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# FIELD INVESTIGATION REPORT FOR WASTE MANAGEMENT AREA S-SX

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Abstract: This field investigation report for WMA S-SX addresses the results and modeling efforts from field investigation over the last three years (1997 through 2000).

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## EXECUTIVE SUMMARY

This *Field Investigation Report for Waste Management Area S-SX* presents the most recent comprehensive assessment of existing and new information to clarify the current understanding of the nature and extent of past releases in the S and SX tank farms that comprise waste management area (WMA) S-SX. This report evaluates the potential of corrective actions to reduce or eliminate the consequences of these past releases on human health and the environment. This report presents the results of the most thorough field investigation ever conducted on the impacts associated with tank leaks from S and SX farm single-shell tanks. Also presented are computer simulation results of future groundwater impacts from such past releases, as well as a risk assessment. The *Resource Conservation and Recovery Act of 1976* (RCRA) Corrective Action Program and its implementing regulations require a rigorous investigative process to maintain a high degree of technical integrity and usefulness to decision makers. This task included the integrated efforts of the Tank Farm Vadose Zone Project; other U.S. Department of Energy (DOE), Office of River Protection (ORP) tasks; the Hanford Groundwater/Vadose Zone Integration Project; Hanford Groundwater Program; and National Laboratories and universities funded from DOE Headquarters.

This *Field Investigation Report for Waste Management Area S-SX* was mandated by the RCRA Corrective Action Process, as documented in *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas*.<sup>1</sup> That work plan provides the overall framework to guide groundwater and vadose zone investigation and decision making for single-shell tank WMAs at the Hanford Site. The approved *Hanford Federal Facility Agreement and Consent Order*<sup>2</sup> (HFFACO a.k.a. Tri-Party Agreement) Change Package M-45-98-03 establishes that this field investigation report is to support the development and implementation of interim measures and interim corrective measures and support single-shell tank waste retrieval and closure activities through integration with other projects (e.g., Hanford Groundwater/Vadose Zone Integration, Single-Shell Tank Retrieval).

Major conclusions of this report follow.

- Waste from tanks in the SX tank farm has impacted groundwater most likely due to enhanced contaminant transport caused by nearby waterline leaks, with technetium-99 groundwater concentrations reaching over 80,000 pCi/L. The drinking water standard<sup>3</sup> for technetium-99 is 900 pCi/L.

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<sup>1</sup> DOE-RL, 2000, *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas*, DOE/RL-99-36, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

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

<sup>3</sup> 40 CFR 141, "National Primary Drinking Water Regulations," *Code of Federal Regulations*, as amended.

- Waste from WMA S-SX is projected to significantly impact groundwater in the future, resulting in a projected maximum incremental lifetime cancer risk of 0.01 for an industrial worker near the tank farm boundary. This is a theoretical calculation for an industrial worker consuming 2 L of water a day from a groundwater well at the tank farm boundary.
- Predictions of future contaminant behavior and groundwater impact are most sensitive to estimates of total inventory and recharge.
- Control of moisture movement through the tank farms soils presents the greatest opportunity to minimize future impacts on groundwater resources.
- The geochemistry associated with the movement of cesium-137 from tank leaks in WMA S-SX has been understood, thus providing an explanation of the depth of cesium-137 contamination associated with these tank leaks. Significant additional movement of cesium-137 is not expected.
- The field, laboratory, and computational results associated with this effort have strengthened the support for conceptual models on moisture flow and contaminant transport and provide an improved understanding of contaminant profiles in highly impacted regions of the WMA S-SX tank farm vadose zone.
- The fine-grained sediments associated with the undifferentiated Hanford formation/Plio-Pleistocene unit have retarded migration of many of the contaminants released from the tanks.
- Interim measures have been identified and completed in WMA S-SX that are expected to significantly reduce future consequences.
- Drilling technology advancements developed under this project have resulted in improved sample quality and reduced costs over past drilling efforts in highly radiologically contaminated areas.

Recommendations in this report address interim measures, accelerated corrective measures, future tank operations, collection of additional WMA S-SX data and information, lessons learned, and restructuring of the RCRA Corrective Actions Program schedule.

Key recommendations are the following.

- The interim measures (waterline isolation and leak testing, runoff/runoff controls, groundwater remediation) should be extended to other tank farms. Periodic waterline testing should be conducted.
- An engineering study is required to determine the costs and impacts of placing an interim surface barrier to determine the impact to tank farm operations and planned waste retrieval actions.
- Aboveground piping should be used whenever possible for improved leak detection.

- Future liquid waste retrieval activities should evaluate the use of either limited water-based or dry waste retrieval methods instead of supernate where significant cesium-137 exists in soils.
- A limited number of additional characterization activities that may be useful in making long-term remedial action decisions have been identified. Additional data collection is warranted only if the data collected are anticipated to have a significant impact on the findings presented in this report. Additional data are not necessary to support interim action decisions.

The following sections provide further details and support:

- Section 1.0. Introduction
- Section 2.0. Investigative Approach
- Section 3.0. Investigative Results and Conclusions
- Section 4.0. Summary and Conclusions of the Impact (Risk) Evaluations
- Section 5.0. Conclusions
- Section 6.0. Recommendations.

### **Section 1.0, Introduction and Section 2.0, Investigative Approach**

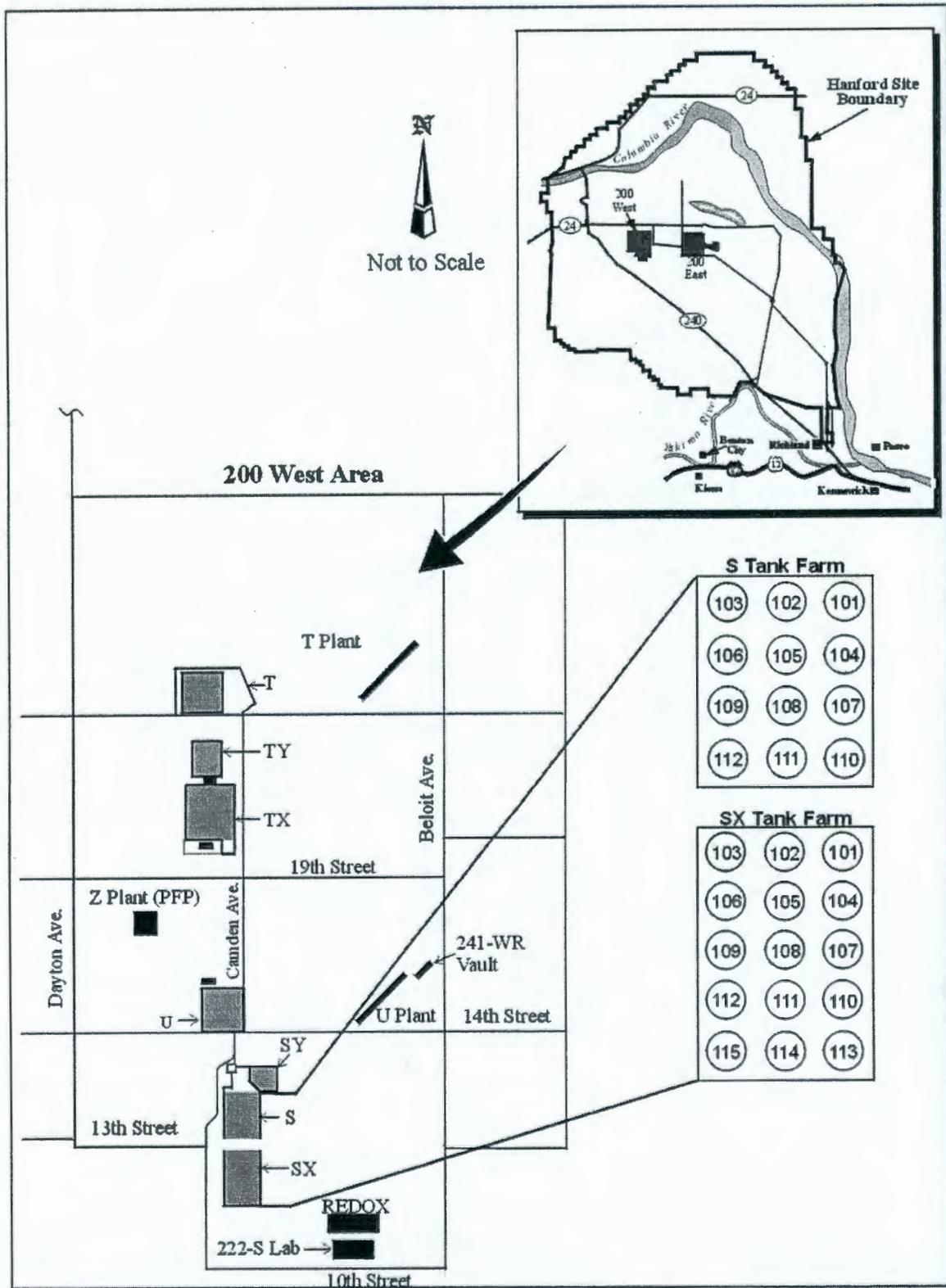
Twelve 23-m (75-ft) diameter underground tanks in the S tank farm and 15 similar tanks in the SX tank farm have stored hazardous, high-level radioactive mixed wastes for several decades. These tanks, along with their associated infrastructure for WMA S-SX, are located in the 200 West Area of the Hanford Site (Figure ES.1). This WMA was placed in RCRA groundwater monitoring assessment because of elevated specific conductance and high-levels of technetium-99 in downgradient monitoring wells.<sup>4</sup> Based on the groundwater impacts at WMA S-SX and similar determinations for other SST farm releases, DOE established the RCRA Corrective Action Program to characterize the vadose zone and groundwater; to perform analyses to aid in the understanding of contaminant fate, moisture movement, and contaminant transport; and to estimate future environmental impacts from past leaks.

The framework for the investigative approach for the RCRA Corrective Action Program was developed through negotiations with the Washington State Department of Ecology and DOE in *Hanford Federal Facility Agreement and Consent Order Change Package M-45-98-03*. The RCRA facility investigation/corrective measures study work plan<sup>1</sup> encompasses the aspects of work common to all WMAs and establishes the regulatory and programmatic framework for the overall RCRA Corrective Action Program.

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<sup>4</sup> Caggiano, J.A. 1996, *Groundwater Water Quality Assessment Monitoring Plan for Single-Shell Tank Waste Management Area S-SX*, WHC-SD-EN-AP-191, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

**Figure ES.1. Location Map of Single-Shell Tank Waste Management Area S-SX and Surrounding Facilities in the 200 West Area**



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To ensure appropriate data were collected to meet the needs for field investigation reports as identified in site-specific work plans, an implementation plan was prepared as Appendix J of the RCRA facility investigation/corrective measures study work plan.<sup>1</sup> Key to the implementation plan approach is first understanding what efforts would be most appropriate for a field investigation report and then addressing assimilation of data necessary to complete those evaluations. As documented in the Appendix J implementation plan, the key evaluation for assessing effectiveness of interim measures and the need for additional data is that of the potential risk to a human receptor.

The effort for WMA S-SX included collecting and analyzing available information, identifying data gaps, and planning future field characterization activities. The extensive available information is summarized in *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination*<sup>5</sup> and in *Subsurface Physical Conditions Description of the S-SX Waste Management Area*.<sup>6</sup> This information was used in a set of data quality objectives processes to determine data gaps. Data gaps were filled under two field programs documented in *Preliminary Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX*<sup>7</sup> and *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX*<sup>8</sup>. These work plan addenda were approved by DOE and the Washington State Department of Ecology. Other work, particularly that of the national laboratories and universities funded by DOE headquarters, is in addition to and complements the work presented in the work plan addenda.

### Section 3.0, Investigative Results and Conclusions

Much new data were collected as part of the total WMA S-SX characterization effort. This discussion is divided into three main sections:

- Field activities, which involves the collection of soil samples and geophysical measurements
- Laboratory analyses of those soil samples
- Data evaluations of these measures and analyses as well as numerical simulations of past events.

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<sup>5</sup> Jones, T.E., R. Khaleel, D.A. Myers, J.W. Shade, and M.I. Wood, 1998, *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination*, HNF-2603, Rev. 0, Lockheed Martin Hanford Corporation, Richland, Washington.

<sup>6</sup> Johnson, V.G., T.E. Jones, S.P. Reidel, and M.I. Wood, 1999, *Subsurface Physical Conditions Description of the S-SX Waste Management Area*, HNF-4936, Fluor Daniel Hanford, Incorporated, Richland, Washington.

<sup>7</sup> Henderson, J.C., 1999, *Preliminary Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX*, HNF-4380, Rev. 1B, Fluor Daniel Hanford, Incorporated, Richland, Washington.

<sup>8</sup> Rogers, P.M. and A.J. Knepp, 2000, *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX*, HNF-5085, Rev. 1, CH2M Hill Hanford Group, Incorporated, Richland, Washington.

**Field Activities.** Major field investigations defined in the work plans were conducted at the following locations (see Figure ES.2):

- Installation of a RCRA-compliant groundwater well (299-W23-19) southwest of tank SX-115
- Sediment sampling and decommissioning of borehole 41-09-39 (well 299-W23-234)
- Collection of vadose zone characterization data from the installation of three RCRA groundwater monitoring wells (299-W23-48, -49, and -50)
- Installation of an exploratory slant borehole (299-W23-64) beneath tank SX-108
- Shallow vadose zone soil investigation around tank S-104.

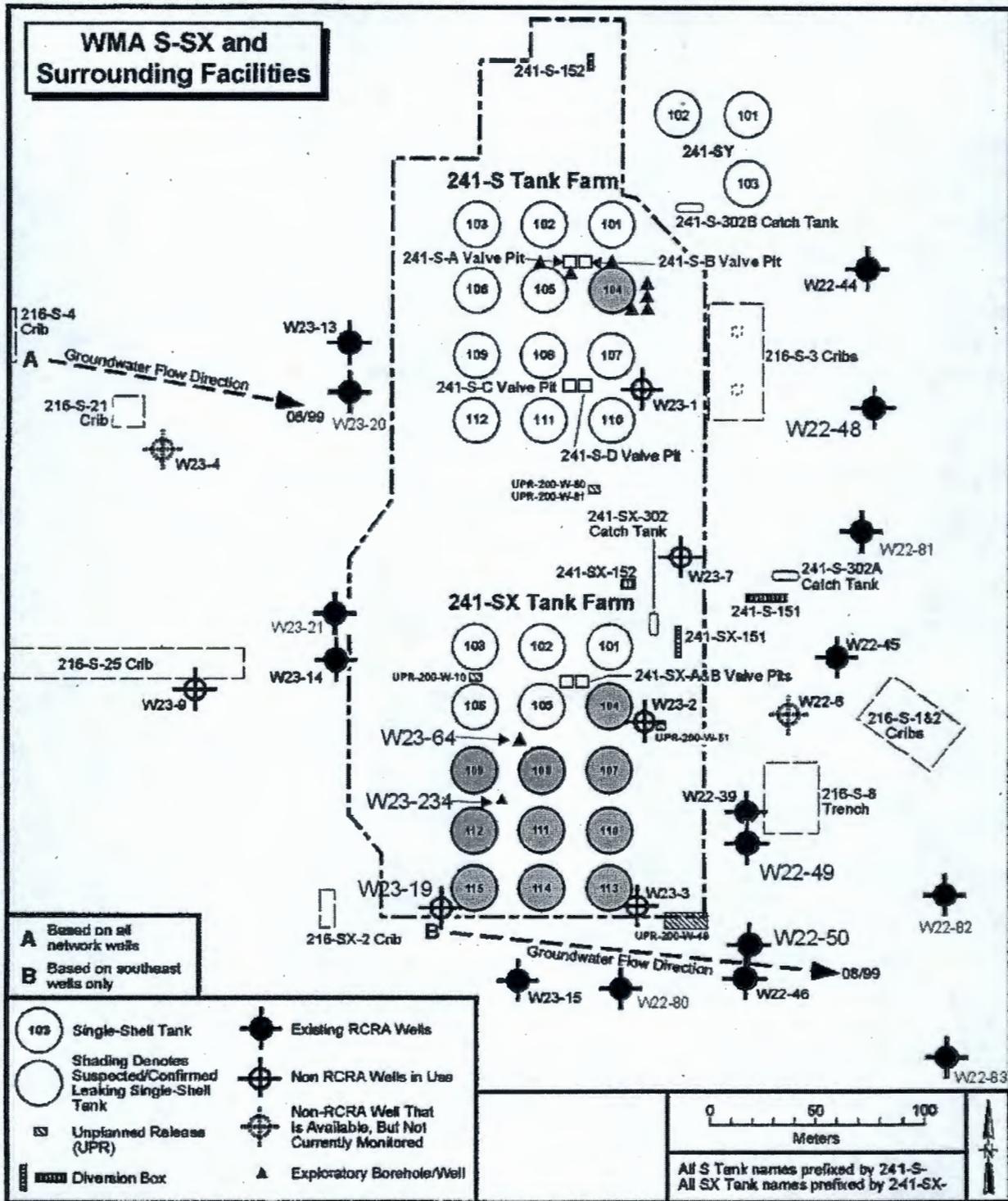
For each of the boreholes drilled, soil samples were retrieved for laboratory analyses and geophysical logging was performed. In each of these boreholes, gamma logging (to measure the concentration of gamma-emitting radionuclides) and neutron logging (to measure moisture content) were performed. In addition, thermal logging (to measure the temperature of the borehole casing and hence the soil temperature) was performed on borehole 41-09-39 and the SX-108 slant borehole. Finally, neutron activation measurements were done on borehole 299-W23-19 to determine concentrations of certain nuclides. The shallow soil investigation performed gamma logging and limited soil collection.

Additional geophysical logging was performed in existing boreholes within WMA S-SX. To supplement earlier gamma-logging work, boreholes with high gamma radiation were relogged with a high-rate detector to quantify the highest concentrations of cesium-137 contamination. Such information was used in the determination of the amount and extent of this radionuclide. In addition, neutron logging was performed on most of the existing boreholes in the south end of the SX tank farm.

The major field characterization accomplishments included the following.

- Improvements in drilling technology allowed safe and efficient sample collection of contaminants in the high radiation zone beneath tank SX-108. Other improvements aided the program in a variety of areas.
- Use of the specially developed sampler is an effective means for sample collection in high radiologically contaminated areas.
- Air rotary drilling can be performed in the tank farms but is not cost effective due to the high cost of contamination confinement and associated air release risk to the environment.
- The distribution of moisture content, on the basis of drywell measurements, helps to identify areas where potential sources of recharge from water-line leaks may exist.

Figure ES.2. Waste Management Area S-SX, Location Map of Characterization Activities, Surrounding Facilities, and Wells



Note: All wells are preceded by 299-.

**Laboratory Analyses.** Extensive analyses were performed by the RCRA Corrective Action Program on the samples gathered from the boreholes. Because the amount of soil collected during the shallow vadose zone soil investigations was limited, analyses of those samples were much more selective. In addition to the RCRA Corrective Action Program activities, the national laboratories and universities investigated certain samples with highly advanced techniques.

Typical RCRA Corrective Action Program laboratory analyses included the measurement of physical properties (density, moisture content, specific conductivity) and elemental and isotopic concentrations. Concentrations were measured using water and strong acid extracts from the soil samples as well as using porewater. Anions typically investigated included nitrate, nitrite, chloride, fluoride, and sulfate. Cations typically investigated included aluminum, arsenic, boron, calcium, chromium, cobalt, iron, magnesium, manganese, molybdenum, nickel, potassium, selenium, silicon, sodium, strontium, and zinc. The major isotopes are technetium-99 and cesium-137. Isolated occurrences of slightly elevated uranium are present and very small quantities of iodine-129 are observed in the some soils from the SX-108 slant borehole.

Key findings from the RCRA Corrective Action Program-sponsored work include the following.

- Groundwater samples collected from groundwater wells 299-W23-15, 299-W23-19, 299-W22-48, 299-W22-49, 299-W22-50, 299-W22-80, 299-W22-81, and 299-W22-82 ranged from less than 10 pCi/L to 81,500 pCi/L for technetium-99. The drinking water standard<sup>3</sup> is 900 pCi/L for technetium-99. The highest technetium-99 groundwater concentration on the Hanford Site is in well 299-W23-19. Multiple groundwater sources of technetium-99 within the WMA boundary are indicated.
- Analyses of tank farm soils show elevated concentrations of several constituents that are attributed to tank fluid leakage (primarily tanks SX-108 and SX-115) into the soil column. High concentrations of cesium-137 were found 16 to 30 m (52 to 100 ft) below ground surface, with concentrations as high as 96,000,000 pCi/g. High concentrations of more mobile contaminants (technetium-99, chromium, nitrate) in porewater or water extract samples were found deeper (down to 49 m [160 ft] below ground surface) in all 3 boreholes drilled inside the SX tank farm, primarily in the lower subunits of the Hanford formation (H1 and H2) and the upper Plio-Pleistocene unit (subunit PPlz). In the high-concentration depth intervals (21 to 49 m [70 to 160 ft] below ground), porewater concentrations of technetium-99 ranged from 95,000 to 240,000,000 pCi/L; chromium ranged from 3 to 21,800 mg/L; and nitrate from 6,000 to 1,000,000 mg/L.
- The bulk of the matric potential measurements for sediments from four boreholes (W22-48, W22-50, W23-19, and W23-234) in and around WMA S-SX suggest a draining profile throughout the Hanford formation. For the two boreholes inside the tank farm the matric potential profiles indicate draining throughout the vadose zone. For two boreholes outside the tank farm fences the matric potential profiles suggest that the anthropomorphic activities (removal of vegetation) resulted in an enhanced wetting front that has traveled through the Hanford formation and is presently very slowly wetting the deeper sediments. That is, for the two boreholes outside the tank farm fences, the deeper

sediments in the Plio-Pleistocene unit and Ringold Formation are wetting as opposed to draining.

The Science and Technology activity of the Hanford Groundwater/Vadose Zone Integration Project conducted focused fundamental research in the areas of mineralogy, geochemistry, reactive transport modeling, and determination of field hydrologic parameters to address specific tank farm vadose zone issues. Laboratory experiments on tank farm sediment have provided results that led to an understanding of complex relationships between sodium ion concentrations and the mobility of cesium-137 in the Hanford vadose zone. Other laboratory studies have led to the development of a plausible hypothesis to explain the unexpected 'apparent' retardation of chromium(VI) in the Hanford sediments. These studies indicate that approximately 50% of the chromium(VI) may be immobilized in the vadose zone by post emplacement reduction to chromium(III). Desorption kinetic studies with chromium and cesium contaminated sediments have produced release-rate models that can be used for defensible projections of the future mobility of these sorbed contaminants. Isotope geochemistry studies have suggested that additional insight into multiple tank leak events can be developed by coupling Hanford irradiated fuel composition records with trace isotope analyses. Fluid flow, heat transport, and nonisothermal multiphase fluid flow and transport numerical modeling studies have provided considerable insight into the impacts of high-heat tank waste storage and leakage on the vadose zone geochemical environment. Finally, large-scale field investigations provide a better understanding of realistic hydrologic parameters required for transport modeling studies.

In particular, a key finding from this Science and Technology activity effort is that:

- The mobility of cesium is now quantitatively understood.

Cesium is quite mobile under high aqueous sodium conditions (e.g., the initial phase of the tank SX-108 leak), but is highly retarded for low concentrations of sodium (e.g., SX-115 leak). Thus, the observations that greatly contributed to the creation of the RCRA Corrective Action Program (the unexplained presence of a material far from its source, which was thought to be highly retarded in its movement) are now explained. Central to this explanation is the current belief that sodium concentrations in some of the leaked tank supernate (e.g., SX-108) were higher than originally thought. These concentrations may have exceeded 15 mol/L, a concentration that virtually eliminates the retardation of cesium. The existence of these high sodium concentrations, which resulted from the boiling and self-concentration of the wastes, was suggested by modeling performed by the Science and Technology effort and porewater characterization data from the slant borehole samples.

**Data Evaluation.** Data from previous efforts and from current laboratory measurements were extended by data evaluation efforts, particularly in the areas of inventory, recharge, and thermal modeling.

Previous estimates of soil inventories resulting from the major tank leaks have been enhanced. Improved estimates of in-tank inventories as a function of time have been derived from the Hanford defined waste model, thus allowing better estimates of the composition of the waste at the time of leak. Because of the extensive measurements of cesium-137 soil concentrations and because of the known ratios of other contaminants to cesium-137 in tank waste, cesium-137

became a key contaminant for inventory analyses. Multiple kriging analyses were completed using a variety of cesium-137 data sources. In particular, the last analysis included gamma data from existing boreholes, lateral tubes beneath the tanks, as well as cesium-137 concentrations from soil samples gathered in this field investigation. Combining the results of these efforts with contaminant concentrations from the new borehole samples greatly increased the knowledge of the level and extent of the leaked waste.

Key inventory estimates for WMA S-SX include the following:

- The total amount of tank waste leaked is 435,275 L (115,000 gal), with 90,800; 57,500; 56,775; and 189,250 L (24,000; 15,200; 15,000; and 50,000 gal) leaked, respectively, from tanks S-104, SX-108, SX-113, and SX-115.
- The total amount of cesium-137 leaked in the SX tank farm is 100,000 Ci, with 41,000 Ci from tank SX-108 as well as 19,000 Ci from tank SX-115 and 17,000 from tank SX-107.
- The total amount of technetium-99 leaked in the SX tank farm is 30 Ci, with 12 Ci from tank SX-108 as well as 5.5 Ci from tank SX-115 and 5 Ci from tank SX-107.

Because no site-specific recharge measurements are available, estimates of natural recharge are based primarily on analogous Hanford Site measurements (e.g., lysimetry studies). Results of an evaluation of recharge conducted to estimate drainage through the vadose zone indicate that natural and artificial recharge influence contaminant migration. Shedding from the tank domes enhances recharge. In the absence of site-specific data, natural recharge estimates at the tank farm are assumed to range from 10 mm/yr (0.4 in./yr) to 100 mm/yr (4.0 in./yr). Artificial recharge due to leaking water lines can overwhelm natural recharge and hence significantly enhance contaminant migration, as suggested by the groundwater measurements near tank SX-115.

The Science and Technology activity of the Hanford Groundwater/Vadose Zone Integration Project performed a series of numerical simulations to investigate the effects of temperature on moisture flow. The temperatures in many SX tanks exceeded 100 °C (212 °F) in the 1950s and 1960s because of the high concentration of short-lived fission products in the REDOX high-level waste. The simulations indicate that there was significant dry-out of the soils beneath such tanks, and that the presence of a 'heat pipe' effect may have caused liquid moisture to move from surrounding vadose zone sediments toward the tank. A key finding is that:

- Thermal effects will have minor impact on moisture movement (and hence contaminant transport) after year 2000. However, in-ground temperatures are and will remain well above ambient temperature at depth in the vadose zone, and such temperatures do have implications for both chemical and hydrologic processes.

### **Section 3.5, Interim Measures**

The field investigations for WMA S-SX suggest that anthropomorphic water sources have resulted in accelerated contaminant migration. Therefore, interim measures were identified and have been completed to minimize the infiltration from these sources. These interim measures include the following:

- Upgradient surface water run-on control measures
- Cut and capped two water lines running to the SX tank farm and leak-tested two water lines running to the S and SY tank farms
- Released water-line status maps for the S, SX, and SY tank farms.

The Office of River Protection has implemented interim measures related to upgradient surface water run-on control measures, cutting and capping water lines at other 200 West Area tank farms and plans to implement these same interim measures in the 200 East Area during fiscal year 2002. The key finding is that:

- The leak testing and cutting of water pipelines and building of run-on/run-off barriers should be performed for all single-shell tank farms.

Efforts have also been started to investigate the feasibility of remediating the groundwater technetium in the vicinity of the tank SX-115 borehole (well 299-W23-19).

#### **Section 4.0, Summary and Conclusions of the Impact (Risk) Evaluations**

To estimate the future impact of past tank leaks, a suite of numerical simulations was performed. For the most important simulations, the results were converted into risk values.

*Modeling Data Package for S-SX Field Investigation Report (FIR)*<sup>9</sup> provided the models and parameters used in the two-dimensional numerical simulations for the 13 cases studied. The simulations started in the year 2000, using an initial contaminant distribution in the vadose zone based on the results of the inventory data evaluation. A period of 1,000 years was simulated. Potential leaks from tank waste retrieval and from tank closure were not included. In all scenarios, a final closure barrier was in place by 2040. Important cases analyzed the effect of an interim surface barrier, different recharge rates, and the initial distribution of contaminants in the vadose zone. The modeling focused primarily on the WMA S-SX boundary. To meet the requirements established by the Washington State Department of Ecology, three additional compliance points were analyzed at the 200 West Area fence, 200 Area exclusion zone boundary, and the Columbia River.

Key findings from the numerical simulations include the following.

- Projected groundwater concentrations for technetium-99, nitrate, and chromium exceeded the drinking water standard<sup>3</sup> at the WMA S-SX boundary for all scenarios and cases except for projected nitrate groundwater concentrations for the two low recharge cases (i.e., 30 and 10 mm/yr).

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<sup>9</sup> Khaleel, R., T.E. Jones, A.J. Knepp, F.M. Mann, D.A. Myers, P.M. Rogers, R.J. Serne, and M.I. Wood, *Modeling Data Package for S-SX Field Investigation Report (FIR)*, RPP-6296, Rev. 0, CH2M Hill Hanford Group, Inc., Richland, Washington.

- For the base case (100 mm/yr recharge and a closure surface barrier) and the case having an interim surface barrier, simulated technetium concentrations exceed the drinking water standard at the WMA S-SX boundary and 200 West fence.
- For the base case, the estimated arrival times of the peak concentration for technetium-99 at the WMA S-SX boundary is estimated to be year 2046.
- The placement of an interim surface barrier in the year 2010 would reduce peak technetium-99 concentrations at the WMA S-SX boundary by about a factor of 2, yielding peak concentrations still above drinking water standards.
- The key factors affecting the estimation of risk near the S and SX tank farms as estimates of vadose zone contaminant inventory and recharge.

Arrival times for peak concentrations for chromium and nitrate are projected to be similar to those for technetium-99, with the differences being primarily due to the initial inventory distributions. Because of its retardation factor and radioactive decay, cesium-137 is projected to be undetectable at the WMA S-SX boundary for all simulation runs.

The interim surface barriers, as expected, reduce fluxes to the water table. The technetium-99 peak concentrations were reduced by over a factor of 2 with placement of barriers that causes the earlier reduction of recharge relative to the base case (which has only a closure surface barrier). However, the use of interim surface barriers did not result in projected contaminant concentration levels below drinking water standard maximum contaminant levels.

Simulation results indicate that two key drivers affecting future contaminant migration are estimates of vadose zone contaminant inventory and recharge. The contaminant inventories have a major influence on the peak concentrations and arrival times of long-lived mobile radionuclides and chemical species at the WMA S-SX boundary. The inventory mass (i.e., curies or kilograms) has a much more significant influence on estimated groundwater concentrations than the spatial distribution of the contaminants. Sensitivity analyses indicate that recharge estimates have a major influence on the peak concentrations and their arrival times. As discussed earlier, no tank farm-specific recharge estimates are presently available.

Risk and dose were evaluated for five of these 13 cases using the *Hanford Site Risk Assessment Methodology*<sup>10</sup> and "Model Toxics Control Act"<sup>11</sup> Method B (unrestricted) and Method C (industrial) exposure scenarios. The major findings include the following.

- Incremental lifetime cancer risk ranges from  $9.98 \times 10^{-3}$  to  $1.33 \times 10^{-6}$  at the four points of compliance for the industrial worker scenario. Technetium-99 is the key contaminant of concern for cancer risk.

<sup>10</sup> DOE-RL, 1995, *Hanford Site Risk Assessment Methodology*, DOE/RL-91-45, Rev. 3, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

<sup>11</sup> "Model Toxics Control Act," RCW 70.105D, *Revised Code of Washington*, as amended.

- The hazard index ranges from 0.0045 to 300 at the four points of compliance for the industrial worker scenario. Chromium is the key contaminant of concern for the hazard index.

## Section 5.0, Conclusions

Eight major outcomes have resulted from this work.

- A workable, effective approach has been developed to improve the characterization of vadose zone contamination in all the tank farm WMAs, to interpret past contamination events, and to estimate future contaminant migration.
- A set of data collection activities has been completed to fill major gaps in the database that quantify the nature, extent, and mobility of contamination in the vadose zone. From these data, a conceptualization of contaminant migration events has evolved.
- Through cooperation with the Science and Technology activity of the Hanford Groundwater/Vadose Zone Integration Project and other Hanford Site projects, resources normally unavailable to the RCRA Corrective Action Program were put to use on soil and groundwater issues. These activities provided significant insight into their resolution.
- The insertion of DOE national laboratory and university laboratory expertise was directed at important issues and yielded significant results over a very short time period.
- Future migration patterns and associated risk from groundwater contamination have been projected for the next 1,000 years.
- A series of interim measures have been identified and implemented that immediately reduce the potential of accelerated contaminant migration.
- The approach used by the RCRA Corrective Action Program is successful and should be used for future efforts. The approach of the RCRA Corrective Action Program (gather existing data, identify gaps, collect new data based on gaps, analyze the consequence of the data obtained, and document all the efforts) worked extremely well.
- The current conceptual model should be the basis for further RCRA Corrective Action Program activities and modeling.

In addition, some more general conclusions can be reached. These conclusions involve the approach taken by the program itself and the conceptual models used.

Prior to the initiation of the WMA S-SX characterization effort, a conceptual model was developed from the existing data to explain contamination events that lead to the current state of contamination in the WMA S-SX vadose zone and nearby unconfined aquifer. This conceptual model pictured the contaminant transport having two stages (an early stage driven by the chemical constituents of the leak including enhanced moisture flow, followed by a second stage

where the natural systems of the vadose zone reasserted themselves). In general, this conceptual model has been strengthened by the new information gathered.

## Section 6.0, Recommendations

This section provides recommendations for further investigations and decisions based on findings from the WMA S-SX vadose zone and groundwater characterization activities. Recommendations for further investigations and decisions are provided for the following:

- Interim measures
- Accelerated corrective measure studies
- Future tank farm operations
- Collection of additional data and information
- Lessons learned
- Restructuring of the RCRA Corrective Action Program.

**Interim Measures.** Interim measures (leak testing and capping of waterlines as well as run-on/run-off controls) were identified and have already been completed at WMAs S-SX, U, T, and TX-TY. Such measures should be performed for all tank farms and are planned.

Work has begun to test the feasibility of remediating the technetium groundwater plume identified at well 299-W23-19 located near tank SX-115. This work should continue to determine the need for and most appropriate means for remediation, if necessary.

**Accelerated Corrective Measure Studies.** A possible corrective measure would be the placement of interim surface barriers. Numerical simulation results suggest that compared to the final-surface-barrier-only alternative, placement of an interim surface barrier provides a twofold improvement in peak concentrations for mobile contaminants because of the earlier reductions in recharge. However, contaminant concentrations even with an interim barrier are still projected to be higher than drinking water standards. An engineering study with full tank farm staff involvement should be performed to determine the impacts from placing interim barriers inside the tank farms on tank farm operations as well as on waste retrieval and closure activities.

