

**Pacific Northwest
National Laboratory**

Operated by Battelle for the
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**Characterization of Vadose Zone
Sediment: Borehole C3103 Located in
the 216-B-7A Crib and Selected
Samples from Borehole C3104 Located
in the 216-B-38 Trench Near the BX
Tank Farm**

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Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

The overall goals of the of the Tank Farm Vadose Zone Project, led by CH2M HILL Hanford Group, Inc., are 1) to define risks from past and future single-shell tank farm activities, 2) to identify and evaluate the efficacy of interim measures, and 3) to aid via collection of geotechnical information and data, the future decisions that must be made by the Department of Energy regarding the near-term operations, future waste retrieval, and final closure activities for the single-shell tank Waste Management Areas. For a more complete discussion of the goals of the Tank Farm Vadose Zone Project, see the overall work plan, *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas* (DOE 1999). Specific details on the rationale for activities performed at the B-BX-BY waste management area are found in *Site Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA B-BX-BY* (Rogers and Knepp 2000).

To meet these goals, CH2M HILL Hanford Group, Inc. tasked scientists from the Pacific Northwest National Laboratory to perform detailed analyses of vadose zone sediment, both uncontaminated and contaminated, from within the B-BX-BY Waste Management Area.

Specifically, this report contains a summary of the geologic, geochemical, and selected physical characterization data collected on vadose zone sediment recovered from borehole C3103 (B7A crib), a few sediment samples from C3104 (trench 216-B-38), and supplemental data provided from borehole C3104 reported by Bechtel Hanford, Inc. in *Borehole Summary Report for Boreholes C3101, C3341, C3342, C3343, and C3344, in the 216-B-38 Trench and 216-B-7A Crib, 200-TW-2 Tank Waste Group Operable Unit* (Todd and Trice 2002).

This document describes all the characterization data collected and interpretations assembled by the Applied Geology and Geochemistry Group within the Pacific Northwest National Laboratory Environmental Technology Division and will be incorporated in *Field Investigation Report Waste Management Area B-BX-BY* (Knepp 2002). This report is divided into sections that describe the geology, the geochemical characterization methods employed, the geochemical results, as well as the summary and conclusions, and references cited.

Acknowledgments

This work was conducted as part of the Tank Farm Vadose Zone Project led by CH2M HILL Hanford Group, Inc. in support of the U.S. Department of Energy Office of River Protection. The authors wish to thank Anthony J. Knepp, Fredrick M. Mann, David A. Myers, Thomas E. Jones, and Harold A. Sydnor with CH2M HILL Hanford Group, Inc.; Marc I. Wood with Fluor Hanford, Inc.; and Raziuddin Khaleel with Fluor Federal Services for their support of this work. We would also like to express our gratitude to Robert Yasek with the Department of Energy Office of River Protection. Finally, we wish to thank David Payson and Rose Urbina, both with Pacific Northwest National Laboratory, for their editorial and production support.

Acronyms and Abbreviations

%	percent
°C	°Celsius
°F	°Fahrenheit
µg/g	micrograms/gram
µm	micrometer
bgs	below ground surface
Ci	curies
cm	centimeter
DOE	U.S. Department of Energy
EC	electrical conductivity
EPA	U.S. Environmental Protection Agency
ft	feet
g	grams
gal	gallons
GEA	gamma energy analysis
ICP-MS	inductively coupled plasma-mass spectrometry
ICP-OES	inductively coupled plasma-optical emission spectrometry
in.	inches
L	liters
m	meters
M	molar
MDA	minimum detectable activity
mm	millimeters
mS	millisiemens
pCi/g	picocuries/gram
PNNL	Pacific Northwest National Laboratory
TRU	transuranics
WMA	Waste Management Area

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1.0 Introduction

The overall goals of the Tank Farm Vadose Zone Project, led by CH2M HILL Hanford Group, Inc., are 1) to define risks from past and future single-shell tank farm activities, 2) to identify and evaluate the efficacy of interim measures, and 3) to aid, via collection of geotechnical information and data, the future decisions that must be made by the U.S. Department of Energy (DOE) regarding the near-term operations, future waste retrieval, and final closure activities for the single-shell tank Waste Management Areas (WMA). For a more complete discussion of the goals of the Tank Farm Vadose Zone Project, see the overall work plan, *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for the Single-Shell Tank Waste Management Areas* (DOE 1999). To meet these goals, CH2M HILL Hanford Group, Inc. tasked scientists from Pacific Northwest National Laboratory (PNNL) to perform detailed analyses of contaminated vadose zone sediment collected during the emplacement of borehole C3103 through the 216-B-7A crib.

The 216-B-7A crib is located just north of the B tank farm and consists of an open-interior wooden structure. The crib was constructed as a box measuring 3.7 meters (m) long by 3.7 m wide by 1.3 m high (12 feet [ft] by 12 ft by 4 ft) of 0.18-m (6-inch [in.]) square timbers. The crib was in operation from 1946 to 1967 and received more than 20 million liters (L) (5 million gallons [gal]) of waste from the 221-B Building. The primary waste stream discharged to the crib was a low-salt, neutral-to-basic solution that contained transuranics (TRU) and fission products. The radionuclide inventory discharged to the 216-B-7A and 216-B-7B cribs consisted of 43 curies (Ci) of cesium-137, 2,000 Ci of strontium-90, 0.25 Ci of plutonium, and 600 Ci of uranium. Gross gamma logging of boreholes in the vicinity of the 216-B-7A/7B cribs (boreholes 299-E33-18, 299-E33-58, 299-E33-59, and 299-E33-75) identified elevated gamma activity to a depth of approximately 30 m (100 ft) below the 216-B-7A/7B cribs. In addition, the groundwater beneath these cribs is contaminated with uranium.

This document describes the borehole characterization data collected and interpretations assembled by the Applied Geology and Geochemistry Group within the PNNL Environmental Technology Division for a borehole drilled through the 216-B-7A crib. Specifically, this report contains geologic, geochemical, and selected physical characterization data collected on vadose zone sediment recovered from borehole C3103; a location map is presented in Section 2.

2.0 Geology

2.1 Drilling and Sampling

Borehole C3103 was drilled directly through the 216-B-7A crib (Figure 2.1). This borehole was initially drilled to a depth of 17.2 m (56.5 ft), backfilled with silica sand, and then redrilled to final depth of 67.8 m (222.5 ft) (DOE-RL 2002). The borehole was drilled using cable tool-drive barrel methods. Splitspoon samples were collected from 14 discrete depths throughout the borehole, with 10 of these locations occurring in the top 12.2 m (40 ft). DOE-RL (2002) reported the results of laboratory analyses of these samples and subsamples. Grab samples, primarily collected from the contents of the drive barrel

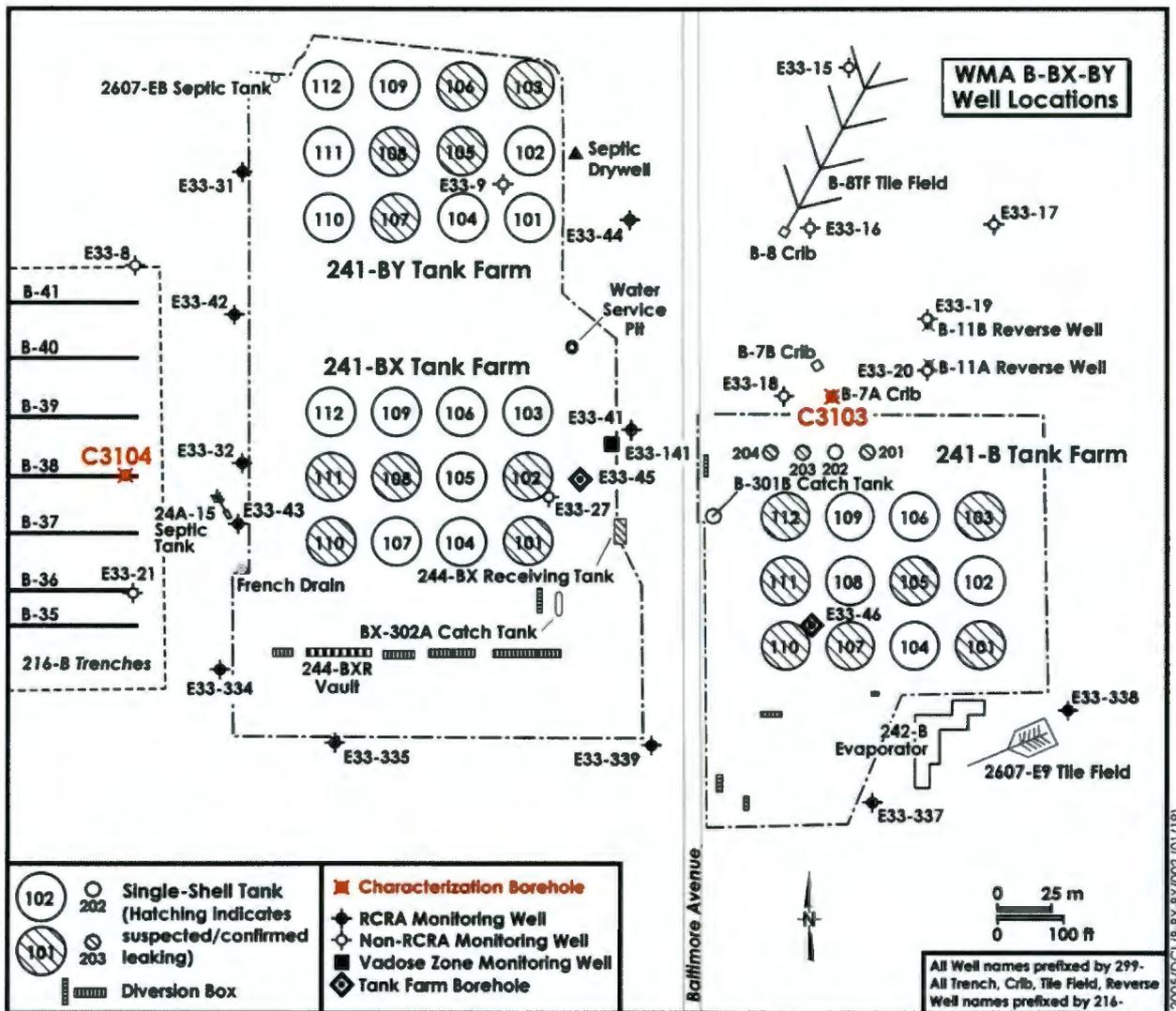


Figure 2.1. Map Showing the Location of the Boreholes in 216-B-38 Trench and 216-B-7A Crib

(DOE-RL 2002), were collected at roughly 10-ft intervals throughout the lower 61 m (200 ft) of the borehole. Borehole geophysical logging was also conducted, using both spectral gamma and neutron-neutron moisture tools (DOE-RL 2002).

2.2 Borehole Geology

The geologic materials penetrated by this borehole have been interpreted primarily from the geologists' logs of the borehole cuttings, the borehole geophysical logs, and correlations with other recently installed boreholes. DOE-RL (2002) identified four principal geologic materials: 1) backfill, 2) gravel-dominated Hanford formation, 3) sand-dominated Hanford formation, and 4) Hanford formation/Plio-Pleistocene unit silt.

2.2.1 Backfill

DOE-RL (2002) identified the backfill as extending from the surface to a depth of 70.1 m (23 ft), with the wooden crib structure encountered at a depth of 6.4 m (21 ft), and the base of the crib estimated to be at 70.1 m (23 ft); this is consistent with the depth reported by Maxfield (1976). The geologists' logs indicate that the backfill consists primarily of brown (10YR5/3), very poorly sorted, silty, sandy gravel to moderately sorted, slightly silty, gravelly sand with 10 to 50% gravel. The gravel fraction was described as mainly medium to very coarse pebble with a maximum particle size of 55 millimeters (mm) with the exception of a boulder encountered in the top 0.76 m (2.5 ft). These materials were further described as moist with a strong reaction to dilute hydrochloric acid. The geologists logs report finding wood (presumably from the crib structure) at a depth of 6.4 to 7.01 m (21 to 23 ft). The logs also reported that the materials from this depth (6.4 to 7.01 m [21 to 25 ft]) were very moist (but not saturated) and that the wood was wet.

2.2.2 Hanford Formation

DOE-RL (2002) describes the Hanford formation beneath the backfill as consisting of a gravel-dominated sequence (equivalent to the Hanford H1 unit) and a sand-dominated sequence (equivalent to the Hanford H2 unit). A less coarse (gravelly sand) unit equivalent to the Hanford H3 unit found in nearby wells (Serne et al. 2002a, 2002b; Lindenmeier et al. 2002) has not been identified. However, a thin fine-grained sequence of silty sand and slightly-silty sand found between depths of 51.3 to 54.8 m (168.5 to 180 ft) may be equivalent to fined-grained materials found above the Hanford H3 unit (where identified).

