washington.

DOE O 414.1C, *Quality Assurance*, as amended, U.S. Department of Energy, Washington, D.C.

DOE/RL-2004-66, 2005, *Focused Feasibility Study for the BC Cribs and Trenches Area Waste Sites*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Ecology, EPA, and DOE, 1989, *Hanford Federal Facility Agreement and Consent Order*, 2 vols., Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington, as amended.

EPA/240/B-01/003, 2001, *EPA Requirements for Quality Assurance Project Plans*, EPA QA/R-5, Quality Assurance Division, U.S. Environmental Protection Agency, Washington, D.C.

EPA/240/B-06/001, 2006, *Guidance on Systematic Planning Using the Data Quality Objectives Process*, EPA QA/G-4, Office of Environmental Information, U.S. Environmental Protection Agency, Washington, D.C.

EPA/240/B-06/002, 2006, *Data Quality Assessment: A Reviewers Guide*, EPA QA/G-9R, Office of Environmental Information, U.S. Environmental Protection Agency, Washington, D.C.

EPA/600/R-93/100, 1993, *Methods for the Determination of Inorganic Substances in Environmental Samples,* Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

EPA/600/R-94/111, 1994, *Methods for the Determination of Metals in Environmental Samples, Supplement 1*, U.S. Environmental Protection Agency, Washington, D.C.

EPA/600/R-96/055, 2000, *Guidance for the Data Quality Objectives Process*, EPA QA/G-4, as amended, U.S. Environmental Protection Agency, Washington, D.C. (superseded by EPA/240/B-06/001, 2006)

EPA/600/4-79/020, 1983, *Methods of Chemical Analysis of Water and Wastes*, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Hanford Environmental Information System, Hanford Site database.

NAD83, 1991, *North American Datum of 1983*, National Geodetic Survey, Federal Geodetic Control Committee, Silver Spring, Maryland, as revised.

PNNL-16531, 2007, *K_d Values for Agricultural and Surface Soils for use in Hanford Site Farm, Residential, and River Shoreline Scenarios*, Pacific Northwest National Laboratory, Richland WA.

Routson, R. C., R. W. Wildung, and R. J. Serne, 1973, "A Column Cation-Exchange-Capacity Procedure for Low-Exchange Capacity Sands," in *Soil Science*, Vol. 115, p. 107.

Rucker, *Draft Laboratory Method*, hydroGEOPHYSICS, Inc., Tucson, Arizona. (See SGW-32737)

SGW-32480, 2007, *Data Quality Objectives Summary Report for the BC Cribs and Trenches Area – High-Resolution Resistivity Correlation*, Draft A, Fluor Hanford, Inc., Richland, Washington.

SGW-32737, in work, *Field Petrophysics Test Method*, Fluor Hanford, Inc., Richland, Washington. (Contains Rucker's HGI *Draft Laboratory Method* for apparent resistivity of soil/sediments)

SW-846, 2005, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, Third Edition; Final Update III-B*, as amended, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C. Available on the Internet at www.epa.gov/SW-846/main.htm .

WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," *Washington Administrative Code*, as amended, Washington State Department of Ecology, Olympia, Washington.

Washington Administrative Code, as amended, Washington State Department of Ecology, Olympia, Washington.

Waste Information Data System Report, Hanford Site database.

WHC-SD-EN-TA-004, 1996, *Feasibility of CPT-Deployed Vertical Electrode Array in Single-Shell Tank Farms*, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

APPENDIX A

EXPLANATION OF ELECTRICAL RESISTIVITY SURFACE GEOPHYSICAL TECHNIQUE

This page intentionally left blank.

CONTENTS

A1.0 APPARENT ELECTRICAL RESISTIVITY A-1
A1.1 TARGET DISCRIMINATION WITH APPARENT RESISTIVITY A-4
A1.2 DEPTH OF INVESTIGATION A-6

A2.0 TWO- AND THREE-DIMENSIONAL RESISTIVITY INVERSION A-6
A2.1 BC CRIBS AND TRENCHES AREA ELECTRICAL RESISTIVITY DATA A-8

A3.0 REFERENCES A-9

FIGURES

Figure A-1. Setup of the Resistivity Four-Pole Array and Pseudo-Section Plotting Methodology. A-3

Figure A-2. Apparent Resistivity Pseudo-Section Comparisons for the Schlumberger, Pole-Dipole, Dipole-Dipole, and Pole-Pole Array Types for a Discrete Conductive Target in a Resistive Homogeneous Background. A-4

Figure A-3. A) Vertical Slices through Apparent Resistivity Data for Schlumberger, Dipole-Dipole, and Pole-Pole at 65 m (beside target) and 81 m (within target); B) Schematic of Linear and Nonlinear Pseudo-Section Plotting. A-5

Figure A-4. Contours of Resistivity for the Different Interpretation Algorithms Including Linear Pseudo-Section, Nonlinear Pseudo-Section, Robust Inversion (L_1-Normalization), and Smooth Inversion (L_2-Normalization). A-7

Figure A-5. Vertical Slices for Comparison of Interpretation Algorithms Including Pseudo-Section Apparent Resistivity and Inverted True Resistivity for a Discrete Conductive Target at A) 10 m Belowground Surface, B) 20 m Belowground Surface, and C) 30 m Belowground surface. A-8