**Future Tank Farms Operations.** Numerous tank waste leaks have occurred in the SST farms through overfilling of tanks or through leaks in ancillary equipment (e.g., piping) during transfers of waste from one tank to another. This characterization program has shown how important the effects of manmade leaks from tank infrastructure have been in the migration history of tank leaks. Therefore, the recent use of aboveground piping and similar types of best management practices should be continued before, during, and after waste retrieval activities to minimize potential releases to the environment in the future during waste retrieval activities.

The new enhanced understanding of cesium migration implies that new sodium sources should not be applied to the vadose zone. Without such sources, the cesium-137 is not expected to move significant distances. Thus, future liquid waste retrieval activities should evaluate the use of either limited water-based or dry waste retrieval methods instead of sodium-rich supernate as the waste retrieval media to ensure cesium does not migrate further downward, especially on known past leaking tanks like tank SX-108.

**Collection of Additional WMA S-SX Data and Information.** Additional data collection is warranted only if the data collected are anticipated to have a significant impact on the findings presented in this report. Additional data do not appear to be necessary to support interim action decisions.

To reduce uncertainty, additional data could be obtained in WMA S-SX:

- Quantify gamma activity directly beneath the tanks through the use of the laterals located beneath SX farm tanks
- Quantify recharge rates for tank farm sediments
- Obtain vadose zone samples near tanks SX-107, S-104, and SX-115 and analyze those samples for important contaminants.

The matric potential and moisture measurements for sediment samples in WMA S-SX are valuable in determining the tank farm soil moisture regime and potential for contaminant migration. These measurements can and should be extended to other tank farms. In FY 2001, a plan similar to that used for analyses of gross gamma measurements was developed to analyze previously collected moisture content measurements. Such analyses should be performed for all SST farms to aid in identifying opportunities for enhanced contaminant migration.

Data and models have been developed by the Science and Technology activity that can be used to evaluate the effects of aqueous sodium releases on the remobilization of cesium-137 that is sorbed to sediments in the vadose zone. These models can be used to evaluate the effects of different retrieval scenarios and leak losses on the stability of the sorbed, in-ground cesium pool.

**Lessons Learned.** Much has been learned from the characterization, laboratory analyses, and modeling done for WMA S-SX. For example, the drilling techniques developed from the SX-108 slant borehole may be applied to characterization of the TX tank farm. The use of a tiered analysis approach has greatly decreased costs while prioritizing areas of greatest interests. Finally, non-isothermal and isothermal modeling has improved the assessment of future releases to the groundwater and an understanding of thermal effects for contaminant migration through the vadose zone.

The main lesson learned is the approach used in creating this field investigation report was successful and should be repeated for other field investigation report efforts. The FIRs will provide the baseline information to support tank waste retrieval and tank farm closure.

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## LIST OF TERMS

bgs	below ground surface
BTC	breakthrough curve
CHG	CH2M HILL Hanford Group, Inc.
CMS	corrective measures study
CoC	contaminant of concern
CoPC	constituent of potential
DOE	U.S. Department of Energy
DQO	data quality objectives
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FIR	field investigation report
FY	fiscal year
HDW	Hanford defined waste (model)
HFFACO	<i>Hanford Federal Facility Agreement and Consent Order</i>
HGL	HydroGeologic, Inc.
HLW	high-level waste
HSRAM	Hanford Site Risk Assessment Methodology
ICM	interim corrective measure
ILCR	incremental lifetime cancer risk
MSU	Montana State University
MTCA	Model Toxics Control Act
ORP	Office of River Protection
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
REDOX	reduction-oxidation
RFI	RCRA facility investigation
RPP	River Protection Project
S&T	Science and Technology
SST	single-shell tank
TWRS EIS	Tank Waste Remediation System Environmental Impact Statement
WMA	waste management area

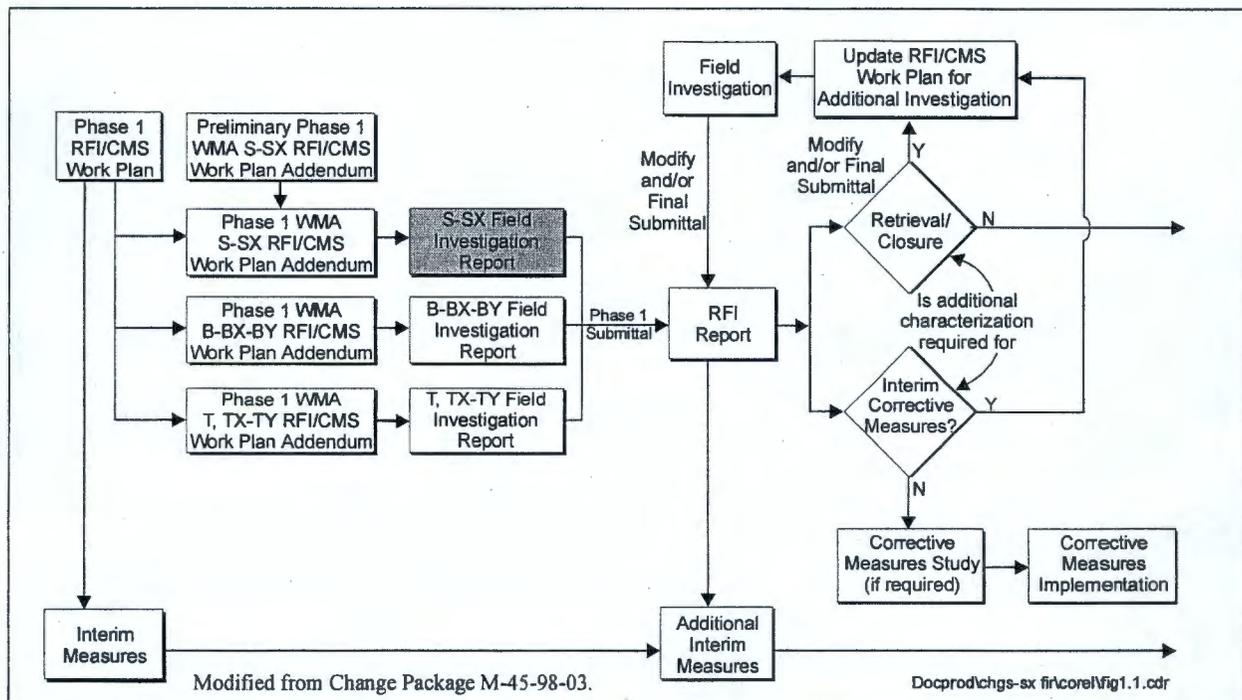
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## 1.0 INTRODUCTION

This *Field Investigation Report for Waste Management Area S-SX* has been prepared for the *Resource Conservation and Recovery Act of 1976 (RCRA) Corrective Action Program* for single-shell tank (SST) farms at the U.S. Department of Energy (DOE) Hanford Site. The DOE Office of River Protection (ORP) initiated the SST RCRA Corrective Action Program to address the nature and extent of contamination and associated risk impacts of past and potential future tank waste releases to the environment. This document is prescribed under the *Hanford Federal Facility Agreement and Consent Order (HFFACO; Ecology et al. 1989)* that is signed by the Washington State Department of Ecology (Ecology), the U.S. Environmental Protection Agency (EPA), and DOE. Issuance of this document to Ecology fulfills HFFACO Milestone M-45-55-T01.

This document fulfills the SST RCRA Corrective Action Program process criteria between completion of the initial site-specific field investigations at waste management area (WMA) S-SX and preparation of an RCRA facility investigation (RFI) report for the eight SST farms (i.e., S, SX, B, BX, BY, T, TX, and TY) that are currently part of the SST RCRA Corrective Action Program. Figure 1.1 provides a logic diagram of the RCRA Corrective Action Program process.

**Figure 1.1. Resource Conservation and Recovery Act Corrective Action Process Flow Diagram**



Placement of the WMA S-SX field investigation report (FIR) at this point in the process facilitates an early opportunity for decision makers to consider implementation of interim measures or an accelerated interim corrective measures study (CMS) at WMA S-SX. This document closely parallels the structure of an RFI report because the intent of the Tri-Parties

(i.e., Ecology, EPA, and DOE) is to combine this document with two other FIRs that will then become the basis of one consolidated RFI report that addresses the eight SST farms.

## 1.1 PURPOSE AND OBJECTIVES

Based on a high-level annotated outline defined in Appendix H of *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas* (DOE-RL 2000), a FIR has two major documentation functions that define the overall approach.

- **Document the data.** This includes the sampling approaches, the data itself, initial data reduction, and interpretation of subsurface conditions. The sampling approaches and resulting data are associated with site-specific WMA field characterization efforts. Data from other sources are integrated into the site-specific WMA data to enhance the interpretation of subsurface conditions. The data include geologic, hydrologic, geochemical, and vadose zone contaminant inventories.
- **Document the impact assessment of various conditions and scenarios.** This includes an assessment of present conditions and early identification of those areas that may require an interim measure or accelerated interim corrective measure (ICM) that might be applied to the WMA. These assessments provide predictions of groundwater impacts and associated human health risks at compliance point(s) over a period of 1,000 years.

The purpose of this WMA S-SX FIR is to fulfill the following:

- Summarize data and evaluations from the site-specific field investigation activities at WMA S-SX and from other information sources
- Evaluate the data to the extent necessary to determine the potential risk associated with hypothetical exposure to soil and groundwater at the WMA boundary
- Recommend one or more interim measures to mitigate the risk or initiation of an accelerated CMS to evaluate and compare more complex ICMs, if the potential for near-term risk is excessive
- Collect data to support waste retrieval from SSTs.

The project objectives fulfilled in this document are defined in the two work plan addenda for this effort: *Preliminary Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX* (Henderson 1999) and *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX* (Rogers and Knepp 2000) and *Activity Plan: Extension of Borehole 41-09-39 SX Tank Farm* (Myers 1997). The objectives identified in the work plan addenda are as follows:

- Collect data to support an improved understanding of the nature and extent of contaminants in the vadose zone from surface to groundwater
- Collect data to support an improved understanding of the nature and extent and fate and transport of contaminants to perform a risk assessment

- Provide WMA-specific information on source, nature, and extent of contamination for planned activities identified in the work plans
- Provide WMA-specific characterization programs data to address data gaps identified through a data quality objectives (DQO) process.

In accordance with the Phase 1 RFI/CMS work plan (DOE-RL 2000), this document includes a qualitative and limited assessment of contamination impacts on human health, but it does not include evaluations of impact to ecological receptors.

## 1.2 OVERVIEW

The Hanford Site is managed by DOE and encompasses approximately 1,517 km<sup>2</sup> (586 mi<sup>2</sup>) in the Columbia Basin of southcentral Washington State. The Hanford Site is divided into a number of waste management units, including the 200 Areas located near the center of the Site. The 200 Areas comprise the 200 East, 200 West, and 200 North Areas. The 200 East and 200 West Areas contain waste management facilities and inactive, irradiated fuel-reprocessing facilities. The 200 North Area was formally used for interim storage and staging of irradiated fuel. Some of these waste management sites are treatment, storage, and/or disposal units that include the SSTs.

The 149 SSTs, which are grouped into 12 SST farms, are regulated under the Washington State "Hazardous Waste Management Act" and its implementing requirements in the state "Dangerous Waste Regulations" (WAC 173-303). Waste in these SSTs consists of liquid; sludges; and salt cake (i.e., crystallized salts). Over the years, much of the liquid stored in the SSTs has been evaporated or pumped to double-shell tanks. The SSTs are operating under interim status pending closure. The 12 SST farms are grouped into 7 WMAs for the purpose of groundwater monitoring. Closure of the SST farms is the largest project at the Hanford Site and involves numerous activities aimed at the design, construction, and operation of waste retrieval, treatment, and storage facilities. Cleanup of the SSTs is under the purview of the ORP and River Protection Project (RPP). CH2M HILL Hanford Group, Inc. (CHG) is the current tank farm contractor in charge of carrying out the RPP mission at the tank farms. All projects associated with vadose zone characterization at the tank farms are under purview of the CHG Tank Farm Vadose Zone Project. All groundwater monitoring at the tank farms is under the purview of Pacific Northwest National Laboratory and is integrated with the Tank Farm Vadose Zone Project through the Hanford Groundwater/Vadose Zone Integration Project.

The S and SX tank farms comprise WMA S-SX. These tank farms are located in the southern portion of the 200 West Area, near the Reduction-Oxidation (REDOX) Plant (Figure 1.2).

The S tank farm is comprised of the following:

- 12 SSTs, each with a 2,900,000 L (758,000 gal) capacity
- Waste transfer lines
- Leak detection systems
- Tank ancillary equipment.



The SX tank farm is comprised of the following:

- 15 SSTs, each with a 3,785,000 L (1 million gal) capacity
- Waste transfer lines
- Leak detection systems
- Tank ancillary equipment.

The SSTs in both tank farms are 23 m (75 ft) in diameter. The S farm SSTs are approximately 11.4 m (37.3 ft) tall from base to dome, and the SX farm SSTs are approximately 13.4 m (44 ft) tall from base to dome. The sediment cover from the apex of a tank dome to ground surface is approximately 2.5 m (8.1 ft) at the S tank farm and 1.8 m (6 ft) at the SX tank farm. The general configuration of tanks in WMA S-SX is shown in Figure 1.3. The SX farm SSTs were the first SSTs designed for self-boiling (i.e., self-concentrating) waste; however, the S farm SSTs received REDOX Plant waste that self-boiled. The S and SX farm SSTs were constructed with cascade overflow lines in three-tank series to allow gravity flow of liquid waste between the tanks. These cascade lines were not used in the SX tank farm. Ten of the 15 tanks in the SX tank farm and 1 of the 12 tanks in the S tank farm are classified as assumed leakers (Hanlon 2001).

The following sections provide an overview of the background conditions at WMA S-SX and the role of this FIR in the overall regulatory framework.

### 1.2.1 General Background

WMA S-SX was placed in assessment groundwater monitoring in August 1996 because of elevated specific conductance and technetium-99 in downgradient monitoring wells (Caggiano 1996). Technetium-99, nitrate, uranium, gross alpha, gross beta, tritium, iron, manganese, carbon tetrachloride, and aluminum are the only constituents to have exceeded drinking water standards (Johnson and Chou 1998).

Spectral gamma logging (i.e., collection of baseline gamma-specific radioisotope information in the upper vadose zone) was completed at the SX tank farm in fiscal year (FY) 1995 and at the S tank farm in FY 1996. The spectral gamma logging program builds on a previous program in which gross gamma data were collected as a means of leak detection from the SSTs.

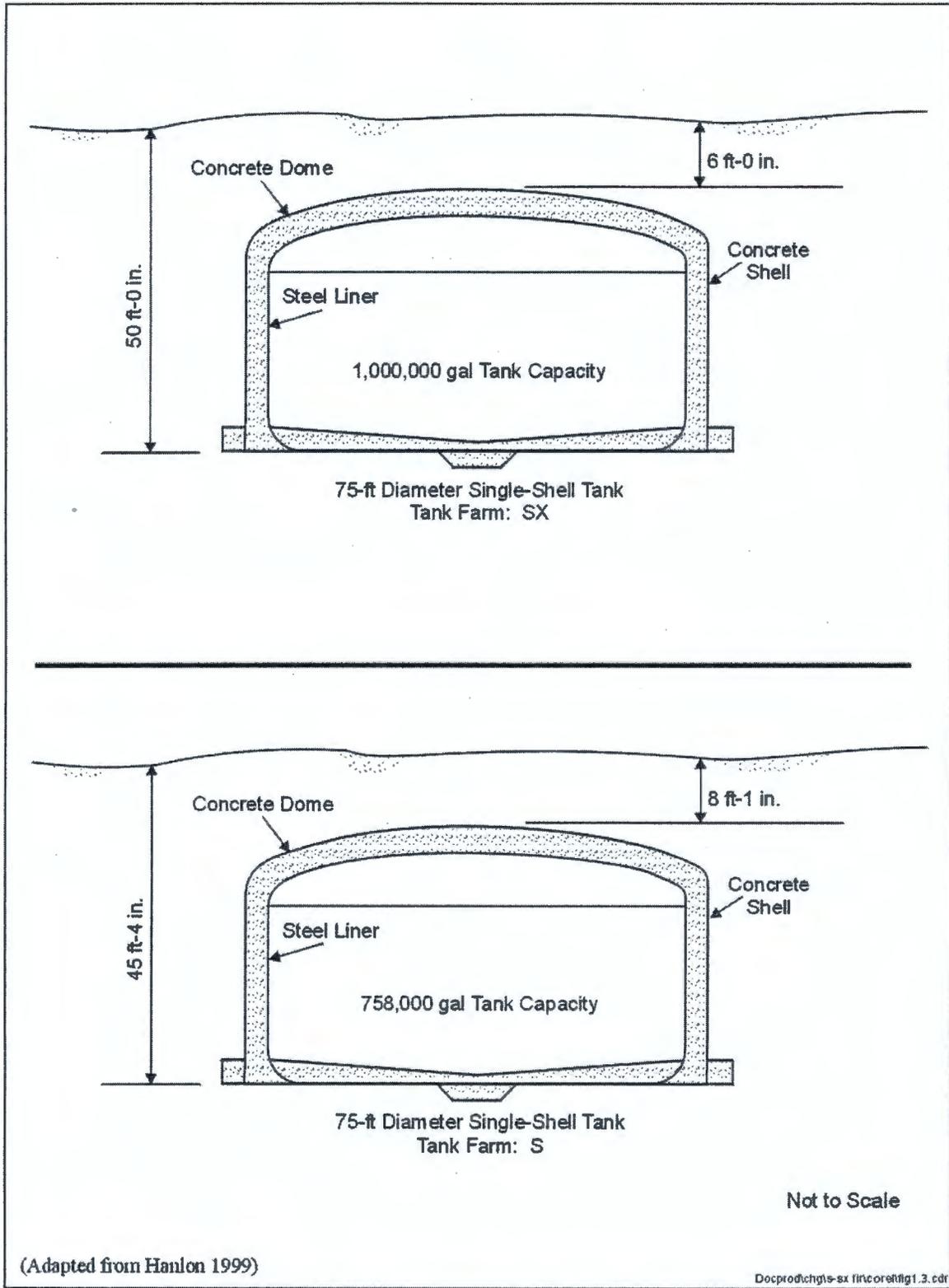
Both programs used the network of drywells installed around each tank in each SST farm.

*Vadose Zone Characterization Project at the Hanford Tank Farms: SX Tank Farm Report* (DOE-GJPO 1996), dated July 1996, is the report on spectral gamma logging at the SX tank farm and indicates contaminant cesium-137 at a maximum depth of 43 m (140 ft) below ground surface (bgs) near tank SX-102 and contaminants at depths of 39.6 m (130 ft) bgs near tanks SX-108 and SX-109. *Hanford Tank Farms Vadose Zone S Tank Farm Report*

(DOE-GJPO 1998), dated February 1998, is the report on spectral gamma logging at the S tank farm and indicates contaminants cesium-137, cobalt-60, and europium-154 at a maximum of 18.3 m (60 ft) bgs near tank S-102 and cesium-137 at 29 m (95 ft) bgs near tank S-104.

The network of drywells installed around each tank was intended for leak detection and was generally installed between 22.8 m and 45.7 m (75 to 150 ft) bgs; thus, the maximum detection depth is limited by the drywell depth.

Figure 1.3. General Configuration of Tanks in Waste Management Area S-SX



In 1996 DOE formed a panel to evaluate issues associated with vadose zone contamination in the Hanford Site tank farms. Following a review of available data, the panel recommended a series of measures to improve characterization of the vadose zone and recommended installation of new boreholes in the SX tank farm to address issues associated with contaminant migration through preferential pathways (e.g., boreholes) and through the Hanford formation (DOE-RL 1997b; DOE-RL 1999d). Two new drywells were installed (boreholes 41-12-01 and 41-09-39).

Based on the information obtained from the extension of borehole 41-09-39 (Myers et al. 1998) and the results of the groundwater assessment for WMA S-SX (Johnson and Chou 1998), the two site-specific work plans (Henderson 1999; Rogers and Knepp 2000) were prepared. The work plans describe the following field investigation activities:

- Decommissioning (i.e., abandonment) and sediment sampling of the upper portion (0 to 39.6 m [0 to 130 ft] bgs) of borehole 41-09-39 (Henderson 1999)
- Installation of a new borehole southwest of tank SX-115 (well 299-W23-19) (Henderson 1999)
- Sampling of a new RCRA groundwater monitoring well south and southeast of the SX tank farm (well 299-W22-50) (Henderson 1999)
- Slant borehole northwest of tank SX-108 extending beneath the tank (Rogers and Knepp 2000)
- Near-surface characterization in the S tank farm (Rogers and Knepp 2000).

These five characterization activities provided the data to support the nature and extent of contamination collected from the field investigations conducted in WMA S-SX. These activities contribute to the basis for the conclusions and recommendations of this report.

Ongoing Hanford Site programs and projects that also contribute to the FIR evaluations include the following:

- Hanford Groundwater/Vadose Zone Integration Project
- Integrated Technology and Research Demonstration Project
- Environmental restoration of past-practice sites
- Hanford Site Groundwater Monitoring Program.

These programs and projects all provide valuable data and information that are expected to enhance the FIR evaluations.

### 1.2.2 Regulatory Framework

Based on the results of the groundwater assessment, Ecology requested on July 10, 1998 that DOE develop and submit a corrective action plan for the four WMAs with documented leaks (i.e., WMAs S-SX, B-BX-BY, T, and TX-TY). Pursuant to HFFACO Change Package M-45-98-03 and the Phase 1 RFI/CMS work plan (DOE-RL 2000), the RCRA Corrective Action

Program process is used to establish the framework within which vadose zone investigations at the SSTs are planned and implemented. The sequence of investigations and evaluations for WMA S-SX, as prescribed in the Change Package, is as follows:

- Initiation of preliminary characterization efforts in FY 1999 based on the preliminary work plan addendum (Henderson 1999) to fulfill HFFACO Milestone M-45-52-T01
- Characterization of the remainder of WMA S-SX in FY 2000 based on the work plan addendum (Rogers and Knepp 2000) to fulfill HFFACO Milestone M-45-52
- Preparation of this document, the *Field Investigation Report for Waste Management Area S-SX*, in FY 2001 and FY 2002 to fulfill HFFACO Milestone M-45-55-T01
- Preparation of an RFI report in FY 2003 and FY 2004 that rolls up the results and recommendations from the FIRs on WMAs S-SX, B-BX-BY, T, and TX-TY to fulfill HFFACO Milestone M-45-55.

This sequence is illustrated in Figure 1.1.

### 1.3 DOCUMENT STRUCTURE

This report follows the prescribed outline for a FIR provided in Appendix H of the Phase 1 RFI/CMS work plan (DOE-RL 2000). Seven sections and nine appendices are included in this WMA S-SX FIR. The document is structured to provide the information necessary to describe the vadose zone and associated groundwater field and laboratory investigation results at WMA S-SX from 1997 to present. The following are the sections and appendices that comprise this report.

- **Section 1.0** – Introduction to the WMA S-SX FIR that provides an overview of background and purpose.
- **Section 2.0** – Overview of the investigative approach that is based on two work plans and an activity plan. Deviations from the plans are also addressed. Environmental setting and potential contamination information before the field investigation activities commenced under the RCRA Corrective Action Program are described.
- **Section 3.0** – Summary of the major findings of the field investigations and associated analyses and the interim measures and ICMs available for implementation.
- **Section 4.0** – Summary of the methodology and results for potential impacts to human health and the environment based on numerical modeling. The contaminant exposure pathways used in the numerical modeling conceptual exposure pathway model for WMA S-SX are presented. A comparison of these results to regulatory standards is provided.
- **Section 5.0** – Conclusions based on information provided in Sections 3.0 and 4.0.
- **Section 6.0** – Recommendations based on the conclusions.

- **Section 7.0** – List of the references used to develop the WMA S-SX FIR main text.
- **Appendix A** – Details of the investigative approach developed in the work plan addenda to support characterization efforts.
- **Appendix B** – Results of the work plan field investigation activities.
- **Appendix C** – Field and laboratory results developed through the integration process that were not directly collected in the field based on the work plans. This appendix presents interpretation results developed from geological, geophysical, hydrologic, and inventory data.
- **Appendix D** – Science and Technology (S&T) activities evaluation of data related to chemical and physical attributes of the effects of the waste stream related to WMA S-SX.
- **Appendix E** – Impact assessment approach and results derived from numerical modeling and the associated human health risk and dose.
- **Appendix F** – Cost and implementability of ICMs and interim measures at WMA S-SX.
- **Appendix G** – Regulatory analyses based on field investigation results.
- **Appendix H** – Quality assurance and quality control documentation for sampling and laboratory procedures in conjunction with RCRA regulations.
- **Appendix I** – List of the preparers of the WMA S-SX FIR.

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## 2.0 INVESTIGATIVE APPROACH

This section describes the investigative approach used in this WMA S-SX FIR. The regulatory framework for the investigative approach used in the WMA S-SX field investigation was developed through negotiations with Ecology and DOE in HFFACO Change Package M-45-98-03. The technical framework for the investigative approach that identifies data needs is provided in *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination* (Jones et al. 1998). The Phase 1 RFI/CMS work plan (DOE-RL 2000), preliminary work plan addendum (Henderson 1999), and work plan addendum (Rogers and Knepp 2000) provide the documentation for implementation of the field investigation activities. Appendix A provides detailed information on the investigative approach. The Phase 1 RFI/CMS work plan provides a single document that encompasses the aspects common to all WMAs and establishes the regulatory and programmatic framework for the overall RCRA Corrective Action Program. The other two documents are site-specific work plan addenda for WMA S-SX. Before initiation of the RCRA Corrective Action Program, a vadose zone investigation was conducted in the SX tank farm. Reference to *Activity Plan: Extension of Borehole 41-09-39, SX Tank Farm* (Myers 1997) is included in this report for completeness to acknowledge all recent vadose zone characterization activities conducted at WMA S-SX. The investigative approach was greatly enhanced by the careful selected field investigations discussed in the work plans. The work plans provide a basis for verifying the extensive knowledge base that exists for WMA S-SX associated with geology; hydrology; geophysics; groundwater chemistry; waste chemistry; and releases from the tank systems (i.e., transfer pipelines). These selected field investigations provide a basis for integrating extensive databases that lead to a reasonable understanding of the important contaminants of concern (CoCs). These contaminants are modeled and the transport modeling results then lead to human health risk assessments to assist in determining whether implementation of interim measures are required.

To ensure appropriate data are collected to meet the needs for the FIRs as identified in site-specific work plans, an implementation plan is prepared as Appendix J of the Phase 1 RFI/CMS work plan (DOE-RL 2000). Key to the implementation plan approach is first understanding what evaluations would be most appropriate for a FIR and then addressing assimilation of data necessary to complete those evaluations. As documented in Appendix J of the implementation plan, the key evaluation for assessing effectiveness of interim measures and the need for additional data would be that of the potential risk to a human receptor.

The needs to complete the WMA S-SX evaluation are complicated and the answers to those needs become less certain when WMA-specific factors are considered. Those factors include the following:

- Long time span over which the SSTs operated (i.e., 1950 through 1980)
- High cost of site-specific data collection
- Transient geochemical conditions that have existed from the time of waste releases to present

- Associated cribs and waste sites adjacent to the WMA boundary that have contributed to groundwater contamination with the same CoCs.

## 2.1 PREVIOUS DATA AND INFORMATION

Because so much data on the S and SX tank farms exist, the site-specific work plan addenda (Henderson 1999; Rogers and Knepp 2000) include the following actions:

- Collect and assimilate previously obtained data including that related to tank inventory; planned and unplanned releases; subsurface conditions; and occurrences (e.g., leaking water lines)
- Develop a preliminary understanding of the distributions of contaminants in the vadose zone from review and evaluation of the gross gamma and spectral gamma geophysical logs
- Identify additional data needs
- Identify methods to gather data to address the data needs through a DQO process.

### 2.1.1 Previously Obtained Data

Because of the large amounts of existing S and SX tank farms data, only a summary of that collected and assimilated data is given in this report. The Tank Farm Vadose Zone Project created *Subsurface Physical Conditions Description for S-SX Waste Management Area* (Johnson et al. 1999) to be the primary reference for such previous knowledge. However, for the preliminary work plan (Henderson 1999), data obtained prior to Johnson et al. (1999) provided the planning basis for the RCRA site-specific investigations and the framework for the initial generalized conceptual models. The following are the major supporting data documents for Henderson (1999):

- *Historical Tank Content Estimate for the Southwest Quadrant of the Hanford 200 West Area* (Brevick et al. 1994)
- *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination* (Jones et al. 1998)
- *Vadose Zone Characterization Project at the Hanford Tank Farms, SX Tank Farm Report* (DOE-GJPO 1996)
- *Characterization of Subsurface Contamination in the SX Tank Farm* (Raymond and Shdo 1966)
- *Tank 241-SX-108 Leak Assessment* (WHC 1992a)
- *Tank 241-SX-109 Leak Assessment* (WHC 1992b)
- *Tank 241-SX-115 Leak Assessment* (WHC 1992c).

In these preparatory documents, existing data relevant to the tank waste leak events and associated vadose zone and unconfined aquifer contamination in WMA S-SX are summarized and used to develop conceptual models of the leak events and subsequent contaminant migration in the subsurface. Geologic descriptions of soils taken from boreholes, geophysical data, and water elevation measurements have been collected to quantify site-specific geologic and unconfined aquifer hydrologic characteristics. Historical records, gamma logging data, chemical and radiological sample analyses of site-specific soils and nearby groundwater, and sorption/desorption data have also been collected to quantify soil column contamination. The most informative data from each of these topical areas are summarized in the following sections. Additional details are provided in Appendices B and C.

**2.1.1.1 Hydrogeologic Data.** A physical model of the geologic strata underlying WMA S-SX in the vadose zone and the unconfined aquifer was developed from numerous geologic well logs and geophysical logging data (e.g., gamma logging of naturally occurring radionuclides and moisture content from neutron logs) taken at boreholes and drywells within and near WMA S-SX. From these data, the characteristics (e.g., spatial orientation, thickness, particle size distribution) of the geologic units underlying WMA S-SX were developed. Consistency of the site-specific physical model with sitewide geology was also demonstrated.

The vadose zone and unconfined aquifer underlying WMA S-SX is made up of the three primary formations that are present throughout much of the Hanford Site:

- Ringold Formation, which rests on the underlying Columbia River Basalt Group
- Plio-Pleistocene unit, which overlies the Ringold Formation
- Hanford formation, which overlies the Plio-Pleistocene unit.

The thickness of the vadose zone for the Ringold Formation ranges from 15.8 m (52 ft) to 23.5 m (77 ft) from west to east. The thickness of the Plio-Pleistocene unit ranges from 11.6 m (38 ft) to 4.3 m (14 ft) from west to east. The thickness of the Hanford formation ranges from 37.2 m (122 ft) to 41.2 m (135 ft) from west to east. The thicknesses of these formations are based on wells 299-W23-19 and 299-W22-48. Based on previous data the thickness corresponds within 1.5 m (5 ft) of well 299-W23-19.

Directly underneath WMA S-SX, these strata tend to be of fairly uniform thickness and nearly flat-lying. Some units (i.e., Hanford formation subunit H1 and the Plio-Pleistocene unit) dip gently to the southwest. A more detailed description is provided in Section C.4.0 of Appendix C.

A subunit of particular interest is a gravel-rich layer in the Hanford formation, subunit H1, that lies close to the bottoms of tanks SX-107, SX-108, and SX-109 and that contains the majority of cesium-137 from leaks from these tanks. This association suggests that subunit H1 acted as a stratigraphic control for initial tank leak migration into the soil column.

At WMA S-SX the water table lies within the Ringold Formation. In 1998 the water table depth was about 65.5 m (215 ft) bgs and dropping. Both water level and general direction of groundwater flow in this region have been altered multiple times by high-volume wastewater discharges to various ponds throughout Hanford operations history. Most recently (i.e., 1980s) a groundwater mound in this area was maintained by liquid discharge to U pond just northwest

of WMA S-SX, elevating the water table and imposing a northwest to southeast trend in groundwater flow under WMA S-SX. Since the cessation of liquid discharge to U pond in 1985, the water table has been dropping about 0.6 m (2 ft) a year, and the general flow direction is rotating into a more easterly path. A water table depth of about 71.6 to 73.2 m (235 to 240 ft) bgs is anticipated when the groundwater mound completely dissipates.

**2.1.1.2 Soil Contamination Data.** The genesis and current state of contamination in the vadose zone and the unconfined aquifer underlying WMA S-SX is derived from three primary sources: the historical record, gamma logging data, and radiochemical and chemical analyses of soils and groundwater. The historical record identifies the following:

- Tank farm operations that supported various fuel processing, thereby providing the basis for estimating tank contents
- Specific tank leak events where liquid level measurements in the tanks or gamma radiation spikes measured in drywells surrounding the tanks indicate leakage of tank waste into the soil column
- Unplanned release events that discharged various amounts of fluids into the soil column.

Significant events provided in the record of S and SX tank farm history that relate to vadose zone contamination include several large leaks that occurred and contained substantial concentrations of contaminants (i.e., leaks from tanks S-104, SX-108, and SX-115). Leaks from other tanks are also assumed but their contributions to environmental contamination appear to be much less. The source of the waste that leaked from the tanks is primarily from the REDOX Plant (Section 3.0 and Jones et al. 2000a). Numerous unplanned releases are also known.

Two types of gamma ray logging data have been collected for WMA S-SX from a set of drywells placed around and between tanks in the S and SX farms. A gross gamma logging program operated from 1961 to 1994 (readily useable data are available dating from 1974) and a spectral gamma database was developed in the mid 1990s. Gross gamma logging of laterals extending under and across 7 tanks about 3.3 m (10 ft) below tank bottoms in the SX tank farm was also conducted. The gross gamma logging program provided a record of gross gamma intensities over time in numerous locations, allowing some perspective on the locations of contaminant occurrence and movement in the vadose zone over time and the fraction of total gamma-emitting contaminants involved in migration. The spectral gamma database provided a three-dimensional quantification of specific gamma-emitting radionuclide concentrations.

Soil sample analyses provide the most direct means of quantifying specific contaminants and their concentrations in the vadose zone. Analysis of gamma-emitting radionuclides (usually cesium-137) permits corroboration of gamma logging data. Two separate soil-sampling programs were completed prior to compilation of Johnson et al. (1999). In 1965 soils were sampled near tanks SX-108 and SX-115 at tank bottom depths; the cesium-137 concentration in those soils was determined from those samples (Raymond and Shdo 1966). Total waste volume and cesium-137 inventory lost was estimated from the soil sample data, gross gamma data from nearby drywells and laterals, and supernate analyses.

In 1998 samples were taken from borehole 41-09-39, located southeast of tank SX-108, and analyzed (Myers et al. 1998). For this study the borehole was extended from about 39.6 m (130 ft) bgs to groundwater, about 65.5 m (215 ft) bgs. Contamination in this borehole comes primarily from the tank SX-108 leak. Geophysical logging was completed. Samples between 39.9 and 65.2 m (131 and 214 ft) bgs were analyzed for radionuclides and inorganic chemistry. Soils were also leached with water, which was subsequently analyzed for radionuclides, inorganic constituents, pH, and electrical conductivity. These analyses showed that relative concentrations of cesium-137, technetium-99, and nitrate originating in the tank waste change as a function of depth, providing an indication of tank waste migration in the vadose zone over the last 40 years. Cesium-137 concentrations peak at around 40 and 41 m (131 to 135 ft) bgs and technetium-99 concentrations peak around 41 m (135 ft) bgs.