2.2.3 Gravel-Dominated Sequence (Hanford H1 Unit)

The gravel-dominated sequence is believed to be equivalent to the Hanford H1 unit. DOE-RL (2002) defines the gravel-dominated sequence as occurring between the depths of 7.01 m and 10.7 m (23 ft and 35 ft) below ground surface (bgs). The geologists' logs describe these materials as a very dark grayish brown (10YR3/2), very poorly sorted, silty sandy gravel. The materials are 25 to 35% gravel, generally consisting of fine to medium pebble ranging up to 50 millimeters (mm), and composed mainly of basalt. The materials were described as wet at 7.6 to 7.9 m (25 to 26 ft) bgs and moist below that, with no to weak reaction to dilute hydrochloric acid.

2.2.4 Sand-Dominated Sequence (Hanford H2 unit)

DOE-RL (2002) reported the sand-dominated sequence as extending from a depth of 35 ft to 218 ft. This sequence is believed to be equivalent to the Hanford H2 unit. The top 1.5 m (5 ft) of this unit (10.6 to 66.4 m [35 to 40 ft]) is described as gravelly, silty sand containing approximately 13% gravel up to 32 mm and 12% silt. The sand fraction is described as predominantly fine to medium sand.

The next 32 m (105 ft) (12.1 to 44.2 m [40 to 145 ft] bgs) is generally described as moderately sorted sand, ranging from mostly coarse to medium sand, to very coarse to medium sand, with occasional pebbles up to 10 mm. The materials are described as very loose to weakly cemented, with little to no reaction to dilute hydrochloric acid (with the exception of one zone from 15.2 to 17 m [50 to 56.5 ft] bgs described as having a weak to strong reaction to hydrochloric acid). The materials are generally dark grayish brown (10YR4/2) with the sand composed mostly (60 to 90%) of basalt.

Numerous cemented zones are identified starting at the 44.2-m (145-ft) depth. Here the sand is described as less sorted (poorly sorted) coarse to fine sand, with a strong reaction to dilute hydrochloric acid. From 45.7 to 51.4 m (150 to 168.5 ft) bgs, this coarse to fine sand (with 5 to 10% silt) is further described as interstratified with very coarse to medium sand. These materials are still weakly cemented with weak to strong reactions to dilute hydrochloric acid.

A thin, fine-grained sequence of silty sand and slightly-silty sand was encountered between the depths of 168.5 ft and 180 ft bgs. A 0.15-m (0.5-ft) thick silty sand was encountered from 51.4 to 51.5 m (168.5 to 169 ft) bgs, and was described as brown (10YR5/3), moist, and poorly sorted, with 25 to 35% silt and mostly medium to very coarse sand. The materials were further described as non-plastic and weakly cemented, with strong reaction to hydrochloric acid. Below this depth, the materials are described as brown (10YR4/3) slightly-silty sand, with 10 to 15% silt, and mostly very fine to coarse sand. The materials were described as very weakly cemented, with only a weak reaction to hydrochloric acid. A second silty sand stringer was encountered at 52.6 m (172.5 ft) bgs.

From 55 to 66.4 m (180 to 218 ft) bgs, the materials are described as poorly sorted sand with 5 to <10% silt and very little gravel. The sand ranged from mostly very coarse to fine, to very coarse to medium. The maximum gravel size ranged from 4 to 15 mm. The material was described as brown (10YR4/3) to light brown (10YR6/3), moist to nearly dry, weakly cemented, and with weak to no reaction to hydrochloric acid. Basalt content ranged from 40 to 60%. Material deeper in the profile (61 m to 66.4 m [200 to 218 ft] bgs) contained some zones described as very compact with some intact clumps recovered that exhibited strong reaction to hydrochloric acid.

2.2.5 Hanford Formation/Plio-Pleistocene Unit (PPlz)

DOE-RL (2002) correlates the material below 66.4 m (218 ft) bgs to the bottom of the borehole (67.8 m [222.5 ft]) with the Hanford formation/Plio-Pleistocene unit described by Serne et al. (2002a, 2002b, 2002c) and Wood et al. (2000). The field geologist described these materials as light grayish brown (10YR6/2) silt, well sorted, with strong reaction to hydrochloric acid. The material was described as moist with a zone of saturation occurring between the depths of 66.7 and 67 m (219 and 219.5 ft) bgs.

3.0 Geochemical Methods and Materials

This section discusses the methods and philosophy used to determine which borehole samples would be characterized and the parameters that would be measured and analyzed in the laboratory. It also describes the materials and methods used to conduct analyses of the physical, geochemical, and radioanalytical properties of the sediment from borehole C3103.

3.1 Sample Inventory

The Applied Geology and Geochemistry Group received a total of 27 grab samples from borehole C3103 for analysis and evaluation. The sample depths ranged from 6.7 m (22 ft) to 67.5 m (221.5 ft) bgs. Samples were identified using a project-specific prefix, in this case either 7A or B100, followed by a specific sample identification suffix, such as 7A-22 or B10024.

3.2 Approach

The objective of the 216-B-7A crib characterization study was to quantify the extent of penetration of mobile contaminants into the vadose zone sediment from the intentional discharge of more than 20 million liters (5 million gallons) of waste solutions to the environment. During initial examination of the grab samples, they were subsampled for moisture content, gamma-emission radiocounting, 1:1 water extracts (which provided soil pH, electrical conductivity [EC], cation, and anion data), total carbon and inorganic carbon content, and 8 M nitric acid extracts (which provided a measure of the total leachable sediment content of contaminants). The remaining sediment from each grab sample was then sealed and placed in cold storage.

3.3 Materials and Methods

During subsampling of the grab samples, every effort was made to minimize moisture loss and prevent cross-contamination between samples. Depending on the sample matrix, very coarse pebbles and larger material (i.e., >32 mm) were avoided during subsampling. Larger substrate was excluded to provide moisture content representative of counting and 1:1 sediment:water extract samples. Therefore, the results from the subsample measurements may contain a possible bias toward higher concentrations for some analytes that would be preferentially associated with the smaller sized sediment fractions.

Procedure ASTM D2488-93 (1993) was followed for visual descriptions and geologic description of all grab samples.

3.3.1 Moisture Content

Gravimetric water contents of the sediment samples from each grab sample were determined using PNNL procedure PNL-MA-567-DO-1 (PNL 1990). This procedure is based on the American Society for Testing and Materials procedure "Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass" (ASTM D2216-98 [ASTM 1998]). One representative subsample of at least 15 to 70 grams (g) was taken from each grab sample. Sediment samples were placed in tared

containers, weighed, and dried in an oven at 105°Celsius (°C) (221°Fahrenheit [°F]) until constant weight was achieved, which took at least 24 hours. The containers were removed from the oven, sealed, cooled, and weighed. At least two weighings, each after a 24-hour heating, were performed to ensure that all moisture was removed. All weighings were performed using a calibrated balance. A calibrated weight set was used to verify balance performance before weighing samples. The gravimetric water content was computed as the percentage change in soil weight before and after oven drying.

3.3.2 1:1 Sediment:Water Extracts

The water-soluble inorganic constituents were determined using a 1:1 sediment:deionized-water extract method. This method was chosen because the sediment was too dry to easily extract vadose zone porewater. The extracts were prepared by adding an exact weight of deionized water to approximately 60 to 80 g of sediment subsampled from each grab sample. The weight of deionized water needed was calculated based on the weight of the field-moist samples and their previously determined moisture contents. The sum of the existing moisture (porewater) and the deionized water was fixed at the mass of the dry sediment. An appropriate amount of deionized water was added to screw cap jars containing the sediment samples. The jars were sealed and briefly shaken by hand, then placed on a mechanical orbital shaker for one hour. The samples were allowed to settle until the supernatant liquid was fairly clear. The supernate was carefully decanted and separated into unfiltered aliquots for conductivity and pH determinations, and filtered aliquots (passed through 0.45 micrometer [μm] membranes) for anion, cation, carbon, and radionuclide analyses. More details can be found in Rhoades (1996) and in *Methods of Soils Analysis - Part 3* (ASA 1996).

3.3.3 pH and Conductivity

Two, approximately 3-mL aliquots of the unfiltered 1:1 sediment:water extract supernates were used for pH and conductivity measurements. The pHs of the extracts were measured with a solid-state pH electrode and a pH meter calibrated with buffers 4, 7, and 10. Electrical conductivity was measured and compared with potassium chloride standards with a range of 0.001 molar (M) to 1.0 M.

3.3.4 Anions

The 1:1 sediment:water extracts were analyzed for anions using an ion chromatograph. Fluoride, chloride, nitrite, bromide, nitrate, carbonate, phosphate, and sulfate were separated on a Dionex AS17 column with a gradient elution of 1 mM to 35 mM sodium hydroxide and measured using a conductivity detector. This methodology is based on U.S. Environmental Protection Agency (EPA) Method 300.0A (EPA 1984) with the exception of using the gradient elution of sodium hydroxide. Water extract chromatograms were visually scanned to assure there were no unidentified peaks caused by other constituents. No unexpected peaks were found in the water extracts from the background or contaminated sediments.

3.3.4.1 Cations and Trace Metals

Major cation analysis was performed using an inductively coupled plasma-optical emission spectrometry (ICP-OES) unit using high-purity calibration standards to generate calibration curves and

verify continuing calibration during the analysis run. Dilutions of 100x, 50x, 10x, and 5x were made of each 1:1 water extract for analysis to investigate and correct for matrix interferences. Details of this method are found in EPA Method 6010B (EPA 2000a). The second instrument used to analyze trace metals, including technetium-99 and uranium-238, was an inductively coupled plasma-mass spectrometer (ICP-MS) using PNNL-AGG-415 method (PNNL 1998). This method is quite similar to EPA Method 6020 (EPA 2000b).

3.3.4.2 Gamma Energy Analysis

Gamma energy analysis (GEA) was performed on subsamples (40 to 250 g) from each of the grab samples received from borehole C3103. All samples for gamma energy analysis were analyzed using 60% efficient intrinsic germanium gamma detectors. All germanium counters were efficiency calibrated for distinct geometries using mixed gamma standards traceable to the National Institute of Standards and Technology. Field-moist samples were placed in 150-cm³ counting containers and analyzed for 100 minutes in a fixed geometry. All spectra were background-subtracted. Spectral analysis was conducted using libraries containing most mixed fission products, activation products, and natural decay products. Control samples were run throughout the analysis to ensure correct operation of the detectors. The controls contained isotopes with photo peaks spanning the full detector range and were monitored for peak position and counting rate at the full-width half-maximum point. Details are found in *Gamma Energy Analysis, Operation, and Instrument Verification using Genie2000™ Support Software* (PNNL 1997).

4.0 Results and Discussion

This section presents the geochemical and physical characterization data collected on grab samples from borehole C3103, which was drilled directly through the 216-B-7A crib. The laboratory activities emphasized tests that were cost-effective or key to determining the vertical distribution of mobile contaminants in the vadose zone sediments. Information on the borehole sediments presented in this section includes moisture content and total and inorganic carbon content of the sediments, pH, and electrical conductivity of 1:1 sediment:water extracts, and measurements of major cations, anions, trace metals, and radionuclides in both the sediment and 1:1 sediment:water extracts. A gamma energy analysis of the sediments was also performed to search for any detectable man-made gamma emitting radionuclides.

4.1 Geophysical and Moisture Content Measurements

Laboratory moisture content measurements of each of the samples as a function of depth are shown in Table 4.1. Down-hole geophysical measurements including a high purity germanium spectral gamma log and a neutron-neutron log compared with laboratory moisture content measurements are shown in Figure 4.1. No samples were preserved by the environmental restoration contractor that could be used to measure matric potential for the borehole at this disposal facility.

4.2 Soil Water Chemistry Measurements

An extensive water chemistry analysis has been completed for borehole C3103 samples collected between 4 and 68 m (12 and 222 ft) bgs. Water extract pH and electrical conductivity measurements with depth are listed in Table 4.2 and graphed in Figure 4.2. Elevated pH values (greater than 8.5) are measured between 11 and 30 m (35 and 100 ft) with maximum pH values (9.0 to 9.5) occurring between 11 and 27 m (35 and 90 ft) bgs. Because pH values are expected to decrease as increasing interaction with soil and soil water occurs, the location of increased pH values suggest that the approximate location of initial wastewater interaction with the soil column is between 11 and 30 m (35 and 100 ft). Increases in electrical conductivity above background also indicate wastewater interactions with soils. In this borehole, the notable increases between 15 and 50 millisiemens/centimeter (mS/cm) occur between 14 and 46 m (45 and 150 ft) bgs. The elevated EC zone occurs at about the same location in the soil column relative to the elevated pH zone but extends about 15 m (50 ft) bgs deeper.