Figure A-6. Comparison of Apparent and 3-D Inverted Electrical Resistivity with Nitrate Concentrations in Borehole C4191. ..... A-9

TERMS

3-D	three-dimensional
DIC	depth of investigation characteristics
DQO	data quality objective
ERT	electrical resisitivity tomography

METRIC CONVERSION CHART

Into Metric Units			Out of Metric Units		
If you know	*Multiply by*	*To get*	*If you know*	*Multiply by*	*To get*
Length			**Length**		
inches	25.40	millimeters	millimeters	0.0394	inches
inches	2.54	centimeters	centimeters	0.394	inches
feet	0.305	meters	meters	3.281	feet
yards	0.914	meters	meters	1.094	yards
miles (statute)	1.609	kilometers	kilometers	0.621	miles (statute)
Area			**Area**		
sq. inches	6.452	sq. centimeters	sq. centimeters	0.155	sq. inches
sq. feet	0.0929	sq. meters	sq. meters	10.764	sq. feet
sq. yards	0.836	sq. meters	sq. meters	1.196	sq. yards
sq. miles	2.591	sq. kilometers	sq. kilometers	0.386	sq. miles
acres	0.405	hectares	hectares	2.471	acres
Mass (weight)			**Mass (weight)**		
ounces (avoir)	28.349	grams	grams	0.0353	ounces (avoir)
pounds	0.454	kilograms	kilograms	2.205	pounds (avoir)
tons (short)	0.907	ton (metric)	ton (metric)	1.102	tons (short)
Volume			**Volume**		
teaspoons	5	milliliters	milliliters	0.034	ounces (U.S., liquid)
tablespoons	15	milliliters	liters	2.113	pints
ounces (U.S., liquid)	29.573	milliliters	liters	1.057	quarts (U.S., liquid)
cups	0.24	liters	liters	0.264	gallons (U.S., liquid)
pints	0.473	liters	cubic meters	35.315	cubic feet
quarts (U.S., liquid)	0.946	liters	cubic meters	1.308	cubic yards
gallons (U.S., liquid)	3.785	liters			
cubic feet	0.0283	cubic meters			
cubic yards	0.764	cubic meters			
Temperature			**Temperature**		
Fahrenheit	(°F-32)*5/9	Centigrade	Centigrade	(°C*9/5)+32	Fahrenheit
Radioactivity			**Radioactivity**		
picocurie	37	millibecquerel	millibecquerel	0.027	picocurie

APPENDIX A

EXPLANATION OF ELECTRICAL RESISTIVITY SURFACE GEOPHYSICAL TECHNIQUE

A1.0 APPARENT ELECTRICAL RESISTIVITY

Electrical resistivity (ρ) is a volumetric property that describes the resistance of electrical current flow within a medium. Direct electrical current is propagated in rocks and minerals by electrolytic means. Electronic conduction only occurs in metallic-luster sulfide minerals, where free electrons are available. Rocks and non-metallic minerals have extremely high resistivities (i.e., low conductivities), and direct current transmission through this material is difficult. On the other hand, porous media can carry a current through ions by way of electrolytic conduction. Electrolytic conduction relies on the dissociated ionic species within a pore space. Here, the conduction varies with the mobility, concentration, and degree of dissociation. Electrolytic conduction is relatively slow with respect to electronic conduction due to mass transfer rate limiting processes and is strongly influenced by the structure of the medium.

Estimating resistivity is not a direct process. When current (I) is applied and voltage (V) measured, Ohms law is assumed and resistance is measured. Resistivity and resistance are then related through a geometric factor over which the measurement is made. The simplest example is a solid cylinder with a cross-sectional area of A and length, L:

$$\rho = R\frac{A}{L} \tag{1}$$

In such cases where the actual volume involved in the measurement is known, the result is called the "true" resistivity and is considered to be a physical property of that material. However, field measurements involve an unknown volume of earth. Consequently, resistivity calculations are based on the hypothetical response for the given electrode geometry over a homogeneous, isotropic, and half-space. This results in what is termed "apparent" resistivity, but which is more accurately called a "half-space" resistivity.

Field data generally are acquired using an established electrode array. A four-electrode array employs electric current injected into the earth through one pair of electrodes (transmitting dipole) and the resultant voltage potential is measured by the other pair (receiving dipole). The ratio of the transmitted current and observed potential is called the transfer resistance. Some common electrode configurations are dipole-dipole, Wenner, and Schlumberger arrays. Their use depends on site conditions and the information desired. Figure A-1A, adapted from Telford et al., 1990, *Applied Geophysics*, shows a schematic of the dipole-dipole configuration, where C1 and C2 are connected to the current source (i.e., transmitting electrodes), and P1 and P2 are connected to the volt-meter (i.e., receiving electrodes). For the four-electrode array, the geometric factor, K is

$$K = 2\pi \frac{1}{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)}, \tag{2}$$