Sorption and desorption experiments conducted on some of the collected soil samples with a variety of liquids, including both tank and groundwater simulants, showed that cesium-137 sorption, normally quite high under disturbed conditions, can be substantially reduced by introducing large concentrations of sodium into the environment. Desorption experiments showed that cesium-137 is currently highly immobile in these soils as long as natural water contacts these soils.

Recent groundwater contaminant data in RCRA monitoring wells surrounding tank farms provide indications of tank waste having reached the unconfined aquifer (Johnson and Chou 1998; Johnson and Chou 1999). Significant data include elevated concentrations of constituents in groundwater also known to be present in the vadose zone because of tank leaks and knowledge of groundwater flow direction derived from water table levels in the monitoring network. When these data are combined with the identification of potential upgradient sources in the vadose zone, general causal relationships can be inferred. Wells surrounding WMA S-SX have shown transient elevated levels (spikes) of technetium-99, nitrate, and chromium in wells running along the southern edge of the SX tank farm and along the eastern edges of the S and SX tank farms since 1986.

When considering all the data provided by the four main sources of information, the primary observation is that three main areas of contamination exist in the vadose zone underlying WMA S-SX. These include the areas around the following:

- Tanks SX-107, SX-108, SX-109
- Tank SX-115
- Tank S-104.

There is fairly strong evidence from the historical record that the largest leaks in WMA S-SX came from these tanks or associated infrastructure and that the primary gamma-emitting radionuclide still in the vadose zone is cesium-137. Comparison of gamma data within these three areas shows cesium-137 to be much more extensively distributed both horizontally and vertically in the area around tanks SX-107, SX-108, and SX-109. In the areas around tanks SX-115 and S-104, cesium-137 is measured in one drywell very close to the side of each tank.

### 2.1.2 Conceptual Models

Conceptual models provided in Johnson et al. (1999) and Jones et al. (1998) integrate available data into plausible hypotheses of events and controlling physical and chemical processes that have caused the current state of contamination in the vadose zone and unconfined aquifer. Hypotheses have been developed for each of the three main areas of contamination because the database suggests enough differences in contaminant occurrence and migration exist in the different areas to warrant distinct explanations. The conceptual models were developed to aid the evaluation of potential impacts and to plan additional characterization efforts.

In Johnson et al. (1999), the contamination in the area around tanks SX-107, SX-108, and SX-109 is described as being focused on a leak from tank SX-108. Outstanding features of this contamination event included the following:

- High cesium-137, sodium, and aluminum concentrations in the supernate
- Apparent rapid and high-volume discharge
- Extensive horizontal and vertical extent of cesium-137 contamination in the vadose zone
- Slightly contaminated groundwater directly below these three tanks.

From these observations, a gross two-step process for how the leak occurred was postulated. In the first step, rapid release of the leaking fluid occurred, forcing fluid to move rather rapidly through the vadose zone. Stratigraphic variability in the vadose zone geology exerted sufficient influence to induce a high degree of movement in the horizontal direction to the southwest. The supernate chemistry controlled the local geochemical conditions to greatly mobilize cesium-137 (sodium successfully competing with cesium-137 for sorption sites) so that it was poorly retarded and migrated essentially with the tank fluid. In the second step, the hydraulic impetus of the leak event ceased and water movement reverted to control of natural infiltration that induced slow downward percolation. Local water chemistry conditions reverted to more natural soil-water conditions causing cesium-137 to sorb strongly. Subsequent movement of cesium-137 has been minimal. Technetium-99 and other mobile constituents, nitrate and chromium, remain mobile but are migrating rather slowly. Minimal groundwater contamination in the immediate vicinity suggests that little if any contamination from these sources has reached the unconfined aquifer.

Outstanding features of contamination in the area around tank SX-115 include the following:

- Dilute fluid chemistry relative to tank SX-108 supernate, including cesium-137 concentrations one tenth of that in tank SX-108 supernate
- Apparent rapid and high-volume discharge from the tank bottom into the soil column
- High cesium-137 concentrations in the soil column measured near one edge and beneath tank SX-115
- Inferred large water-line leakage west and south of tank SX-115 (well 299-W23-19) after the initial leak event

- Repeated occurrences of technetium-99, nitrate, and chromium in downstream groundwater monitoring wells.

From these observations, a less extensive migration of cesium-137 appears to have occurred, and a more extensive migration of mobile constituents apparently occurred relative to the area around tank SX-108. The cesium-137 distribution suggests that tank fluid chemistry was not sufficient to radically enhance cesium-137 mobility from the tank SX-115 leak allowing the cesium-137 to migrate with the tank fluid. Consequently, no marker remains to indicate the initial distribution of tank fluid in the vadose zone. However, presence of mobile constituents in nearby downgradient wells strongly indicates the tank SX-115 contaminants as the source. Hydraulic forces other than the initial discharge and natural recharge apparently have caused this extensive migration. This supposition is supported by the presence of a water line and a growing cottonwood tree south of tank SX-115 outside of the WMA boundary in the area in the early 1990s. The cottonwood tree supports the theory of sufficient water leakage into the vadose zone over an extended period of time that thereby provided the necessary driving force to push mobile constituents initially discharged to the vadose zone into the unconfined aquifer.

Outstanding features of contamination in the area around tank S-104 include the following:

- High-volume tank S-104 leak
- High cesium-137 concentration zone in one drywell near tank S-104
- Several technetium-99 occurrences downstream of tank S-104 in a series of wells along the east side of the S and SX tank farms
- Several incidents of high rain and snowmelt events coupled with topographic lows on the east side of S tank farm
- One large known water-line failure of 1,892,500 L (500,000 gal) in 1996.

These data are more ambiguous than those available for the other two areas. However, it is postulated that the release and migration pattern here is generally similar to that around tank SX-115 where initially released tank fluid is distributed in the vadose zone and cesium-137 sorbs rapidly on soil and separating from the migrating liquid. Subsequently, technetium-99 is driven to the unconfined aquifer at an accelerated pace due to a combination of tank infrastructure leaks and short-term, high-volume natural precipitation events.

### 2.1.3 Data Needs

Early in the history of the Tank Farm Vadose Zone Project, project personnel recognized a need to compile existing information concerning all SST farms so that gaps in the state-of-knowledge could be assessed. This study resulted in publication of Jones et al. (1998) in December 1998. This document has served as the basis upon which to build the ongoing data needs to be resolved by the Tank Farm Vadose Zone Project. The document was not developed to address specific regulatory requirements nor was any attempt made to cite regulatory requirements for actions that were assumed to take place in the future.

Areas of investigation and analysis identified in Jones et al. (1998) are ranked in terms of whether or not there was a direct impact to human health or the environment, the current state-of-knowledge, and whether or not the collection of additional data was feasible. The highest-ranking identified elements are listed in Table 2.1. The items listed in Table 2.1 focused primarily on developing a better understanding of contaminant inventory and pertinent soil properties. These primary items have guided the project in the development of DQO and in the design of investigations conducted in the S and SX tank farms.

**Table 2.1. Data and Analysis Needs**

Item	Rank
Radionuclide and chemical concentration in vadose zone	IA
Leak volumes	IA
Composition of leaked tank waste	IA
Correlation of estimated vs. measured inventory	IA
Projection of contaminant migration	IA
Change in hydraulic properties in contaminated soils	IB
Temperature distribution in contaminated soils	IB

IA: Impact is direct and knowledge level is low; resources should be directed toward implementing activity.

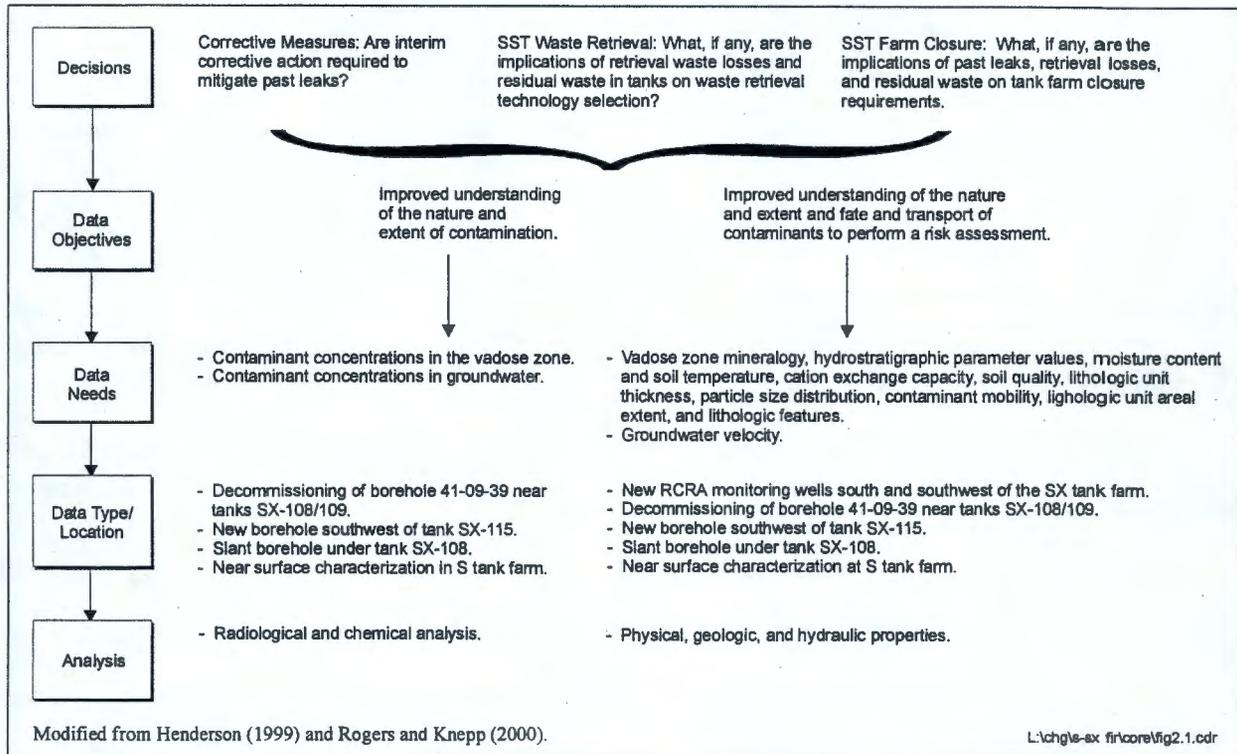
IB: Impact is unclear and knowledge level is low; resources should be directed toward implementing activity.

#### 2.1.4 Data Quality Objectives Process

Using historical information summarized in Jones et al. (1998), the most important data needs for filling in gaps in state-of-knowledge were confirmed in a DQO process (see Figure 2.1).

The data needs for the vadose zone component are summarized in Table 2.2. To some extent, these are the data needed to populate vadose zone models (i.e., two-dimensional cross-sectional models through selected tanks, see Section 4.0). Otherwise, the data are needed to provide confidence in the generalized conceptual model, validate WMA-specific assumptions, and support numerical modeling assumptions. The data type; how it is used (i.e., directly or indirectly); and remarks are provided in Table 2.2.

Figure 2.1. Data Quality Objectives and Data Needs



Based on input from Ecology, DOE, and the DQO process participants, the initial characterization activities in support of the objectives and data needs identified for WMA S-SX are illustrated in Figure 2.1.

Table 2.3 identifies the individuals who were involved in the DQO process between February 16 and April 5, 1999.

**Table 2.2. Data Needs to Evaluate Contaminant Flow and Transport Through the Vadose Zone (2 Sheets)**

Data Need or Activity	Data Use	Remarks
<b>Refine Vadose Zone Conceptual Model</b>	Provides the basis for the quantitative assessment of impacts to groundwater.	The conceptual model captures and documents the relevant hydrogeology, geochemistry, geologic, and hydrologic processes. It includes the understanding of various contaminant mobility phenomena, infiltration, and sediment parameter values relative to moisture movement, contaminant transport, and contaminant characteristics.
<b>Source Term</b> – The subsurface distribution of CoCs and their chemical characteristics.	Directly used in impact assessment as an initial condition. WMA-specific data are required on the spatial distribution, concentration, and chemical form of the CoCs.	This is sometimes referred to as the ‘nature and extent’ of contamination. Not possible to adequately describe the source term based solely on WMA-specific data. Source term definition is supplemented by historical leak loss and inventory data.
<b>Stratigraphy</b> – The sedimentary layering, including thickness and orientation, of the various strata and tank farm subsurface infrastructure (e.g., transfer lines and pits).	Directly used in impact assessment as the framework of the vadose zone model. Site-specific data are required to describe stratigraphy.	Large- and small-scale heterogeneities in the subsurface require interpolation between relatively sparse data points. It is not possible to adequately describe the subsurface stratigraphy based solely on site-specific data. Stratigraphy is supplemented with extrapolation from nearby data points and site analogs such as outcrops.
<b>Hydraulic Parameters</b> – The parameters that, together, are used to calculate moisture movement and include soil characteristic curves (e.g., moisture retention, saturated, and unsaturated hydraulic conductivities).	Directly used in impact assessment as vadose zone model input parameters.	Samples from within the WMA are anticipated to be too contaminated to cost effectively perform hydraulic testing. A database of hydraulic parameters has been developed from samples collected elsewhere on the Hanford Site.

**Table 2.2. Data Needs to Evaluate Contaminant Flow and Transport Through the Vadose Zone (2 Sheets)**

Data Need or Activity	Data Use	Remarks
<p><b>Transport Parameters</b> – The parameters that, together with moisture movement, are used to calculate contaminant transport and include: molecular diffusion coefficient; longitudinal and transverse dispersivity; bulk density; and geochemical parameters (e.g., contaminant distribution coefficient and contaminant solubility).</p>	<p>Directly used in impact assessment as vadose zone model input parameters.</p>	<p>Samples from within the WMA are anticipated to be too contaminated to cost-effectively determine transport parameters. The contamination also limits the use of in situ tests that might be used in an otherwise uncontaminated area. Extensive laboratory testing of Hanford Site sediments and typical tank waste (e.g., Tc-99, Cs-137, Se-79) has resulted in a large distribution coefficient database, which is a key parameter. Site-specific data will not be available except for contaminant distribution coefficients and bulk density values determined in the laboratory from selected samples.</p>
<p><b>Infiltration*</b> – The rate at which water enters and percolates through the vadose zone and enters the underlying unconfined aquifer. This includes infiltration from direct precipitation, surface water run on, and water from WMA activities and events such as water-line leaks.</p>	<p>These data are some of the vadose zone model input parameters.</p>	<p>Infiltration is an input parameter that can vary based on conditions (e.g., graveled surface versus interim surface barrier). Hanford Site data exist from simulated current tank farm groundcover conditions and for anticipated surface barriers that could be applied as a part of closure. WMA-specific data will not be available.</p>

Source: DOE-RL (2000).

\*Infiltration is not an independent input. Infiltration is related to the character of the surface, including an engineered barrier and vegetation as well as the topography and the effects run-on, temperature, and the time and rate of precipitation.

CoCs = contaminants of concern.

WMA = waste management area.

**Table 2.3. Data Quality Objectives Process Participants**

Participant Name	Company	Participant Name	Company
S. Anderson	MACTEC-Meier	K. Lindsey	D. B. Stephens and Associates
S. Blacker	MACTEC, Inc.	Z. Maine-Jackson	Ecology
L. E. Borneman	Fluor Daniel Hanford, Inc.	F. M. Mann*	Fluor Daniel Northwest
H. L. Boston	Lockheed Martin Hanford Corp.	R. G. McCain	MACTEC-ERS
C. R. Cole	PNNL	P. M. McCarthy	Los Alamos Technical Associates
S. J. Coleman	Informatics	D. J. Minter*	Los Alamos Technical Associates
J. D. Crumpler*	Jacobs Engineering Group Inc.	D. A. Myers*	IT Group
S. Dahl	Ecology	D. Olson	DOE Richland Operations Office
R. E. Day*	CH2M HILL, Inc.	R. W. Ovink*	CH2M HILL Hanford, Inc.
D. Dunning	Oregon DOE	J. A. Poppiti	DOE Richland Operations Office
B. H. Ford*	Bechtel Hanford, Inc.	R. R. Randall	Three Rivers Scientific
D. J. Foust*	Lockheed Martin Hanford Corp.	K. D. Reynolds	Waste Management Federal Services
E. A. Fredenburg	Lockheed Martin Hanford Corp.	W. Riggsbee	Yakama Indian Nation
G. W. Gee	PNNL	R. S. Schreiber	Jacobs Engineering Group Inc.
D. Goodman	Montana State University	R. J. Serne*	PNNL
D. Goswami	Ecology	K. Singleton*	CH2M HILL Hanford, Inc.
M. J. Graham	Bechtel Hanford Inc.	R. M. Smith	PNNL
C. J. Grando	Waste Management Federal Services	S. Sobczyk	Nez Perce Tribe
C. C. Haass	Lockheed Martin Hanford Corp.	P. Staats*	Ecology
J. C. Henderson*	Jacobs Engineering Group Inc.	T. L. Stewart	PNNL
R. A. Holten	DOE Richland Operations Office	W. J. Stokes	Lockheed Martin Hanford Corp.
L. M. Johnson*	CH2M HILL Hanford, Inc.	T. Valero	Ecology
V. G. Johnson	PNNL	R. L. Weiss*	CH2M HILL Hanford, Inc.
T. E. Jones*	MACTEC-Meier	R. C. Wilson	CH2M HILL Hanford, Inc.
J. Kelly	MACTEC-Meier	J. Williams	Fluor Daniel Hanford, Inc.
R. Khaleel*	Fluor Daniel Northwest	M. I. Wood*	Waste Management Federal Services
A. J. Knepp*	Bechtel Hanford, Inc. now CHG	R. M. Yasek*	DOE/ORP
J. L. Kovach	Independent Consultant	J. W. Yokel	Ecology
D. C. Larsen	Lockheed Martin Hanford Corp.	J. M. Zachara	PNNL
S. Leja	Ecology*		

Note: Lockheed Martin Hanford Corporation is not CH2M HILL Hanford Group, Inc.

\*These individuals participated in both data quality objectives processes.

CHG = CH2M HILL Hanford Group, Inc.

DOE = U.S. Department of Energy.

ORP = Office of River Protection.

PNNL = Pacific Northwest National Laboratory.

## 2.2 SUMMARY OF WORK PLAN ADDENDA

### 2.2.1 Overview

The initial field characterization efforts (Henderson 1999) implemented in FY 1999 and FY 2000 included the collection of vadose zone and groundwater data from the following:

- Installation of a new borehole southwest of tank SX-115 (well 299-W23-19)
- Decommissioning of borehole 41-09-39
- Installation of three RCRA groundwater monitoring wells (wells 299-W22-48, -49, and -50).

Ecology and DOE determined that characterization activities should (1) provide data that would support decisions on additional interim measures or ICMs, tank waste retrieval, and tank farm closure and (2) include installation of a new borehole and collection of vadose zone data from new RCRA groundwater monitoring wells. These decisions and the decision by DOE to proceed with the decommissioning of borehole 41-09-39 were the starting point for the DQO process (Henderson 1999). The following summarize the decisions reached by Ecology and DOE based on the DQO process.

- **Decommissioning of borehole 41-09-39** – This borehole was installed as a temporary borehole during two separate drilling campaigns: one beginning in December 1996 in which the borehole was driven to 40.1 m (131.5 ft) with a closed-end steel casing, and one beginning in September 1997 in which the borehole was deepened to 69 m (225.3 ft). Groundwater sampling activities conducted as part of the Hanford Groundwater Program have been completed. The decommissioning activities have been completed, which included introduction of a tracer into the groundwater, borehole geophysical logging, sidewall sediment sampling of selected intervals, and removal of temporary materials and proper sealing of the hole in accordance with *Washington Administrative Code* requirements.
- **Installation of a new exploratory borehole southwest of tank SX-115** – The DQO process resulted in the identification of several potential locations for the proposed new borehole (e.g., near tanks SX-108 and SX-115). DOE and Ecology selected a borehole location southwest of tank SX-115. This location is near a past tank leak. The new borehole, designated 299-W23-19, was installed using a drive-and-drill, dual-wall, reverse air circulation rotary drilling technique. The technique drove conductor casing with staged (telescoping) casings to reduce the likelihood of cross-contamination from penetrating through highly contaminated zones. Split- spoon driven sediment samples and drill cutting samples were collected from about 3 m (10 ft) bgs to just below the water table. The water table was encountered at about 64 m (210 ft) bgs. Selected portions of the samples were analyzed for chemical, radiological, and physical characteristics. A suite of geophysical surveys was performed, and groundwater samples were collected for chemical and radiological analysis. The new borehole was completed as a RCRA-compliant groundwater monitoring well and meets “Minimum Standards for the Construction and Maintenance of Wells” (WAC 173-160) requirements. This new

well is included in the RCRA groundwater monitoring network for routine groundwater sampling and analysis.

- Collection of vadose zone characterization data from RCRA groundwater monitoring wells** – Vadose zone samples were collected during the installation of three RCRA groundwater monitoring wells planned in support of the ongoing RCRA groundwater monitoring effort. The three wells are to replace existing RCRA groundwater monitoring wells because groundwater levels in WMA S-SX are declining by up to 0.6 m/yr (2 ft/yr), and some of the existing monitoring wells are going dry. The southern-most proposed monitoring well (well 299-W22-50) is located about 50 m (164 ft) southeast of tank SX-113. From this well, continuous driven samples were collected from about 6 m (20 ft) bgs to refusal (near the top of the Ringold Formation). Continuous drill cuttings were collected from refusal to the water table. The other two RCRA groundwater monitoring wells are located east of WMA S-SX. In cooperation with the Hanford Groundwater/Vadose Zone Integration Project, continuous drill cuttings were collected and described from one of these two wells. Selected portions of the split-spoon driven samples and cuttings were analyzed for physical, hydraulic, and chemical properties.

The follow-on field characterization efforts (Rogers and Knepp 2000) conducted in FY 2000 included the collection of vadose zone data from (1) installation of a slant borehole beneath tank SX-108 and (2) shallow vadose zone soil investigations in the north end of the S tank farm. The following summarize the field activity decisions reached by Ecology and DOE based on the DQO process.

- Installation of a slant exploratory borehole underneath tank SX-108** – The past leak associated with tank SX-108 and the high radiation content resulted in this tank being identified during the DQO process as the best location for a slant borehole. This borehole was to be installed to the top of the Plio-Pleistocene unit (39.6 m [130 ft] bgs) or maximum depth of contamination, whichever is deeper.
- Shallow vadose zone soil investigation** – This investigation collected sediment samples via direct-push technology in the northern portion of the S tank farm. The shallow investigation consisted of collecting gamma measurements at 8 areal locations from the ground surface and approximately 16.7 m (55 ft) bgs. Sediment samples were collected with the direct-push technology from three pushes. The main emphasis was on characterizing unplanned releases within these areas of concern. Three separate areas were characterized: the vicinity of tank S-102, the vicinity of tank S-104, and the vicinity of the S transfer vault. These sites exhibit separate instances of cesium-137 in vadose zone drywells that may be indicative of near-surface sources. A total of eight push sites were attempted. Two sites met predetermined criteria for sampling and were sampled, providing three samples.

The data collected for both site-specific addenda (Henderson 1999; Rogers and Knepp 2000) included radiological and chemical concentration values for the CoCs including the mobile constituents (e.g., technetium-99 and nitrate) that may impact groundwater and the relatively immobile constituents (e.g., cesium-137) that would impact worker health and safety.

## 2.2.2 Characterization Locations

The location of the characterization efforts that span from FY 1999 to FY 2000 are shown in Figure 2.2. The figure shows the location for decommissioned borehole 41-09-39 (299-W23-234), new RCRA well 299-W23-19 southwest of tank SX-115, the slant borehole northwest of tank SX-108, and the near-surface characterization effort in S tank farm by tanks S-102 and S-104.

## 2.2.3 Characterization Techniques

Six distinct techniques were employed in field characterization of WMA S-SX:

- Borehole geophysical logging
- Moisture content measurements
- Cone penetrometer-based exploration
- Cable-tool drilling and sampling with side-wall sampling
- Air-rotary drilling and sampling
- Percussion-driven drilling and sampling.

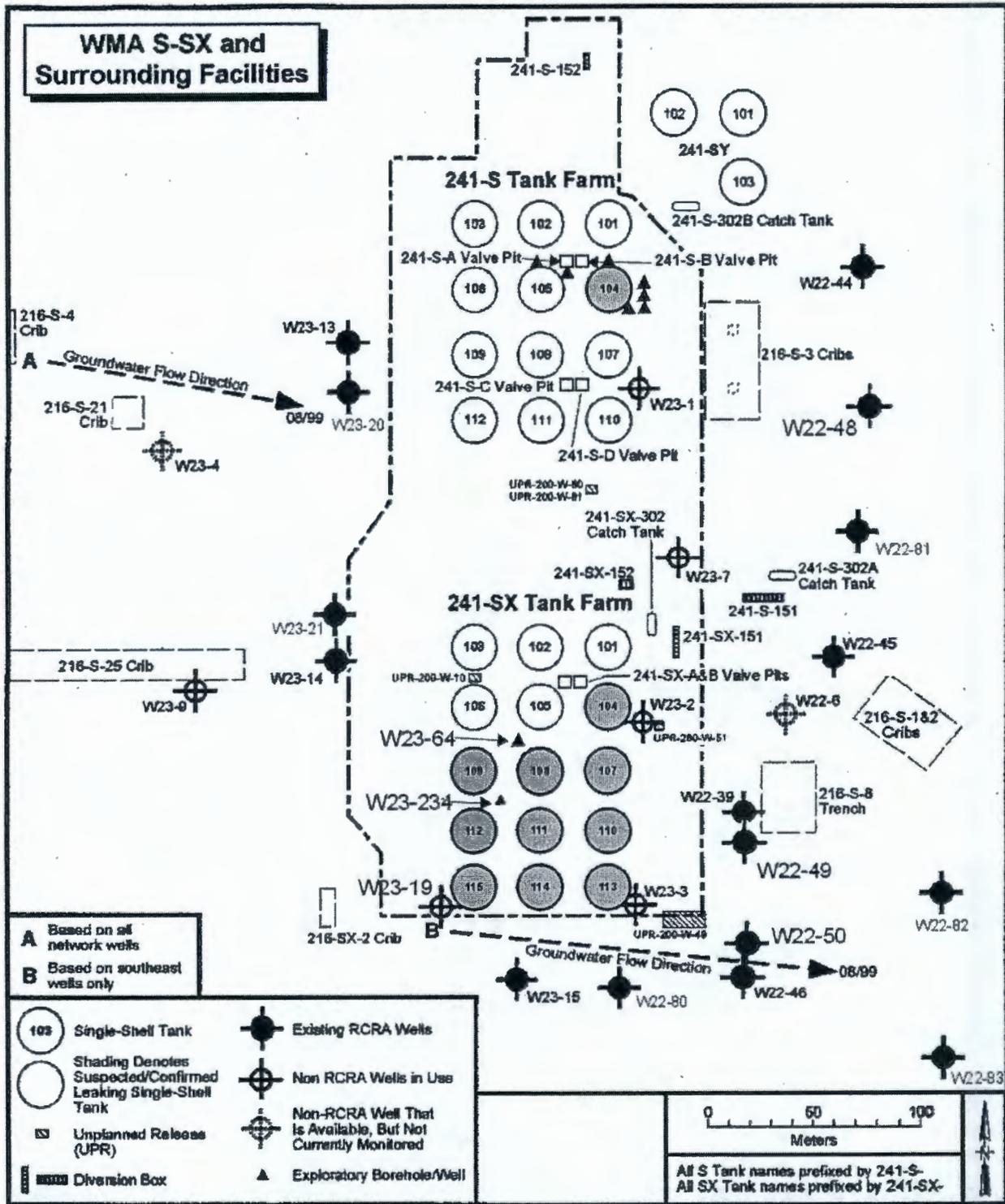
Each technique was applied to provide specific samples or information meeting project needs that were either identified in Myers (1997), Henderson (1999), or Rogers and Knepp (2000) or later identified as important for understanding the physical or chemical processes at work in the vadose zone. Improvements in drilling technology sponsored by this activity allowed safe and efficient sample collection in the high radiation zone beneath tank SX-108. Other improvements aided the programs in a variety of areas.

**2.2.3.1 Borehole Geophysical Logging.** Spectral gamma logging was performed on all available boreholes within WMA S-SX (DOE-GJPO 1996, 1998, 2000a, 2000b). These logs provided the basis for work conducted. Logging consisted of measurements taken with one of two sondes; a 35% high-purity intrinsic germanium sonde was the standard. In zones where contamination levels rendered this tool ineffective, a high-rate (low-efficiency) high-purity intrinsic germanium sonde was deployed. Measurements were generally taken as 200-second counts at 15 cm (0.5 ft) intervals.

Analysis of historical gross gamma logging records (Myers 1999; Myers et al. 1999) identified several boreholes in WMA S-SX where changes in the gamma flux were taking place.

**2.2.3.2 Moisture Content Measurements.** Measurement of soil moisture content was not included in the preliminary work plan (Henderson 1999). The distribution of moisture content in the southern portion of the SX tank farm (Myers 2001c) was determined to be an important piece of information leading to determining sources of recharge. Moisture content measurements were taken with a neutron moisture probe instrument (i.e., 503DR Hydroprobe®) that was calibrated to the steel casing sizes common to the tank farm. Measurements were taken at 30 cm (1 ft) intervals from a maximum depth of 44 m (133 ft) to ground surface. Sixteen-second counts were used.

Figure 2.2. Waste Management Area S-SX, Location Map of Characterization Activities, Surrounding Facilities, and Wells



Note: All wells are preceded by 299-

**2.2.3.3 Cone Penetrometer-Based Exploration.** Two cone penetrometer-based devices were deployed around tanks S-102 and S-104. The primary tool was a sodium-iodine-based gross/spectral gamma system. The secondary tool was a sampling tool. A series of pushes were made in regions determined through the Spectral Gamma Program (DOE-GJPO 1997) to potentially be contaminated due to tank losses or piping leaks. Calibration of the system is documented in *Calibration of the Cone Penetrometer Gamma Probe* (Myers 2001a) and results documented in *Cone Penetrometer Tests with Gross and Spectral Gamma at the S-Tank Farm, 200 West Area, Hanford Site, Richland, Washington* (Myers 2001b).

**2.2.3.4 Cable-Tool Drilling and Sampling.** Cable-tool drilling was used to advance borehole 41-09-39 (299-W23-234) from 43 m (132 ft) to total depth. Both drive-barrel and hard-tool techniques were used. During decommissioning of the borehole a sidewall sampling device was deployed using a work-over rig operating as a cable-tool system.

**2.2.3.5 Air-Rotary Drilling and Sampling.** Air-rotary drilling was used to advance well 299-W23-19 from ground surface to total depth. Near continuous sampling was accomplished using the down-hole air hammer to advance split-spoon samplers into the formation. Once the sampler had been retrieved to the surface, the borehole was reamed to full diameter and the drill casing advanced to maintain the hole. Extensive efforts were taken to control discharges from this system. These efforts included double-encasing the discharge hose, diverting the hose through a cyclone to capture the coarsest materials, and then routing all air through an entrained filtration system (i.e., Torit®) to remove fine-grained material. Finally, all exhaust air was routed through a high-efficiency particulate air filtration system. The cyclone and Torit® were further contained inside a sealed, limited-access tent.

**2.2.3.6 Percussion-Driven Drilling and Sampling.** A specially constructed percussion drilling machine and sampling system was employed to advance the slanted borehole (299-W23-64) beneath tank SX-108. The purpose of this system was to collect samples from the very highly contaminated region beneath an SST. No drill cuttings were brought to the surface as the hole was driven. Driving force was transmitted from a 1,814 kg (4,000 lb) diesel pile driver through the outer casing and an inner drill string. Once the drill string reached a predetermined sample depth the inner string was removed, which opened the end of the outer casing to the formation. An internally shielded split-spoon sampler was then attached to the inner drill string centered in the drive casing and lowered to the sampling horizon. The sampler was then driven into the formation using the diesel hammer. The inner string was extracted and the sampler detached and prepared for shipment. The drive-head was reconnected to the inner string, lowered to the bottom of the bore, and the process repeated. All contaminated materials were handled remotely by a mechanical arm.

## **2.2.4 Deviations from Waste Management Area Addenda**

Deviations from the two work plan addenda and the activity plan for WMA S-SX (Henderson 1999; Rogers and Knepp 2000; Myers 1997) were documented as approved Engineering Change Notices issued against the original documents. By updating the plan in this manner, there were no true deviations from the planned work. There were, however, moderate differences between how the work was originally planned and how the work was actually accomplished for two tasks: borehole 41-09-39 and the SX-108 slant borehole. There were no deviations for the other three

tasks (i.e., borehole 299-W23-19, RCRA groundwater wells, or the shallow soil investigations). The following sections summarize the deviations encountered at borehole 41-09-39 and at the SX-108 slant borehole.

**2.2.4.1 Borehole 41-09-39 (299-W23-234).** Borehole 41-09-39 was originally driven from the surface to 40.1 m (131.5 ft) using a closed-end casing. The borehole was then extended to a depth of 68.6 m (225 ft) using the cable-tool method to drive sampling devices and casing. After the bore reached groundwater a temporary screen was set, a series of groundwater samples were collected, and tests were conducted to provide information on the unconfined aquifer. The borehole was decommissioned and vadose zone soil samples were collected from the upper 40.1 m (131.5 ft) of the borehole.

Some of the water used to cool the milling tool while cutting the heavy wall casing was lost to the formation. The original design of the casing shoe for the 11.4 cm (4.5 in.) casing called for a flush outside surface. Friction buildup against the casing increased the force required to drive this casing to the point where advancement was not possible. The casing was removed from the bore and a more standard, under-reaming casing shoe was deployed. Minimal carry-along took place following this change.

A change was implemented to carry out a test using borehole 41-09-39 as an injection site for sodium-bromide tracer.

Decommissioning of the lower portion of the borehole went according to plan (Henderson 1999). However, several changes were necessary to decommission the upper portion of the bore. Additional cuts of the heavy wall casing were needed to enable the casing to be removed. The first cut was to remove the casing drive shoe and the second was to overcome an apparent bend in the casing. Sections of casing were grouted in place.

Changes in implementing laboratory analyses were also made. The work plan (Henderson 1999) called out specific samples to be analyzed. As the borehole extension progressed, it became evident that more information would be garnered if the samples to be selected for detailed analyses were selected based on the screening analyses performed on every sample. The samples for detailed analyses were selected by a group representing Ecology, DOE, and Tank Farm Vadose Zone Project personnel and subcontractors.

Changes to the original work plans for extending and decommissioning borehole 41-09-39 were communicated to Ecology via formal Engineering Change Notices made to work plans and by including personnel in meetings and discussions where selections of which samples to be analyzed for what constituents were made.

**2.2.4.2 SX-108 Slant Borehole (299-W23-64).** The surface location of the SX-108 slant borehole was established based on the intended target zone beneath the tank, the surface and subsurface infrastructure of the farm, and the restrictions on how close to the base of the tank the borehole would be allowed to pass. Ground-penetrating radar was used to map and confirm the locations of subsurface utilities. From a three-dimensional map the surface location was selected.