Water extract anion concentrations as a function of depth are listed in Table 4.3 and graphed in Figure 4.3. The primary indicators of wastewater occurrence are nitrate, carbonate, and fluoride. Normally, nitrate is the dominant contaminant in soils contacted by tank waste fluids. However, in this case, all three anions contribute to the electrical elevated conductivity profile. Nitrate is the only contributor to elevated EC at the bottom of the zone measuring elevated EC values.

Elevated bicarbonate concentrations (between 3,000 and 10,500 mg/L) are measured in borehole C3103 from 9 to 34 m (30 to 110 ft) bgs. Maximum bicarbonate values (~10,000 mg/L) occur at 15 m (48 ft) bgs. Elevated fluoride concentrations (between 225 and 1,000 mg/L) occur between 8 and 27 m (25 and 90 ft) bgs. Nitrate shows elevated concentrations throughout most of the soil column

Table 4.1. Moisture Content of Sediments in Borehole C3103

Lithologic Unit	Sample Identification	Mid Depth ft bgs ^(a)	% Moisture
<i>Backfill</i>			
Backfill	7A-22.0	22	12.10%
<i>H1 Coarse Sand</i>			
H1	7A-25.0	25	9.13%
H1	7A-30.0	30	5.67%
<i>H2 Hanford formation H2 Unit– Upper Sequence</i>			
H2	7A-35.0	35	13.48%
H2	7A-35 Dup	35	13.48%
H2	7A-48	48	3.63%
H2	B10024	60	3.52%
H2	B10025	70	4.30%
H2	B10026	80	4.29%
H2	B10027	90	5.90%
H2	B10027 Dup	90	5.90%
H2	B10028	100	2.79%
H2	B10031	110	3.38%
H2	B10032	120	2.33%
H2	B10033	130	3.81%
H2	B10034	140	2.96%
H2	B10035	150	2.63%
H2	B10036	160	2.82%
H2	B10037	168	8.39%
H2	B10038	170	2.98%
H2	B10039	172.5	4.67%
H2	B10040	180	3.06%
H2	B10041	190	3.29%
H2	B10042	200	4.84%
H2	B10043	210	4.77%
H2	B10043 Dup	210	4.77%
<i>Plio-Pleistocene Mud Unit (PPLz)</i>			
PPLz	B10044	218	16.39%
PPLz	B10045	221.5	29.66%
PPLz	B10046	219	29.44%
PPLz	B10047	221.5	26.94%

(a) Multiply by 0.3048 to convert to meters.

Borehole C3103

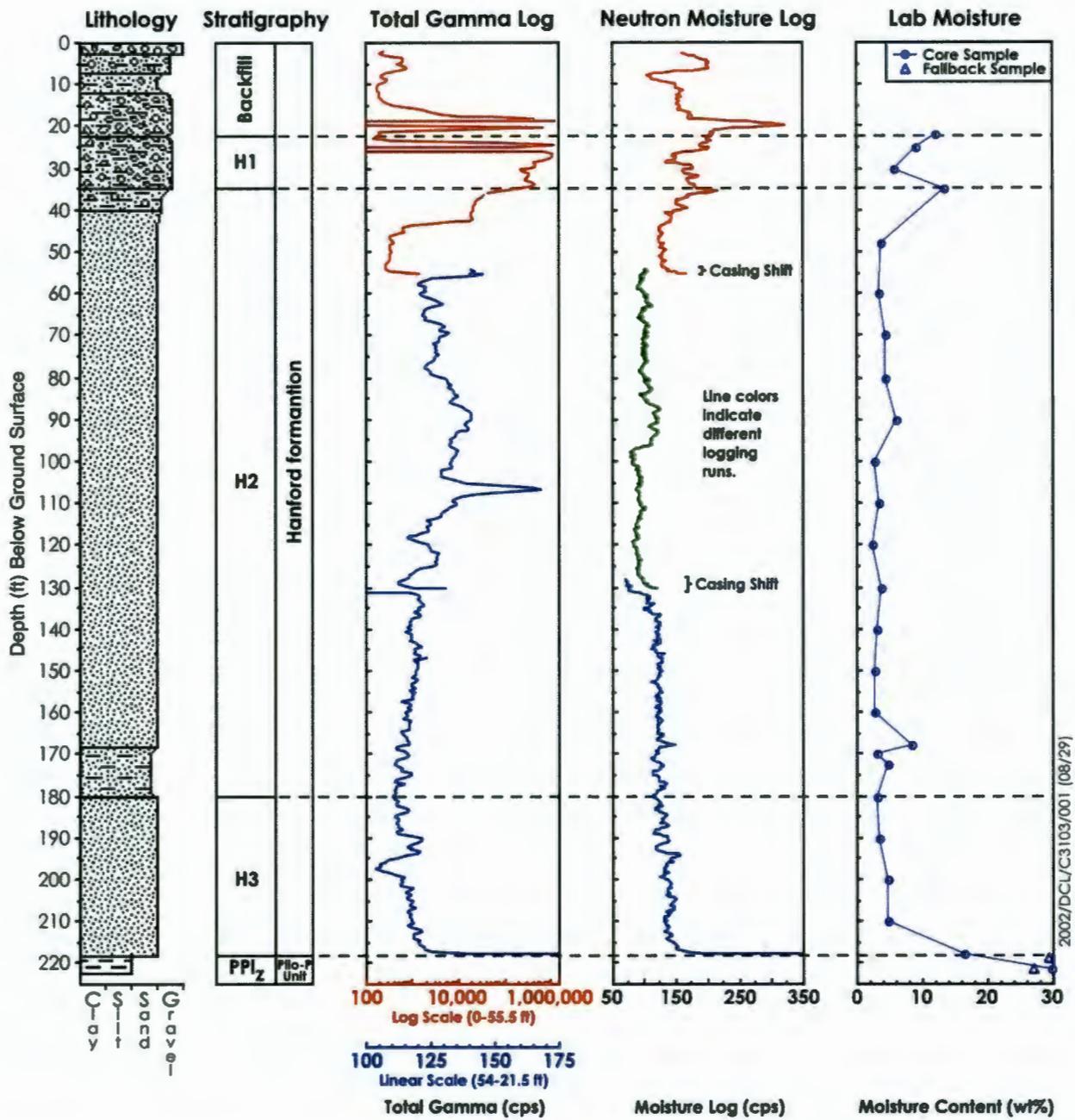


Figure 4.1. Borehole C3103 Lithology, Stratigraphy, Geophysical Logs, and Moisture Distribution as a Function of Depth

Table 4.2. Water Extract pH and Electrical Conductivity Values for Borehole C3103

Sample Identification	Mid Depth ft bgs ^(a)	Dilution Factor	1:1 pH	1:1 EC mS/cm	Pore EC mS/cm
<i>Backfill</i>					
7A-22.0	22	8.30	7.9	0.49	4.04
<i>H1 Coarse Sand</i>					
7A-25.0	25	10.97	7.92	0.69	7.56
7A-30.0	30	17.62	8.26	0.63	11.05
7A-35.0	35	7.42	9.08	1.09	8.07
<i>H2 Hanford formation H2 Unit – Upper Sequence</i>					
7A-35 Dup	35	7.43	9.11	1.12	8.32
7A-48	48	27.59	9.53	0.92	25.33
B10024	60	28.47	9.58	1.12	31.77
B10025	70	23.64	9.45	0.65	15.27
B10026	80	23.31	9.64	0.98	22.77
B10027	90	16.96	9.52	1.30	22.09
B10027 Dup	90	16.94	9.53	1.04	17.60
B10028	100	35.85	8.93	0.57	20.29
B10031	110	29.62	8.45	0.69	20.56
B10032	120	42.95	7.32	0.61	26.07
B10033	130	26.28	7.2	1.31	34.35
B10034	140	33.74	7.23	0.75	25.13
B10035	150	37.99	7.08	1.31	49.76
B10036	160	35.51	7.22	0.53	18.75
B10037	168	11.92	7.31	0.30	3.54
B10038	170	33.60	7.24	0.22	7.42
B10039	172.5	21.45	7.26	0.22	4.70
B10040	180	32.86	7.18	0.28	9.14
B10041	190	30.36	7.34	0.23	6.89
B10042	200	20.68	7.28	0.27	5.56
B10043	210	20.97	7.28	0.23	4.84
B10043 Dup	210	21.21	7.23	0.25	5.22
<i>Plio-Pleistocene Fine-Grained Mud Unit (PPlz)</i>					
B10044	218	6.10	8.04	0.84	5.14
B10045	221.5	3.38	9.45	2.00	6.74
B10046	219	3.40	8.54	1.33	4.52
B10047	221.5	3.71	9.43	3.49	12.97
(a) Multiply by 0.3048 to convert to meters. EC = electrical conductivity.					

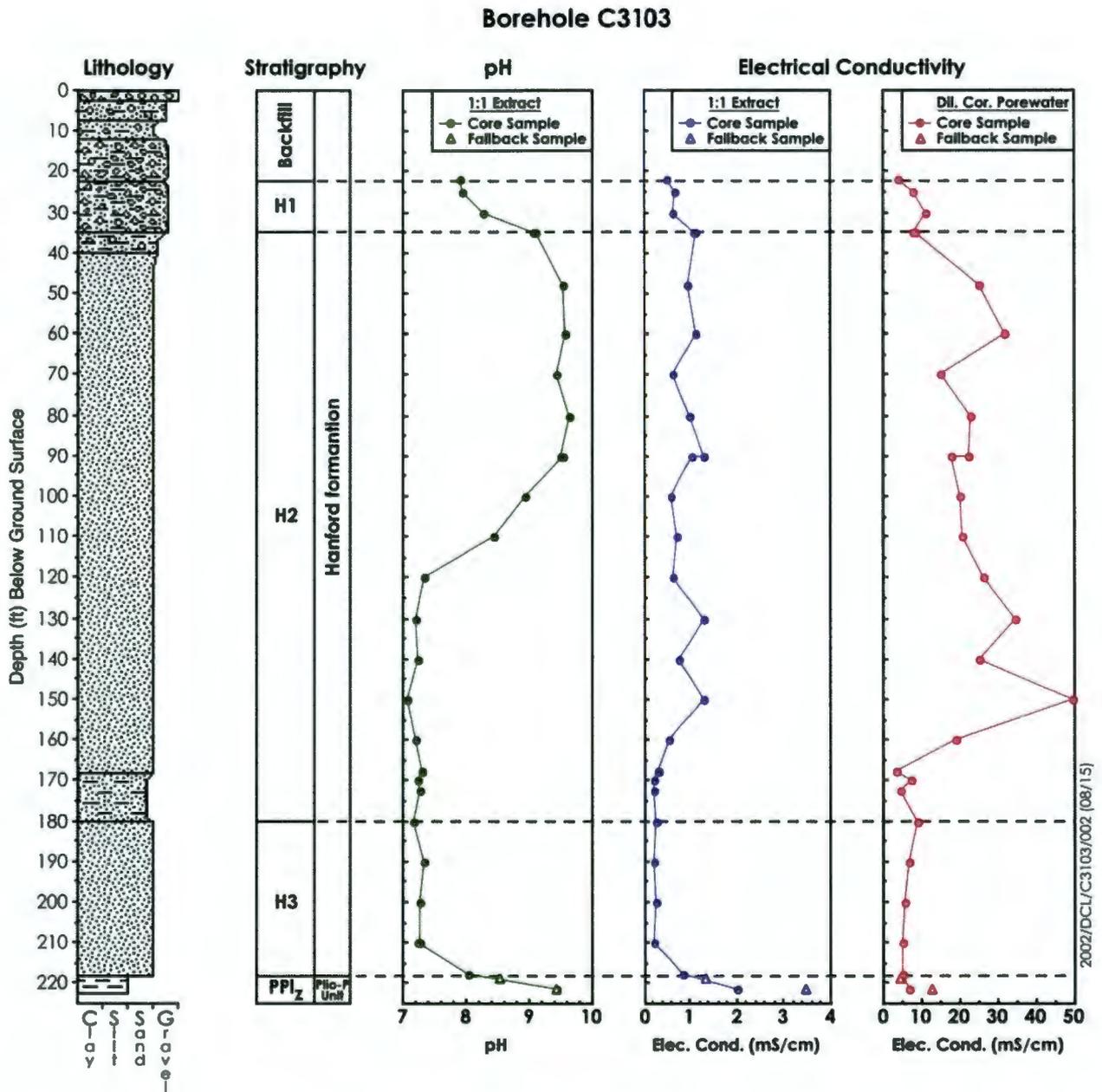


Figure 4.2. Moisture Content, Water Extract pH, and Calculated Porewater Electrical Conductivity for Borehole C3103