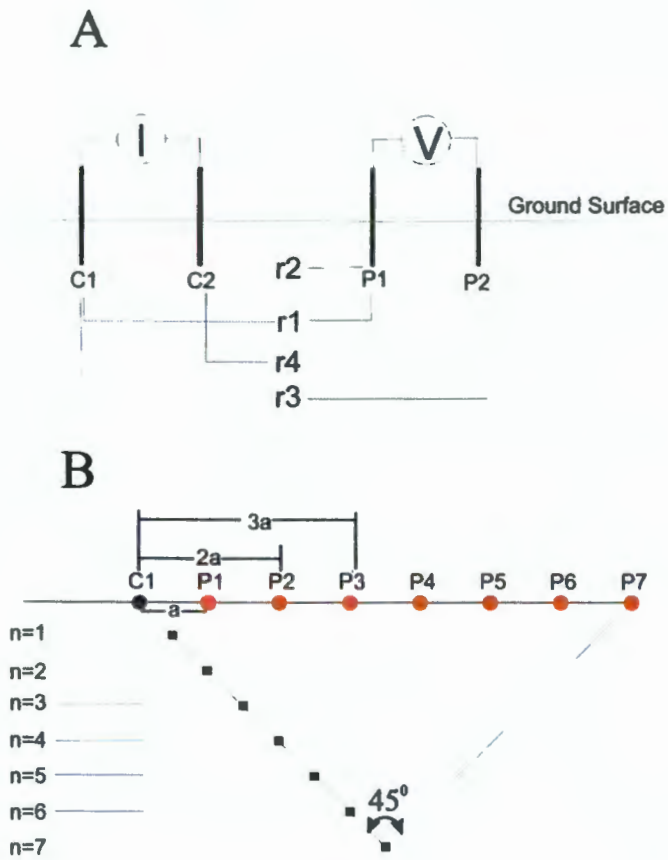
where r_1 through r_4 are defined in Figure A-1A. Equations (1) and (2) are used to estimate an apparent resistivity, which assumes that each measurement of transfer resistance was a result of point electrodes on the surface of a homogeneous, isotropic, and half-space:

$$\rho_a = 2\pi \frac{V}{I} K \tag{3}$$

where subscript "a" in ρ_a denotes the *apparent* resistivity. The apparent resistivity is not necessarily the true resistivity of the formation, but a simplified resistivity that provides a starting point for subsurface evaluation. Other assumptions used in Equation 3 are isotropy (i.e., no directional dependence of resistivity), no displacement currents (using a DC or low frequency current application), and that resistivity is constant throughout such that Laplace's equation can be assumed. Because the degree of heterogeneity is not known *a priori*, a true resistivity is not calculated from Equation 3. To obtain a true resistivity, electrical resistivity tomography (ERT) is required, which generates a model of true resistivity using an iterative inverse methodology given the measurements of apparent resistivity, electrode arrangement, and other boundary conditions. Discussions of ERT and the methods by which the true resistivity is calculated can be found in several sources, including Loke and Barker, 1996, "Rapid Least-Squares Inversion of Apparent Resistivity Pseudosections by a Quasi-Newton Method"; LaBrecque et al., 1996, "The Effects of Noise on Occam's Inversion of Resistivity Tomography Data"; and Oldenburg and Li, 1999, "Estimating Depth of Investigation in DC Resistivity and IP Surveys."

An alternative to the four-electrode array is the two-electrode pole-pole array. For the pole-pole array, one electrode from each of the current and potential pairs is fixed effectively at infinity, while the other current and potential electrodes act as "rover" electrodes within the survey transect. Practically, the infinite electrodes are spaced approximately 5 to 10 times the distance of the furthest separation of the rover electrodes, which can be up to 300 m apart for a near surface geophysical survey. The pole-pole array provides higher data density and increased signal to noise ratio, and requires less transmitted energy. Roy and Apparao, 1971, "Depth of Investigation in Direct Current Methods," discuss the superiority of the pole-pole method when conducting shallow surveys. Additionally, in some very conductive environments, where potential gradients are low, one may be forced to use the pole-pole array to simply measure a signal above the noise level of the data acquisition instrument.

Figure A-1. Setup of the Resistivity Four-Pole Array and Pseudo-Section Plotting Methodology.



The calculation of apparent resistivity is simplified in the pole-pole array:

$$\rho_a = 2\pi \frac{V}{I}(n * a) \tag{4}$$

where a is the basic electrode spacing and n is the integer multiplier as the current and potential electrodes incrementally separate. Figure A-1B demonstrates a linear transect of electrodes on the surface with the a-spacing being the separation between each electrode and the n spacing increasing as the potential electrode moves away from the current electrode. For a complete survey, each electrode has one turn at transmission, while potential measurements occur at all other electrodes in the array. Automated resistivity meters, such as the SuperSting R8[1], have the ability to conduct multi-channel sweeps of potential measurements to significantly decrease measurement time.

[1] SuperSting R8 is a trademark of AGI Advanced Geosciences, Inc., Austin, Texas.