This borehole was advanced at an angle 30° from vertical passing approximately 3 m (10 ft) from the base of tank SX-108. Ten samples were called out in the work plan for this effort (Rogers and Knepp 2000); that number was increased to 17 to more fully characterize this environment. One of the 17 samples was lost from the sampler during drilling, but 16 were successfully recovered. The borehole was advanced to a depth of 43.9 m (144 ft) vertically, 52.2 m (171.2 ft) absolute distance (Sydnor 2000). The last sample collected was from the fine-grained sediments of the undifferentiated Hanford formation/Plio-Pleistocene unit silty sands.

The borehole was geophysically logged and subsequently decommissioned. Because the driven casing could not be successfully cut, the final decommissioning was carried out under a variance granted by Ecology.

The analytical scheme developed in conjunction with Ecology was significantly altered. The analytical program developed early in the planning of this work was designed to be the same as that applied to boreholes 41-09-39 and 299-W23-19. Based on the lessons learned from those efforts, many of the analyses that would have been conducted during the second or third phases were run during the initial phase. Sharing of samples with the S&T activity of the Hanford Groundwater/Vadose Zone Integration Project has resulted in an extensive suite of analyses being run that were not part of the planning document.

The number of intervals sampled was increased to ensure that critical zones of interest were not overlooked. Because sampling could only take place at 1.5 m (5 ft) intervals, bypassing zones where potentially significant information could be gathered was determined to be inappropriate. The analytical scheme was changed to take advantage of the information collected during preceding characterization efforts and to make most efficient use of laboratory resources. The S&T activity, with its access to research facilities across the nation, expressed keen interest in the knowledge to be gained from these unique samples. Because of this interest, the sum of information to be gained has been exponentially expanded.

Because the changes increased the level of effort and increased the amount of information to be gained from this portion of the work plan, only oral notification of the changes was made. Formal documentation of the changes associated with decommissioning were made and written confirmation of these alterations received.

### **2.3 INTEGRATION WITH OTHER PROJECTS**

Other projects from the Hanford Site as well as from offsite have contributed significantly to this document. Because much of the effort was actually made inside the tank farm fences, the active support of RPP Tank Farm Operations staff was crucial to success. Much of the information gathered during these tasks will not only affect the RCRA Corrective Action Program activities performed by the Tank Farm Vadose Zone Project, but will also support the activities needed for SST retrieval and closure. Other projects (e.g., Hanford Groundwater Program, 200 Area Remedial Action Project, the Hanford Groundwater/Vadose Zone Integration Project, and projects supported by DOE Headquarters) contributed during the planning and often provided specialized analyses.

### **2.3.1 River Protection Project Tank Farm Operations**

The CHG Tank Farm Vadose Zone Project worked with the RPP Tank Farm Operations to ensure that characterization activities were conducted safely, within the bounds of established procedures, and fit within the authorization basis (Goetz 1999).

Work to be performed within the bounds of any tank farm is planned in accordance with nine CHG enhanced work plan procedures. Once the scope of work is established in an approved work plan, the details of how, where, and who will do the work are further defined through the enhanced working plan process. The end result of an enhanced working plan process is a work package that defines all elements of a piece of work. A draft work package is often prepared and then presented to those individuals who will be directly involved as well as representatives from Radiological Control, Health and Safety, Authorization Basis, and management.

To the extent possible, for the work described by this report a single work crew was assigned. Continuity of the work crew contributed significantly to the successful completion of in-farm work.

### **2.3.2 River Protection Project Single-Shell Tank Retrieval and Closure Project**

The CHG Tank Farm Vadose Zone Project worked with the RPP SST Retrieval and Closure Project to ensure appropriate data were collected to aid in waste retrieval decisions. Various meetings were held with SST Retrieval and Closure Project personnel to ensure information obtained during the field investigation could be incorporated into planned SST waste retrieval operations. The sharing of information assists the waste retrieval program in establishing the appropriate retrieval technologies and in setting criteria for leak detection, monitoring, and mitigation strategies.

The past leak model results were incorporated into the ongoing retrieval performance evaluation modeling effort for S tank farm (Thompson 2001) to ensure consistency among the two programs. Although there are differences in the duration of analysis (i.e., 1,000 vs. 12,000 years), the information for the past leak source term used in the retrieval performance evaluation for S tank farm is the same as presented in Section 4.0 and Appendix E.

### **2.3.3 Hanford Groundwater Project**

The Hanford Groundwater Project is responsible for monitoring and remediation (where necessary) of the groundwater at the Hanford Site.

**2.3.3.1 Geological Investigation.** Both the Hanford Groundwater Project and the Tank Farm Vadose Zone Project have interest in the role of the geologic system in controlling the movement of contaminants. The Tank Farm Vadose Zone Project has participated in ensuring that at least one new monitoring well being drilled through the Hanford Groundwater Project is sampled in a near-continuous manner at each WMA. Adjacent to WMA S-SX, the Tank Farm Vadose Zone Project has participated in the sampling of three such wells.

**2.3.3.2 Completion of Borehole 41-15-08 as Monitoring Well 299W-23-19.** The vadose zone characterization borehole adjacent to tank SX-115 was advanced, per the work plan

(Henderson 1999), into the groundwater to permit one-time sampling of that medium under the Hanford Groundwater Project. Analytical results from that groundwater sample showed significant technetium-99 contamination to be present. A decision was made to convert the test borehole to a RCRA-compliant groundwater monitoring well so that this occurrence could be monitored over time. Personnel have been trained in tank farm entry procedures to permit the well to be sampled.

**2.3.3.3 Sampling and Tracer Test in Borehole 41-09-39.** Borehole 41-09-39 was made available to the Hanford Groundwater Project for sampling and testing before it was decommissioned. The groundwater in this borehole was essentially free of contaminants. This well exhibited the highest levels of vadose zone contamination known to date when the sampling was accomplished. The high contamination was present predominantly in the upper regions of the vadose zone. The borehole presented an opportunity to directly measure the rate and direction of groundwater movement beneath the WMA. A groundwater tracer test using sodium-bromide was proposed, planned, and implemented. Because groundwater movement is only about 50 m/yr (164 ft/yr), the tracer has not yet reached the nearest downgradient groundwater monitoring wells. Additional reasons for not reaching downgradient groundwater monitoring wells include change in groundwater flow direction, uncharacterized heterogeneity, and well screen locations.

#### **2.3.4 200 Area Remedial Action Assessment**

Interaction with the 200 Area remedial investigation/feasibility study work in adjacent cribs included sharing and review of work plans, site conditions description report, and data that became available as work progressed. Work in and around the tank farms conducted by the RPP is ahead of work scheduled to be done under the Environmental Restoration Program.

#### **2.3.5 Hanford Groundwater/Vadose Zone Integration Project**

The work reported in this FIR was done with full cooperation and input from the Hanford Groundwater/Vadose Zone Integration Project. Progress reports were made through the DOE Headquarters-mandated Integration Project Expert Panel, convened by the Integration Project as well as through other public meetings hosted by the Integration Project. Input from this body of experts was used to help guide the direction taken by the Tank Farm Vadose Zone Project. In addition, the Integration Project offered numerous opportunities to enhance the investigation beyond the requirements of the accepted work plans, thus expanding the state-of-knowledge upon which decisions will be made. The following sections outline contributions from specific organizations within the Hanford Groundwater/Vadose Zone Integration Project.

**2.3.5.1 Science and Technology Activity.** The S&T activity of the Integration Project is an important aspect of the team effort that produced this document. The following outline some of the S&T activity functions.

- **Liaison with DOE Headquarters-Funded Efforts.** Samples collected during drilling of the characterization and RCRA-supported boreholes were made available to researchers in the Environmental Management Sciences Program for additional analyses.

- **Enhanced Analyses.** In addition to DOE Headquarters funding, the Integration Project funded enhanced analyses of the samples from the characterization and RCRA-supported boreholes. Appendix D summarizes much of the important efforts.
- **Advanced Modeling.** Although the modeling done by the Tank Farm Vadose Zone Project was relatively complex, some effects (e.g., thermal, transient chemical effects) are not included. The S&T activity investigated the impacts of such effects. Appendix D summarizes much of their important efforts.
- **Inventory Modeling.** As part of the effort to understand the Hanford Site inventory as a whole, the inventory modeling activity reinvestigated the process knowledge of tank waste transfers and, importantly, what the inventory of tanks were at the times of potential leakage. These efforts are described as part of the inventory effort.
- **Venue for Presenting Results.** Cooperation with the S&T researchers provides a venue by which individual research efforts are presented through a variety of media, including peer-reviewed journal articles. This wider audience and availability for outside review increases the technical acceptance of the entire program.

**2.3.5.2 Input to System Assessment Capability.** The System Assessment Capability Project is intended to provide the means by which the impact of all Hanford activities can be assessed. One of the potential impacts on the Columbia River and the surrounding environment is the inventory of wastes lost from the SSTs over the 50-year operating history of the Hanford Site. Direct and frequent interaction with the developers of the System Assessment Capability has been and will continue to be an important focus of the Tank Farm Vadose Zone Project.

**2.3.5.3 Expert Panel Review.** The Integration Project's panel of experts provided continuing review and advice on how to optimize the value of information gathered during the field investigation. Data derived from the investigation were scrutinized by the panel and the panel provided independent interpretations of those data; this level of review helped to ensure that all reasonable explanations for the findings were considered.

**2.3.5.4 Public Interactions.** The Integration Project provides a variety of venues where the public can learn about tank farm activities. Two public meetings a month are normally held. Additional special meetings (e.g., with the Oregon Office Of Energy) are often held.

### **2.3.6 DOE Headquarters-Funded Activities**

Through the Environmental Management Sciences Program, DOE Headquarters has funded a number of researches to study vadose zone issues. Many of these researches are taking advantage of using the soil samples taken from this characterization effort to perform advanced analyses. A summary of some of these activities is provided in Appendix D.

### 3.0 INVESTIGATIVE RESULTS AND CONCLUSIONS

The WMA S-SX field investigation included the following activities:

- Installation of a RCRA-compliant groundwater well southwest of tank SX-115
- Installation of an exploratory slant borehole beneath tank SX-108
- Sediment sampling and decommissioning of borehole 41-09-39
- Shallow vadose zone soil investigation around tank S-104
- Collection of vadose zone characterization data from the installation of three RCRA groundwater monitoring wells (299-W23-48, 299-W23-49 and 299-W23-50).

The major investigation findings are summarized as follows.

- Radiologic and chemical analyses of water extract samples of soils were taken from three characterization boreholes in the SX tank farm (299-W23-19, 41-09-39, and SX-108 slant borehole) with depth. Similar analyses were also done for soils from two RCRA boreholes (299-W22-48 and 299-W22-50) that were not exposed to tank fluids. Comparison of these analyses for tank farm versus non-tank farm soils shows elevated concentrations of several constituents in the tank farm borehole soils that are attributed to tank fluid leakage (primarily tanks SX-115 and SX-108) into the soil column. The set of tank leak constituents includes technetium-99, cesium-137, chromium, and nitrate. With the exception of cesium-137, high concentration depth intervals were observed in all three boreholes, primarily in the lower subunits of the Hanford formation (H1 and H2) and the upper Plio-Pleistocene unit (PPlz). In these high concentration depth intervals, technetium-99 ranged from 95,000 to 237,000,000 pCi/L; chromium ranged from 3 to 218,000 mg/L; and nitrate ranged from 6,000 to 994,000 mg/L. High cesium-137 concentrations were found in the two boreholes contaminated by the tank SX-108 leak (41-09-39 and SX-108 slant borehole). High cesium-137 concentration ranges occurred in subunits H1 and H2 between 125,000 and 95,700,000 pCi/g.
- Groundwater samples have been collected from monitoring wells adjacent to WMA S-SX including 299-W23-15, 299-W23-19, 299-W22-48, 299-W22-49, 299-W22-50, 299-W22-80, 299-W22-81, and 299-W22-82 beginning in the early 1990s. Most recently published values are provided in Appendix C, Section C.7 from Johnson and Chou (2001). Also unpublished data are available in the Hanford Environmental Information System database. Collectively, maximum concentrations of 81,500 pCi/L, 220 mg/L, and 562,000 µg/L for technetium-99, chromium, and nitrate were measured. Of these well data, a strong indication of tank leak waste sources is found only at well 299-W23-19 next to tank SX-115. In this well, the highest technetium-99 concentrations (up to 81,500 pCi/L) have been measured and currently the concentration values have reduced to 36,000 pCi/L (September 2001). Maximum values for all three contaminants exceed current drinking water standards (900 pCi/L for technetium-99, 50 µg/L for chromium, and 45,000 µg/L for nitrate).

- The bulk of the matric potential measurements for sediments from four boreholes in and around WMA S-SX suggest a draining soil profile. Because no site-specific recharge measurements are available, estimates of natural recharge are based primarily on other Hanford Site measurements (e.g., lysimeter studies). These data suggest that recharge in the tank farms under current conditions can be as high as 100 mm/yr (4 in./yr). Recharge also appears to have occurred as a result of manmade events (e.g., water-line leaks, particularly near tank SX-115). Recharge rates from these events are highly uncertain and quantitative estimates are not available.
- Improvements in drilling technology sponsored by this activity allowed safe and efficient sample collection in the high radiation zone underneath SX-108. Other improvements aided the programs in a variety of areas (Section 2.2).

Because the investigative results (particularly soil and groundwater data near tank SX-115) suggest that manmade water sources have accelerated contaminant migration (Section 3.4.2), interim measures (Section 3.5) have been initiated to minimize the infiltration from manmade sources. These measures include capping monitoring wells, cutting water pipelines, and building berms around the S and SX tank farm boundaries.

Section 3.1 provides the geology and hydrology information collected or interpreted from the field investigation activities. Section 3.2 provides the geochemical information collected or interpreted from the field investigation activities. Section 3.3 provides the nature and extent of contamination for the soils and groundwater data sampled and analyzed from the field investigation activities. Section 3.4 provides the conceptual model based on the preceding three sections. Section 3.5 discusses interim measures and ICMs as being conducted or planned in FY 2001 and 2002.

### **3.1 HYDROGEOLOGIC CONDITIONS**

Geologic and hydrologic characteristics of the Hanford Site and local areas within the Hanford Site (e.g., WMA S-SX) have been extensively studied. In this section the results of those studies, both regional and site-specific, are summarized. More detailed discussion of the geologic and hydrologic characteristics of the WMA S-SX vadose zone and unconfined aquifer are provided in Appendix C, Sections C.4.0 and C.5.0, respectively. Geologic cross-sections used in numerical modeling and impact assessment (Section 4.0) are included in Appendix E.

#### **3.1.1 Geology**

The Hanford Site is located within the Columbia Plateau of southeastern Washington State. This broad plain, situated between the Cascade Mountains to the west and the Rocky Mountains to the east, is underlain by a thick sequence of Miocene age tholeiitic basalt flows (the Columbia River Basalt Group). These basalt flows have been folded and faulted, creating broad structural and topographic basins, separated by asymmetric anticlinal ridges. Sediments of late Miocene, Pliocene, and Pleistocene age have accumulated up to 518 m (1,700 ft) thick in some of these basins. The Hanford Site lies within one of the larger of these basins, the Pasco Basin. This basin is partially bisected by the Umtanum-Gable Mountain anticline creating two subordinate synclinal basins. The largest of these is the Cold Creek syncline, which is further subdivided into two basins, the Wye Barricade depression and the Cold Creek depression. The Cold Creek depression underlies the principal WMAs (200 East and 200 West Areas) of the Hanford Site. The generalized stratigraphy beneath the Hanford Site consists of, in ascending

order, the Columbia River Basalt Group, the Ringold Formation, the Plio-Pleistocene unit, and the Hanford formation (Figure 3.1). Thin veneers of Holocene alluvium, colluvium, and eolian sediments discontinuously overlie these principal geologic units.

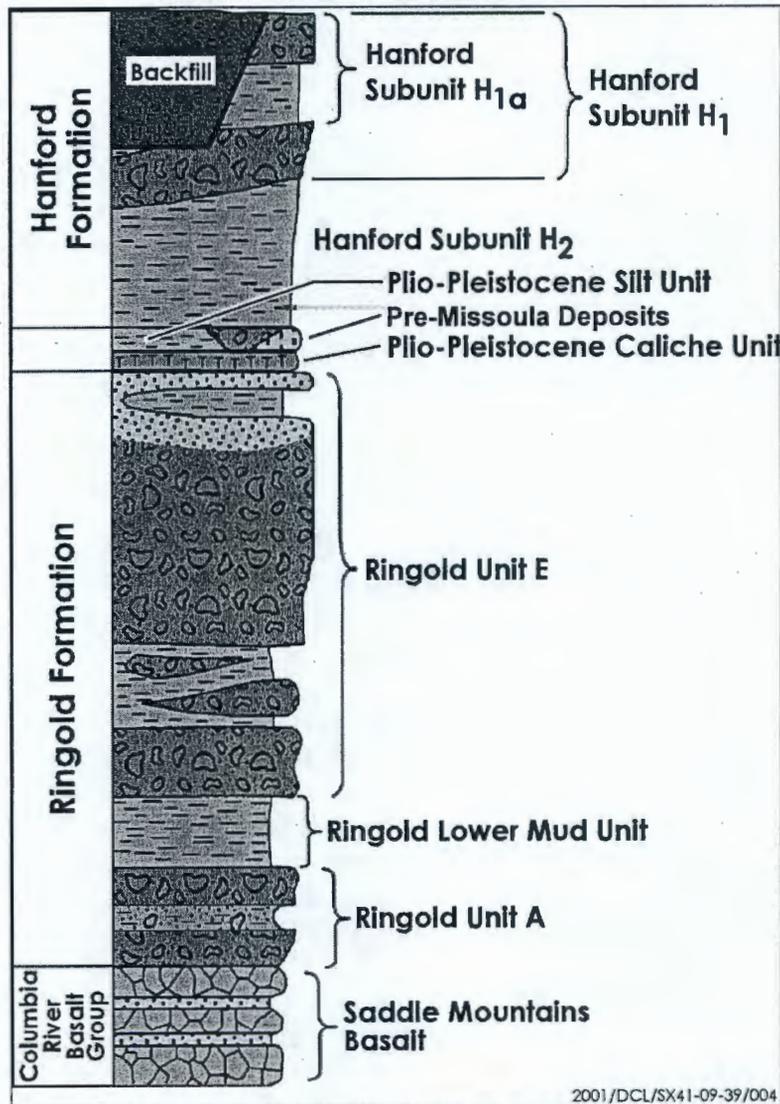
The WMA S-SX stratigraphic characteristics are shown by a northeast-to-southwest cross-section across the SX tank farm (Figures 3.2 and 3.3). The S and SX tank farms were constructed into the upper Hanford formation sediments underlying the 200 West Area, along the north limb of the Cold Creek syncline, which exists just west of WMA S-SX and is oriented generally north to south. Stratigraphic units in the vadose zone underlying or adjacent to these tank farms (in descending order) include backfill materials and naturally occurring Hanford formation sediments, the Plio-Pleistocene unit, and the Miocene- to Pliocene-age Ringold Formation. Because these units are part of the synclinal structure, there is a general tendency for these units to dip west to southwest in this area. The water table lies in the Ringold Formation, and the unconfined aquifer is located entirely in the Ringold Formation.

The Hanford formation sediments are divided into three subunits in WMA S-SX. In descending order, the subunits are H1a, H1, and H2. Their characteristics are described as follows.

- **Subunit H1a** – Comprised predominantly of interstratified slightly silty, medium to very fine sands (Figure 3.3), ranging in thickness from 0 m (0 ft) where it was removed during excavation of the S and SX tank farms, to about 9 to 12 m (30 to 40 ft) to the southwest (Figure 3.3). The top of this unit dips slightly (approximately 2°) to the southwest.
- **Subunit H1** – Comprised primarily of a gravel to gravelly sand intercalated by coarse sand (Figure 3.3) that appears to correlate beneath the SX tank farm. This sequence ranges in thickness from 1 m (3 ft) to nearly 10 m (30 ft) beneath the S tank farm. Sobczyk (2000) reports subunit H1 to be thickest beneath tank S-102 (Figure 3.4) where coarse-grained flood deposits backfilled an apparent channel eroded into the top of the underlying subunit H2. This subunit is also notable because of its high cesium-137 content in the area south and west of tank SX-108.
- **Subunit H2** – Comprised predominantly of silty fine sand that ranges in thickness from about 24.3 m (80 ft) east of the SX tank farm to approximately 10.7 m (35 ft) west of the tank farm (Figure 3.5). Johnson and Chou (1998) suggests that this thinning may signify some scouring on top of the subunit, perhaps associated with a secondary flood channel, similar to the north-south trending flood channel that bisects Cold Creek bar (Figure 3.6). The top of this subunit generally dips about 6° to the southwest, with some local relative highs and lows present throughout. The base of this subunit is indicated by a diagnostic increase in total gamma activity on borehole geophysical logs.

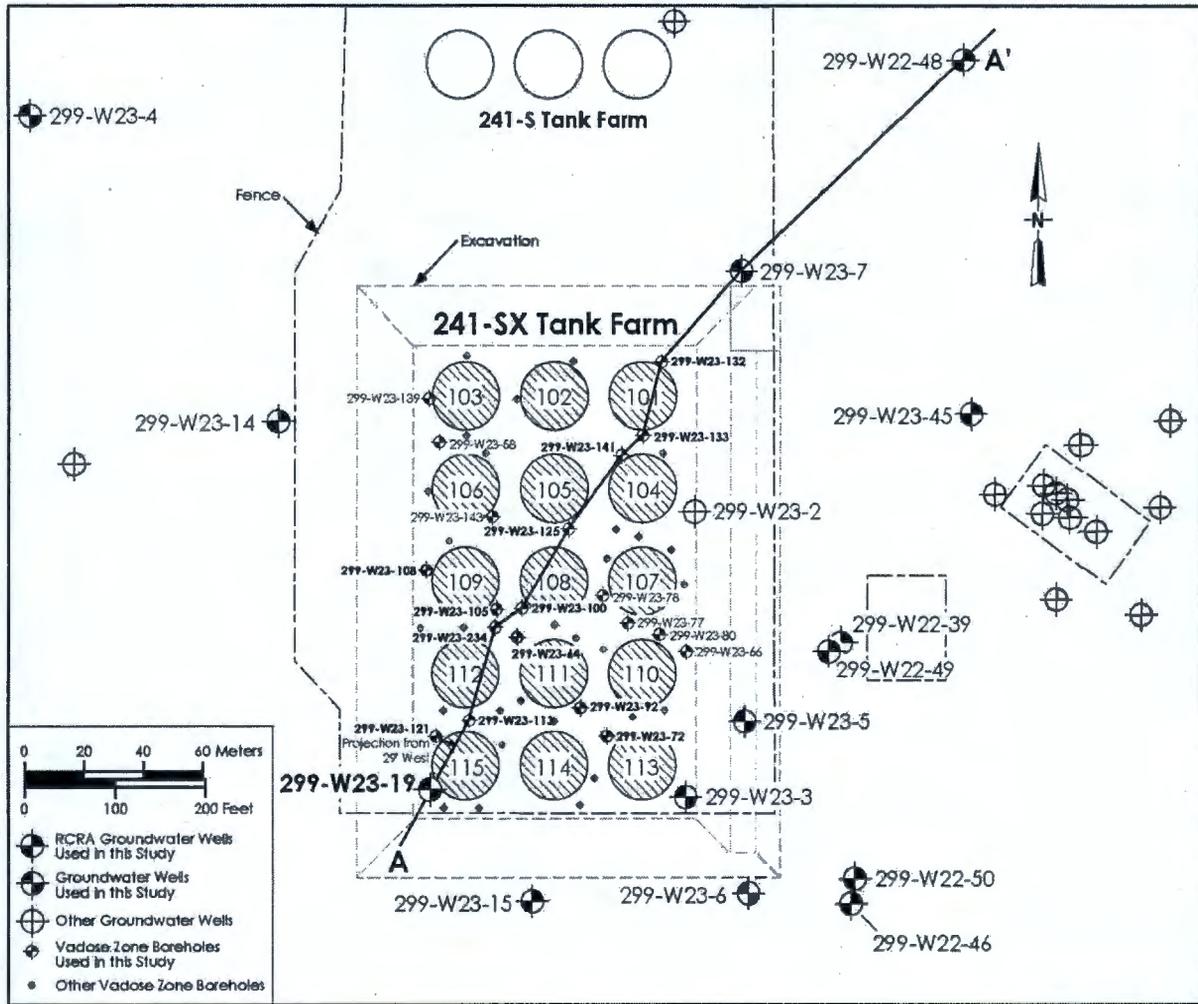
The Plio-Pleistocene unit sediments are divided into two distinct facies in WMA S-SX, subunits PPlz and PPlc, in descending order. Subunit PPlz is characterized by an abundance of silt interstratified with fine sand and clay. Subunit PPlc is characterized by an abundance of pedogenic calcium-carbonate cement, often in multiple carbonate-cemented zones. Calcium-carbonate contents do not exceed 10 wt% in the SX tank farm boreholes evaluated in the WMA S-SX field investigation. The combined total thickness of the Plio-Pleistocene unit is up to 13.1 m (43 ft) in the vicinity of the SX tank farm (Figure 3.5). Subunit PPlz is relatively thick (up to 10.7 m [35 ft]), compared to subunit PPlc, which measures only 1 to 4 m (4 to 13 ft) in thickness.

**Figure 3.1. Generalized, Composite Stratigraphy for the Late Cenozoic Sediments Overlying the Columbia River Basalt Group on the Hanford Site**



Sources: Johnson and Chou (1998); Johnson and Chou (1999).

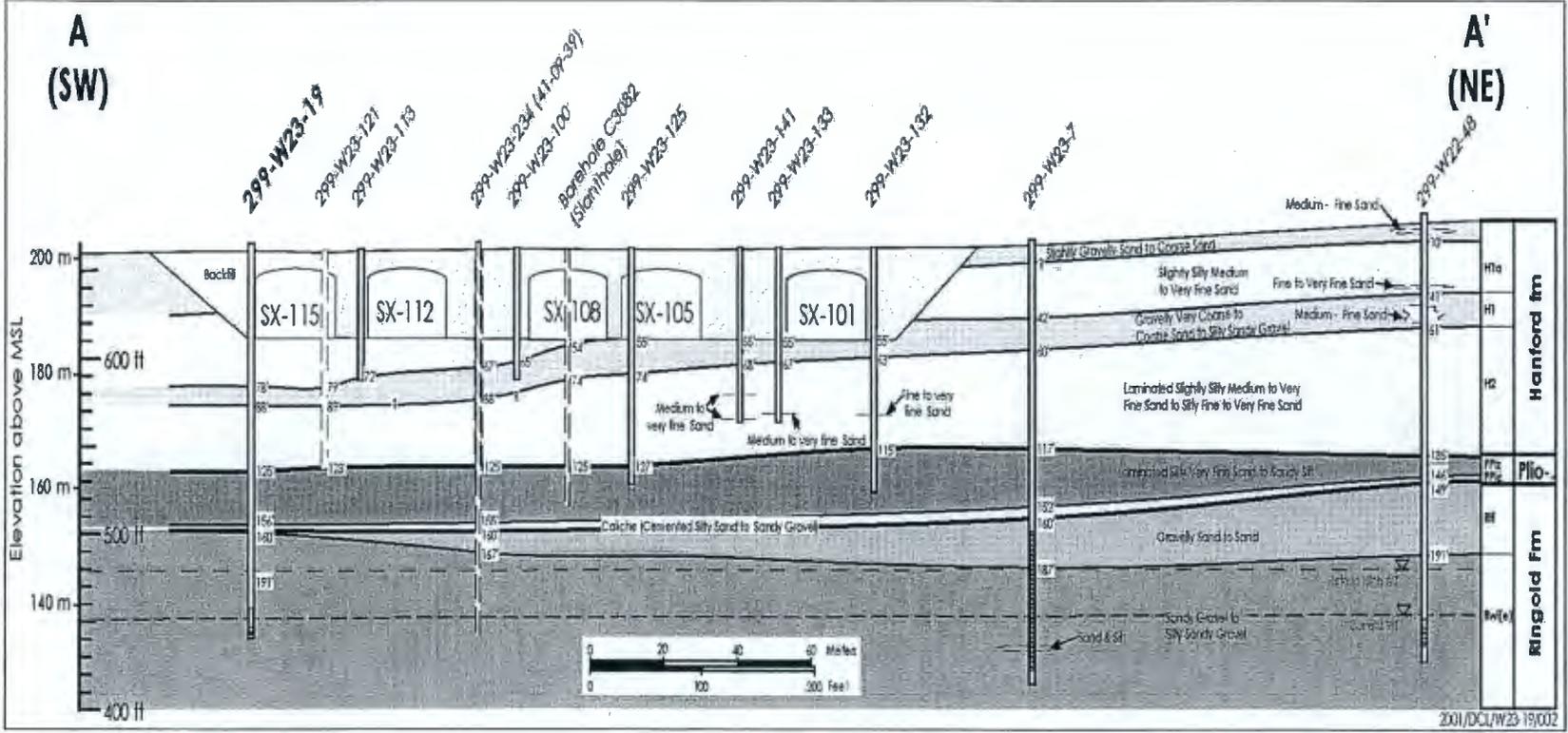
Figure 3.2. SX Tank Farm and Vicinity Showing Location of Borehole 299-W23-19



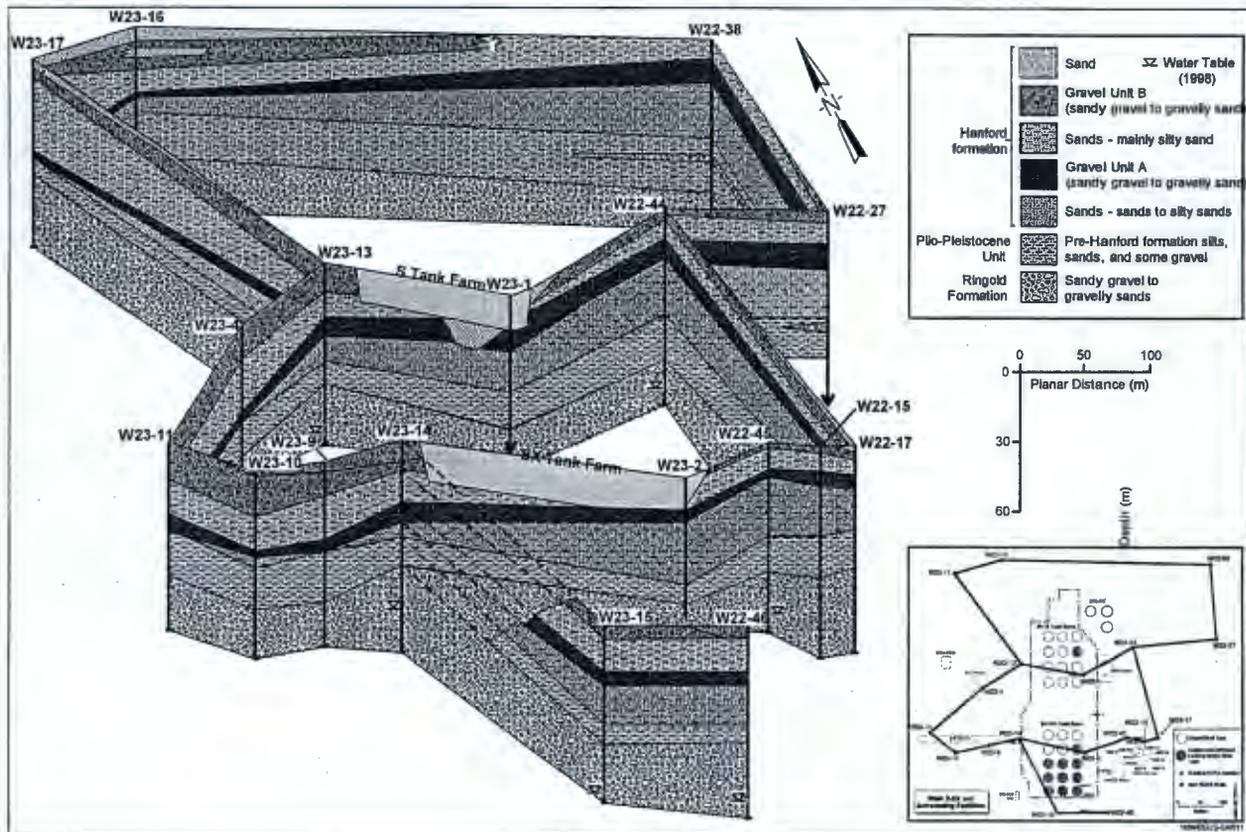
Note: Location of cross-section A-A', represented in Figure 3.3.