Table 4.3. Anion Content of Water Extracts for Borehole C3103

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	1:1 Extracts in mg/L							Dilution Corrected Porewater mg/L						
			NO3	F	NO2	Cl	SO4	PO4	HCO3	NO3	F	NO2	Cl	SO4	PO4	HCO3
<i>Backfill</i>																
7A-22.0	22	8.30	20.77	5.63	1.23	6.68	24.71	0.45	224.47	172.3	46.7	10.24	55.4	205.0	3.73	1862.38
<i>H1 Coarse Sand</i>																
7A-25.0	25	10.97	110.82	23.96	<0.08	6.29	29.05	0.66	170.79	1215.3	262.7	<0.88	69.0	318.6	7.23	1873.02
7A-30.0	30	17.62	30.66	23.61	<0.08	1.88	22.86	0.51	225.09	540.3	416.1	<1.41	33.1	402.8	8.98	3966.65
<i>H2 Hanford formation H2 Unit – Upper Sequence</i>																
7A-35.0	35	7.42	100.48	32.05	<0.08	4.96	40.92	0.69	351.67	745.3	237.7	<0.59	36.8	303.5	5.14	2608.44
7A-35 Dup	35	7.43	115.44	33.26	<0.08	5.57	48.60	0.58	343.10	858.2	247.3	<0.59	41.4	361.3	4.29	2550.56
7A-48	48	27.59	15.59	21.80	<0.08	2.08	12.57	2.15	374.19	430.2	601.5	<2.21	57.5	346.7	59.44	10324.60
B10024	60	28.47	188.66	21.54	0.57	6.53	10.36	1.02	289.19	5370.9	613.2	<16.09	185.8	295.1	28.93	8232.84
B10025	70	23.64	9.33	12.58	<0.08	0.74	3.50	0.50	297.58	220.5	297.3	<1.89	17.5	82.8	11.85	7033.89
B10026	80	23.31	23.85	42.85	<0.08	1.19	6.57	<0.24	338.41	555.9	998.6	<1.86	27.8	153.1	<5.59	7886.98
B10027	90	16.96	188.46	16.60	<0.08	9.17	26.96	1.44	383.32	3196.9	281.7	<1.36	155.6	457.3	24.49	6502.31
B10027 Dup	90	16.94	97.41	11.83	<0.08	4.91	13.22	1.29	353.74	1650.4	200.4	<1.36	83.1	224.0	21.79	5993.35
B10028	100	35.85	125.77	2.76	<0.08	4.96	14.79	0.30	168.15	4509.1	99.0	<2.87	177.9	530.3	10.81	6028.26
B10031	110	29.62	247.49	0.38	0.10	5.18	17.20	<0.24	105.41	7331.6	11.3	3.10	153.4	509.6	<7.11	3122.82
B10032	120	42.95	248.47	0.25	0.14	4.56	10.76	<0.24	<50.00	10671.1	10.7	5.99	195.8	462.1	<10.31	<2147.35
B10033	130	26.28	625.53	0.23	0.22	9.18	14.97	<0.24	<50.00	16438.9	6.1	5.76	241.2	393.4	<6.31	<1313.99
B10034	140	33.74	319.51	0.23	<0.08	4.69	10.18	<0.24	<50.00	10779.1	7.9	2.70	158.2	343.4	<8.10	<1686.81
B10035	150	37.99	629.88	0.20	<0.08	9.53	20.02	<0.24	<50.00	23927.4	7.6	3.04	362.0	760.5	<9.12	<1899.37
B10036	160	35.51	207.48	0.21	<0.08	4.26	16.98	<0.24	<50.00	7367.5	7.6	2.84	151.3	602.9	<8.52	<1775.45
B10037	168	11.92	53.77	0.48	<0.08	4.16	30.64	<0.24	70.37	641.1	5.7	0.95	49.6	365.4	<2.86	839.11
B10038	170	33.60	24.30	0.37	<0.08	2.94	25.37	<0.24	65.53	816.2	12.5	2.69	98.7	852.4	<8.06	2201.43
B10039	172.5	21.45	22.80	0.44	<0.08	1.89	25.86	<0.24	69.44	489.1	9.3	1.72	40.5	554.8	<5.15	1489.76
B10040	180	32.86	45.39	0.34	<0.08	4.94	35.67	<0.24	<50.00	1491.7	11.2	2.63	162.2	1172.4	<7.89	<1643.17

Table 4.3. (contd)

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	1:1 Extracts in mg/L							Dilution Corrected Porewater mg/L						
			NO3	F	NO2	Cl	SO4	PO4	HCO3	NO3	F	NO2	Cl	SO4	PO4	HCO3
B10041	190	30.36	16.45	0.49	<0.08	3.88	31.02	0.27	<50.00	499.5	14.9	2.43	117.8	941.8	8.22	<1517.97
B10042	200	20.68	19.75	0.57	<0.08	7.77	40.02	<0.24	<50.00	408.4	11.7	1.65	160.7	827.5	<4.96	<1033.82
B10043	210	20.97	19.62	0.33	<0.08	8.86	29.20	<0.24	<50.00	411.4	6.9	1.68	185.7	612.3	<5.03	<1048.36
B10043 Dup	210	21.21	19.53	0.32	<0.08	8.81	37.08	<0.24	<50.00	414.2	6.7	1.70	186.9	786.3	<5.09	<1060.29
<i>Plio-Pleistocene Fine-Grained Mud Unit (PPlz)</i>																
B10044	218	6.10	71.84	22.32	<0.08	17.22	142.28	<0.24	118.20	438.3	136.2	0.49	105.0	868.1	<1.46	721.20
B10045	221.5	3.38	217.50	64.80	<0.08	15.29	88.07	6.00	571.43	734.5	218.8	0.27	51.7	297.4	20.26	1929.72
B10046	219	3.40	57.30	44.81	<0.08	31.14	158.47	0.96	333.21	194.7	152.2	0.27	105.8	538.4	3.26	1132.08
B10047	221.5	3.71	591.85	132.13	3.61	26.97	182.49	3.91	688.70	2197.6	490.6	13.42	100.1	677.6	14.51	2557.26
(a) Multiply by 0.3048 to convert to meters.																
< indicates instrument returned a negative value, therefore, value reported as less than instrument detection limit.																