A1.1 TARGET DISCRIMINATION WITH APPARENT RESISTIVITY

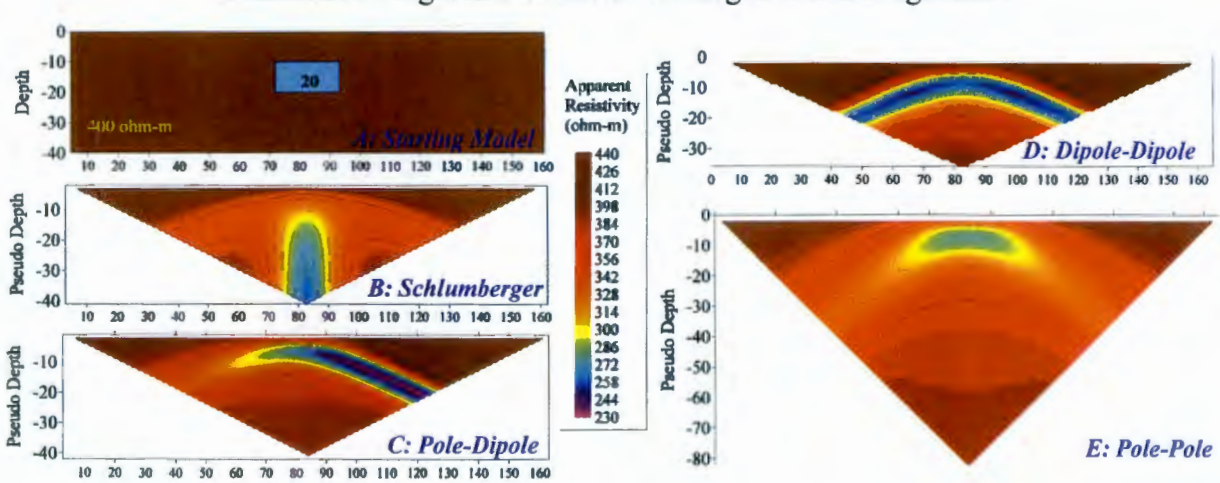
The linear transect arrangement of electrodes produces a two-dimensional data set of apparent resistivity as a function of x and z, where z is the dimension into the earth and x is along the surface. Although apparent resistivity is a function of the volume over which the measurement is made, its location typically is plotted as a point for ease of representation. The location of the point is a function of n and is loosely related to the depth of investigation. Hallof, 1957, "On the Interpretation of Resistivity and Induced Polarization Measurements," demonstrated that the intersection of two 45^0 lines extending downward from each of the current and voltage potential electrodes would produce a suitable pseudo-section for interpretation. Others have used similar techniques to plot, for example, the depth to the maximum sensitivity in the electrode separation (see Roy and Apparao, 1971). Using the Hallof approach, the pole-pole array has data plotted at a pseudo-depth of:

$$-z_{pseudo} = 0.5na\,, \tag{5}$$

which is a linear plotting method.

Figure A-2 is an apparent resistivity demonstration of several array types, including the pole-pole array with a resistive half-space earth (400 ohm-m) and a graded conductive target (20 ohm-m). The target dimensions are 21 by 10 m, and the top of the target is located at 10 m belowground surface. The target was modeled with a forward resistivity model in EarthImager2D[2] using the basic algorithm of Dey and Morrison, 1979, "Resistivity Modeling for Arbitrarily Shaped Three-Dimensional Structures." Many electrical resistivity modeling codes use some elements of this algorithm, including RES2DINV (Loke and Barker 1996) and DCIP2D (Li and Oldenburg, 1994, "Inversion of 3-D DC Resistivity Data Using an Approximate Inverse Mapping").

Figure A-2. Apparent Resistivity Pseudo-Section Comparisons for the Schlumberger, Pole-Dipole, Dipole-Dipole, and Pole-Pole Array Types for a Discrete Conductive Target in a Resistive Homogeneous Background.