2001/DCL/W23-19/001

Figure 3.3. Hydrogeologic Cross-Section of the Vadose Zone Beneath the SX Tank Farm

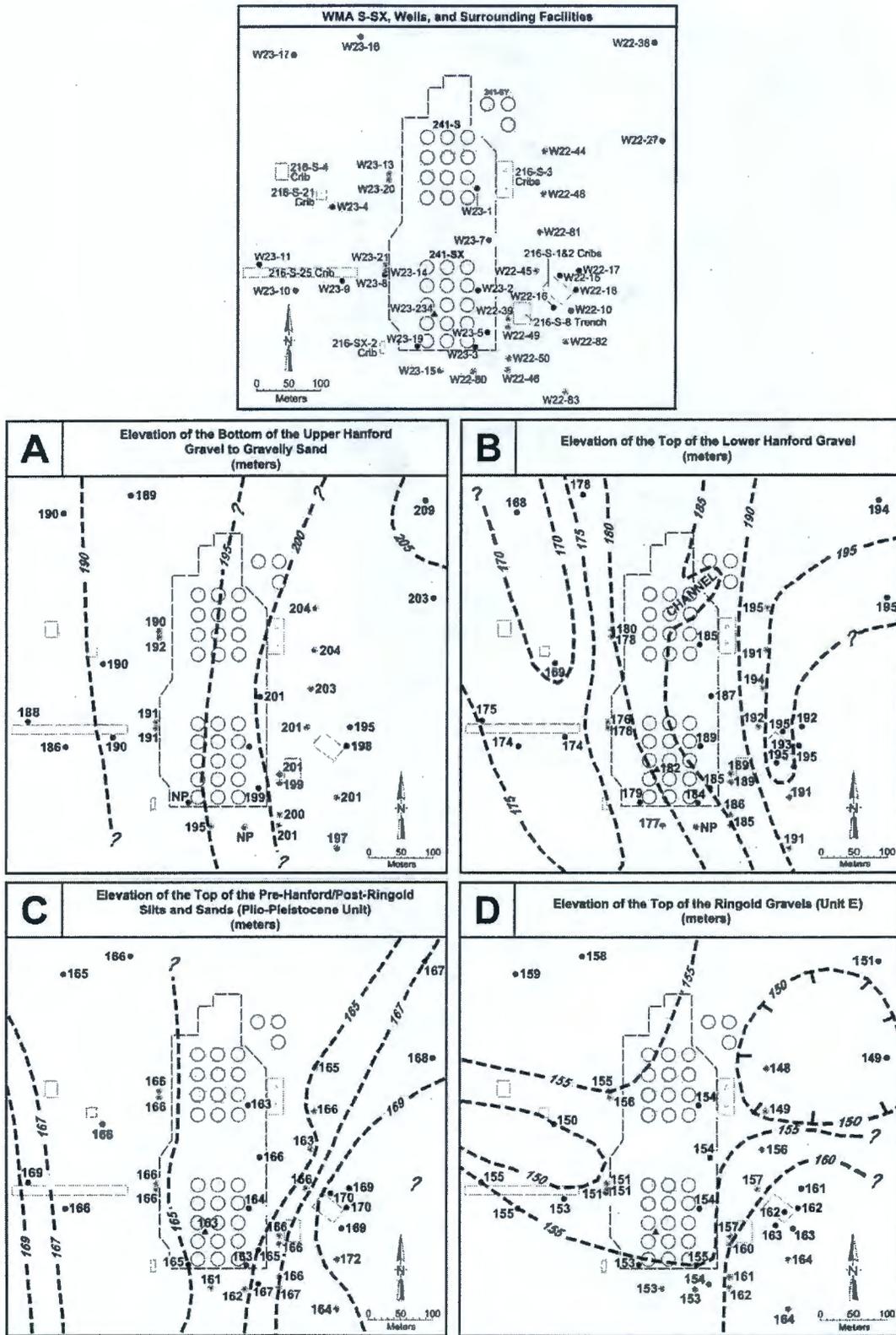


**Figure 3.4. Fence Diagram of Vadose Zone Stratigraphy Underlying Waste Management Area S-SX\***



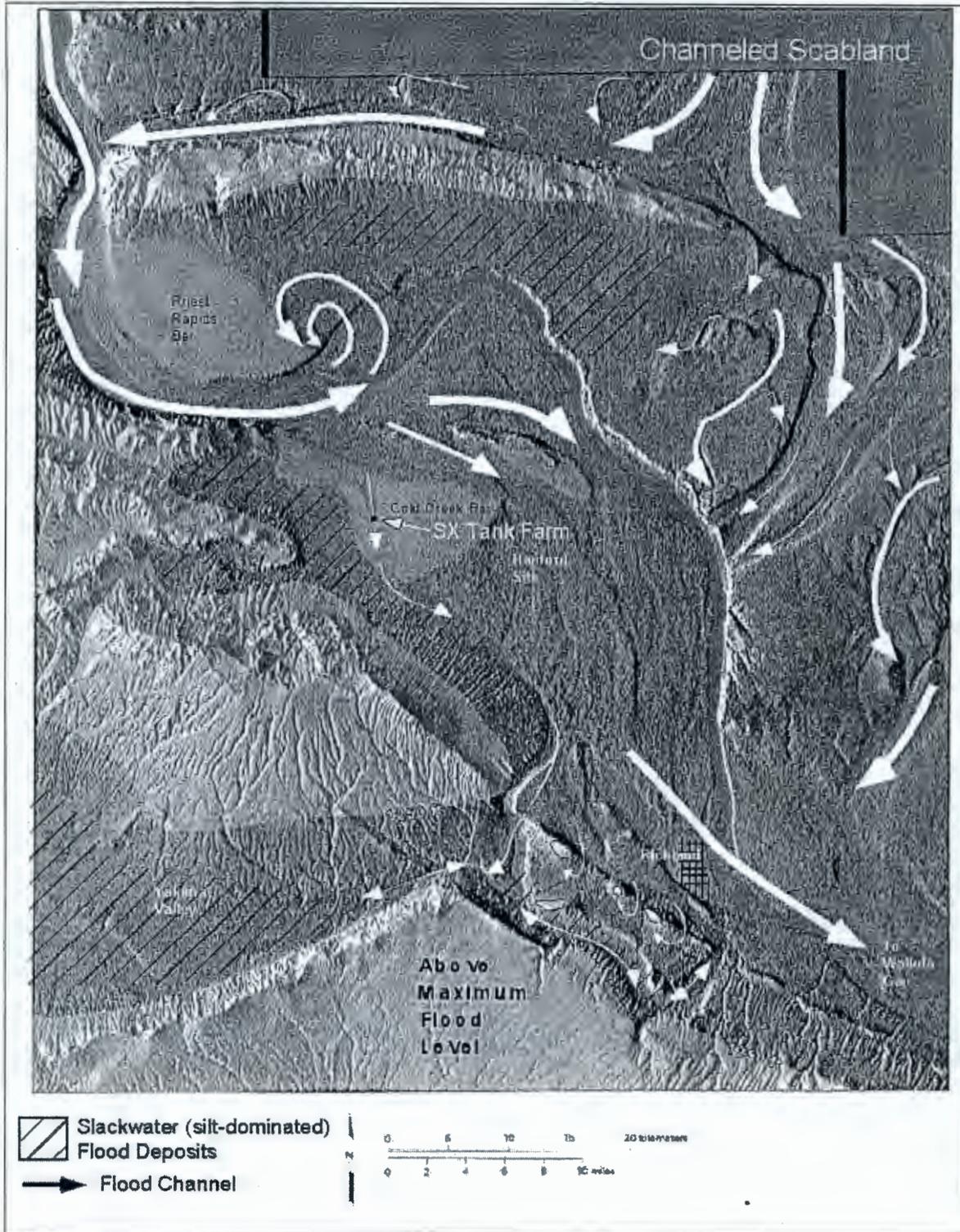
\*The top sand layer corresponds to subunit H1a. Gravel Unit B is subunit H1 and the next three lower units (sand, Gravel Unit A, and sand) comprise the subunit H2.

**Figure 3.5. Elevation Maps of Stratigraphic Unit Tops Underlying Waste Management Area S-SX\***



\*Elevation contours in subgraphs A and C mark the bottom of subunits H1 and H2.

**Figure 3.6. Digital Elevation Model Map of a Portion of the Pasco Basin Showing Routes and Facies Distributions for the Last Pleistocene Cataclysmic Floods**



The Ringold Formation lies directly on top of the Columbia River Basalt Group and is approximately 125 m (410 ft) thick beneath the S and SX tank farms. A relict erosional and weathered surface occurs at the top of the Ringold Formation beneath the SX tank farm and dips to the southwest beneath that tank farm. The northwest-southeast trending trough-shaped surface appears to conform to an ancestral Cold Creek channel and drainage system that developed following late Pliocene incision of the Ringold Formation, and prior to early Pleistocene cataclysmic flooding, during the period between approximately 2 to 3 million years ago. The Ringold Formation locally consists of three principal stratigraphic units (see Figure 3.1):

- Fluvial gravels of unit A
- Fine-grained, paleosol-lacustrine sequence referred to as the lower mud unit
- Fluvial gravels of unit E.

Ringold unit E contains the main unconfined aquifer beneath 200 West Area.

In addition to the primary stratigraphic units described, clastic dikes may be present in the WMA S-SX vadose zone. Although clastic dikes have been observed in numerous locations around WMA S-SX, none have been observed in the WMA S-SX vadose zone itself. Clastic dikes are vertical to near-vertically oriented sedimentary structures that cut across horizontal bedding planes. The dikes have been observed in all types and ages of geologic materials found beneath the Hanford Site including basalt; interbed sediments; the Ringold Formation; and the sands, mud, and gravels of the Hanford formation (Fecht et al. 1999). Clastic dikes are especially notable within the sand- and silt-dominated facies of the Hanford formation where they have been observed to be a few centimeters to more than a meter thick and extend to depths of 36 m (120 ft) bgs or more.

### 3.1.2 Hydrology

Tank leaks occur under variably saturated conditions, making natural recharge from meteoric water (from winter precipitation and snowmelt), artificial recharge from operations-related sources, and vadose zone hydrology important drivers for contaminant movement to groundwater. Recharge, vadose zone, and groundwater conditions for WMA S-SX are briefly discussed in the following sections.

**3.1.2.1 Recharge.** S and SX tank farm surfaces are covered with gravel to prevent vegetation growth and provide radiation shielding for site workers. Bare gravel surfaces, however, enhance net infiltration of meteoric water, compared to undisturbed, naturally vegetated surfaces. Infiltration is further enhanced in the tank farms by the effect of percolating water being diverted by an impermeable, sloping surface of the tank domes. This umbrella effect is created by the 23 m (75 ft) inside diameter buried tank domes. Water, shed from the tank domes, flows down the tank walls into underlying sediments. Sediments adjacent to the tanks, while remaining unsaturated, can attain elevated moisture contents (Kline and Khaleel 1995). Enhanced infiltration from a gravel-covered tank dome can provide potential for faster transport of contaminants to the water table. In addition, other sources of recharge include unintentional surface spills, infiltration of surface runoff from leaking water lines, and ancillary tank-related equipment.

Natural recharge can vary greatly depending on factors such as climate, vegetation, surface condition, and soil texture. Studies conducted at the Hanford Site suggest that recharge rates can vary from less than 0.1 mm/yr (0.004 in./yr) on a variety of soil and vegetative combinations to greater than 130 mm/yr (5.1 in./yr) on bare basalt outcrops or bare, gravel-covered waste sites (Gee et al. 1992). Data from experimental sites such as the Field Lysimeter Test Facility and the prototype Hanford barrier, both in the 200 East Area, suggest that recharge through gravels can vary from 15% to 70% of precipitation, with the lower amount occurring under vegetated conditions (Gee et al. 1993; Fayer and Walters 1995; Fayer et al. 1996; Gee et al. 1996). With a long-term annual average precipitation of 160 mm (6.3 in.), the higher percentage translates into a recharge rate of about 100 mm/yr (4.0 in./yr) and was observed on clean gravels that were kept free of vegetation. Drainage from bare sands is about 70 mm/yr (2.8 in./yr) under Hanford Site climatic conditions (Ward et al. 1997). However, there has been no direct measurement of recharge on tank farm gravels, which are known to contain a larger amount of fines than clean gravels. Thus, it is entirely possible that the tank farms experience a recharge rate that ranges between that observed for bare sand and clean gravels (Ward et al. 1997).

Recharge estimates based on environmental tracer techniques (Prych 1995; Murphy et al. 1996) are generally consistent with those based on lysimeter studies. However, the tracer techniques, while powerful, are not applicable to disturbed sites such as the tank farms. Also, these techniques have been unable to measure significant recharge at sites with coarse soils and shallow-rooted vegetation, because of deep percolation of natural tracer at these sites.

Soil matric potential is often used as an indicator for deep drainage (recharge) conditions. However, it should be noted that, while matric potentials can provide useful information about the variability of recharge across WMA S-SX, they cannot discern differences in contribution to recharge from natural and artificial sources.

Matric potential measurements are available for sediments from four boreholes (Serne et al. 2001a, 2001b, 2001c):

- RCRA boreholes 299-W22-48 and 299-W22-50 outside of the SX tank farm
- Contaminated borehole 41-09-39 near tank SX-109
- Contaminated borehole 299-W23-19 near tank SX-115.

The matric potential measurements for the 10 sleeves from borehole 299-W23-19 are relatively high (sediments relatively wet) throughout the sediment profile, and the measurements suggest a draining profile. Unit gradient conditions persist throughout the profile. Serne et al. (2001b) postulates that a recharge estimate of 50 to 100 mm/yr (2.0 to 4.0 in./yr) would not be inconsistent with the measured matric potentials for borehole 299-W23-19 samples. However, it should be noted that it is more likely that an artificial source, rather than meteoric recharge, is responsible for the high matric potential values at borehole 299-W23-19 near tank SX-115. There is a huge depression south of tank SX-115 and an 8-in. water line running directly south of the tank. Water lines are prone to leaks and the depression south of tank SX-115 provides an excellent location for collection of water from water-line leaks. In fact, a cottonwood tree has grown in this area (Johnson and Chou 1998). This, combined with the upward trend of technetium-99 in borehole 299-W23-19 directly west-southwest of tank SX-115, provides circumstantial evidence that the matric potential data for borehole 299-W23-19 are more of a

reflection of artificial than natural recharge. (The technetium-99 concentration in borehole 299-W23-19 increased from 39,000 pCi/L in October 1999 to 81,500 pCi/L in March 2001.)

For the two RCRA boreholes outside of the SX tank farm (299-W22-48 and 299-W22-50), it appears that at 30 m (100 ft) bgs, the measured matric potentials are low (the sediments are relatively dry), compared to sediments in the contaminated borehole 299-W23-19. Unlike borehole 299-W23-19, matric potential data for the two RCRA borehole sediment samples do not suggest unit gradient conditions (Serne et al. 2001a). However, matric potential data for sediment samples from the upper horizon do indicate that meteoric recharge (or recharge from man-made sources) has penetrated to a depth of at least 30 m (100 ft) bgs at the two RCRA borehole sites. Below that depth, sediments from these two RCRA well sites are significantly drier, compared to those from the contaminated borehole 299-W23-19. This suggests that the wetting front has not penetrated the lower horizons and non-equilibrium conditions persist below 30 m (100 ft) bgs.

Lysimeter studies (Gee et al. 1992) suggest that sediments kept free of vegetation can cause accelerated drainage. Such conditions are believed to exist at the two RCRA borehole sites. With the disruption caused by the initial construction of the tank farms in the late 1950s, one could assume that there has been nearly 40 years of elevated drainage resulting from the severe disturbance and vegetation removal. It is clear that, at a disturbed site such as the RCRA borehole sites where vegetation has been removed, equilibrium is altered and non-equilibrium conditions can persist for quite some time.

Unlike matric potential data for samples from borehole 299-W23-19 near tank SX-115, measurements from borehole 41-09-39 samples near tank SX-109 show considerable variability. While the majority of the data are indicative of a draining profile, a number of measurements suggest an upward flow (Serne et al. 2001c). Serne et al. (2001c) attributes this to the drying effect resulting from the heat load from high-heat tank SX-108. Given the large variability of the measured matric potentials for the 30 samples and the lack of unsaturated hydraulic properties for the SX tank farm sediments, it is not possible to estimate the magnitude of deep drainage (recharge) at this borehole site.

For the purposes of field investigative report modeling, a base case recharge estimate of 100 mm/yr (3.9 in./yr) is used. Such an estimate is similar in magnitude to measured drainage rates from gravel surfaces kept free of vegetation (Gee et al. 1992). For simulations involving tank farms with an interim barrier, a recharge rate of 0.5 mm/yr (0.02 in./yr) is used. This is based on experimental data from a prototype Hanford barrier that has been designed and built in 200 East Area to limit recharge to less than 0.5 mm/yr (0.02 in./yr) (DOE-RL 1999a). This is also supported by the numerical simulation results in Smoot et al. (1989) where it is reported that with a relatively impermeable barrier over the tank farm, the drainage to a 2 m (7 ft) backfill depth decreased to less than 0.5 mm/yr (0.02 in./yr) after 8 years for cases of either a backfill or a clean graveled surface.

The closure barrier for tank farms is assumed to be an enhanced RCRA Subtitle C barrier with a design life of 500 years. The recharge through such a barrier is estimated to be 0.1 mm/yr (0.004 in./yr) (Fayer et al. 1999). For a degraded closure barrier, recharge rates are expected to return to predevelopment conditions (i.e., the same as a shrub-steppe ground cover) with a

recharge estimate of 3.5 mm/yr (0.14 in./yr). Such an estimate is within the range of values reported in Fayer and Walters (1995). Table 3.1 summarizes the timeline estimates for barrier emplacement at the S and SX tank farms and the corresponding recharge estimates.

**Table 3.1. Timeline Estimates for Emplacement of Interim and Closure Barriers at the S and SX Tank Farms and Corresponding Recharge Estimates**

Condition Simulated	Recharge Estimate (mm/yr)
No barrier [years 2000 to 2010]	100
Interim barrier [years 2010 to 2040]	0.5
Closure barrier (design life 500 yrs) [years 2040 to 2540]	0.1
Degraded closure barrier (after 500 yrs) [years 2540 to 3000]	3.5

**3.1.2.2 Vadose Zone Hydrology.** Because water movement is the primary mechanism for radionuclide and chemical transport, an objective of the WMA S-SX field investigation was to evaluate the potential for radionuclide and chemical transport beneath the tank farms by considering the nature and distribution of flow within the vadose zone. In general, two types of moisture movement can occur in the vadose zone beneath the tank farms.

- **Piston flow** – Uniform moisture movement through the soil matrix whereby infiltrated water displaces initial water (wetting-front infiltration). Under piston-like flow conditions most, if not all, preexisting water ('old' water) is displaced and moved ahead of the 'new' infiltration water added from above this zone. Under natural recharge conditions, the medium- to coarse-grained sands at tank farm sites are expected to be quite conducive to piston flow.
- **Preferential flow** – Process whereby water and contaminants move along preferential pathways. Preferential pathways can be natural (e.g., clastic dikes) or anthropomorphic (e.g., unsealed monitoring wells). While preferential flow has been recognized and widely studied under saturated or near-saturated flow conditions (Nkedi-Kizza et al. 1983; De Smedt and Wierenga 1984), there is little evidence of it in arid and semiarid climates or under low water fluxes, particularly where soils are coarse-grained such as those under tank farms. Thus, under natural recharge conditions, precipitation at arid sites is usually too low to invoke preferential flow; much of the water in the dry soils is simply adsorbed onto the grain surfaces and cannot move along preferred pathways.

Other potential preferential pathways during tank leaks include wetting front instability or 'fingering' flow. Wetting front instability, reported in petroleum-related literature, is a special case of interface instability during immiscible fluid displacement in porous media. The phenomenon is triggered by unfavorable differences between the viscosities and densities of two fluids across their interface—a condition that can potentially exist during tank leaks.

Among potential preferential pathways, the probability of a tank encountering a clastic dike is substantial. For example, numerous clastic dikes occur at the US Ecology site southwest of the 200 East Area that may serve as conduit for preferential flow. While a clastic dike can potentially increase flow rate, it is less likely to intersect large segments of leaked wastes, and when it does the cross-sectional area of the intersection is small (DOE-RL 1997b). Therefore, presence of clastic dikes in unsaturated media appears unlikely to contribute much to the transport to groundwater of the bulk quantity of leaked tank wastes. Nonetheless, as described in Appendix E, the clastic dike effects are included in modeling.

A field study in the 200 East Area south of the Plutonium-Uranium Extraction Plant demonstrated the effect of geologic heterogeneities on water contents in a natural arid setting (Sisson and Lu 1984). The observed higher water contents were strongly correlated with fine soil layers, which have a higher water-holding capacity than coarse soils. In addition, the observed profiles were remarkably similar for the 15-year interval between measurements at the field site (Fayer et al. 1995). This suggests that, in the absence of artificial recharge, the 'natural' moisture contents of the sediments are essentially determined by the nature of geologic heterogeneity, and the vadose zone water content profiles are at quasi-equilibrium with the natural recharge rate. This is also demonstrated by the moisture content profiles in RCRA boreholes 299-W22-50 and 299-W22-48 (Serne et al. 2001a) and contaminated boreholes 41-09-39 (Serne et al. 2001c), 299-W23-19 (Serne et al. 2001b), and 299-W10-196 (Freeman-Pollard et al. 1994) near tank T-106. The measured water contents are much higher in the Plio-Pleistocene unit than in the Hanford formation.

The dominance of lateral movement is a unique feature of unsaturated flow, especially in an arid setting (Yeh et al. 1985a, 1985b). Horizontal stratification enhances such movements, because at high tension (i.e., dry soil) hydraulic conductivities of fine-textured materials are relatively high and the fluid prefers to spread laterally in the fine media than to move vertically through the coarse media. Such a phenomenon is referred to as moisture-dependent anisotropy and can potentially be a dominant mechanism for lateral flow. This has important implications for vadose zone contaminant transport from tank leaks. For example, measurements of vadose zone contamination at the SX tank farm (DOE-GJPO 1996b) and the tank T-106 leak (Routson et al. 1979) suggest significant lateral movement. As described in Appendix E, moisture-dependent anisotropy effects are included in modeling.

A description of geologic heterogeneities as well as soil hydraulic properties (i.e., moisture content versus matric potential and unsaturated hydraulic conductivity versus moisture content relationships) is needed to evaluate the storage and flow properties of tank farm soils. Furthermore, assessing the ability of the vadose zone to act as a buffer requires properly accounting for conditions whereby the tank leak chemistry itself may affect physical and hydraulic properties of the soil and therefore the mobility of contaminants.

No site-specific data on soil moisture characteristics are available for vadose zone sediments in the S and SX tank farms. However, several data catalogs exist on physical and hydraulic properties for sediments in the 200 and 100 Areas (Khaleel and Freeman 1995; Khaleel et al. 1995; Khaleel and Relyea 1997; Khaleel 1999; Khaleel et al. 2000; Khaleel and Relyea 2001). As part of other Hanford Site projects, particle-size distribution, saturated hydraulic conductivity, moisture retention, and unsaturated hydraulic conductivity data have

been collected in the vicinity of the S and SX tank farms. Sediment samples were collected in the vicinity of the Environmental Restoration Disposal Facility, tank T-106, and operable units 200-UP-1 and 200-UP-2 in the 200 West Area. Also available are physical and hydraulic properties data for the sandy gravel sediments in the 100 Area along the Columbia River (Khaleel and Relyea 2001). These samples were used as surrogates to represent the hydraulic properties for the gravel-dominated sequence at the S and SX tank farms. Details are provided in the WMA S-SX FIR modeling data package (Khaleel et al. 2000). The data used in modeling are summarized in Appendix E. Appendix E also provides effective (upscaled) values of flow and transport parameters for the vadose zone at the S and SX tank farms.

**3.1.2.3 Groundwater Conditions.** The water-table map for March 2000 (Hartman et al. 2001) indicates that the direction of groundwater flow in the southern portion of the 200 West Area is primarily toward the east, with a slight southeastern component. The natural flow pattern in this area was altered by the formation of groundwater mounds created by the discharge of large volumes of wastewater at disposal facilities. The southeastern trend is more apparent in the area of the decommissioned U pond. These mounds are declining, and groundwater flow is gradually returning to pre-Hanford conditions. The water table is gradually declining at the rate of approximately 0.6 m/yr (2 ft/yr), which may result in a future shift to a more easterly direction and decreased flow rates as the gradient declines.

The unconfined aquifer in WMA S-SX resides in partially cemented Ringold Formation sands and gravels. The cementing is not present at greater depths. This may result in a more transmissive aquifer in the future as the water table continues to decline.

Hydraulic conductivities based on slug tests for RCRA wells 299-W22-48, 299-W22-49, and 299-W22-50 cover a range of 1.55 to 8.2 m/day (0.5 to 27 ft/day) (Johnson and Chou 2001). Such a range brackets the averaged, large-scale hydraulic conductivity estimate used in the Hanford Site-wide groundwater model for the WMA S-SX region (Appendix E). Estimates for effective porosity, based on tracer test analysis, range between 0.068 and 0.257 (Johnson and Chou 2001); such a range falls within that usually reported for semi-consolidated to unconsolidated alluvial aquifers of 0.05 to 0.30, and again brackets the large-scale value used in the Hanford Site-wide groundwater model (Appendix E). Hydraulic gradient, based on tracer test analysis, is about 0.002 whereas the groundwater velocity ranges from 0.013 to 0.374 m/day (0.04 to 1.2 ft/day) (Johnson and Chou 2001).

## 3.2 GEOCHEMICAL CONDITIONS

Geochemical conditions in WMA S-SX are determined by in situ undisturbed vadose zone characteristics, the chemistry of leaked tank fluids, and the interactions between fluids and the soil-soil water system. Because tank fluids of varying composition were distributed over parts of the vadose zone at various times, geochemical conditions affecting contaminant and other constituent behavior vary, temporally and spatially. The effect of these variable conditions on contaminant mobility is of key interest. This section focuses on those aspects of vadose zone geochemistry that influence contaminant migration. The four contaminants of interest identified by these studies are cesium-137, technetium-99, chromium, and nitrate.

A substantial database has been developed to quantify past and current geochemical conditions in contaminated areas in WMA S-SX. The majority of data used to understand geochemical conditions are soil sample and soil water analyses from boreholes drilled in contamination areas inside the SX tank farm and in nearby relatively undisturbed zones (see Appendix B for detailed discussion). Also, laboratory studies and analyses focused on mechanisms controlling contaminant migration (see Appendix D for detailed discussion) provide useful insights. Geochemical conditions are of greatest interest in soils contaminated by the tanks SX-107, SX-108, SX-109, and SX-115 leaks. Because the tank leak fluid chemistry has some significant differences that have affected contaminant migration, geochemical conditions are discussed separately for each contamination area as well as the undisturbed area east of WMA S-SX.

### 3.2.1 Undisturbed WMA S-SX Vadose Zone Soil Geochemical Conditions

Two RCRA groundwater monitoring wells (299-W22-48 and 299-W22-50) were drilled on the east side of WMA S-SX where vadose zone soils have not been subjected to tank leaks. The soils analysis database (Serne et al. 2001a) shows a standard set of soil minerals (primarily quartz, feldspars, and minor amounts of smectite, illite, chlorite, kaolinite, and calcite) and particle-size distribution typical of the stratigraphic units in this area. Cation exchange capacity varies between 6 and 40 meq/100 g depending on the procedure used.

For the most part, soil water chemistry derived from 1:1 extracts is fairly consistent throughout the soil column. The pH values in both boreholes fall into a normal range (7 to 8.5) except at 18 to 21 m (60 to 68 ft) bgs in borehole 299-W22-50 where elevated pH values (about 10 and 9) are measured. The reason for this increase is not clear. Primary anions are nitrate, chloride, and sulfate concentrations. Other than slight enrichment of nitrate and sulfate in Plio-Pleistocene subunit PPlc, the profiles are undistinguished.

Water extract cation concentrations as a function of depth are listed for borehole 299-W22-48 in Appendix B, Table B.21 and graphed in Appendix B, Figure B.28. Appendix B, Table B.22 provides cation concentrations for borehole 299-W22-50. Primary cations are sodium, magnesium, potassium, and calcium. Generally, total anion concentrations are 50 to 60 mg/L. In both boreholes slight elevations of calcium and natural strontium occur in subunit PPlc because of the relatively high quantities of calcium carbonate (40 wt%). A slight unexplained calcium enrichment anomaly occurs at 18 m (60 ft) bgs in borehole 299-W22-50.

### 3.2.2 Tanks SX-107, SX-108, SX-109 Vadose Zone Soil Geochemical Conditions

Soil samples from two boreholes near tanks SX-107, SX-108, and SX-109 were collected and analyzed. The SX-108 slant borehole was drilled beneath tank SX-108 to collect samples as close to the leak point from the tank and beneath the tank, a location that had not been previously sampled. Borehole 41-09-39 lies about 20 m (66 ft) southwest of tank SX-108, and soils from this borehole represent a location far enough removed from the tank leak point to demonstrate the effects of lateral movement on tank fluid distribution in the vadose zone.

Based on the presumed volumes leaked and gamma radiation measurements taken in many drywells, the tank SX-108 leak is considered to be the primary source of tank waste contamination in borehole 41-09-39 and the SX-108 slant borehole. Estimates of tank fluid

chemistry (Section 3.3; Appendix C, Section C.3.0; and Appendix D, Section D.7.3) that had a dominating impact on local chemical conditions and contaminant mobility are extremely high pH, and extremely high cesium-137, sodium, aluminum, and nitrate concentrations. High cesium-137 concentrations in the upper subunits of the soil column (17 to 26 m [55 to 86 ft bgs]) in both boreholes (Appendix B, Sections B.2.0 and B.4.0) indicate that cesium-137 was highly mobile initially, essentially migrating with the tank fluid for some limited time. This pattern of cesium-137 migration is rarely seen in Hanford Site soils.

Extensive laboratory experiments (Appendix D, Section D.3.0) clearly demonstrate the importance of competition for sorption sites between cesium-137 and sodium and show that estimated tank fluid composition was suitable for favoring sodium versus cesium-137 sorption, thereby mobilizing cesium-137. The current distribution of tank fluid constituents in the soil column also explains why cesium-137 is currently fairly immobile. Geochemical conditions have changed over time as tank fluid has migrated and continued to interact with the soil column. Water extract data in soil columns from both boreholes show a distinct chromatographic separation of cesium-137 and sodium with depth. Once cesium-137 and sodium were sufficiently separated, cesium-137 sorption became favorable, fixing it in place. Empirical sorption data, estimated by ratioing cesium-137 concentrations in water extractions versus total concentration based on gamma logging data, show increasing sorption with decreasing sodium concentrations.

Little data exist, suggesting that nitrate behavior is affected either by tank fluid chemistry, the soil-soil water system, or chemical interactions between them. Consequently, the vertical extent of tank fluid migration in both boreholes is indicated by nitrate concentration profiles with depth. The profiles in both boreholes indicate that tank fluids have not penetrated beyond the Plio-Pleistocene unit. The borehole soil sample analyses show that technetium-99 concentration profiles generally match well with nitrate showing that technetium-99 is also essentially unreactive with solids. Therefore, past and present in situ geochemical conditions have no real affect on their mobility.

Chromium mobility apparently has been slightly influenced by geochemical reactions. High chromium concentration zones are slightly shallower than high technetium-99 zones, indicating occurrence of a small degree of retardation and chemical interaction for chromium species. Over time, interactions between tank fluid and the soil column have created a combined porewater chemistry characterized by intermediate pH values and total dissolved solids concentrations. Laboratory tests and chromium species characterization (Appendix D, Section D.4.0) indicate that the limited retardation of chromium in the soil column has occurred because iron(II)-bearing minerals reduce chromium from the VI to the III valence state which allows sorption or co-precipitation to occur. Chromium(III) was also measured in soil samples. The results also indicate that highly caustic solutions dissolved iron(II)-bearing minerals, thereby facilitating the kinetics of chromium reduction.

### **3.2.3 Tank SX-115 Vadose Zone Soil Geochemical Conditions**

Soil samples from borehole 299-W23-19 just southwest of tank SX-115 were collected. Geochemical conditions in this borehole, based on soil water extract data, are generally similar to those in borehole 41-09-39 and the SX-108 slant borehole. Soil water extract compositions show

a moderate pH with zones of higher concentrations of tank fluid constituents (nitrate, sodium, and technetium-99) at different depths in the soil column. The significant exception is that there are only trace quantities of cesium-137 at tank bottom depth in this borehole. This difference is readily explained by the initial tank fluid composition estimates (Table 3.2), which show a much more dilute solution with much reduced cesium-137 and sodium content. Because of this initial condition, insufficient competition for sorption sites occurred, and cesium-137 sorbed very quickly into soil as the tank fluid leaked from the tank.

**Table 3.2. Summary of Selected Tank Supernate/Salt Concentrations at Time of Leak**

Tank	S-104	SX-107	SX-108	SX-109	SX-110	SX-111	SX-112	SX-113	SX-114	SX-115
Assumed Leak Date	1965	Ave. 1964-1967	Ave. 1965-1966	Ave. 1964-1967	1974	1973	1969	1962	1972	1964
Chemicals	(mole/L)	(mole/L)	(mole/L)	(mole/L)	(mole/L)	(mole/L)	(mole/L)	(mole/L)	(mole/L)	(mole/L)
Sodium	8.7E+00	1.9E+01	2.0E+01	1.5E+01	6.1E+00	5.3E+00	1.3E+01	8.0E+00	8.9E+00	3.6E+00
Aluminum	1.6E+00	3.3E+00	3.4E+00	2.6E+00	7.3E-01	5.3E-01	2.2E+00	1.3E+00	9.7E-01	8.3E-01
Chromium	1.6E-01	3.9E-01	4.1E-01	3.2E-01	6.8E-02	5.9E-02	2.1E-01	1.7E-01	1.0E-01	5.1E-02
Nitrate	3.0E+00	4.9E+00	5.5E+00	4.5E+00	1.7E+00	1.5E+00	3.5E+00	2.8E+00	2.5E+00	1.2E+00
Nitrite	1.6E+00	4.5E+00	4.4E+00	3.2E+00	1.3E+00	1.1E+00	3.1E+00	1.3E+00	1.9E+00	7.8E-01
Radionuclides	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)	(Ci/L)
Technetium-99	4.2E-05	2.4E-04	2.3E-04	1.6E-04	1.6E-04	2.1E-04	1.6E-04	4.4E-05	2.9E-04	2.9E-05
Cesium-137	1.2E-01	8.4E-01	7.7E-01	5.2E-01	1.27E-01	5.8E-02	5.3E-01	1.3E-01	1.4E-01	9.9E-02

The relative positionings of nitrate, technetium-99, and chromium are similar to those shown in borehole 41-09-39 and the SX-108 slant borehole. Nitrate and technetium-99 are concentrated at the bottom of the tank-fluid-soil-interaction zone at the Plio-Pleistocene unit, and the high chromium zone occurs at a shallower depth. As before, it is concluded that nitrate and technetium-99 are essentially unaffected by geochemical conditions and partial reduction of chromium has occurred, aided by higher pH tank fluids.

### 3.3 NATURE AND EXTENT OF SUBSURFACE CONTAMINATION

A reasonable understanding of the nature and extent of subsurface contamination in WMA S-SX is required to complete transport modeling and risk calculations (Section 4.0 and Appendix E). Initially, this understanding was developed through extensive reviews of historical records and integration of data from previous field investigations. In this characterization effort, additional and complementary studies were completed to improve estimates of WMA S-SX vadose zone contamination, including the following:

- Additional inventory estimates derived from the historical records of tank operations
- Kriging analyses to determine cesium-137 distribution and total inventory
- Speciation analyses using thermodynamic concepts

- Analysis of soil samples contaminated by tank waste taken from exploratory boreholes in the SX tank farm.

Results of these studies, summarized in the following sections, provide a consistent correlation between theoretical inventory estimates and field measurements of vadose zone contamination. This observation improves confidence that tank inventory estimates are reasonable source term estimates for flow and transport modeling and risk evaluation.

The current WMA S-SX field investigations have not addressed the near-surface contamination that resulted from routine tank farm operations. The current state of understanding of near-surface contamination is found in Appendix B, Section B.6.0.

### 3.3.1 Tank Leak Inventory Estimates

The importance of developing quantitative inventory estimates for tank waste materials lost to the soil column during leak events was fully appreciated during development of the technical basis for the current SST vadose zone characterization program (Jones et al. 1998). The impacts for a given contaminant are proportional to the amount of contaminant in the soil column and thus to the initial amount of the contaminant lost from the tanks. As noted in the discussions of cesium-137 migration in the vadose zone in Section 3.2.2, the rate of movement of contaminants in the soil column may be impacted by other co-contaminants. Therefore, the goal was to develop reasonably complete inventories for tank wastes lost to the vadose zone.

The approach for developing inventory estimates has focused on combining leak volume estimates with waste composition estimates (Jones et al. 2000a). The development of tank leak inventory estimates was made possible by a number of recent SST waste investigations. Efforts to develop current tank waste inventory estimates led to both a compilation of tank waste transfer records (Agnew et al. 1997) and a model providing current inventory estimates in all Hanford Site SSTs and double-shell tanks (Agnew 1997). These models have been used to predict inventories of tank wastes at times of suspected leaks and proposes an approach for estimating leak volumes for high-heat tanks (Agnew and Corbin 1998).