Borehole C3103

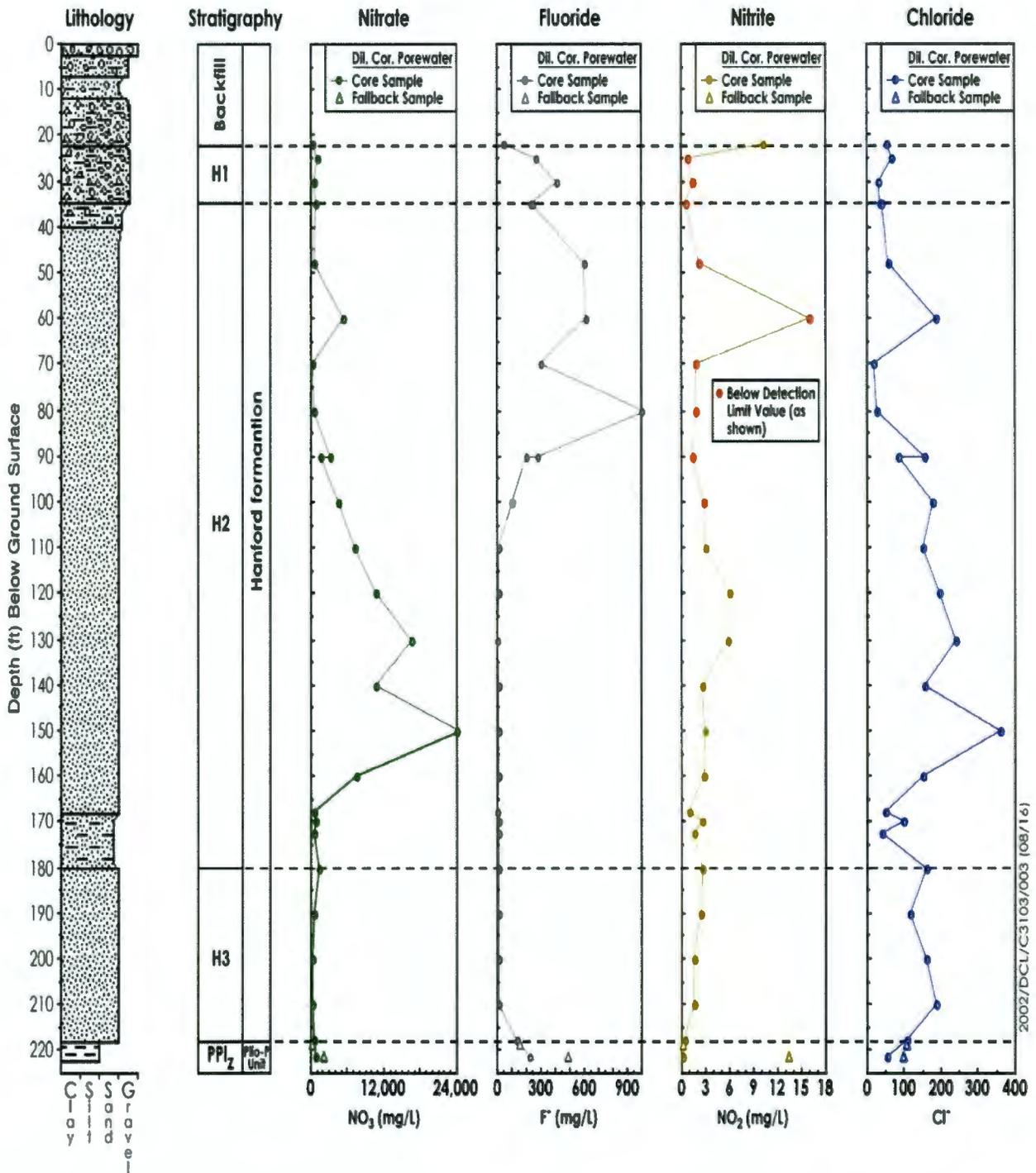


Figure 4.3. Porewater Anions Calculated from Water Extracts for Borehole C3103

Borehole C3103

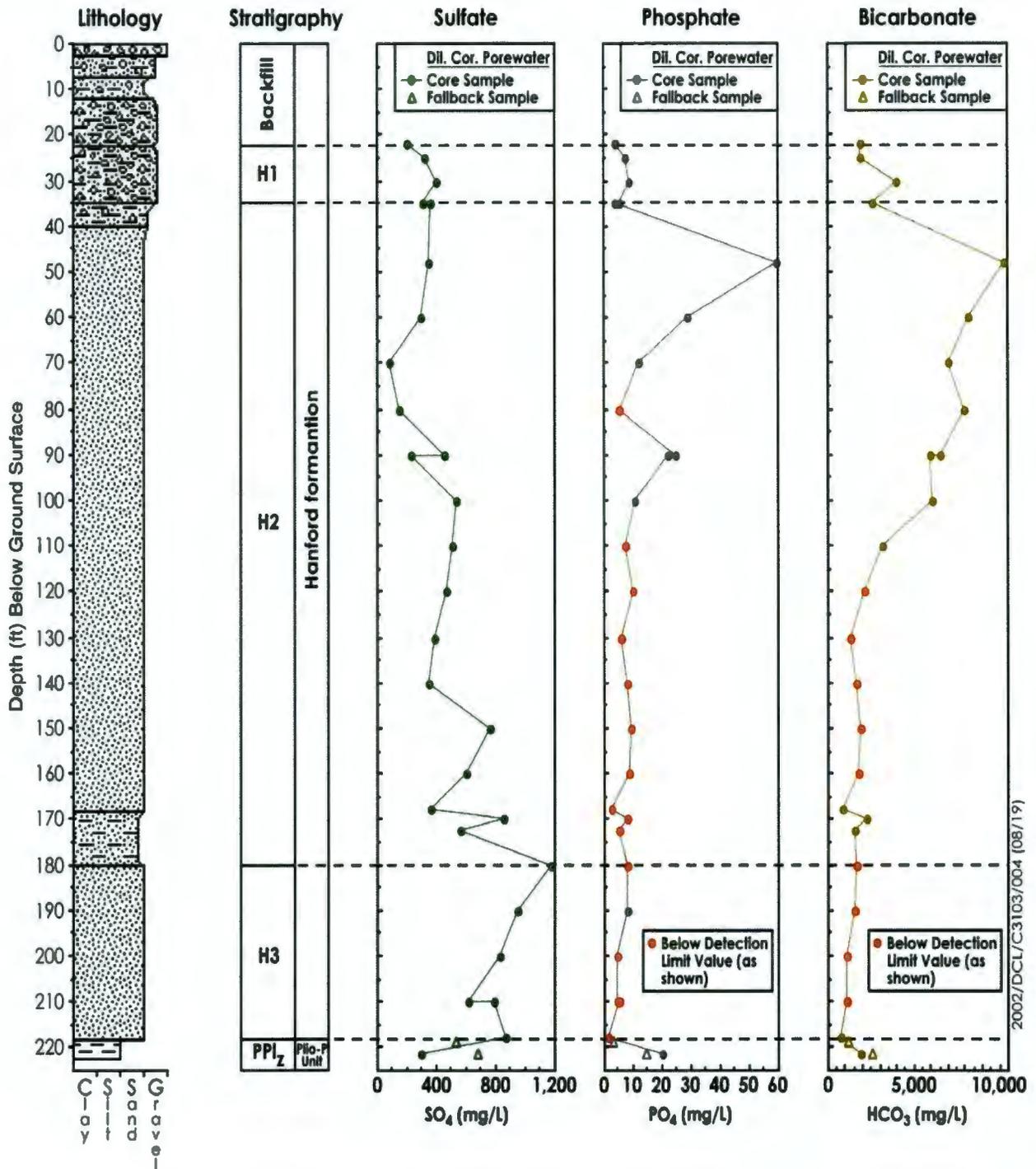


Figure 4.3. (contd)

(>200 mg/L) and maximum concentrations at greater depth in the soil column relative to carbonate and fluoride indicating that it is largely non-reactive with the soil column. Maximum nitrate values (between 7,000 and 24,000 mg/L) are measured between 34 and 49 m (110 and 160 ft) bgs coincident with the largest carbonate concentrations. Given their location in the soil column, both carbonate and fluoride have been chemically reactive with vadose zone soils.

The other anion with elevated concentrations is sulfate. Like nitrate, sulfate occurs at elevated concentrations (>100 mg/L) throughout most of the soil column. The highest concentrations (between 600 and 1,200 mg/L) occur between 30 and 61 m (180 and 220 ft) bgs. By comparison, calculated sulfate concentrations vary from 70 to 400 mg/L at the clean 299-E33-338 borehole.

Water extract cation concentrations as a function of depth are graphed in Figure 4.4 and listed in Table 4.4. Among the cations, elevated sodium concentrations are the primary indicators of wastewater occurrence in the soil column. Sodium concentrations in most samples are elevated throughout the soil column (>300 mg/L). Highest concentrations (1,900 and 6,200 mg/L) exist between 9 and 40 m (30 and 130 ft) bgs. The other monovalent cation, potassium, is present at lower but still elevated concentrations (200 to 600 mg/L) and is more evenly distributed in the soil column.

Other cations showing elevated concentrations include magnesium (between 75 and 1400 mg/L) and calcium (between 250 and 1,400 mg/L) between 37 and 64 m (120 and 210 ft) bgs. These cations are also depleted between 8 and 34 m (25 and 110 ft) bgs. The combined pattern of sodium, potassium, calcium, and magnesium distribution in the soil column is a classic example of ion exchange creating a chromatographic effect in the column. This occurs as sodium in the infiltrating fluid preferentially displaces the divalent cations originally sorbed on soil phases causing them to be depleted in the interaction zone and to migrate ahead of the sodium front in the direction of flow.

The last group of analyzed constituents included radionuclides and trace metals, as shown in Table 4.5 and Figure 4.5. The only radionuclides found in these soils were uranium and cesium-137. Uranium concentrations (between 22 and 330 micrograms/gram [$\mu\text{g/g}$]) were elevated between 7 and 11 m (22 and 35 ft) bgs. In the remainder of the soil column, uranium concentrations were <3 $\mu\text{g/g}$ and are assumed to be naturally occurring soil concentrations. Cesium-137 is also concentrated at the top of the soil column between 7 and 12 m (22 and 48 ft) bgs. Concentrations range between 7 to 90,800 picocuries/gram (pCi/g). In the remainder of the soil column, cesium-137 was only detected at 58 m (190 ft) bgs at a low concentration of 0.2 pCi/g.

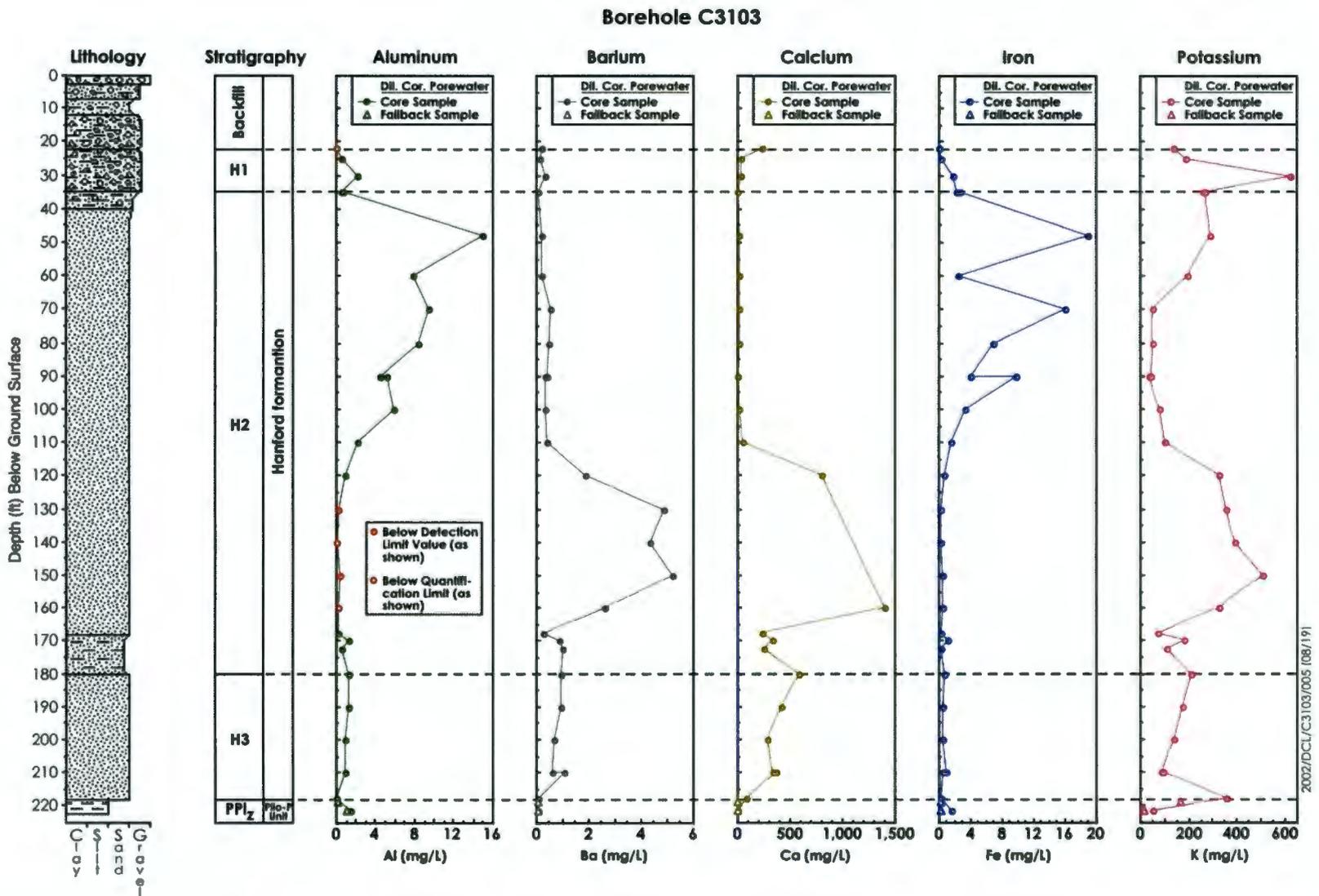


Figure 4.4. Porewater Cations Calculated from Water Extracts for Borehole C3103

Borehole C3103

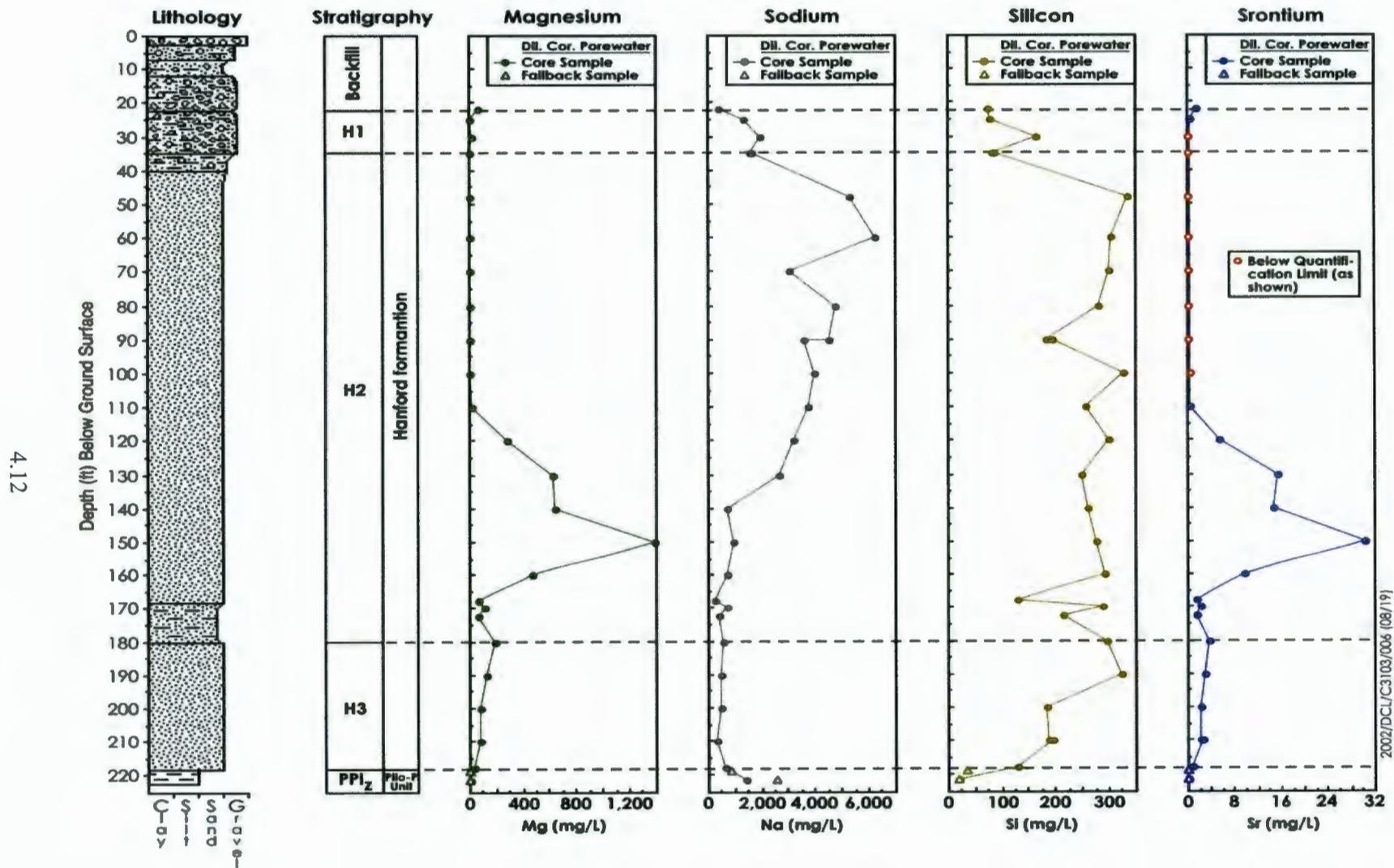


Figure 4.4. (contd)