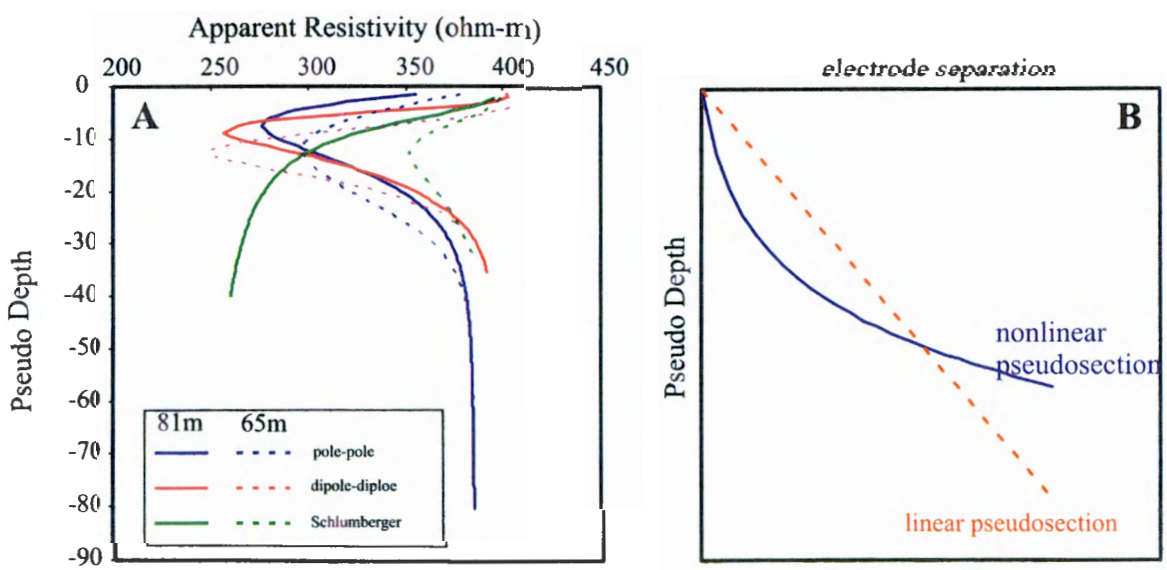


[2] EarthImager is a trademark of AGI Advanced Geosciences, Inc., Austin, Texas.

Qualitatively, the pole-pole apparent resistivity pseudo-section in Figure A-2 resembles the starting target more closely than the other arrays. The dipole-dipole and pole-dipole show extremely conductive "pantleg" effects, where the target's edge has been smeared diagonally downward, when the data are analyzed using an apparent resistivity algorithm. Because the apparent resistivity plotting routine contains information based on a volume-averaged measurement, artifacts such as pantleg effects can be expected. The apparent resistivity plot of the Schlumberger array shows a straight vertical smearing as if it were an intrusive conductive dike. On the other hand, the pole-pole array measures the electrical potential gradient relative to a fixed pole at infinity. In the earth, the infinite pole should essentially have no interaction with the electrical field and is modeled near the boundary condition of $V|_{\infty} = 0$. The result is a measurement of the actual potential as opposed to the gradient in potential measured for closely spaced dipoles, and a less pronounced pantleg smearing effect.

Another view of the apparent resistivity data can be seen in Figure A-3, where vertical slices of data have been extracted at 81 m (center of the domain) and at 65 m. Figure A-3A shows these slices as a function of the pseudo-depth for all but the pole-dipole array. In general, the pole-pole and dipole-dipole array show a decrease in resistivity at 81 m (solid lines) that is loosely coincident with the target depth, while the Schlumberger array does not resemble the character of the target at all. Off-center at 65 m (dashed lines), where the actual resistivity is a resistive homogeneous body, the pseudo-section of the pole-pole shows less of an effect than the dipole-dipole. The Schlumberger array resembles the actual background better at the 65 m slice.

Figure A-3. A) Vertical Slices through Apparent Resistivity Data for Schlumberger, Dipole-Dipole, and Pole-Pole at 65 m (beside target) and 81 m (within target); B) Schematic of Linear and Nonlinear Pseudo-Section Plotting.



A1.2 DEPTH OF INVESTIGATION

The depth of investigation stems from a need to relate a measurement made at the surface to some particular depth in order that survey parameters can be optimized for target identification (Barker, 1989, "Depth of Investigation of Collinear Symmetrical Four-Electrode Arrays." Before tomographic inversion was common practice among geophysicists to estimate the true resistivity from measured apparent resistivity, apparent resistivity pseudo-sections were used primarily for interpretation of subsurface electrical anomalies. Field practitioners became quite efficient at locating the depth to specific targets, such as ore bodies. The presentation of the pseudo-section is important in these regards. Additionally, the pole-pole array, above all others, provides the weakest edge effects, thereby facilitating the direct interpretation of these data more reliably (Robain et al., 1999, "The Location of Infinite Electrodes in Pole-Pole Electrical Surveys: Consequences for 2D Imaging").

The traditional linear pseudo-section of Hallof (1957) has limitations with respect to a physical meaning of the earth. Therefore, many researchers have taken a closer examination of the plotting method to allow for a more reasonable geological interpretation. The most widely accepted depth of investigation studies are those presented by Roy and Apparao (1971), Roy, 1972, "Depth of Investigation in Wenner, Three-Electrode, and Dipole-Dipole DC Resistivity Methods," and Koefoed, 1972, "Depth of Investigation in Direct Current Methods," who defined a depth of investigation characteristics (DIC) model for determining the depth of a measurement. The DIC was determined by finding the depth at which a thin horizontal layer within a homogeneous background makes the maximum contribution to the total measured signal at the surface. The results were consistent in that the depth of investigation is a nearly logarithmic function of electrode spacing, regardless of how the depth of investigation is defined. This suggests a modification of the linear pseudo-section (Edwards, 1977, "A Modified Pseudosection for Resistivity and IP," and Fink, 1980, "Logarithmic Pseudosections"). Figure A-3B shows an example of a nonlinear pseudo-section, based on a logarithmically-based depth interpretation based on the electrode separation.

To facilitate the nonlinear depth plotting of apparent resistivity data, a function of the logarithm of the n-spacing value can be used. The coefficients of the function usually are determined by using collocated borehole data or based on standardized values developed over years of experience. The consequences of a nonlinear pseudo-section are shown in Figure A-3B, where the resistivity values near the surface are pushed deeper relative to the linear pseudo-section and the deeper resistivity is pulled up relative to the linear pseudo-section. At one point, the two plotting strategies have the same depth location for a given electrode separation.