The long-term gross gamma logging (Myers 1999; Myers et al. 1999) and more recent spectral gamma logging data (DOE-GJPO 1996, 1998, 2000a, 2000b) have provided by far the best overall understanding of the nature and extent of gamma-emitting radionuclide contamination in the SST farms. Analysis of the gamma logging data and other soil analysis data provided quantitative estimates of cesium-137 contamination in the SX tank farm vadose zone (Goodman 2000; Sullivan et al. 2001). The development of work plan addenda for WMA S-SX was greatly enhanced by a number of expert panel reports (DOE-RL 1997b; DOE-RL 1999d) and supporting documents (Johnson et al. 1999). As described in the following sections, information gleaned from these sources provided a basis for developing preliminary inventory estimates for most known tank leaks in the 12 SST farms (Jones et al. 2000a; Jones et al. 2000b; Corbin et al. 2001; Jones et al. 2001). Although the discussion focuses on the WMA S-SX field investigation results, this broader perspective provides a better basis for developing conceptual models for tank leak events. As constrained by the available modeling programs, the initial tank-leak inventory estimates were provided on a total elemental and curie basis (with the exception of a few anions such as chloride and nitrate).

A more complete understanding of the long-term impacts of tank leaks on the vadose zone environment requires specific knowledge of chemical species present in the leaked tank waste. Two speciation-modeling analyses of the materials lost from tanks in WMA S-SX have been completed (Appendix D, Section D.7.3; Jones et al. 2000a). The speciation modeling results provide (1) a better understanding of the bounding conditions for REDOX boiling-waste system operations and (2) guidance for geochemical modeling required to better understand radionuclide and chemical migration in the vadose zone.

Section 3.3.1.1 describes the present understanding of tank waste composition at the time of a tank leak. Building on the gamma logging data (Section 3.3.1.2) and on soil data analyses (Section 3.3.4), the amount and distribution of cesium-137 leaked into the soil is determined (Section 3.3.1.3). Knowing the tank waste composition and the amount of tank waste leaked, estimates of all the major contaminants are derived and presented (Section 3.3.1.4). Speciation is described in Section 3.3.2. The results are summarized in Section 3.3.3.

**3.3.1.1 Waste Composition Estimates.** There has long been an interest in using flowsheet data from various Hanford Site chemical processes coupled with waste transfer records to develop tank waste inventory estimates (Jungfleisch 1984). Researchers at Los Alamos National Laboratory, supported by many individuals associated with the Hanford tank waste characterization program (Agnew 1997) brought the approach developed by Jungfleisch to fruition. The Los Alamos National Laboratory task involved two major activities.

- The extensive waste transfer records were centralized into a single document, *Waste Status and Transfer Record Summary (WSTRS Rev. 4)* (Agnew et al. 1997).
- Flowsheet information was coupled with an understanding of the chemistry of each waste stream to develop estimates of solid and liquid compositions for each waste stream.

The composition of each major waste stream was coupled with the waste volumes for each of the transfers into and out of each Hanford Site waste tank. Using simple waste mixing rules for the sum of waste transfers through individual tanks, current waste compositions and total inventories were calculated for each Hanford Site waste tank. This approach is termed the Hanford defined waste (HDW) model (Agnew 1997). The HDW model develops two waste composition estimates:

- Sludge composition, estimated by the tank layering model
- Supernate composition, estimated by the supernatant mixing model.

The waste composition estimates from the supernatant mixing model module are a combination of liquid and salt cake (Agnew 1997).

Although the driver for the HDW model was to develop 'current' tank inventory estimates, the HDW model provides the capability for developing inventory estimates at any point in time in each tank. As noted above, the HDW model results for selected SX tank farm high-heat tanks are used in Agnew and Corbin (1998) to develop the 'Hanford leak model,' which projects preliminary leak volume estimates for tanks SX-108, SX-109, SX-111, and SX-112. The Agnew and Corbin (1998) approach for developing tank composition estimates at specific points in time was used in estimating tank leak events in WMA S-SX (Jones et al. 2000a) and in other WMAs

(Jones et al. 2000b; Corbin et al. 2001; Jones et al. 2001). Table 3.2 contains the waste composition estimates for selected contaminants for the 10 tanks in the S and SX tank farms thought to have leaked (see major discussion in Jones et al. 2000a). Complete waste composition estimates for those 10 tanks are listed in Appendix C.

Complete waste compositions can be coupled with leak volumes to develop leak inventory estimates. However, published leak volume estimates (Hanlon 2001) are highly uncertain for a number of the SX tank farm leaks (Jones et al. 2000a). Thus, it was necessary to use other data sources to develop leak volume estimates. This process is discussed in the following sections.

**3.3.1.2 Gamma Logging Data.** Since the early 1960s gamma logging data have been used as a secondary tank leak monitoring system (Isaacson and Gasper 1981). In practice, strategically placed shallow boreholes (24 to 46 m [80 to 150 ft] bgs), called 'drywells,' were routinely monitored for changes in total gamma activity. Hence, the activity is known as gross gamma logging. Drywells were located approximately 3.1 m (10 ft) from the tanks and generally 4 to 8 drywells surrounded each 'active' tank (that is, leak monitoring concentrated on tanks currently being used to store liquid wastes). Tanks known to have leaked (e.g., tank SX-113) where all pumpable liquids had been removed, were not given high priority to be monitored for additional leakage. For additional leak monitoring capability, 10 of the 15 tanks in the SX tank farm had laterals (i.e., horizontal pipes radiating from a central caisson) installed approximately 3.1 m (10 ft) below the base of the tank. Except for tank SX-113, each tank had three laterals radiating from a nearby caisson. As the prototype for laterals as the tank leak monitoring system, tank SX-113 had five laterals installed under it.

During the routine gross gamma logging program, changes in gamma activity in a borehole would suggest potential leakage from a nearby waste storage tank or waste transfer line. Although the gross gamma logging data were stored electronically from 1974 to the end of the logging program in 1994, data comparisons within any specific drywell were restricted to short time intervals. Gross gamma logging data were treated as being of value only for 'real-time' leak monitoring of active SSTs.

As part of the WMA S-SX vadose zone characterization, historic gross gamma logging data are assessed in Myers (1999) and Myers et al. (1999). Although the gamma logging instrumentation underwent major modifications (particularly the probes) over the 20 years of data collection, the data exhibited surprising reproducibility as shown in stack plots (Myers et al. 1999). The data analysis also provided useful information about the potential movement of gamma emitting radionuclides over the 20-year period.

The validity of gross gamma logging methodology as a tank leak detection system was critically evaluated in *A Scientific Basis for Establishing Dry-Well Monitoring Frequencies* (Isaacson and Gasper 1981). One of the conclusions from the evaluation was that the gross gamma data provided far more insight into the migration of radionuclides in the soil than it did about potential leaks in active tanks. With the passage of time and thus decay of the short-lived mobile gamma emitting radionuclides (e.g., ruthenium-106) the 1981 conclusions are more valid than ever.

In 1994 a baseline spectral gamma-logging program was initiated to assess the nature and extent of gamma emitting radionuclides in the tank farms vadose zone (DOE-GJPO 1995a, 1995b, 1995c; DOE-RL 1996) by using the unique radiation emitted to identify and quantify the radionuclides. Essentially all existing drywells within each tank farm were logged with a system designed to provide specific isotopic composition of gamma-emitting radionuclides. Baseline spectral gamma logging results were published for each tank farm. The gamma-logging probe selected for the initial logging runs became saturated at approximately 1,000 pCi/g of cesium-137. Thus, in the most highly contaminated zones, quantitative values were not determined. At a later date the highly contaminated zones were re-logged using a less sensitive probe and updated results were published in supplemental tank farm reports. Ninety-eight drywells were logged in the SX tank farm and results were published in *Vadose Zone Characterization Project at the Hanford Tank Farms, SX Tank Farm Report* (DOE-GJPO 1996) and its supplement, *Addendum to the SX Tank Farm Report* (DOE-GJPO 2000b). Seventy-two drywells were logged in the S tank farm; results are published in DOE-GJPO (1998) and its supplement, *Addendum to the S Tank Farm Report* (DOE-GJPO 2000a).

The baseline spectral gamma-logging program has made major contributions to the current tank farm vadose zone characterization efforts. The main radionuclide found was cesium-137. Only very small amounts (i.e., a few pCi/g) of cobalt-60 and/or europium-154 were found in the S and SX tank farms.

**3.3.1.3 Kriging Analysis.** The SX tank farm gamma logging and soil analysis data for cesium-137 represent 'point measurements' along a vertical, horizontal, or slant direction. The goal of kriging analysis of the cesium-137 data was to establish mathematically defensible inventory estimates associated with the gamma contamination around each tank in the SX farm. Two separate data analyses were conducted. The first, conducted by Professor Dan Goodman, Montana State University (MSU) beginning in 1998, combined gross gamma and spectral gamma logging data with soil analysis data from borehole 41-09-39 and historical soils data (Raymond and Shdo 1966; Goodman 2000). The MSU results are referred to as 'MSU kriging results' in this document. The second statistical analysis of the SX tank farm cesium-137 data, conducted by HydroGeologic, Inc. (HGL) (Sullivan et al. 2001), began with the same data set as used by MSU but also included newly acquired soils analysis data from the SX-108 slant borehole (Serne 2001d) and the updated spectral gamma logging results (DOE-GJPO 2000b).

The MSU statistical analysis focused on two objectives.

- The gross gamma logging data were evaluated to establish calibration curves so as to use the gross gamma data to develop 'data patches' for the regions of the spectral gamma data set lost because of detector saturation in the initial spectral gamma logging.
- The resulting enhanced gamma logging-based cesium-137 data set was coupled with soils analysis data to develop cesium-137 inventory estimates for the regions around each tank in the SX farm.

The projected cesium-137 inventory estimate for each tank in the SX tank farm is listed in Table 3.3. Inventory estimates are reported at both the 50 and 95 percentiles.

**Table 3.3. SX Tank Farm Cesium-137 Inventory  
Estimates from Kriging Analyses\***

Tank	MSU 50% (pCi)	MSU 95% (pCi)	HGL 50% (pCi)
SX-101	9.1E+09	2.1E+10	2.3E+10
SX-102	0.0E+00	0.0E+00	1.5E+10
SX-103	0.0E+00	0.0E+00	2.1E+10
SX-104	2.7E+08	1.6E+09	7.7E+09
SX-105	5.5E+09	1.3E+10	1.3E+10
SX-106	0.0E+00	0.0E+00	5.9E+09
SX-107	8.0E+15	1.5E+16	4.2E+16
SX-108	1.4E+16	3.6E+16	3.9E+16
SX-109	7.2E+14	2.3E+15	1.6E+15
SX-110	2.0E+12	1.3E+13	7.5E+12
SX-111	2.3E+11	1.1E+12	2.3E+11
SX-112	1.8E+13	9.5E+13	2.9E+13
SX-113	0.0E+00	0.0E+00	6.4E+07
SX-114	0.0E+00	0.0E+00	1.9E+08
SX-115	N/R	N/R	1.1E+14

\*Includes surface spills.

HGL = HydroGeologic, Inc.

MSU = Montana State University.

N/R = not reported.

The second kriging analysis was focused on understanding the impact of the addition of the cesium-137 soils analysis data from the SX-108 slant borehole investigation on the overall cesium-137 inventory estimate. Also included in the second kriging analysis were the updated spectral gamma logging data for cesium-137 from highly contaminated zones (DOE-GJPO 2000b). Thus, the data patches from historical gross gamma data developed by MSU for that kriging analysis were not required for the HGL kriging analysis.

The first step in any kriging process is the development of a variogram model. Vertical and horizontal correlation lengths are determined during the variogram analysis. Significantly different correlation lengths were reported between the two kriging analyses.

- MSU variogram analysis led to a horizontal correlation length of 8.2 m (27 ft) and a vertical correlation length of 3 m (10 ft)
- HGL variogram analysis led to horizontal and vertical correlation lengths of 15 m (49 ft) and 20 m (66 ft), respectively.

The practical result of longer correlation lengths is the projection of somewhat larger plume volumes with the existing data set.

There are a number of reasons for the large correlation lengths reported in the HGL kriging analysis (Sullivan et al. 2001). The most obvious reason is the addition of the cesium-137 concentrations along the SX-108 slant borehole, giving much better definition of the vertical contamination directly below tank SX-108. However, there were also differences in approach. The MSU variogram analysis treated all of the available data within the SX tank farm while the HGL variogram analysis focused on the area around tank SX-108. The decision to estimate correlation lengths using data only from around tank SX-108 focused the analysis in the area where the maximum amount of data was available. The correlation lengths derived from the analysis of data around tank SX-108 were then used in the kriging analysis for all of the SX tank farm data. The intent was to apply the knowledge gained from detailed field investigations around tank SX-108 to the contamination found around and under other SX farm tanks. This was justified because very similar waste types leaked from all failed SX farm tanks and the geology was assumed to be reasonably similar across the SX tank farm. The HGL kriging analysis also reports results of sensitivity studies associated with data processing decisions.

Both kriging analyses used data compression techniques to reduce the size of the data set prior to computations because the data set was too large to be processed with available computer systems. Both groups separated the tank farm area into a 1 m by 1 m (3.3 ft by 3.3 ft) grid size. MSU used a 1 m (3.3 ft) depth to form 1 m<sup>3</sup> (35 ft<sup>3</sup>) sections. The geometric mean of all cesium-137 concentration values within the 1 m<sup>3</sup> (35 ft<sup>3</sup>) was assigned to the point at the center of the cube. The variogram analysis and kriging were completed with this reduced data set. The HGL data process approach was quite similar except the grid size was 1 m by 1 m by 0.5 m (3.3 ft by 3.3 ft by 1.6 ft). Intuitively, reducing the grid size will better reflect the original data.

The cesium-137 inventory estimates developed in the HGL kriging analysis are also listed by tank in Table 3.3. An example of the graphical representation of cesium-137 activity generated in the HGL kriging analysis is shown in Figure 3.7. Graphical representations of cesium-137 activity at other concentrations are found in Appendix C.

The cesium-137 inventory estimates reported by HGL are the mean values. The cesium-137 inventory estimates reported by HGL and listed in Table 3.3 are most directly comparable to the 50 percentile data reported by MSU and listed in Table 3.3.

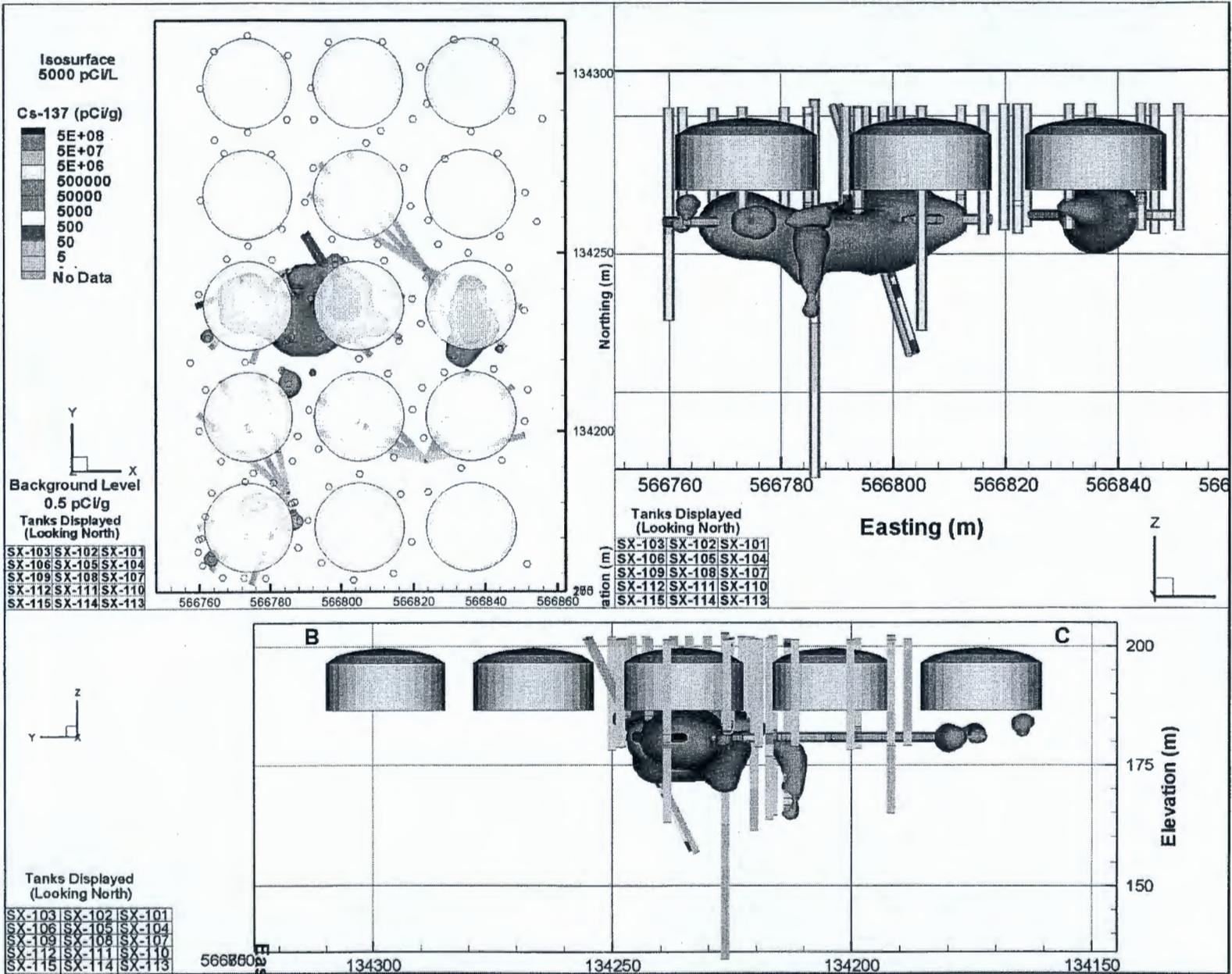


Figure 3.7. Plan and Cross-Section View of Cesium-137 Contaminated Soil Above  $5 \times 10^3$  pCi/g

The geometric mean is commonly used as an approach for compressing large environmental data sets, where values span multiple orders of magnitude (e.g., the spectral gamma logging data in the SX tank farm). However, other approaches could be taken. For example, a more conservative approach would be to assign the data value of the volume space as the maximum value reported within that grid volume. As a sensitivity study, HGL completed a kriging analysis using 'maximum' values rather than geometric means. As expected, the cesium-137 inventory estimates were somewhat higher (by a factor of about two) using the 'maximum' values. Sensitivity study results are included in Appendix C and in the HGL kriging analysis report (Sullivan et al. 2001).

A comparison between MSU and HGL cesium-137 inventory estimates near and under SX farm tanks are shown in Table 3.3. The only major difference in cesium-137 inventory estimates between the two studies involves tank SX-107. Although the HGL kriging analysis results suggest the cesium-137 inventory lost from tank SX-107 to be slightly larger than the total quantity of cesium-137 lost from tank SX-108, the volume of contaminated soil associated with tank SX-107 is less than half of the volume of contaminated soil associated with tank SX-108. The HGL kriging analysis results for tank SX-107 are driven by gamma logging data from the three laterals. One lateral is projected to have cesium-137 activity at levels close to  $8.0 \times 10^8$  pCi/g. With the larger correlation lengths calculated by HGL for tank SX-108 and applied to other tanks in the SX tank farm, this particularly highly radioactive lateral strongly influences overall cesium-137 inventory estimates for tank SX-107. It appears the tank SX-107 cesium-137 inventory estimate is likely an artifact of the data handling methodology. Resolution of this issue will likely require re-logging of the laterals under tank SX-107 with a calibrated spectral gamma tool.

**3.3.1.4 Inventory Estimates for WMA S-SX Tank Leaks.** Leak volume estimates and selected inventory estimates for WMA S-SX tank leaks are listed in Table 3.4. The complete data set is available in Appendix C and Jones et al. (2000a). Leak inventory estimates for tanks SX-107, SX-108, and SX-109 were based on cesium-137 inventories developed by the MSU kriging analysis (Goodman 2000). Leak volumes for these three tanks were estimated from cesium-137 inventory estimates (Goodman 2000) coupled with waste composition estimates. Inventory estimates for tanks S-104, SX-113, and SX-115 were based on documented leak volumes (Jones et al. 2000a; Hanlon 2001). For these three cases, leak volumes were combined with tank waste inventory estimates (see Appendix C, Section C.3.0) to develop inventory estimates for each tank leak.

This discussion will focus on potential modifications to the published WMA S-SX inventory estimates based on the updated HGL kriging results.

The inventory estimates shown in Table 3.4 for tanks SX-107, SX-108, and SX-109 were developed using 95 percentile cesium-137 data from MSU (Goodman 2000). That is, these inventory estimates reported in Jones et al. (2000a) were biased high by using the 95 percentile data rather than the mean or 50 percentile values. The decision to use the higher values was driven by an assumption that the cesium-137 plume estimates reported in Goodman (2000) failed to reflect realistic estimates of the cesium-137 inventories directly below the tanks. (This was one of the conclusions discussed in the MSU report [Goodman 2000] and was one of the technical justifications for drilling the SX-108 slant borehole.)

**Table 3.4. Estimated Inventory Lost to Vadose Zone in the S and SX Tank Farms**

	Estimated Tank S-104 Inventory Loss	Estimated Tank SX-107 Inventory Loss	Estimated Tank SX-108 Inventory Loss	Estimated Tank SX-109 Inventory Loss	Estimated Tank SX-113 Inventory Loss	Estimated Tank SX-115 Inventory Loss
<b>Leak Volume</b>	24,000 gal <sup>a</sup>	6,350 gal <sup>b</sup>	15,200 gal <sup>b</sup>	989 gal <sup>b</sup>	15,000 gal <sup>a</sup>	50,000 gal <sup>a</sup>
<b>Chemicals</b>	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
Sodium	1.82E+04	9.90E+03	2.37E+04	1.54E+03	1.05E+04	1.57E+04
Aluminum	3.83E+03	2.00E+03	4.78E+03	3.11E+02	1.95E+03	4.24E+03
Chromium	7.81E+02	4.71E+02	1.13E+03	7.33E+01	5.08E+02	5.03E+02
Nitrate	1.70E+04	7.40E+03	1.77E+04	1.15E+03	9.96E+03	3.87E+03
Nitrite	6.87E+03	4.49E+03	1.07E+04	6.99E+02	3.50E+03	9.23E+03
<b>Radionuclides</b>	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)	(Ci)
Technetium-99	3.87E+00	5.03E+00	1.21E+01	7.84E-01	2.50E+00	5.52E+00
Cesium-137	1.14E+04	1.71E+04	4.10E+04	2.67E+03	7.34E+03	1.88E+04

<sup>a</sup>Leak volumes from Hanlon (2001).

<sup>b</sup>Leak volumes estimated from MSU kriging analysis of gamma logging data (see Jones et al. 2000a).

Inventory and leak volume estimates developed in Jones et al. (2000a) are listed in Table 3.4 and Appendix C, Section C.3.0. These estimates remain as reasonable estimates for use in leak impact assessment studies (Appendix E, Attachment E1). The HGL kriging analysis was more robust than the MSU efforts because only experimentally determined measurements were used by HGL, and correlation lengths determined by HGL were based on a single tank (i.e., tank SX-108). This was done because extensive data are available for tank SX-108; results based on tank SX-108 were then applied to other SX farm tanks.

If the HGL kriging results had been used in developing the inventory estimates, the values for tanks SX-108 and SX-109 listed in Table 3.4 would have changed very little. However, the tank SX-107 inventory estimates would have been slightly higher than those reported for tank SX-108 in Table 3.4. Leak inventory estimates for tanks S-104, SX-113, and SX-115 were based on historical leak volumes. Leak volumes from tanks SX-113 and SX-115 are well documented (Hanson et al. 1962; Raymond and Shdo 1966) whereas the leak volume from tank S-104 is significantly more uncertain. The 24,000 gal (91,000 L) leak volume currently reported in *Waste Tank Summary Report for Month Ending March 31, 2001* (Hanlon 2001) for tank S-104 is based on long-term liquid level decreases (Agnew et al. 1997). However, the waste footprint (see Appendix B, Section B.6.0) projected from field investigations using cone penetrometer techniques and spectral gamma logging data fail to document the inventory estimates shown in Table 3.4 for tank S-104. Thus, the tank S-104 inventory estimates listed in Table 3.4 are conservative.

### 3.3.2 Speciation Analysis

Significant quantities of high-level waste (HLW) were lost to the soil column from large underground tanks in WMA S-SX during long-term storage of the wastes produced in the REDOX Plant. An understanding of the mechanisms of soil and waste reactions controlling the movement of tank waste through the vadose zone requires knowledge of waste components on a molecular level. However, this level of tank waste chemistry is generally not available because that level of understanding was not required for the original plant operations or for long-term storage and waste management. *REDOX Technical Manual* (GE 1951) and the updated flow sheets in *Standard Inventories of Chemicals and Radionuclides in Hanford Site Tank Wastes* (Kupfer et al. 1998) provide clear guidance as to the conditions required for successful separations process operations but only limited understanding of the underlying fundamental chemistry. Thus, the most practical approach for developing an understanding of the chemical species present in leaked tank waste comes from chemical equilibria-based computer models that develop speciation of bulk waste components. Chemical thermodynamic-based models of aqueous systems can predict reaction products if the controlling thermodynamic parameters are sufficiently well understood. However, the tank waste mixtures are extremely complex and many of the required thermodynamic parameters are only poorly understood. Because any thermodynamic-based modeling exercise involving a tank waste matrix will require many approximations and assumptions, speciation modeling results must be treated with considerable caution.

The preliminary scoping studies for REDOX waste speciation (Jones et al. 2000a) were conducted using the Environmental Simulation Program, a thermodynamic-based chemical process simulator that has been widely applied at the Hanford Site (MacLean and Eager 1998). As discussed in Section 3.3.1.1, the compositions of the wastes in SSTs at the time of suspected leaks were developed using the HDW model (Agnew 1997). The tank waste supernate compositions were then used as input to the Environmental Simulation Program model with the goal of developing a better understanding of chemical speciation of the wastes at the time of suspected leaks (Jones et al. 2000a). A separate S&T activity focusing on contaminant migration in the subsurface conducted speciation analysis of the leaked fluids from tanks SX-108 and SX-115 (Appendix D, Section D.7.3). The results reported in Appendix D, Section D.7.3 represent a far more detailed solution thermodynamic investigation than the results reported in Jones et al. (2000a). Appendix D, Section D.7.3 uses the Pitzer-based formulation for calculation activity coefficients, which is more consistent with contemporary geochemical modeling studies.

The historical records (Harmon 1949; GE 1951; Barney 1976) clearly show that it was well known that the solution chemistry of REDOX HLW was dominated by the aluminum ion solubility and the aluminum solubility was controlled by the free hydroxide ion concentration. Thus, much of the speciation modeling efforts focused on developing a better understanding of aluminum ion chemistry in the REDOX waste matrix. Such an understanding is potentially important in geochemical processes impacting tank waste movement in the subsurface.

The initial Environmental Simulation Program speciation modeling of REDOX HLW, reported in Jones et al. (2000a), assumed a 0.1 M free hydroxide concentration resulting in essentially all of the aluminum residing in the solid phase as aluminum hydroxide. However, in other

calculations (see Appendix C) the aluminum was shown to be primarily in the solution phase, as aluminate anion, at the likely free hydroxide concentrations in REDOX HLW. Much of the information in Appendix C, updating the preliminary speciation analysis reported in Jones et al. (2000a), was developed in response to questions raised in the Appendix D, Section D.7.3 speciation results. The initial step in any speciation modeling exercise is the development of a charge balance for the system. Jones et al. (2000a) fixes the hydroxide at 0.1 M and allows the sodium ion to vary until the overall charge balance is reached, leading to sodium ion concentration near 12 M. Appendix D, Section D.7.3 maintains the sodium ion concentration developed by the HDW model and allows hydroxide to be varied until a charge balance is reached. At equilibrium in tank SX-108 at 100 °C (212 °F), Appendix D, Section D.7.3 predicts the hydroxide to be 5.1 M and the pH to be 14.1 with essentially all of the aluminum to be in solution as aluminate anion. The Appendix D, Section D.7.3 speciation results are consistent with the conditions one would predict from process flow sheet data (GE 1951). Thus, the Appendix D, Section D.7.3 results are the preferred data set for geochemical modeling studies.

Corrections to errors in technetium-99 speciation estimates in Jones et al. (2000a) are also discussed briefly. The preliminary speciation modeling results suggesting that major fractions of the technetium-99 could reside in the solid phase as potassium pertechnetate ( $\text{KTcO}_4$ ) in highly concentrated REDOX HLW (Jones et al. 2000a) are of considerable interest. Initial modeling runs indicated that the majority of technetium-99 in wastes in tank SX-108 was incorporated into the solid phase as potassium pertechnetate but in the more dilute tank SX-115 wastes the technetium-99 remained in the solution phase (Jones et al. 2000a). A detailed review of the supporting information reported along with the speciation modeling results indicated that the potassium pertechnetate solubility was being driven by an unrealistically large activity coefficient term. Resolution of this issue was referred back to OLI Systems,<sup>1</sup> the software vendor, for resolution. The vendor reported that a programming error was found in the code. Basically, the silicate ion activity was being summed with pertechnetate activity leading to errors in solubility estimates. After correcting this programming error, the model predicted that all technetium-99 remained in the solution phase in the tank waste composition in each SX farm tank. Although, to date, no technetium-99 analysis data have been found for REDOX HLW, the suggestion that technetium-99 tends to remain in the solution phase is consistent with experimental data for plutonium-uranium extraction HLW (Godfrey 1971).

### 3.3.3 Summary of Tank Leak Inventory Investigations

The Jones et al. (2000a) preliminary tank leak volume estimates, waste composition estimates, and inventory estimates of tank waste lost to the soil column in WMA S-SX remain as a reasonable data set for tank leak impact investigations. These data are summarized in Table 3.4. Speciation data reported in Appendix D, Section D.7.3 is the preferred source for geochemical modeling studies. Uncertainties remain about inventory estimates for leaks from tanks S-104 and SX-107. Because of these uncertainties, no modifications were made to the leak inventory

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<sup>1</sup> OLI Systems, Inc., Morris Plains, New Jersey.

estimates published in Jones et al. (2000a). Any resolution of these uncertainties will require additional field characterization data.

### 3.3.4 Correlation Between Projected Inventory Estimates and Field Investigation Data

Soil sample analyses from the three boreholes drilled in the SX tank farm (41-09-39, SX-108 slant, and 299-W23-19) near tank leaks provide data that qualitatively validate the reliability of these inventory estimates. The analyses revealed the presence of several constituents (radionuclide and chemical) that either were not derived from natural sources or were naturally occurring but at concentration levels too large to be derived solely from natural sources. These findings clearly demonstrate the existence of a nearby non-natural source, with tank leak fluids being the leading candidate.

In the soils from the two boreholes (borehole 41-09-39 and the SX-108 slant borehole) considered to be contaminated primarily by the tank SX-108 leak, elevated concentrations of cesium-137, technetium-99, nitrate, nitrite, chloride, sulfate, sodium, and chromium are found that originated in the tank SX-108 leak fluid (Appendix B, Sections B.2.0 and B.4.0). These elements are among the more concentrated constituents projected by inventory estimates (Table 3.2 and Appendix C, Tables C.1 and C.2). Higher levels of chloride and sulfate also may be attributed to the leak. Concentration ranges of these constituents in borehole soils are provided in Table 3.5. Similarly, for borehole 299-W23-19, soils are assumed to be contaminated by the tank SX-115 leak and high concentrations of technetium-99, nitrate, nitrite, sodium, chromium, chloride and sulfate are found (Table 3.5).

**Table 3.5. Summary of Tank Leak Constituent Concentrations and Technetium-99 to Nitrate Ratios in the SX Tank Farm Characterization Boreholes**

Borehole		Maximum Concentration Range in the Elevated Concentration Zones		
		41-09-39	SX-108 Slant	299-W23-19
Constituents	Technetium-99 (pCi/L)	3.9E+05 to 1.2E+07	1.65E+07 to 2.37E+08	9.50E+04 to 3.3E+06
	Cesium-137 (pCi/g)	1.25E+05 to 1.76E+07	5.55E+05 to 9.57E+07	Negligible
	Sodium (mg/L)	1.02E+04 to 1.53E+04	6.53E+04 to 3.91E+05	4.78E+02 to 3.08E+03
	Chromium (mg/L)	1.75E+02 to 7.46E+02	5.02E+03 to 2.18E+04	3.22E+00 to 1.22E+02
	Nitrate (mg/L)	1.01E+05 to 4.16E+05	1.98E+05 to 9.94E+05	6.03E+03 to 2.60E+04
	Chloride (mg/L)	3.58E+02 to 4.21E+03	1.38E+03 to 6.71E+03	1.06E+02 to 2.15E+02
	Sulfate (mg/L)	5.79E+02 to 4.58E+03	1.93E+03 to 2.41E+04	1.72E+02 to 9.35E+02
Tc-99/ Nitrate (pCi/mg)		2.61E+01 to 4.44E+02	3.46E+00 to 4.77E+02	4.09E+01 to 3.15E+02
Tc-99/Nitrate (pCi/mg)*		1.72E+02	2.44E+02	1.13E+02

\*The technetium-99/ nitrate ratios are the average of individual ratios by depth in the elevated concentration zones.

A comparison of relative concentrations of these constituents with estimates of relative concentrations in the tank fluid provides another indicator of tank leak fluids as the contaminant

source. This approach is limited because most constituents are distributed differently in the vadose zone as different chemical reactions exist for the constituents, resulting in variable retardation and migration of each constituent. Thus, the comparison is usually difficult to make. The most straightforward comparison is to consider the technetium-99/nitrate ratios in soil versus the technetium-99/nitrate plus nitrite ratios in the inventory estimates. Data and chemical speciation knowledge indicate that technetium-99 and nitrate are essentially nonreactive with soils and migrate together. The soil data indicate that nitrite reacts by oxidizing to nitrate, but migration rates are not affected by this process. Therefore, if the technetium-99/nitrate plus nitrite source is the tank SX-108 fluid and no other sources provide contaminants at the borehole location, the ratios should be consistent. Similarly, if the technetium-99/nitrate plus nitrite source for borehole 299-W23-19 contamination is the tank SX-115 fluid, the ratios between estimated tank fluid inventory values and measured soil values should be comparable.

The zones of elevated technetium-99 and nitrate concentrations in each borehole agree very closely with depth. The average of individual soil sample technetium-99/nitrate ratios by depth in the elevated concentration zones are listed in Table 3.5 for all three boreholes. The technetium-99/nitrate ratios calculated from technetium-99 and the sum of nitrate plus nitrite inventory estimates in Table 3.4 are  $4.3 \times 10^2$  pCi/mg for the tank SX-108 leak fluid and  $4.2 \times 10^2$  pCi/mg for the tank SX-115 leak fluid. These ratios are within factors of two to four of the measured ratios. This is a very close correlation given the natural heterogeneities of fluid migration in the vadose zone. This correlation strongly supports both the causal relationship between tank leaks and soil contamination and increases confidence in the inventory estimate based on historical record.