Table 4.4. Cation Content of Water Extracts for Borehole C3103

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	Dilution Corrected Porewater Concentration of Cations								
			Al mg/L	Ba mg/L	Ca mg/L	Fe mg/L	K mg/L	Mg mg/L	Na mg/L	Si mg/L	Sr mg/L
<i>Backfill</i>											
7A-22.0	22	8.30	(6.67E-02)	1.92E-01	2.42E+02	1.31E-01	1.36E+02	6.96E+01	3.97E+02	7.32E+01	1.60E+00
<i>H1 Coarse Sand</i>											
7A-25.0	25	10.97	5.66E-01	1.14E-01	3.77E+01	2.75E-01	1.89E+02	6.81E+00	1.36E+03	7.96E+01	4.78E-01
7A-30.0	30	17.62	2.15E+00	3.19E-01	3.28E+01	1.77E+00	6.20E+02	1.60E+01	1.93E+03	1.62E+02	(7.24E-02)
<i>H2 Hanford formation H2 Unit – Upper Sequence</i>											
7A-35.0	35	7.42	5.82E-01	6.22E-02	3.42E+00	2.29E+00	2.61E+02	1.13E+00	1.60E+03	8.16E+01	(1.88E-02)
7A-35 Dup	35	7.43	6.95E-01	5.67E-02	3.46E+00	2.60E+00	2.65E+02	1.14E+00	1.61E+03	8.62E+01	(2.11E-02)
7A-48	48	27.59	1.50E+01	2.03E-01	1.30E+01	1.90E+01	2.92E+02	3.85E+00	5.32E+03	3.34E+02	(1.37E-01)
B10024	60	28.47	7.86E+00	2.30E-01	1.68E+01	2.40E+00	1.99E+02	1.96E+00	6.21E+03	3.05E+02	(1.59E-01)
B10025	70	23.64	9.49E+00	5.37E-01	1.10E+01	1.60E+01	5.05E+01	3.64E+00	3.04E+03	3.00E+02	(1.22E-01)
B10026	80	23.31	8.37E+00	4.54E-01	1.25E+01	6.97E+00	5.22E+01	1.59E+00	4.72E+03	2.80E+02	(1.45E-01)
B10027	90	16.96	4.45E+00	3.93E-01	7.72E+00	4.03E+00	4.75E+01	9.56E-01	4.54E+03	1.83E+02	(1.22E-01)
B10027 Dup	90	16.94	5.26E+00	3.08E-01	6.98E+00	9.90E+00	3.87E+01	9.32E-01	3.55E+03	1.93E+02	(1.00E-01)
B10028	100	35.85	5.80E+00	3.25E-01	2.18E+01	3.38E+00	7.85E+01	5.45E+00	3.94E+03	3.29E+02	(2.18E-01)
B10031	110	29.62	2.11E+00	4.33E-01	4.75E+01	1.66E+00	1.05E+02	1.21E+01	3.76E+03	2.56E+02	3.81E-01
B10032	120	42.95	8.51E-01	1.84E+00	8.01E+02	6.17E-01	3.23E+02	2.81E+02	3.20E+03	2.99E+02	5.42E+00
B10033	130	26.28	<2.63E-01	4.89E+00	ND	2.24E-01	3.58E+02	6.16E+02	2.68E+03	2.49E+02	1.54E+01
B10034	140	33.74	(6.62E-02)	4.31E+00	ND	2.28E-01	3.89E+02	6.35E+02	6.86E+02	2.60E+02	1.46E+01
B10035	150	37.99	<3.80E-01	5.22E+00	ND	5.06E-01	5.05E+02	1.38E+03	9.76E+02	2.78E+02	3.03E+01
B10036	160	35.51	(1.96E-01)	2.63E+00	1.41E+03	5.09E-01	3.25E+02	4.71E+02	7.06E+02	2.92E+02	9.47E+00
B10037	168	11.92	2.75E-01	2.90E-01	2.35E+02	1.65E-01	7.45E+01	6.97E+01	2.28E+02	1.27E+02	1.34E+00
B10038	170	33.60	1.27E+00	8.56E-01	3.41E+02	1.22E+00	1.85E+02	1.05E+02	6.72E+02	2.90E+02	2.22E+00

Table 4.4. (contd)

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	Dilution Corrected Porewater Concentration of Cations								
			Al mg/L	Ba mg/L	Ca mg/L	Fe mg/L	K mg/L	Mg mg/L	Na mg/L	Si mg/L	Sr mg/L
B10039	172.5	21.45	5.87E-01	1.01E+00	2.50E+02	3.08E-01	1.07E+02	6.97E+01	3.90E+02	2.16E+02	1.49E+00
B10040	180	32.86	1.24E+00	9.61E-01	5.90E+02	7.37E-01	2.10E+02	1.86E+02	5.30E+02	2.94E+02	3.55E+00
B10041	190	30.36	1.27E+00	9.43E-01	4.16E+02	5.54E-01	1.71E+02	1.30E+02	4.84E+02	3.23E+02	2.84E+00
B10042	200	20.68	9.51E-01	6.54E-01	2.86E+02	4.49E-01	1.37E+02	8.64E+01	4.73E+02	1.85E+02	2.24E+00
B10043	210	20.97	9.34E-01	6.03E-01	3.32E+02	9.26E-01	9.10E+01	7.97E+01	3.14E+02	1.86E+02	2.13E+00
B10043 Dup	210	21.21	9.64E-01	1.06E+00	3.66E+02	4.09E-01	9.58E+01	8.68E+01	3.27E+02	1.96E+02	2.41E+00
<i>Plio-Pleistocene Fine-Grained Mud Unit (PPlz)</i>											
B10044	218	6.10	6.57E-02	9.40E-02	8.66E+01	3.19E-01	3.54E+02	3.68E+01	6.55E+02	1.27E+02	8.14E-01
B10045	221.5	3.38	1.41E+00	6.37E-02	1.93E+00	1.54E+00	5.39E+01	1.20E-01	1.40E+03	2.10E+01	4.24E-02
B10046	219	3.40	1.46E-01	7.54E-02	4.91E+00	2.83E-01	1.64E+02	8.43E-01	8.66E+02	3.58E+01	7.77E-02
B10047	221.5	3.71	1.07E+00	6.04E-02	2.42E+00	2.27E-01	1.70E+01	2.87E-01	2.60E+03	1.85E+01	8.15E-02
<p>(a) Multiply by 0.3048 to convert to meters. Values in parentheses are below level of quantification but spectra look useable. < indicates instrument returned a negative value, therefore, value reported as less than instrument detection limit. ND = no data available; results exceeded calibration limit.</p>											

Table 4.5. Porewater Radionuclides Concentrations Calculated from Water Extracts and Total Cesium-137 in Sediment for Borehole C3103

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	Technetium-99 pCi/L	Uranium-238 µg/L	Cesium-137 pCi/g
<i>Backfill</i>					
7A-22.0	22	8.30	<7.04E+03	5.11E+03	9.08E+04
<i>H1 Coarse Sand</i>					
7A-25.0	25	10.97	<9.30E+03	1.07E+04	6.97E+04
7A-30.0	30	17.62	<1.49E+04	7.78E+04	4.95E+03
<i>H2 Hanford formation H2 Unit- Upper Sequence</i>					
7A-35.0	35	7.42	<6.29E+03	1.31E+04	4.81E+03
7A-35 Dup	35	7.43	<6.30E+03	1.42E+04	5.10E+03
7A-48	48	27.59	<2.34E+04	2.32E+03	7.55E+00
B10024	60	28.47	(9.66E+02)	1.26E+04	<MDA
B10025	70	23.64	<2.00E+04	1.87E+04	<MDA
B10026	80	23.31	<1.19E+03	1.01E+04	<MDA
B10027	90	16.96	<1.18E+04	4.70E+02	<MDA
B10027 Dup	90	16.94	<5.17E+03	3.61E+02	<MDA
B10028	100	35.85	<7.30E+03	6.50E+01	<MDA
B10031	110	29.62	<8.04E+03	2.78E+01	<MDA
B10032	120	42.95	(5.83E+03)	(5827.04)	<MDA
B10033	130	26.28	<2.23E+04	8.83E+00	<MDA
B10034	140	33.74	<2.86E+04	1.19E+01	<MDA
B10035	150	37.99	<3.22E+04	2.34E+01	<MDA
B10036	160	35.51	<3.01E+04	2.34E+01	<MDA
B10037	168	11.92	<1.01E+04	7.47E+00	<MDA
B10038	170	33.60	<2.85E+04	1.24E+01	<MDA
B10039	172.5	21.45	<1.82E+04	8.77E+00	<MDA
B10040	180	32.86	<2.79E+04	1.45E+01	<MDA
B10041	190	30.36	<2.57E+04	1.93E+01	1.18E-01
B10042	200	20.68	<1.75E+04	7.38E+00	<MDA
B10043	210	20.97	<1.78E+04	1.38E+01	<MDA
B10043 Dup	210	21.21	<1.80E+04	1.70E+01	<MDA
<i>Plio-Pleistocene Fine-Grained Mud Unit (PPlz)</i>					
B10044	218	6.10	<5.17E+03	(3.66E-02)	<MDA
B10045	221.5	3.38	(1.72E+03)	1.08E+01	<MDA
B10046	219	3.40	<2.88E+03	4.18E+00	<MDA
B10047	221.5	3.71	<2.33E+03	3.70E+01	<MDA
<p>(a) Multiply by 0.3048 to convert to meters.</p> <p>Values in parentheses are below level of quantification but spectra look useable.</p> <p><MDA = Below minimum detectable activity.</p> <p>< indicates instrument returned a negative value, therefore, value reported as less than instrument detection limit.</p>					

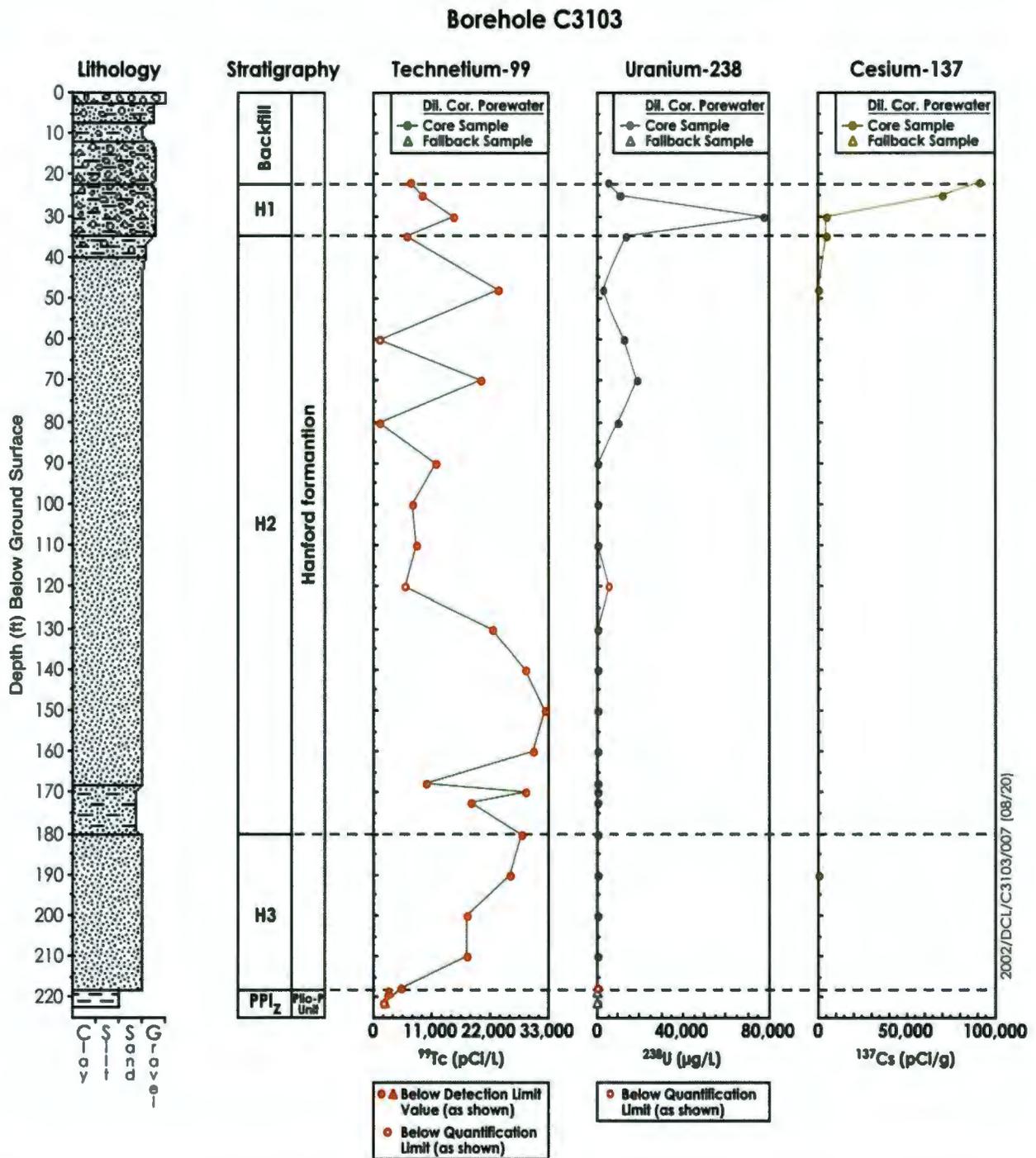


Figure 4.5. Trace Metals and Radionuclides Calculated from Sediment-to-Water Extracts and Measured in Actual Porewaters for Borehole C3103

5.0 Vadose Zone Sediment from Borehole C3104 at Trench 216-B-38

To investigate potential locations and depths of technetium-99 contamination located in WMA B-BX-BY, three samples from drums containing drill cuttings from borehole C3104 at trench 216-B-38 were collected and transported to PNNL for technetium-99 analyses. The samples were collected on January 11, 2002 from 3 separate drums identified as 200E-0100063 with “soils from 106-ft to 118-ft”, 200E-01-0068 with “soils from 198-ft to 217-ft”, and 200E-01-0071 with “soils from 240-ft to 263.5-ft.” A best effort was made to collect samples from target depths of 110 ft, 210 ft, and 250 ft, respectively; however, due to the potential mixing of sediment within these drums during filling, the samples collected should be considered approximations of the target depths.