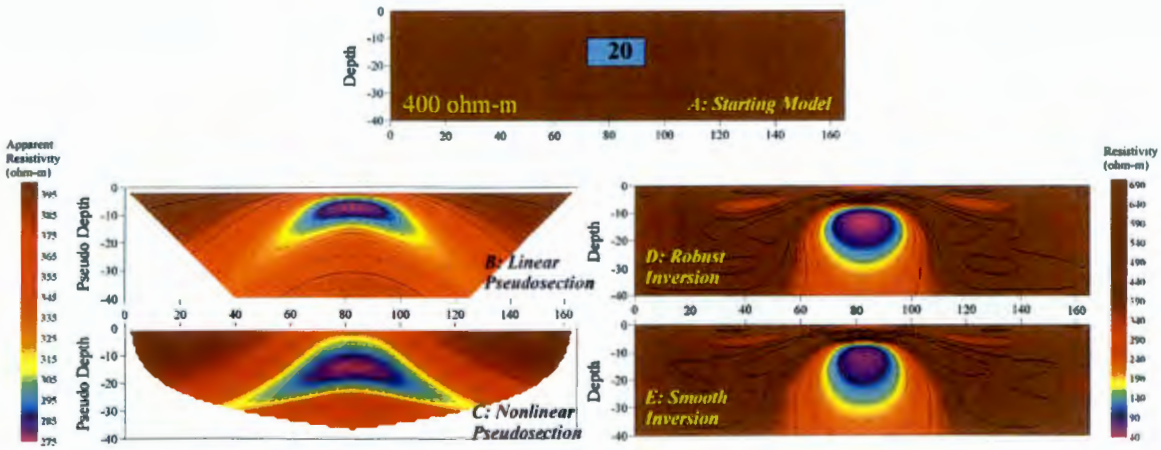
A2.0 TWO- AND THREE-DIMENSIONAL RESISTIVITY INVERSION

Typically after data collection, the apparent resistivity data are run through an inversion routine to estimate the true resistivity values that give rise to the measured resistivity. These models are based on either finite element or finite difference. In any case, the inversion method is nonlinear and requires an iterative solver. During the iterations, distributions of true resistivities are estimated and the forward model calculates the voltage at the surface coincident with electrode locations. The differences between measured and modeled voltages are compared, and

resistivities in regions showing large discrepancies are changed. The inversion model runs until the measured and modeled data are satisfactorily compared. In this way, the objective of the inversion is to minimize the difference between the modeled and measured resistivity, usually in a least squares sense. The objective function can be defined in many different ways, such as using the L_1-normalization (robust inversion) or L_2-normalization (smooth inversion) (Dahlin and Zhou, 2004, "A Numerical Comparison of 2D Resistivity Imaging with 10 Electrode Arrays"). Compared to the damped least squares method with no normalization and L_1-normalization, the L_2-normalization is optimal at resolving smoother boundaries typical for conductive plumes and most hydrologic boundaries (deGroot-Hedlin and Constable, 1990, "Occam's Inversion to Generate Smooth, Two-Dimensional Models from Magnetotelluric Data"; deGroot-Hedlin and Constable, 2004, "Inversion of Magnetotelluric Data for 2D Structure with Sharp Resistivity Contrasts"; and Loke et al., 2003, "A Comparison of Smooth and Blocky Inversion Methods in 2D Electrical Imaging Surveys").

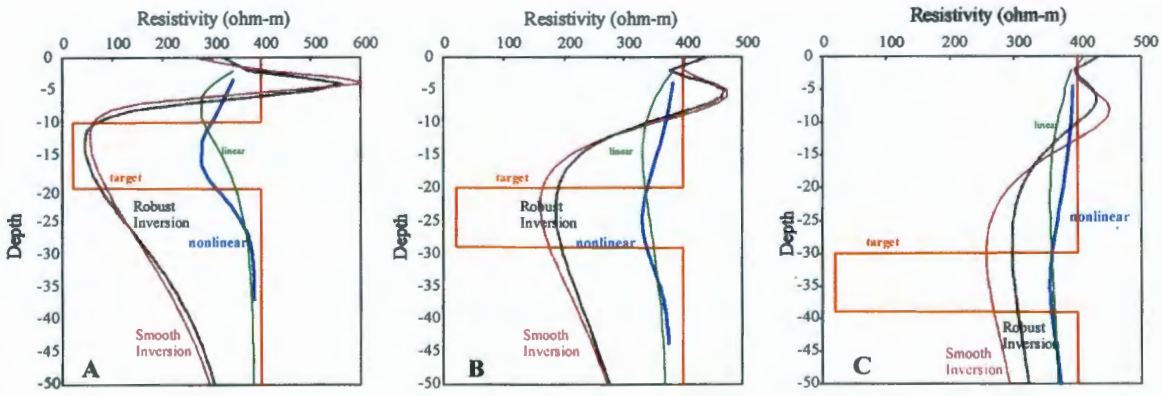
For the simple target problem identified in Figure A-2, the measured apparent resistivity data were inverted using EarthImager2D. Both robust and smooth models were evaluated with the results of the inversion shown in Figure A-4. The final goodness-of-fit statistic, as measured by the root-mean-square error, was 0.91 and 0.67 for the robust and smooth inversion results, respectively. For comparison, the linear and nonlinear pseudo-section data are plotted to the left of the inversion results. All of the contoured resistivity and apparent resistivity data show a target in the general location of the actual target location. Additionally, all methods appear to smear the information laterally or vertically, referring to a smooth condition where boundaries may not be as well defined. For the apparent resistivity plots, the lateral boundaries of the interpreted target are smeared by pantleg effects. For the inverted resistivity plots, the vertical information below the target is smeared.