Other soil and soil-water characteristics that are significant relative to the projected leak inventories are the occurrences of elevated pH in soil column soils at the top of the contaminated zones and the absence of elevated aluminum and strontium-90 concentrations in soil water extracts. In all three boreholes, elevated pH values (greater than 8.5) occur at shallow depths in the Hanford formation subunit H1 and then decrease with depth to values approaching those normal to undisturbed vadose zone soil water (approximately 7.5 to 8). This pattern is consistent with an initial interaction between high pH tank leak solutions (estimated at greater than 12, Appendix D, Section D.7.3) at a depth when tank solution first comes into contact with the borehole soil water followed by longer interaction as tank solutions drain from the initial location and migrate vertically with pH-buffering reactions continuing to lower tank solution pH. The lack of aluminum in these soil samples is consistent with the speciation work (see Section 3.3.2 and Appendix D, Section D.7.3) suggesting that high dissolved aluminum concentrations require very high solution pH. If so, only a small decrease in pH such as would be expected shortly after tank fluid contact with the vadose zone soils would cause immediate formation of aluminum-bearing precipitates very near the leak location. The analyzed soil samples are presumably too far from the source to contain precipitated aluminum.

An unequivocal explanation for the lack of strontium-90 in soil samples cannot be provided. Either strontium-90 was not present in solution as predicted or it sorbed rapidly and fell out of solution near the leak location. If so, as with aluminum, the soil samples would be too far from the source to contain sorbed strontium-90.

### 3.3.5 Integration of Inventory Information for Risk-Producing Contaminants of Concern

In the previous section, a summary of data and inventory estimates is provided for the primary constituents determined to exist in tank leak fluids. Of these, technetium-99 and nitrate are highly mobile in the hydrogeologic environment and may contaminate groundwater at sufficient concentration levels to be of concern. Additional mobile constituents are estimated to be present in tank fluids at smaller concentrations that also must be considered as potential contributors to future environmental contamination (see the modeling and risk analysis discussion in Section 4.0). Given the tank leak inventory estimates, additional mobile radionuclide constituents include carbon-14, selenium-79, iodine-129, and the long-lived uranium isotopes (principally uranium-238 and uranium-234). Hazardous mobile constituents include chromium, fluoride, mercury, nitrate, nitrite, total uranium, and EDTA. Because estimates of human health risk levels provided by each of these constituents are generally proportional to its abundance in the vadose zone, vadose zone inventory estimates must be evaluated thoroughly, using all available information. The combination of both historical estimating approaches and data for contaminated soils provides a complementary and useful basis for completing this evaluation.

All of the identified constituents are listed in the tank leak inventory estimates (Appendix C). Technetium-99, nitrate, nitrite, and chromium are primary constituents and, except for nitrite, have all been detected in the SX tank farm exploratory boreholes at high enough concentrations over large enough depth intervals to clearly indicate a tank leak source. Nitrite is currently at relatively low levels in the vadose zone because it has largely oxidized to nitrate since initial discharge. If these constituents are largely mobile in soils, then their relative concentrations present at the time of leakage should be preserved in the contaminated regions of the vadose zone. Comparison of water extract concentrations with tank inventory estimates of these constituents shows remarkable consistency in relative concentrations between the constituents. This observed consistency increases confidence that inventory estimates are reasonably close to real values. Consequently, these constituents have been incorporated into the risk analysis as legitimate potential contributors to future environmental contamination and risk.

A second set of constituents (carbon-14, selenium-79, mercury, fluoride, and EDTA) are estimated to be present in relatively small quantities in the leaked fluid. Carbon-14 is the more abundant radionuclide and is estimated to occur at concentrations about seven to eight times less than technetium-99. Selenium-79 is estimated to occur at concentrations about 40 times less than technetium-99. Mercury, fluoride, and EDTA are estimated to occur at concentrations more than four orders of magnitude less than nitrate. None of these chemical constituents has been detected in vadose zone soil analyses. Attempts were made to measure mercury and selenium-79, but detection levels were too high to allow a positive measurement. Fluoride was measured but soil concentration values were indistinguishable from natural background. Carbon-14 and EDTA were not measured. For the purposes of modeling and risk calculations, inventory estimates were used as the basis for quantifying vadose zone inventory.

The final two constituents, iodine-129 and uranium isotopes, were measured in a small fraction of samples. Iodine-129 is found only in the SX-108 slant borehole at depths between 24 and 40 m (80 and 130 ft) bgs (Appendix B, Section B.4.0 and Appendix D, Section D.6.1). These soil samples also contain high technetium-99 concentrations. In these soil samples, technetium-99 to iodine-129 activity ratios exceed 2,000. This compares to an estimated

technetium-99 to iodine-129 activity ratio of about 530 assumed for tank SX-108 supernate and supernate in the other assumed leaking tanks in WMA S-SX. Assuming that technetium-99 and iodine-129 are similarly distributed in the vadose zone because of their chemically similar behavior, this is a valid and reasonably close comparison. It is not surprising that the field ratios are lower given that estimates of iodine-129 content in tank fluids ignore the possibility that some portion of iodine-129 volatilizes during fuel processing and never reaches the tanks. For purposes of risk estimates, the estimated supernate iodine content provides a reasonable and conservative source term estimate.

Uranium measurements in vadose zone soils are complicated by the fact that naturally occurring uranium is ubiquitous in vadose zone soils and when measured concentrations are close to natural concentration levels, determination of additional sources is uncertain. In these studies, uranium was analyzed from extracts of water and acid contacted with borehole soils. The largest water extract concentrations (7 to 55  $\mu\text{g/L}$ ) occurred in the tank SX-115 borehole, 299-W23-19, between 22 and 38 m (73 and 126 ft) bgs. This range slightly exceeds water extract values typical for uncontaminated soils (e.g., about 1 to 10  $\mu\text{g/L}$  are measured in water extracts from 299-W22-48 and 299-W22-50, two RCRA boreholes east of the SX tank farm; sitewide background levels range from 0.5 to 13.9  $\mu\text{g/L}$  [DOE-RL 1997a]). Only two samples in the SX-108 slant borehole show elevated uranium water extract concentrations (140 and 210  $\mu\text{g/L}$ ). No samples from borehole 41-09-39 yield water extract uranium values above the natural range.

It is unclear from the water extract data whether the slight elevations in dissolved uranium from these soil samples represent contributions from tank leak sources. To get another perspective on this, it is instructive to compare the uranium to chromium concentration ratios in borehole 299-W23-19 versus the estimated inventory values for the leaked tank SX-115 borehole. This comparison is indicated by the coincidence of highest uranium and chromium water extract values over the same depth interval in the borehole. Although chromium shows slightly retarded migration in these soils it is still a very mobile constituent and could be a surrogate for uranium in the risk analysis. The average uranium to chromium water extract values by mass is about 0.0015. For the tank SX-115 fluid, the estimated uranium to chromium inventory ratio is about 7, a significant discrepancy of about 3 orders of magnitude.

Two explanations are feasible. First, the uranium inventory estimate may be excessively high. Historical records indicate that the uranium would have been in the sludge fraction in the high-hydroxide REDOX wastes (Anderson 1954). Alternately, uranium may be present at high values in the leaking tank fluid, but is not mobile in the soil environment such that the bulk of the uranium is fixed in the soil closer to the tank leak source. In either case, an assumption of a large and mobile uranium inventory as a vadose zone source term for risk calculations is not warranted. Given the proportionality between risk estimates and starting inventory, use of a small uranium inventory indicated by the measured uranium to chromium ratio will result in an insignificant risk estimate compared to the other constituents. In the risk analysis (Section 4.0), uranium has not been included as a risk-producing contributor because of the inventory/risk relationship coupled with uncertainty about the real presence of tank source uranium in the vadose zone.

### 3.4 CONCEPTUAL MODEL DESCRIPTION

An initial conceptualization of contaminant occurrences and characteristics in WMA S-SX was developed to support a work plan for additional characterization (Johnson et al. 1999).

The additional database (referred to in this section as new work or new data) that has been developed has provided support for and clarification of the initial conceptual models. The focus of the conceptual models has been those events and processes that have led to the current state of vadose zone and near-field unconfined aquifer contamination. In this section, a description of the conceptual models is provided in which the new data provided in this WMA S-SX FIR are correlated with the appropriate aspects of the conceptualization. As before, it is most convenient to organize conceptualization by primary areas of contamination. These include the areas around tanks SX-107, SX-108, SX-109; tank SX-115, and tank S-104.

#### 3.4.1 Conceptual Model for the Contamination Area Below Tanks SX-107, SX-108, and SX-109

Recent activities and data relevant to vadose zone contamination in this area include the following:

- Deepening of borehole 41-09-39 and soil samples characterization from 40 m (130 ft) bgs to groundwater; additional characterization of selected soil samples between 8 and 40 m (25 and 130 ft) bgs (see Appendix B, Section B.2.0)
- Drilling of a slant borehole beneath tank SX-108, soil sample characterization from 17 to 41 m (55 to 135 ft) bgs, and gamma/moisture logging with depth
- Additional calculations to estimate tank supernate inventory and speciation chemistry (Appendix C, Sections C.3.4 and C.3.5)
- Kriging estimates of cesium-137 inventory by MSU and HGL (Appendix C, Section C.3.3)
- Modeling of thermal effects on vadose zone moisture and temperature history and contaminant transport in the vadose zone from 1955 to present (Appendix D, Sections D.7.1, D.7.2 and D.7.4).

These data combined with existing data from historical and spectral gamma logging, historical records, limited early soil and tank supernate analyses (Raymond and Shdo 1966), groundwater sample analyses, and hydrogeologic data, provide the basis for the conceptual model.

The vadose zone contamination in this region is dominated by the waste leaked from tank SX-108 between 1962 and 1967. Smaller-volume leaks occurred from tanks SX-107 and SX-109. The vadose zone contamination is primarily derived from the tank SX-108 leak and is the focus of this conceptual model.

Additional studies have been completed to estimate vadose zone contamination derived from these tank leaks (Section 3.4 and Appendix C). Collection of new data has focused on statistical manipulation of cesium-137 spectral gamma data to estimate more directly the total inventory

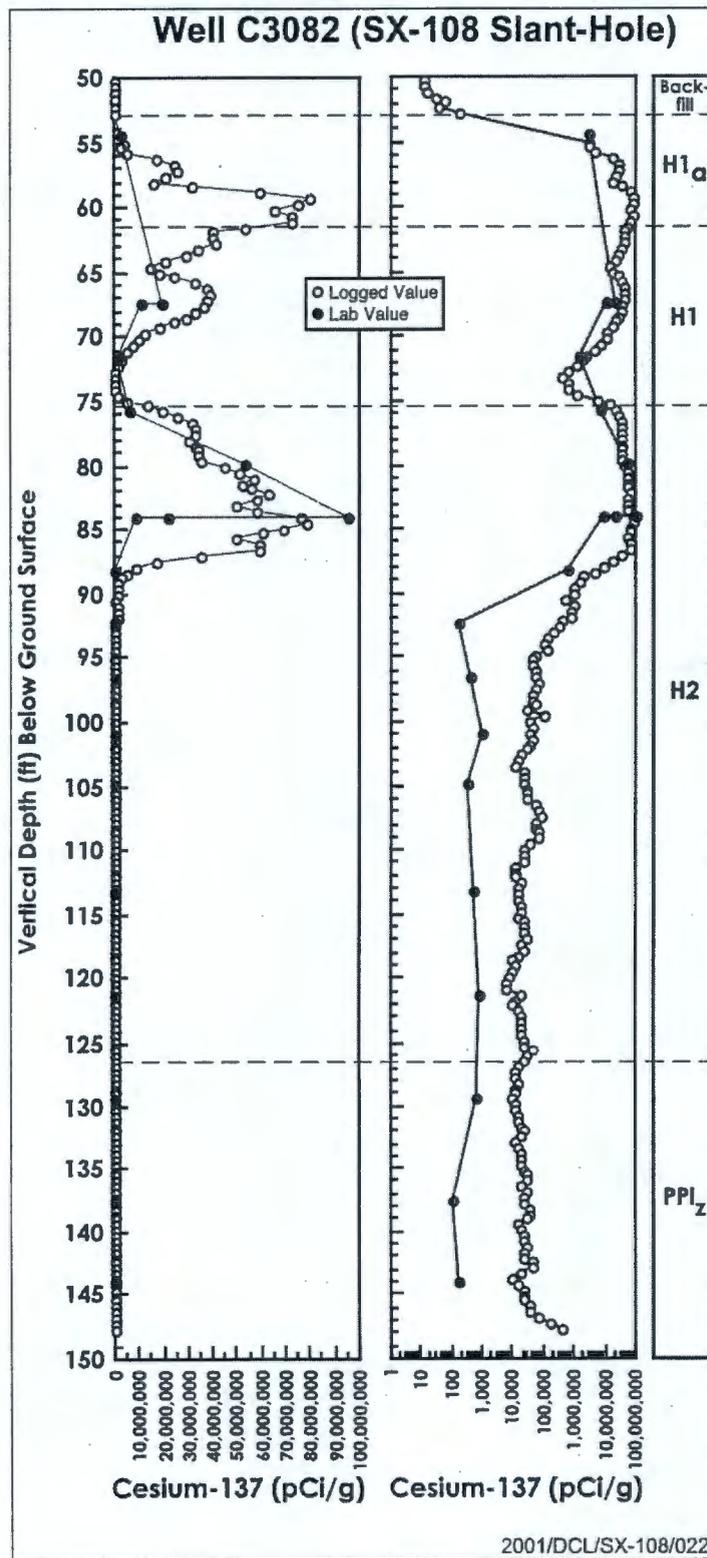
and inventory distribution in the vadose zone (i.e., kriging methods). Estimates of other contaminants of interest are then determined by ratio to cesium-137 inventory in the tank supernate using the HDW model as the basis for estimate. Conversely, earlier inventory estimates (Johnson et al. 1999) were derived using leak volume estimates as the starting point, combined with supernate concentration estimates. The tank SX-108 leak estimates ranging from 9,100 to 770,000 L (2,400 to 203,000 gal) were noted with a similar range in contaminant inventory estimates. The updated database provides a smaller range of vadose zone inventory estimates. These estimates are more consistent with volumes estimated by the historical record.

As in the previous conceptualization, the new database supports the idea of a two-phase process leading to the current state of contamination. The two phases are distinguished by different conditions and mechanisms controlling contaminant migration. In the first phase, one or more rapid releases of tank supernate into the vadose zone occurred, creating a hydraulic driver that superseded natural infiltration. Both vertical and horizontal migration occurred quickly. Elevated temperatures occurred in much of the local vadose zone created by radioactive constituents present inside the tanks and in the leaked tank waste. Temperatures exceeded boiling near tanks SX-107, SX-108, and SX-109, which dried soils and inhibited recharge.

The primary indicator of tank fluid migration in the initial phase is cesium-137 distribution and more indirectly pH measured in soil samples from boreholes 41-09-39 to the west of tank SX-108 and the SX-108 slant borehole. Normally, cesium-137 sorbs near the leak and drops out of solution very quickly; however, in this instance the supernate chemistry controlled the local chemical environment. Historical knowledge of tank supernate chemistry and laboratory sorption work (see Appendix D, Section D.3.0) indicates that the appropriate conditions to create high cesium-137 mobility did exist at the time of tank leak. The primary enabling conditions are a combination of very high sodium and cesium-137 concentrations in tank fluid. Under these conditions, sodium competes successfully with cesium-137 for sorption sites, forcing cesium-137 to remain in solution.

High cesium-137 concentrations (more than  $5 \times 10^5$  pCi/g) in the SX-108 slant borehole (Figure 3.8) begin at 17 m (55 ft) bgs in Hanford formation subunit H1a and continue throughout subunits H1 and H2 between 17 and 27 m (55 and 89 ft) bgs. This is a substantially thicker high-concentration zone than that observed in borehole 41-09-39 where similar concentrations occur between 19 and 25 m (61 and 83 ft) bgs, primarily in subunit H1. This distribution suggests that vertical migration was more significant near the leak origin, although maximum depth of cesium-137 migration is not greatly different in the two boreholes. Conversely, the borehole 41-09-39 data indicate extensive horizontal movement away from the tank that was largely confined to subunit H1, a coarse sand-gravel unit that lies near the tank bottom and dips gently to the southwest (Figure 3.3). This correlation indicates that the hydrologic properties of subunit H1 combined with the high-rate, high-volume tank leak caused extensive horizontal migration. Figure 3.7 illustrates this horizontally biased migration pattern generated by kriging analysis of site-specific spectral gamma data.

Figure 3.8. Cesium-137 in Vadose Sediments at the SX-108 Slant Borehole



Additional features of cesium-137 distribution in these boreholes include separate high-concentration zones or, within the primary high concentration zones, smaller zones of high and low concentrations. For example, in borehole 41-09-39, in addition to the primary high-concentration zone in subunit H1, a secondary peak concentration also occurs in subunit H2 at 31 and 33 m (103 and 109 ft) bgs. This multiple peak characteristic is seen frequently with other tank fluid contaminants as well in these soil columns. These variations could be attributed to variability in hydrologic properties for soil lenses occurring at different depths, geochemical variability affecting contaminant migration, or multiple leak events. The two-leak concept is supported by iodine fission product isotope measurements (iodine-127/iodine-129) in the SX-108 slant borehole (Appendix D, Section D.6.1) showing two distinct isotopic ratio signatures separated by depth in the analyzed soils. The two-leak concept adds complexity to the genesis of current vadose zone contamination from tank leaks but does not significantly alter the proposed conceptualization of contaminant migration.

Thermal-effects modeling results suggest at least two mechanisms that also may have influenced contaminant migration during the initial phase. First, temperatures exceeded 100 °C (212 °F) in soils near the tanks, creating dry zones that may have extended to and below subunit H1 for some time. If so, tank fluid would have boiled off, leaving contaminants in place until temperatures dropped below boiling and allowed re-saturation and a resumption of recharge. Second, a heat-pipe effect may have occurred near the 100 °C (212 °F) isotherm with water vapor being driven away from the heat source until it reached a cooler region and condensed and liquid water being drawn toward the heat source by capillary pressure. Constituents in the water vapor and water being pulled back toward the heat source would tend to concentrate near the point of vaporization. Whether or not this chemical concentration process could have affected tank fluid constituents is not known. The net effect would have been to delay further migration of contaminants by maintaining dry conditions where tank fluid contaminants were initially deposited and preventing recharge until temperatures dropped below 100 °C (212 °F).

The second phase of tank fluid migration began when the leak stopped, reducing and finally eliminating the hydraulic driver for relatively rapid vertical and lateral migration of the tank fluid. Over time, vadose zone soil temperatures dropped below boiling and the physical driver became infiltration from natural events with vertical and lateral migration essentially governed by natural recharge and geologic heterogeneities. The lateral migration is induced by heterogeneities and moisture-dependent anisotropy (Section 3.1.2 and Appendix E). Also, control of local chemical conditions by tank fluid chemistry diminished as tank fluids migrated downward and reacted with the ambient soil phases and pore water. During this time, a complex series of transient conditions evolved, affecting contaminant behavior and other chemical parameters.

The second phase of migration is indicated by the occurrence of tank fluid contaminants other than cesium-137 at different depths in the vadose zone in these boreholes. With downward movement and changing chemical conditions, the more mobile tank fluid constituents migrated deeper in the vadose zone, creating a crude chromatographic profile, an observation common to both boreholes. These data provide examples of a presumably more widespread occurrence over the area marked by cesium-137 distribution attributed to this leak. However, additional data are not available to evaluate the radial lateral or three-dimensional aspects of second-phase migration.

The constituents present at maximum concentrations deepest in the boreholes are nitrate and technetium-99, whose relative concentration profiles with depth are nearly identical. Maximum depths of these high concentration zones in both boreholes are similar but they occur somewhat deeper in the stratigraphic sequence under tank SX-108 (e.g., maximum nitrate and technetium-99 concentrations occur in subunit H2 and into Plio-Pleistocene subunit PPlz versus maximum concentrations in subunit H2 in borehole 41-09-39). Their characteristics are as follows.

- In the SX-108 slant borehole, elevated nitrate concentrations are measured throughout the borehole (17 to 44 m [55 to 145 ft] bgs) with maximum values of 180,000 to 995,000 mg/L measured between 25 and 39 m [81 and 130 ft] bgs (Figure 3.9). In borehole 41-09-39, elevated nitrate concentrations are measured between 20 and 41 m (65 and 136 ft) bgs, with maximum values of 101,000 to 417,000 mg/L between 25 and 39 m (83 and 127 ft) bgs (Figure 3.10).
- In the SX-108 slant borehole, technetium-99 occurs at elevated concentrations throughout the borehole with maximum values of about  $1.6 \times 10^7$  to  $2.4 \times 10^8$  pCi/L between 26 and 42 m (85 and 138 ft) bgs (Figure 3.11). In borehole 41-09-39, elevated technetium-99 concentrations are measured between 17 and 39 m (56 and 127 ft) bgs with maximum values of  $3.9 \times 10^5$  to  $1.2 \times 10^8$  pCi/L between 25 and 39 m (83 and 127 ft) bgs (Figure 3.12).

The depths of high concentration ranges of these constituents compared to cesium-137 clearly show greater vertical migration over time of the mobile constituents as expected. Interestingly, the amount of separation between the centers of mass of cesium-137 versus nitrate and technetium-99 are similar in both boreholes. Assuming the separation length is a qualitative indicator of second-phase migration, recharge conditions are relatively similar in both boreholes.

Tank waste constituents showing intermediate retardation between cesium-137 and nitrate/technetium-99 are sodium and chromium. The high concentration zones occur at a lower depth relative to cesium-137 zones and at a higher depth relative to nitrate/technetium-99 zones. Their characteristics include the following.

- In the SX-108 slant borehole, maximum sodium concentrations begin abruptly at 25 m (81 ft) bgs, remain elevated between 65,000 and 391,000 mg/L through 40 m (130 ft) bgs except at 32 m (105.6 ft) bgs where sodium concentration drops to 691 mg/L (Figure 3.13). In borehole 41-09-39, maximum sodium concentrations begin abruptly at 25 m (81 ft) bgs and remain elevated between 10,000 and 15,000 mg/L through 34 m (112 ft) bgs (Figure 3.14).
- Chromium concentration values in the SX-108 slant borehole increase above background beginning at 20 m (68 ft) bgs and show maximum values between 5,000 and 22,000 mg/L from 25 to 40 m (81 to 130 ft) bgs (Figure 3.11). The peak concentration of more than 22,000 mg/L occurs at 30 m (97 ft) bgs. In borehole 41-09-39, chromium concentration values increase above background beginning at 20 m (66 ft) bgs and reach maximum concentrations between 175 and 750 mg/L between 25 and 34 m (81 and 112 ft) bgs.

Figure 3.9. Anions Calculated and Actual Porewaters for SX-108 Slant Borehole Sediments

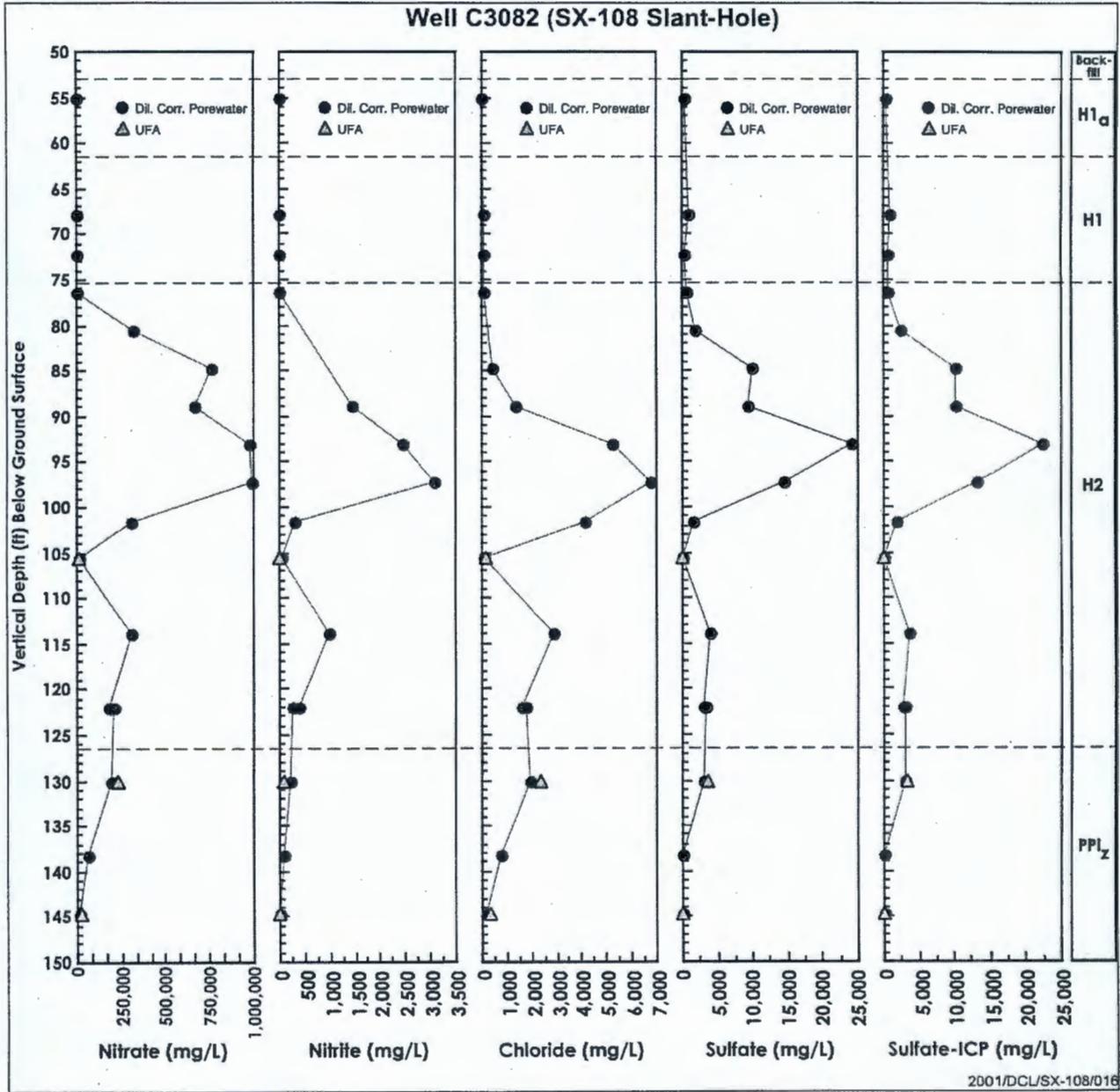


Figure 3.10. Concentrations of pH, Electrical Conductivity, and Nitrate in Dilution-Corrected Water Extract

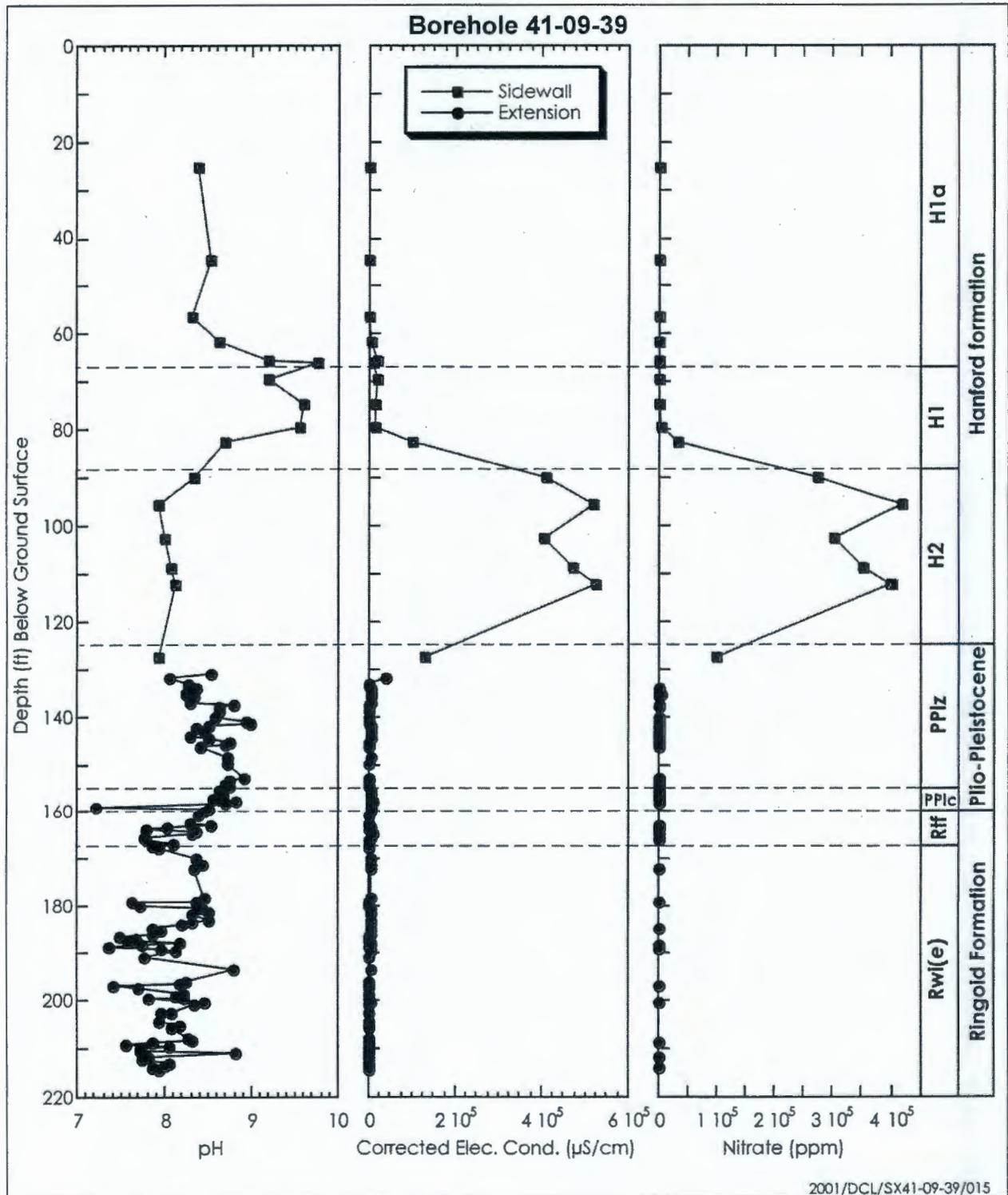


Figure 3.11. Trace Metals Calculated and Actual Porewaters for SX-108 Slant Borehole Sediments

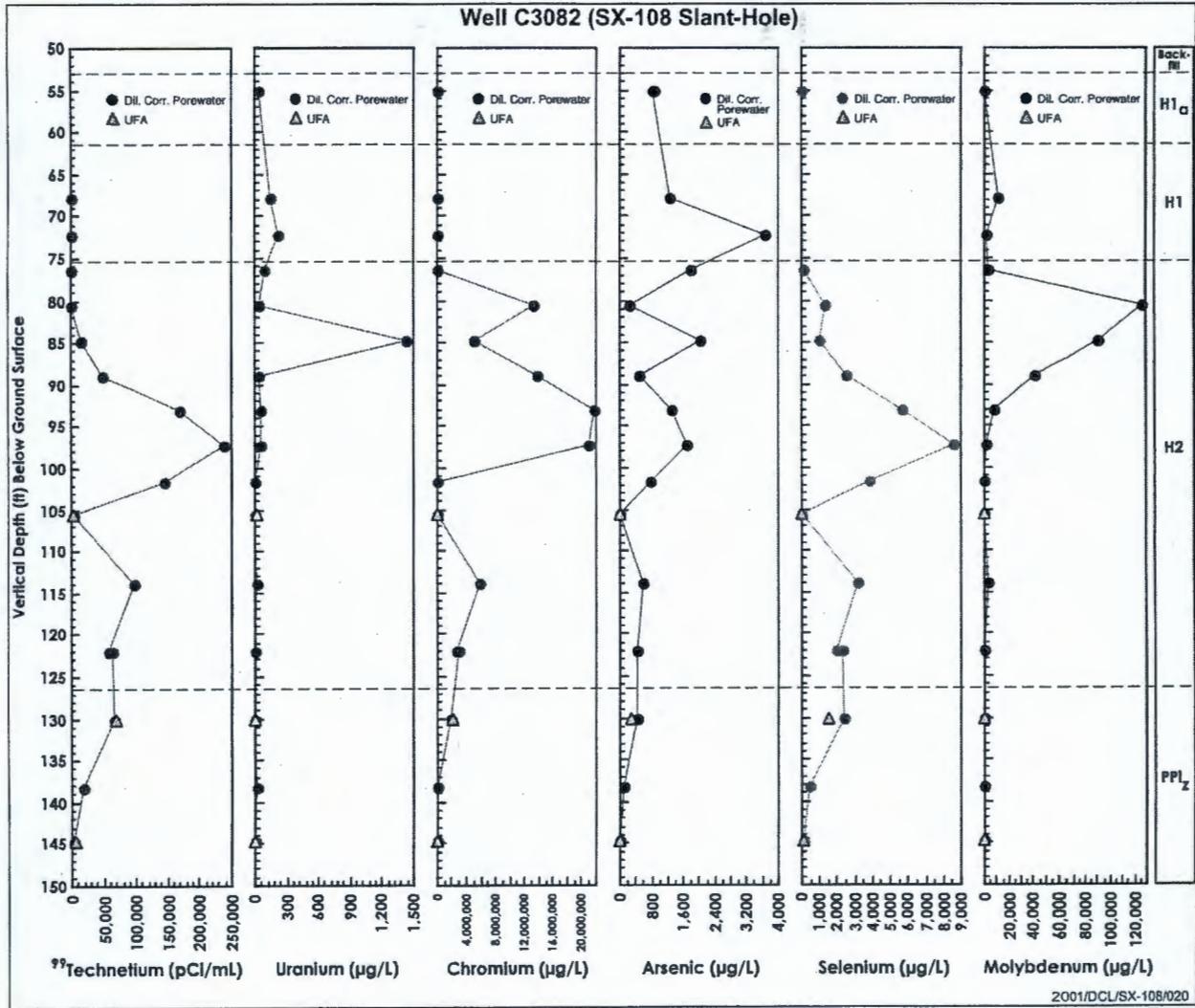


Figure 3.12. Technetium-99 Activity in Porewater in Borehole 41-09-39

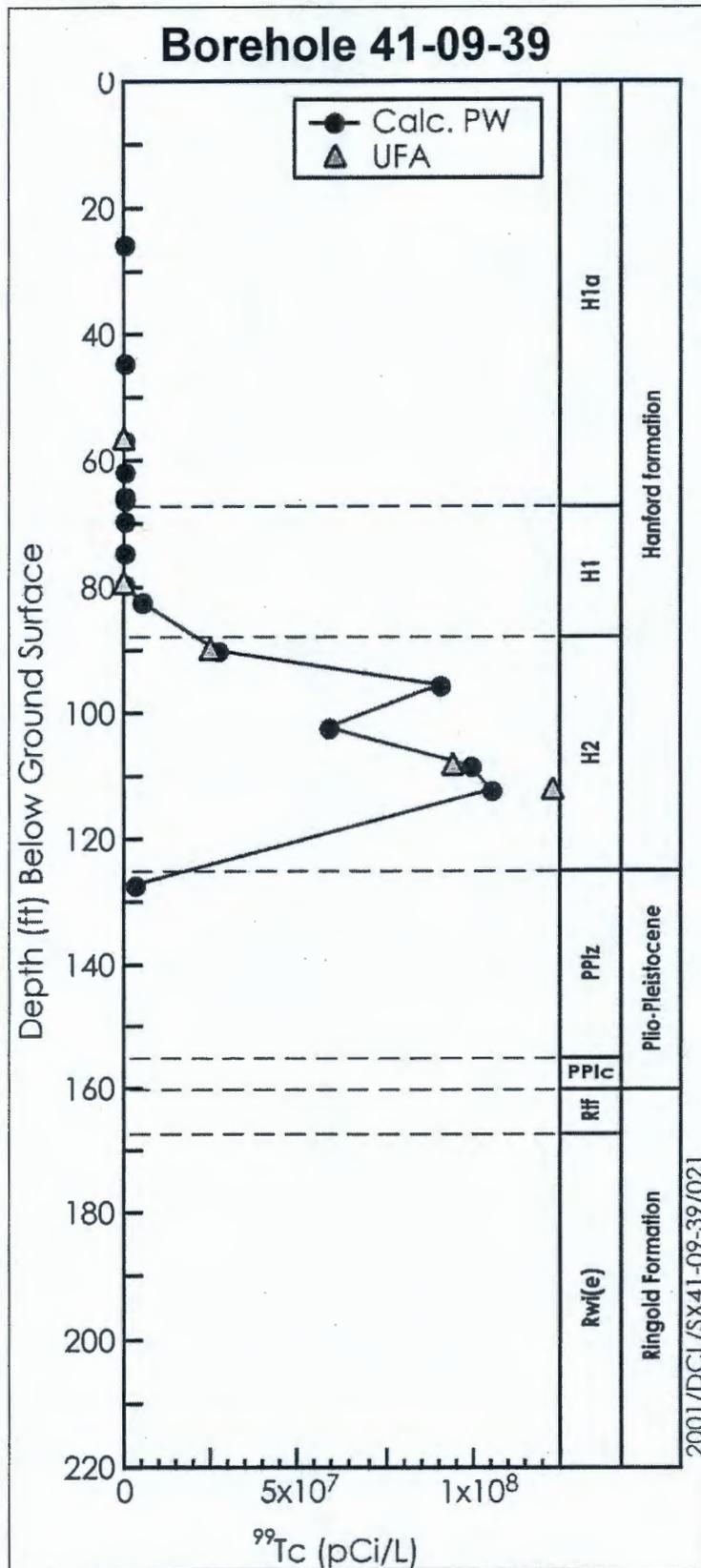


Figure 3.13. Cations Calculated and Actual Porewaters for SX-108 Slant Borehole Sediments