5.1 Soil Moisture and Water Chemistry Measurements

Results from inductively coupled plasma-mass spectrometry (ICP-MS) analysis (Table 5.1) did not show any technetium-99 above the quantification limit for either the water or acid extract methods. Of note was an extremely high porewater corrected nitrate value of 64,142 mg/L found at a depth of ~110 ft bgs. Such elevated nitrate levels are usually associated with technetium-99 contamination if both contaminants are waste discharge constituents. A summary of additional water and acid extract analyses is shown in Tables 5.1 through 5.3.

Table 5.1. Soil Moisture Content of Drum Samples from Borehole C3104

Sample Identification	Mid Depth ft bgs ^(a)	% Moisture
S02021-01-110	110	2.12%
S02021-02-210	210	3.45%
S02021-03-350	250	2.35%
(a) Multiply by 0.3048 to convert to meters.		

Table 5.2. Water Extract pH and Electrical Conductivity Values for Borehole C3104

Sample Identification	Mid Depth ft bgs ^(a)	Dilution Factor	1:1 pH	1:1 EC mS/cm	Pore EC mS/cm
S02021-01-110	110	48.90	7.04	2.4	117.354
S02021-02-210	210	29.56	7.37	0.256	7.567
S02021-03-350	250	42.35	7.52	0.251	10.629
(a) Multiply by 0.3048 to convert to meters.					

Table 5.3. Anion Content of Water Extracts for Borehole C3104

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	NO3	F	NO2	Cl	SO4	PO4	HCO3
<i>1:1 Extracts in mg/L</i>									
S02021-01-110	110	NA	1312.6	0.187	8.662	17.19	30.0	<0.014	58.5
S02021-02-210	210	NA	22.4	0.507	<0.007	1.95	46.5	<0.014	54.0
S02021-03-350	250	NA	6.0	0.651	<0.007	1.90	54.4	<0.014	53.7
<i>Dilution Corrected Porewater mg/L</i>									
S02021-01-110	110	48.90	64182	9.15	423.55	840.6	1469.4	<0.685	2860.9
S02021-02-210	210	29.56	662.2	15.0	<0.216	57.6	1374.5	<0.414	1595.8
S02021-03-350	250	42.35	252.7	27.6	<0.309	80.4	2302.9	<0.593	2272.6
(a) Multiply by 0.3048 to convert to meters. NA = not applicable.									

5.2 Trace Metal and Radionuclide Analysis

Both one-to-one water extracts and acid leachates from each of the three samples were analysed by ICP-MS for uranium and technetium-99 and the results are shown in Table 5.4.

Table 5.4. Porewater and Dry Sediment Concentration of Technetium-99 and Uranium-238 Calculated from Water and Acid Extracts for Borehole C3104

Sample Identification	Depth ft bgs ^(a)	Dilution Factor	Tc-99 pCi/L	U-238 µg/L
<i>Concentration as Porewater</i>				
S02021-01-110	110	48.90	<4107	29.84
S02021-02-210	210	29.56	<2483	14.22
S02021-03-350	250	42.35	<3557	19.95
<i>Concentration as Dry Sediment</i>				
S02021-01-110	110	5.54	<848	628.20
S02021-02-210	210	5.69	<848	455.99
S02021-03-350	250	5.52	<848	498.31
< indicates instrument returned a negative value, therefore, value reported as less than instrument detection limit.				

5.3 Additional Data from Bechtel Hanford, Inc. Borehole C3104 Investigation

Borehole C3104 was drilled through the 216-B-38 trench using the cable tool method to a final depth of 80.3 m (263.5 ft). A total of 18 depths were sampled during the drilling as shown in Table 2.3 of *Borehole Summary Report for Boreholes C3101 and C3104, and Drive Casings C3340, C3341, C3342,*

C3343, and C3344, in the 216-B-38 Trench and 216-B-7A Crib, 200-TW-2 Tank Waste Group Operable Unit (Todd and Trice 2002). Laboratory analyses for soil pH and anions (Table 5.5), major cations (Table 5.6), and radionuclides (Table 5.7) are reported from DOE-RL (2002).

Table 5.5. Soil pH and Anion Concentrations Reported in Terms of Dry Sediment

Sample Identification	Sample Interval ft bgs ^(a)	Date	pH Measurement pH	Chloride µg/kg	Fluoride µg/kg	Nitrate µg/kg	Nitrite µg/kg	Nitrogen in Nitrite and Nitrate µg/kg	Phosphate µg/kg	Sulfate µg/kg	Total Organic Carbon µg/kg
Top	0 – 0.5	7/18/2001	—	—	—	—	—	—	—	—	—
B12C67	3.5 – 5.0	8/1/2001	8.7	5000	5,200 U	94400	2,620 U	23100	8200	51100	1,510,000
B12C68	9.5 – 12.0	8/2/2001	8.8	6900	2,700 U	208000	1,340 U	59100	1600	248000	988,000
B12C63	14.5 – 15.5	8/2/2001	8.9	110 U	7,400 B	193000	69 U	39,500	370 U	114,000 B	274000
B12C64	18 – 20.5	8/2/2001	9.6	100 U	14,200 B	54400	69 U	6,100	27,100 B	35,000 B	1060000
B12DB8	22.5 – 25	8/3/2001	9.4	100 U	20,000 B	67700	69 U	8400	34,100 B	49,100 B	889000
B12DB9	29 – 31.5	8/3/2001	9.6	11,700 B	33,400 B	141000	69 U	25300	67,400 B	151,000 B	151000
B12C88	37.5 – 40	8/5/2001	9.5	24,600 B	32,900 B	615000	69 U	110000	137,000 B	69,800 B	166000
B12DC0	Split	8/5/2001	8.8	20,500 B	28,900 B	522000	69 U	146000	106,000 B	60,600 B	133000
B12C69	52 – 54.5	8/6/2001	9.65	25600	12,900 U	2090000	34300	464000	149000	106000	191000
B12C70	Duplicate	8/6/2001	9.5	26400	12,900 U	2140000	34700	486000	121000	110000	127000
B12C71	97.5 – 100	8/7/2001	9.3	31000	6,400 U	1880000	35200	449000	6,400 U	131000	1610000
B12C72	147.5 – 150	8/8/2001	8.3	41100	6,400 U	3180000	41200	753000	6,400 U	48200	1380000
B12C73	197.5 – 200	8/9/2001	8.8	6600	2,600 U	57600	2,560 U	17800	2,600 U	38100	2760000
B12C74	264 – 265.5	8/10/2001	8.9	2800	1,300 U	1480	1,310 U	200 U	1,300 U	13500	1550000

(a) Multiply by 0.3048 to convert to meters.
 B = The associated quality control sample has a result greater than two times the MDA.
 U = Analyzed for but not detected above the minimum activity in the sample.

Table 5.6. Cation Concentrations Reported in Terms of Dry Sediment

Sample Identification	Sample Interval ft-bgs ^(a)	Date	Aluminum mg/kg	Bismuth mg/kg	Cadmium mg/kg	Calcium mg/kg	Chromium mg/kg	Copper mg/kg	Hexavalent Chromium mg/kg	Iron mg/kg	Lead mg/kg
B12684	0 – 0.5	7/18/2001	—	—	—	—	—	—	—	—	—
B12C67	3.5 – 5.0	8/1/2001	—	—	0.06	—	11.6	12.9	0.42 U	—	6.8
B12C68	9.5 – 12.0	8/2/2001	—	—	0.1	—	11.5	15.1	0.43 U	—	8
B12C63	14.5 – 15.5	8/2/2001	7600	2.2 U	0.021 U	9,610.00	7.1	12.20	0.08 U	18,100	44.5 B
B12C64	18 – 20.5	8/2/2001	7830	2.2 U	0.021 U	8,030.00	10	13.00	0.08 U	19,800	5.9 B
B12DB8	22.5 – 25	8/3/2001	—	—	0.18 U	—	11.1	11.7	0.08 U	—	4.2 B
B12DB9	29 – 31.5	8/3/2001	—	—	0.18 U	—	9.2	9.9	0.08 U	—	3.9 B
B12C88	37.5 – 40	8/5/2001	—	—	0.18 U	—	8	11.4	0.08 U	—	3.4 U
B12DC0	Split	8/5/2001	—	—	0.18 U	—	8	11.8	0.08 U	—	3.3 U
B12C69	52 – 54.5	8/6/2001	—	—	0.07	—	8.4	8.8	0.49	—	3.4
B12C70	Duplicate	8/6/2001	—	—	0.09	—	12.7	13.4	0.62	—	3.1
B12C71	97.5 – 100	8/7/2001	—	—	0.03 U	—	18	12.1	0.41 U	—	3.6
B12C72	147.5 – 150	8/8/2001	—	—	0.03 U	—	14.5	9.4	0.41 U	—	2.9
B12C73	197.5 – 200	8/9/2001	—	—	0.03 U	—	14.4	10.4	0.41 U	—	2.7
B12C74	264 – 265.5	8/10/2001	—	—	0.03 U	—	14	18.8	0.42 U	—	3.1

(a) Multiply by 0.3048 to convert to meters.

B = The associated quality control sample has a result greater than two times the MDA.

U = Analyzed for but not detected above the minimum activity in the sample.

Table 5.6. (contd)

Sample Identification	Sample Interval ft-bgs ^(a)	Date	Magnesium mg/kg	Manganese mg/kg	Mercury mg/kg	Molybdenum mg/kg	Nickel mg/kg	Potassium mg/kg	Silver mg/kg	Vanadium mg/kg	Zinc mg/kg
B12684	0 – 0.5	7/18/2001	—	—	—	—	—	—	—	—	—
B12C67	3.5 – 5.0	8/1/2001	—	—	0.02 U	—	12.1	—	0.05 U	—	—
B12C68	9.5 – 12.0	8/2/2001	—	—	0.02 U	—	10.7	—	0.05 U	—	—
B12C63	14.5 – 15.5	8/2/2001	3,820	287	0.089 B	0.92 U	6.3	1,140	0.11 U	55.1	43.9
B12C64	18 – 20.5	8/2/2001	4,580	317	0.035 B	0.91 U	6.6	1,120	0.1 U	63.9	54.9
B12DB8	22.5 – 25	8/3/2001	—	—	0.025 B	—	8.1	—	0.95 U	—	—
B12DB9	29 – 31.5	8/3/2001	—	—	0.025 U	—	9.9	—	0.96 U	—	—
B12C88	37.5 – 40	8/5/2001	—	—	0.025 U	—	5.8	—	0.95 U	—	—
B12DC0	Split	8/5/2001	—	—	0.025 U	—	5.6	—	0.95 U	—	—
B12C69	52 – 54.5	8/6/2001	—	—	0.02 U	—	8	—	0.05 U	—	—
B12C70	Duplicate	8/6/2001	—	—	0.01 U	—	15.4	—	0.05 U	—	—
B12C71	97.5 – 100	8/7/2001	—	—	0.02 U	—	22	—	0.05 U	—	—
B12C72	147.5 – 150	8/8/2001	—	—	0.02 U	—	13.3	—	0.05 U	—	—
B12C73	197.5 – 200	8/9/2001	—	—	0.02 U	—	14.5	—	0.05 U	—	—
B12C74	264 – 265.5	8/10/2001	—	—	0.02 U	—	12.1	—	0.05 U	—	—

(a) Multiply by 0.3048 to convert to meters.