Figure A-4. Contours of Resistivity for the Different Interpretation Algorithms Including Linear Pseudo-Section, Nonlinear Pseudo-Section, Robust Inversion (L_1-Normalization), and Smooth Inversion (L_2-Normalization).



To demonstrate the vertical smearing effects more concretely, Figure A-5 includes vertical resistivity slices at 81 m along the transect for both sets of inversions and for all three target models examined. In all three models, the minimum resistivity value is closer to the surface for the inversion results than the nonlinear pseudo-section, but not as close as the linear pseudo-section. Another major observation is that the gradient of resistivity is more asymmetrical for the inversion, where the change in resistivity to define the target is high close to the surface and low at depth. With these simplified models, it appears that the apparent resistivity may prove to be a useful tool for preliminary interpretation of simple discrete subsurface targets before inversion. Furthermore, if external information exists such as borehole information, the pseudo-depth can be converted to a depth that is closer to the target horizon.

Figure A-5. Vertical Slices for Comparison of Interpretation Algorithms Including Pseudo-Section Apparent Resistivity and Inverted True Resistivity for a Discrete Conductive Target at A) 10 m Belowground Surface, B) 20 m Belowground Surface, and C) 30 m Belowground surface.



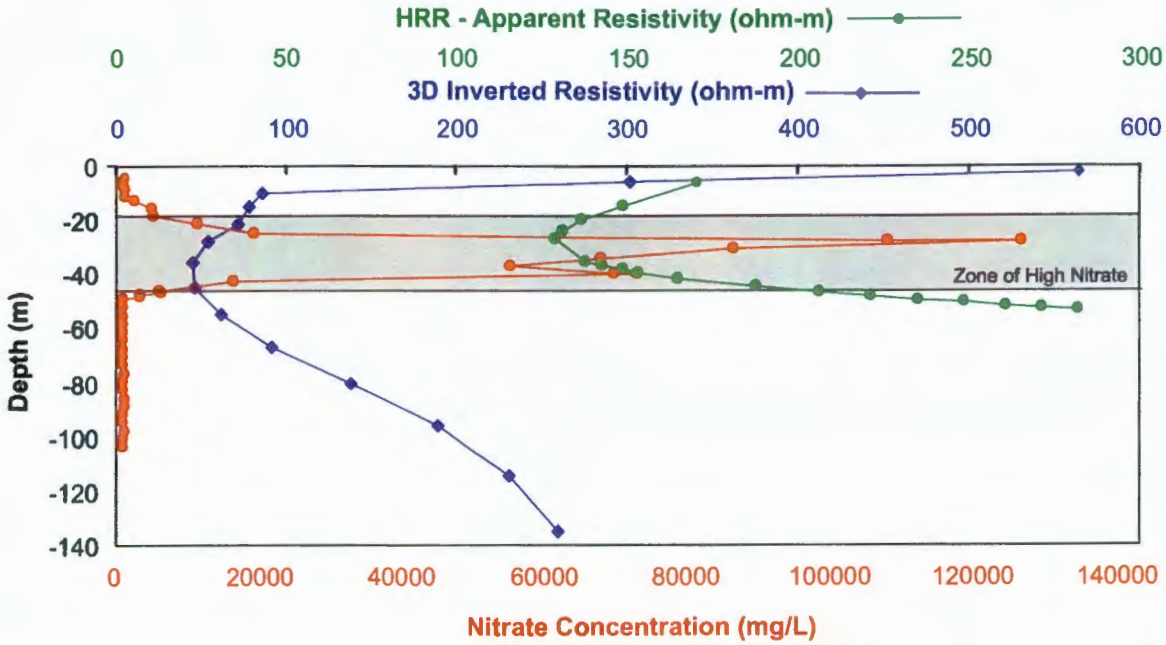
A2.1 BC CRIBS AND TRENCHES AREA ELECTRICAL RESISTIVITY DATA

The electrical resistivity data for the BC Cribs and Trenches Area were processed with EarthImager 3DCL, Version 1.0.1, a three-dimensional (3-D) inversion computer program. The electrical resistivity data for the BC Cribs and Trenches Area were divided into four geographic subsets as shown on the borehole location maps in this sampling and analysis plan. Each geographic subset then was processed with EarthImager 3DCL. The results of the 3-D inversion processing are shown on the location maps and vertical profiles for the five proposed boreholes. The 3-D inverted data are the primary basis for selecting both borehole locations and the planned depth intervals for analyzing soil/sediment samples.