B = The associated quality control sample has a result greater than two times the MDA.

U = Analyzed for but not detected above the minimum activity in the sample.

Table 5.7. Radionuclide Activity Reported in Terms of Dry Sediment

Sample Identification	Sample Interval ft-bgs ^(a)	Date	Total beta Radiostrontium pCi/g	Cesium-137 pCi/g	Potassium-40 pCi/g	Radium-226 pCi/g	Radium-228 pCi/g	Technetium-99 pCi/g
B12684	0 – 0.5	7/18/2001	—	—	—	—	—	—
B12C67	3.5-5.0	8/1/2001	0.175 U	1.82	14	0.594	0.685	-0.1 U
B12C68	9.5-12.0	8/2/2001	-0.06 U	0.036 U	14.5	0.12 U	0.974	-0.04 U
B12C63	14.5 – 15.5	8/2/2001	1390	226000	87 U	62 U	45 U	0.20 U
B12C64	18 – 20.5	8/2/2001	2050	226000	273	86 U	54 U	0.007 U
B12DB8	22.5 – 25	8/3/2001	288	17900	19.3	4.4 U	1.7 U	-0.209 U
B12DB9	29 – 1.5	8/3/2001	50.9	95700	93 U	85 U	40 U	-0.07 U
B12C88	37.5 – 40	8/5/2001	0.129 U	31600	34.2	12 U	4.6 U	0.128 U
B12DC0	Split	8/5/2001	0.164 U	25800	32.9	6.7 U	2.59	0.037 U
B12C69	52 – 54.5	8/6/2001	0.033 U	0.102	15.4	0.438	0.741	1.9 J
B12C70	Duplicate	8/6/2001	-0.032 U	0.11	16.8	0.479	0.827	1.93 J
B12C71	97.5 – 00	8/7/2001	-0.182 U	0.047 U	14.3	0.575	0.751	0.184 U
B12C72	147.5 – 150	8/8/2001	-0.051 U	0.028 U	16.1	0.089 U	0.61	0.888 J
B12C73	197.5 – 200	8/9/2001	-0.007 U	0.165	16	0.489	0.687	-0.043 U
B12C74	264 – 265.5	8/10/2001	-0.018 U	.062 J	11.2	0.447	0.626	0.094 U

(a) Multiply by 0.3048 to convert to meters.

B = The associated quality control sample has a result greater than two times the MDA.

J = Concentration estimated.

U = Analyzed for but not detected above the minimum activity in the sample.

Table 5.7. (contd)

Sample Identification	Sample Interval ft-bgs ^(a)	Date	Plutonium-238 pCi/g	Plutonium-239/240 pCi/g	Thorium-228 pCi/g	Thorium-230 pCi/g	Thorium-232 pCi/g	Total Uranium µg/kg	Uranium-233/234 pCi/g	Uranium-238 pCi/g
B12684	0 – 0.5	7/18/2001	—	—	—	—	—	—	—	—
B12C67	3.5 – 5.0	8/1/2001	0 U	0.029 U	0.431	0.621 J	0.621 J	1600	0.667 J	0.667 J
B12C68	9.5 – 12.0	8/2/2001	0 U	0 U	0.839	0.587 J	0.587 J	1690	0.448 J	0.544 J
B12C63	14.5 – 15.5	8/2/2001	7.85	106	6.44 U	-6.44 U	9.65 U	11300 B	8.15 U	5.82 U
B12C64	18 – 20.5	8/2/2001	3.36	159	1.41 U	-3.26 U	0.93 U	32500	9	5.63 U
B12DB8	22.5 – 25	8/3/2001	3.66 U	64.6	-1.74 U	0 U	2.06 U	19100	8.52 U	7.31 U
B12DB9	29 – 31.5	8/3/2001	3.48	4.64	-0.171 U	-0.854 U	0.525 U	14800	5.16	6.35
B12C88	37.5 – 40	8/5/2001	0.657 J	0.776 J	-0.989 U	0.329 U	0 U	7740	2.72	2.83
B12DC0	Split	8/5/2001	0.324 U	0.883 J	-0.258 U	-0.321 U	0.193 U	8090	2.73	2.48
B12C69	52 – 54.5	8/6/2001	0.051 U	0.051 U	1.26	0.496 J	0.382 J	2900	0.754 J	0.782 J
B12C70	Duplicate	8/6/2001	-0.038 U	0 U	1.84	0.894 J	0.988 J	3500	1.08	1.23
B12C71	97.5 – 100	8/7/2001	0 U	-0.045 U	0.933	0.632 J	0.366 J	934	0.512 J	0.456 J
B12C72	147.5 – 150	8/8/2001	-0.052 U	0 U	0.777	0 U	0.443 J	901	0.272 J	0.431 J
B12C73	197.5 – 200	8/9/2001	0 U	0 U	0.778	0.068 U	0.405 J	862	0.480 J	0.38 J
B12C74	264 – 265.5	8/10/2001	0 U	0.028 U	0.774	0.665 J	0.558 J	790	0.262 J	0.314 J

(a) Multiply by 0.3048 to convert to meters.

B = The associated quality control sample has a result greater than two times the MDA.

J = Concentration estimated.

U = Analyzed for but not detected above the minimum activity in the sample.

6.0 Summary and Conclusions

No specific experiments were completed on soils from borehole C3103 to quantify geochemical reactions influencing contaminant migration. Typically, chemical reactions affecting radionuclides and wastewater chemicals are inferred from the relative locations of these constituents in the soil column, comparison of acid-leachable versus water-leachable concentrations for specific contaminants, and general knowledge of tank fluid chemistry. The primary reactions involving wastewater and the soil column appear to be a reduction of tank fluid pH as it has reacted with lower pH soil water, in situ displacement of ambient divalent cations with high sodium present in the wastewater, and precipitation of uranium and essentially complete sorption of cesium-137 just below the crib bottom.

Best estimates of typical wastewater fluid suggest that a pH between 10 and 11 was likely. The observation of an elevated zone between pH 8.5 and 9 just below the crib bottom indicates partial buffering of the infiltrating wastewater by reaction with soil phases and soil water whose ambient pH values are between 7.0 and 7.5 in this area. The location of a high concentration of cesium-137 at 9.08×10^4 pCi/g from a grab sample analysis is shown in Table 4.4 and is estimated to be between 7 and 11 m (22 and 35 ft) bgs. This value is consistent with the 6.73×10^4 to 1.53×10^5 pCi/g cesium-137 concentration range for this depth as reported in DOE-RL (2002). Further down the soil column (18.3 m), the concentration of cesium-137 becomes nonexistent above background indicating a rapid and essentially complete reaction of this contaminant with the soil-water system. Uranium appears to have migrated down as far as 90 ft bgs. Conversely, other more mobile constituents appear to have migrated down to groundwater as indicated by the elevated concentrations of nitrate and sulfate in almost all samples. The technetium-99 profile was generated using less than values (those values below the detection limit) and subsequently indicated no reportable technetium above the range of 1.1×10^4 to 3.3×10^4 pCi/L porewater corrected.

The results from the analyses of samples from borehole C3104 are consistent with the results of the analyses on samples from borehole C3103 in that no detectable technetium-99 appeared to be associated with high nitrate levels.

7.0 References

ASTM (American Society for Testing and Materials) D2216-98. 1998. *Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials) D2488-93. 1993. *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)*. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASA (American Society of Agronomy). 1996. *Methods of Soil Analysis - Part 3, Chemical Methods*, SSSA Book Series 5, ed. DL Sparks, Soil Science Society of America, Madison, Wisconsin.

DOE. 1999. *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for the SST Waste Management Areas*. DOE/RL-99-36, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL. 2002. *Remedial Investigation Report for the 200-TW-1 and 200-TW-2 Operable Units*, DOE/RL-2002-42, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

EPA. 1984. *Test Method for the Determination of Inorganic Anions in Water by Ion Chromatography, Method 300.0A*. EPA-600/4-84-017, U.S. Environmental Protection Agency, Washington, D.C.

EPA. 2000a. "Inductively Coupled Plasma-Atomic Emission Spectrometry." *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Method 6010B*. EPA Publication SW-846, [Online manual]. Available URL: <http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm>

EPA. 2000b. "Inductively Coupled Plasma-Mass Spectrometry." *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Method 6020*. EPA Publication SW-846, [Online manual]. Available URL: <http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm>

Knepp, AJ. 2002. *Field Investigation Report for Waste Management Area B-BX-BY*, RPP-10098, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

Lindenmeier, CW, RJ Serne, BN Bjornstad, GW Gee, HT Schaef, DC Lanigan, MJ Lindberg, RE Clayton, VL LeGore, IV Kutnyakov, SR Baum, KN Geiszler, MM Valenta, and TS Vickerman. 2002. *Characterization of Vadose Zone Sediment: RCRA Borehole 299-E33-338 Located Near the B-BX-BY Waste Management Area*, PNNL-14121, Draft, Pacific Northwest National Laboratory, Richland, Washington.

Maxfield, HL. 1976. *Routine Environmental Surveillance and Sampling Programs 200 Areas and Environs*, ARH-MA-143, Atlantic Richfield Hanford Company, Richland, Washington.

Pacific Northwest Laboratory (PNL). 1990. *Procedures for Groundwater Investigations*. PNL-MA-567-DO-1, Pacific Northwest Laboratory, Richland, Washington.

Pacific Northwest National Laboratory (PNNL). 1997. *Gamma Energy Analysis Operation and Instrument Verification Using the Genie2000™ Support Software*. PNNL-RRL-01, Pacific Northwest National Laboratory, Richland, Washington.

Pacific Northwest National Laboratory (PNNL). 1998. *Inductively Coupled Plasma Mass Spectrometric (ICP-MS) Analysis*. PNNL-AGG-415, Pacific Northwest National Laboratory, Richland, Washington.

Rhoades, JD. 1996. "Salinity: Electrical Conductivity and Total Dissolved Solids." In *Methods of Soil Analysis Part 3*, ed. JM Bigham, pp. 417-435. American Society of Agronomy, Madison, Wisconsin.

Rogers, PM, and AJ Knepp. 2000. *Site Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA B-BX-BY*, RPP-6072, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

Serne, RJ, GV Last, GW Gee, HT Schaef, DC Lanigan, CW Lindenmeier, MJ Lindberg, RE Clayton, VL LeGore, RD Orr, IV Kutnyakov, SR Baum, KN Geiszler, CF Brown, MM Valenta, and TS Vickerman. 2002a. *Characterization of Vadose Zone Sediment: Borehole 299-E33-45 Near BX-102 in the B-BX-BY Waste Management Area*, PNNL-14083, Pacific Northwest National Laboratory, Richland, Washington.

Serne, RJ, BN Bjornstad, GW Gee, HT Schaef, DC Lanigan, CW Lindenmeier, RD Orr, VL LeGore, RE Clayton, MJ Lindberg, IV Kutnyakov, SR Baum, KN Geiszler, MM Valenta, TS Vickerman, and LJ Royack. 2002b. *Characterization of Vadose Zone Sediment: Borehole 299-E33-46 Near B-110 in the B-BX-BY Waste Management Area*, PNNL-14119, Draft, Pacific Northwest National Laboratory, Richland, Washington.

Serne, RJ, BN Bjornstad, HT Schaef, BA Williams, DC Lanigan, DG Horton, RE Clayton, AV Mitroshkov, VL LeGore, MJ O'Hara, CF Brown, KE Parker, IV Kutnyakov, JN Serne, GV Last, SC Smith, CW Lindenmeier, JM Zachara, and DB Burke. 2002c. *Characterization of Vadose Zone Sediment: Uncontaminated RCRA Borehole Core Samples and Composite Samples*, PNNL-13757-1, Pacific Northwest National Laboratory, Richland, Washington.

Todd, ME, and C Trice. 2002. *Borehole Summary Report for Boreholes C3101 and C3104, and Drive Casings C3340, C3341, C3342, C3343, and C3344, in the 216-B-38 Trench and 216-B-7A Crib, 200-TW-2 Tank Waste Group Operable Unit*, BHI-01607, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Wood, MI, TE Jones, R Schalla, BN Bjornstad, and SM Narbutovskih. 2000. *Subsurface Conditions Description of the B-BX-BY Waste Management Area*, HNF-5507, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

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