Apparent electrical resistivity (i.e., "high resolution resistivity") data for the BC Cribs and Trenches Area previously were correlated with laboratory analytical data from Borehole C4191, which was drilled in Trench 216-B-26. Depth distribution profiles for selected analytes in Borehole C4191 are shown in Figure 1-21 of this SAP. The apparent resistivity, 3-D inverted resistivity, and nitrate concentrations for Borehole C4191 are compared in the vertical profile in Figure A-6. The vertical profile illustrates a strong correlation between relatively high nitrate concentrations and both apparent and inverted electrical resistivity data. The measured electrical

resistivity is lowest in the depth interval where the highest nitrate concentrations are found. Figure A-6 also illustrates a vertical "smearing effect" in the 3-D inverted resistivity data, especially at the lower boundary of the high concentration nitrate zone.

Figure A-6. Comparison of Apparent and 3-D Inverted Electrical Resistivity with Nitrate Concentrations in Borehole C4191.



A3.0 REFERENCES

Barker, R. D., 1989, "Depth of Investigation of Collinear Symmetrical Four-Electrode Arrays," *Geophysics,* 54(8):1031-1037.

Dahlin, T. and B. Zhou, 2004, "A Numerical Comparison of 2D Resistivity Imaging with 10 Electrode Arrays," *Geophysical Prospecting,* 52:379-398.

deGroot-Hedlin, C., and S. Constable, 1990, "Occam's Inversion to Generate Smooth, Two-Dimensional Models from Magnetotelluric Data," *Geophysics,* 55(12):1613-1624.

deGroot-Hedlin, C., and S. Constable, 2004, "Inversion of Magnetotelluric Data for 2D Structure with Sharp Resistivity Contrasts," *Geophysics,* 69(1):78-86.

Dey, A., and H. F. Morrison, 1979, "Resistivity Modeling for Arbitrarily Shaped Three-Dimensional Structures," *Geophysics,* 44(4):753-780.

Edwards, L. S., 1977, "A Modified Pseudosection for Resistivity and IP," *Geophysics,* 43(5):1020-1036.

Fink, J. B., 1980, "Logarithmic Pseudosections," Abstract, Proceedings of the 50th Ann. Mtg. Soc. Expl. Geophysicists.

Hallof, P. G., 1957, "On the Interpretation of Resistivity and Induced Polarization Measurements," PhD Dissertation, Massachusetts Institute of Technology (MIT), Cambridge, Massachusetts.

Koefoed, O., 1972, Discussion on "Depth of Investigation in Direct Current Methods," by A. Roy and A. Apparao, *Geophysics,* 37(5):703-704.

LaBrecque, D. J., M. Miletto, W. Daily, A. Ramirez, and E. Owen, 1996, "The Effects of Noise on Occam's Inversion of Resistivity Tomography Data," *Geophysics,* 61(2):538-548.

Li, Y., and D. W. Oldenburg, 1994, "Inversion of 3-D DC Resistivity Data Using an Approximate Inverse Mapping," *Geophysical Journal International,* 116:527-537.

Loke, M. H., and R.D. Barker, 1996, "Rapid Least-Squares Inversion of Apparent Resistivity Pseudosections by a Quasi-Newton Method," *Geophysical Prospecting,* 44(1):131-152.

Loke, M. H., I. Acworth, and T. Dahlin, 2003, "A Comparison of Smooth and Blocky Inversion Methods in 2D Electrical Imaging Surveys," *Exploration Geophysics,* 34(3):182-187.

Oldenburg, D. W., and Y. Li, 1999, "Estimating Depth of Investigation in DC Resistivity and IP Surveys," *Geophysics,* 64(2):403-416.

Robain, H., Y. Albouy, M. Dabas, M. Descloitres, C. Camerlynck, P. Mechler, Pierre and A. Tabbagh, 1999, "The Location of Infinite Electrodes in Pole-Pole Electrical Surveys: Consequences for 2D Imaging," *Journal of Applied Geophysics,* 41(4):313-333.

Roy, A., 1972, "Depth of Investigation in Wenner, Three-Electrode, and Dipole-Dipole DC Resistivity Methods," *Geophyscial Prospecting,* 20:329-340.

Roy, A., and A. Apparao, 1971, "Depth of Investigation in Direct Current Methods," *Geophysics,* 36(5):943-959.

Telford, W. M., L. P. Geldart, and R. E. Sheriff, 1990, *Applied Geophysics*, Cambridge University Press, Cambridge, United Kingdom.

DISTRIBUTION

Onsite

3	U.S. Department of Energy Richland Operations Office	
	DOE Public Reading Room	H2-53
	B. L. Foley (2)	A6-38
4	Pacific Northwest National Laboratory	
	Hanford Technical Library	P8-55
	C. F. Brown	P7-22
	R. J. Serne	P7-22
	A. L. Ward	K9-33
6	Fluor Hanford, Inc.	
	M. W. Benecke	E6-44
	L. R. Fitch	E6-44
	B. H. Ford	E6-44
	W. R. Thackaberry	E6-35
	R. W. Oldham	E6-35
	C. S. Wright	E6-35
2	Lockheed Martin Enterprise Solutions and Services	
	Administrative Record	H6-08
	Document Clearance	H6-08

This page intentionally left blank.