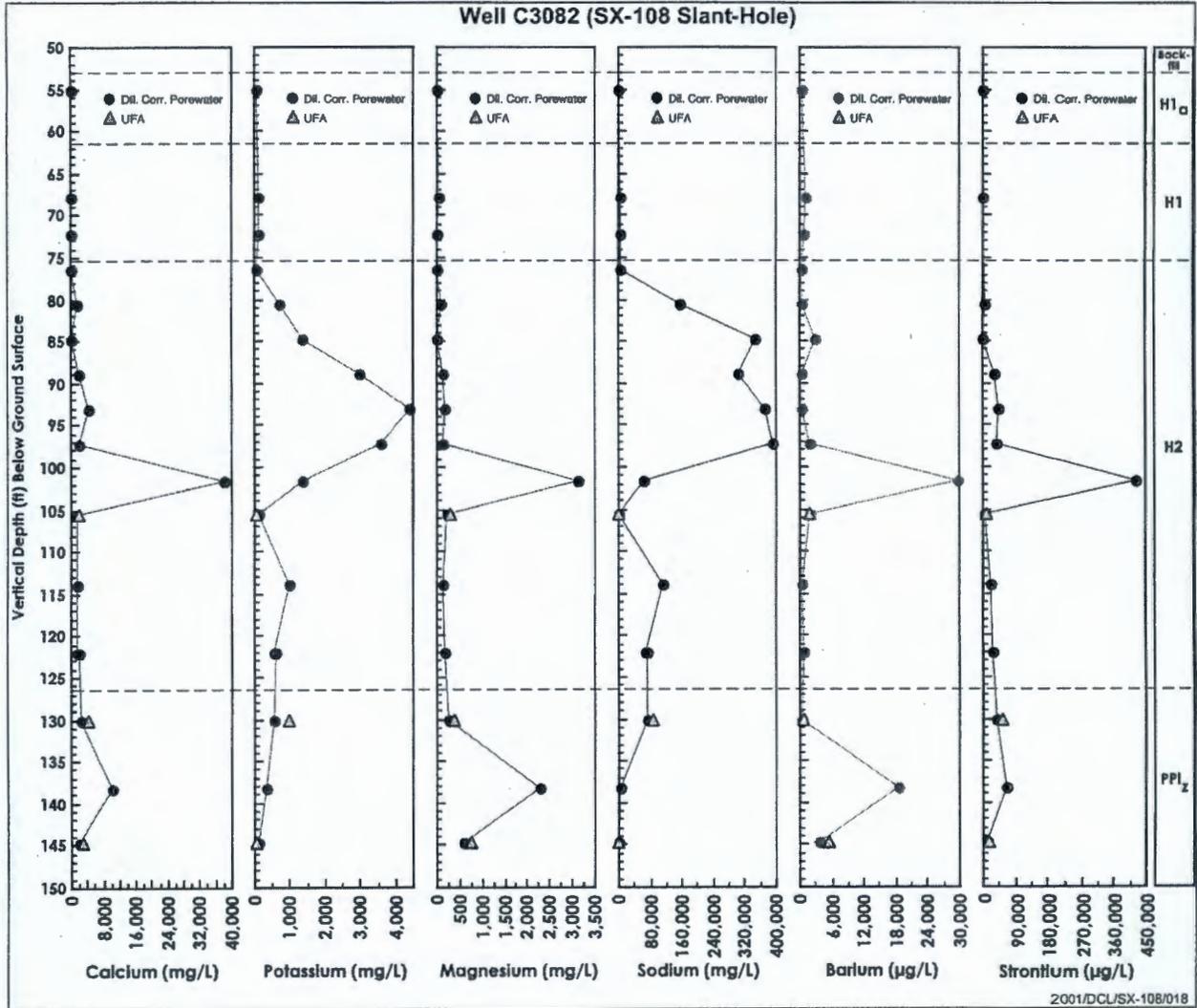
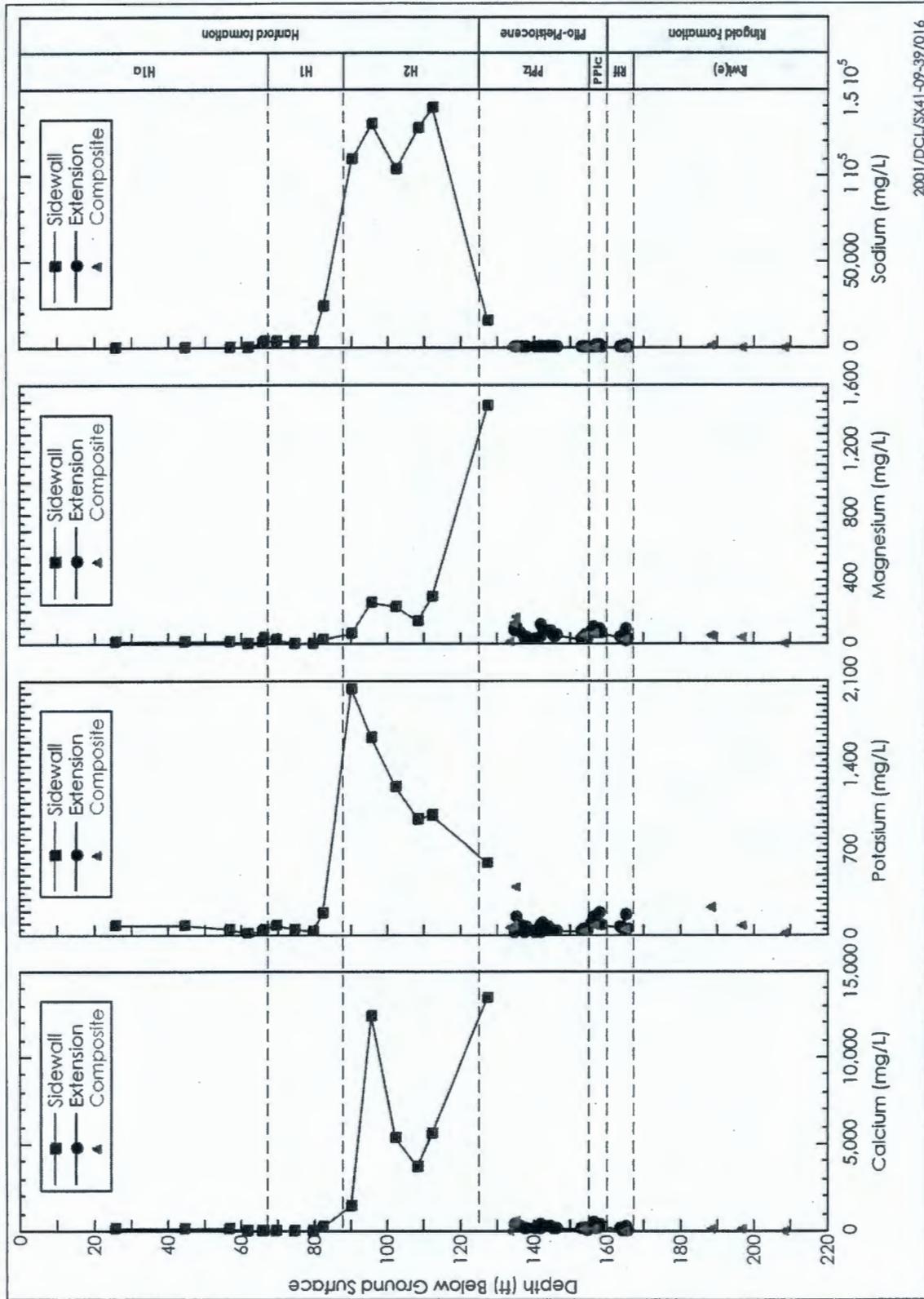


Figure 3.14. Dilution-Corrected Cation Concentrations at Borehole 41-09-39 in 1:1 Sediment to Water Extracts



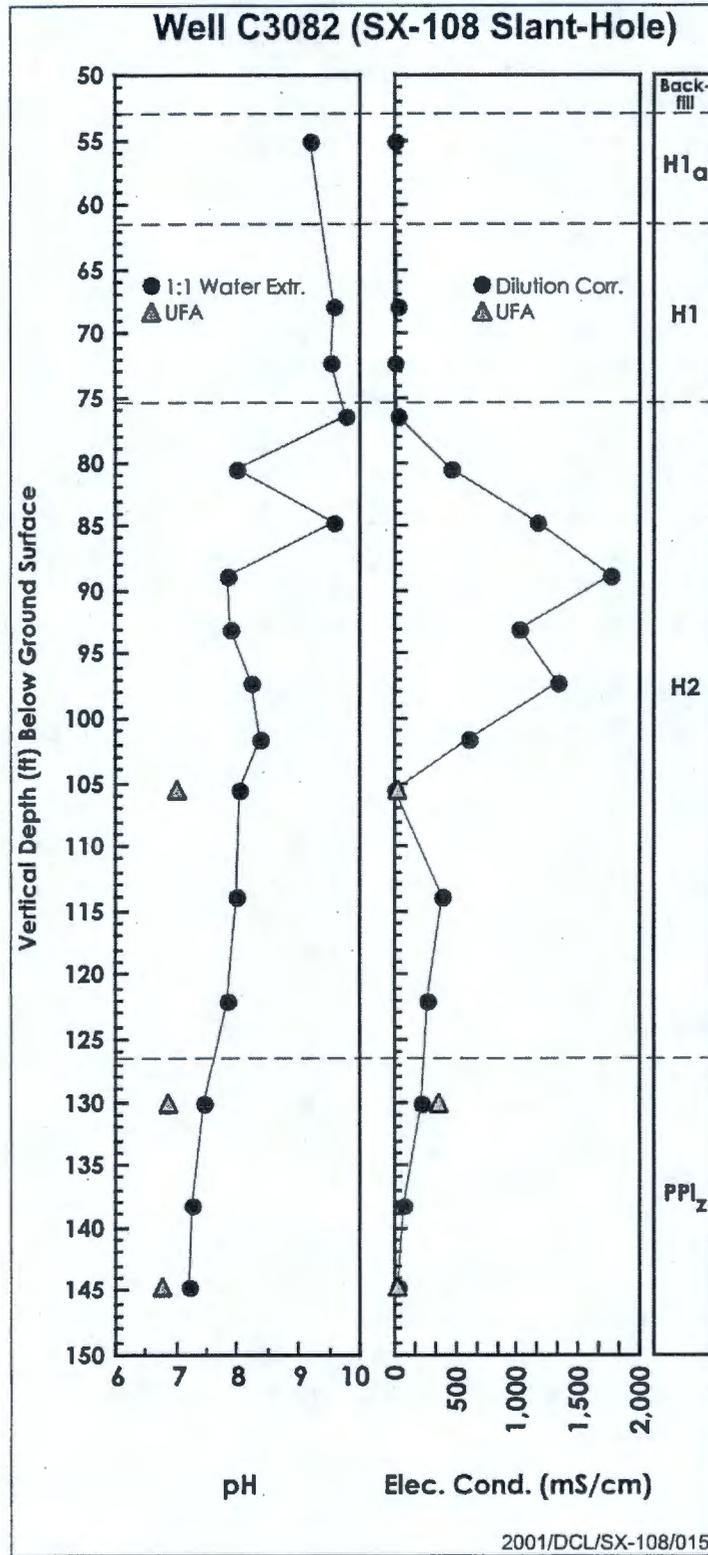
Sodium retardation is attributed to successful competition with divalent cations (cesium-137, calcium, magnesium, and natural strontium) and partial sorption on soil minerals. This hypothesis is supported by depletion of these cations in the high sodium zones and increased concentrations just deeper than the sodium front in both boreholes. The loss of cesium-137 mobility is attributed to the separation of high sodium concentrations from cesium-137 as downward migration of tank fluid occurs carrying excess sodium away. Chromium retardation is attributed to partial reduction by naturally occurring iron(II) in soil minerals.

Both phases of the tank fluid migration history appear to be represented by the changes in pH values with depth measured in borehole 41-09-39 (Figure 3.10) and the SX-108 (Figure 3.15) slant borehole soils. Tank supernate pH was initially much higher than soil water pH (e.g., over 10 for tank supernate, and 7.5 to 8 for soil water). As the tank supernate interactions with soil phases and soil water progress, intermediate pH values should occur and ultimately approach soil water values as the buffering capacity present in the soil column eventually prevails. Assuming that increasing reaction occurs at increasing depth over time, pH values should drop with depth. This behavior is evident in borehole 41-09-39 where pH values are greatest (over 8.7) in Hanford formation subunit H1 coincident with the highest concentration of cesium-137 in the borehole and decrease to about 8 in subunit H2 where the mobile constituents are concentrated.

The fact that the leading edge of the tank fluid plume stops at the Plio-Pleistocene unit in these boreholes creates ambiguity about the direction of recent tank fluid migration and the prediction of future migration. The Plio-Pleistocene unit is a thick, low-permeability unit in this area and could provide a significant retardation to downward moisture movement. As suggested by data in Serne et al. (2001c, 2001d), tank leak fluid may have progressed only to the Plio-Pleistocene unit or may have reached the Plio-Pleistocene unit and been dispersed laterally. Simple calculations assuming enhanced natural recharge rates of 10 cm/yr (4 in./yr) allowed by tank farm gravel covers show that tank fluids could have been driven deeper than the Plio-Pleistocene unit (Serne et al. 2001b). Because tank waste constituents were not encountered below the Plio-Pleistocene unit, the conclusion could be that some lateral migration has also occurred. However, quantification of the effective recharge rate remains uncertain. As discussed in Section 3.1.2, no site-specific recharge estimates are available for tank farm conditions. In the absence of site-specific data, estimates are based on long-term lysimeter experiments that mimic the non-vegetated, gravelly conditions at the tank farms.

In addition to the potential for the Plio-Pleistocene unit acting as a partially effective barrier to vertical flow, soil column heating from radioactive constituents in tank waste and tank leaks may have had a significant impact on recharge, particularly early during tank farm operations when radioactive decay was at a maximum. The thermal modeling results indicate a rather lengthy drying region around the leaks (several decades), a process that could have slowed or prevented local recharge for sometime.

Figure 3.15. SX-108 Slant Borehole pH and Electrical Conductivity Profiles with Depth



### 3.4.2 Conceptual Model of the Tank SX-115 Area Contamination

New activities and data relevant to vadose zone contamination in this area include the following:

- Drilling of vertical borehole 299-W23-19 near the southwest part of tank SX-115, soil sample characterization from 10 to 62 m (32 to 205 ft) bgs, and gamma/moisture logging with depth
- Ongoing collection of groundwater contamination data from groundwater monitoring wells at the south end of the SX tank farm.

These data, combined with existing data from historical and spectral gamma logging, historical records, limited early soil and tank supernate analyses (Raymond and Shdo 1966), and hydrogeologic data, provide the basis for the conceptual model.

The vadose zone contamination in this region is dominated by the leak or leaks from tank SX-115 (190,000 L [50,000 gal] in 1965) and is the focus of the conceptual model. Given the similarity of the leak event and the stratigraphy with the tank SX-108 leak event, a two-stage contaminant migration process is proposed. Unlike the tank SX-108 contamination area where current cesium-137 distribution is postulated to indicate the movement of tank fluid immediately after leakage, no similar indicator is present in the tank SX-115 area. Tank SX-115 supernate chemistry clearly did not enhance cesium-137 mobility causing rapid sorption onto soils very close to the leak location. New data from borehole 299-W23-19 provides little indication of early migration except perhaps for a small zone of elevated pH in subunit H1a that may mark the remnants of early high pH tank fluid with moderately alkaline porewater. No other borehole data are available to provide an indication of horizontal distribution.

Whether or not significant early lateral migration occurred in the vadose zone shortly after initiation of the tank SX-115 leak, subsequent downward movement in the second phase of migration would have had to have been extensive and spatially complex if the presence of high technetium-99 concentrations at the new monitoring well 299-W23-19 is assumed to be derived from the tank SX-115 leak. Specific soils and groundwater sample data from this borehole that support this hypothesis include the following.

- Elevated pH and chromium levels (Figures 3.16 and 3.17, respectively) indicate the depth at which tank fluids first interact with soil, at about 22 m (73 ft), in subunit H1a and within 1.5 m (5 ft) of the subunits H1a/H1c contact. A distinctive maximum pH value zone (pH greater than 9) exists in subunit H1 at 23 to 26 m (75 to 86 ft) bgs. At lower depths, pH values range from 8 to 8.5.
- Tank fluid contamination in this borehole is marked by maximum concentrations of mobile constituents in the Plio-Pleistocene unit (Figures 3.17 and 3.18), including technetium-99 (at 37 to 46 m [123 to 150 ft] bgs), nitrate and chloride (at 38 to 46 m [126 to 150 ft] bgs). Also, slightly elevated technetium-99 concentrations extend from the Plio-Pleistocene unit to the water table in this borehole.
- Technetium-99/nitrate ratios in soil water extracts from the high concentration intervals in the vadose zone are essentially the same as that in the borehole groundwater samples.

Figure 3.16. Calculated and Actual Porewater pH and Electrical Conductivity Values for Borehole 299-W23-19 Sediments

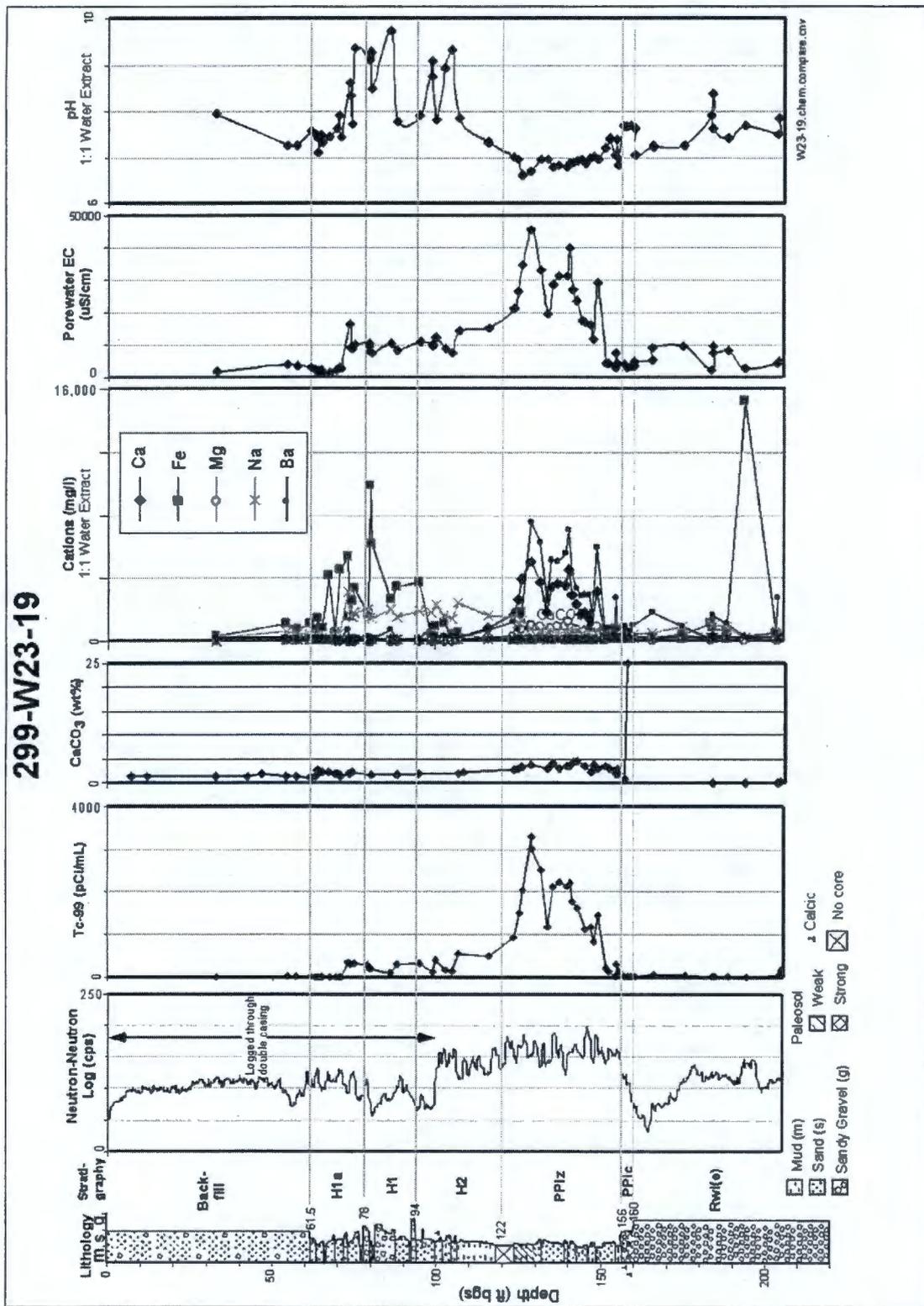


Figure 3.17. Trace Metals Calculated from Sediment Water Extracts and Actual Porewaters for 299-W23-19 Sediment

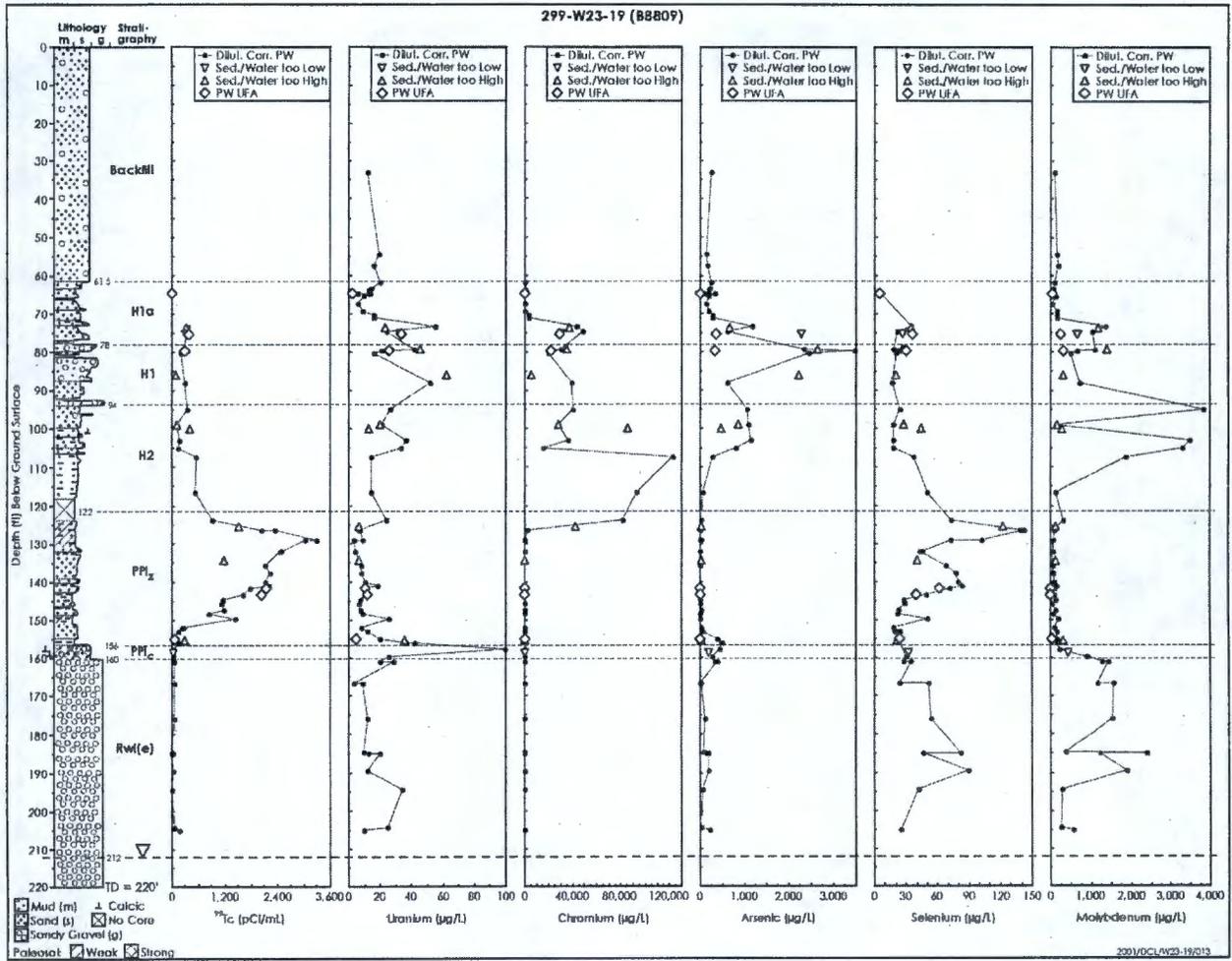
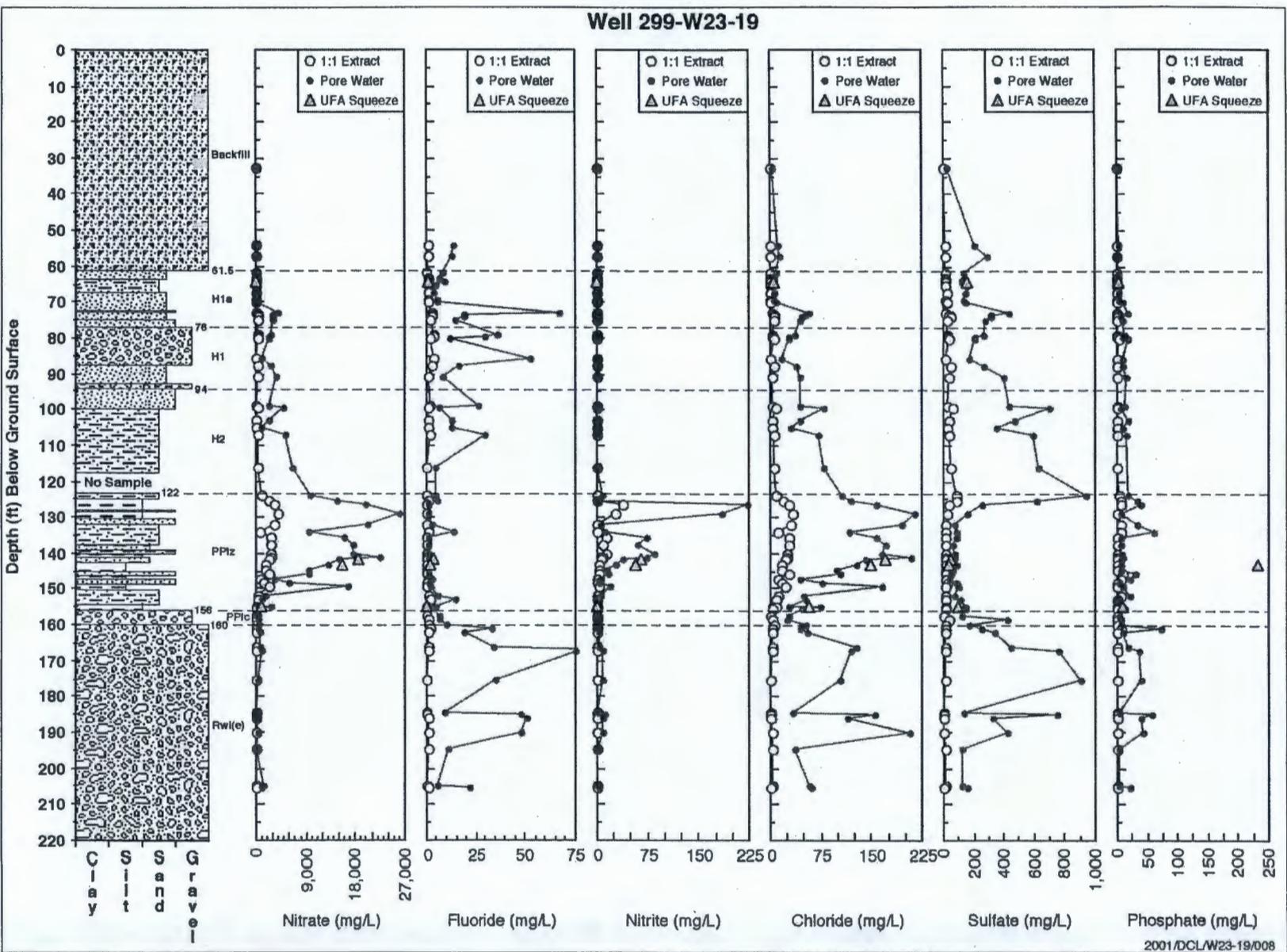


Figure 3.18. Anions Calculated and Actual Porewaters for Borehole 299-W23-19 Sediments

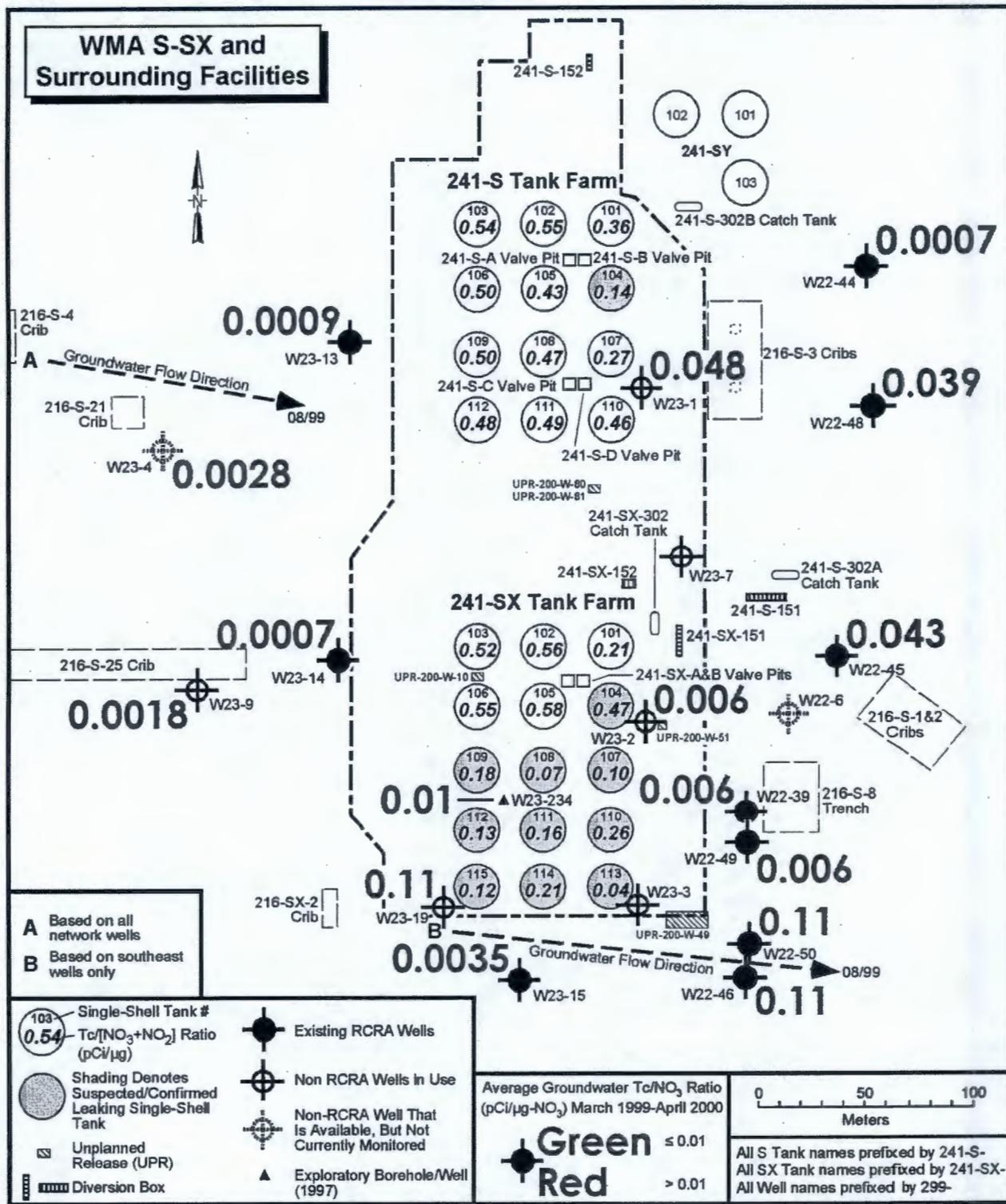


- Soil moisture contents in soils are elevated above undisturbed soil conditions and matric potential measurements indicate drainage.
- Groundwater monitoring data show elevated technetium-99, chromium and nitrate concentrations in a series of wells covering a narrow east-west zone in the unconfined aquifer along the south boundary of the SX tank farm. The maximum technetium-99 concentrations occurred in borehole 299-W23-19 (81,500 pCi/L in March 2001) and are interpreted to be close to the point of contaminant entry into the vadose zone. The technetium-99/nitrate ratios (0.11 pCi/ $\mu$ g) at this borehole are present in boreholes 299-W22-46 and 299-W22-50 (Figure 3.19).

A comparison of current and historical conditions in the tanks SX-107, SX-108, and SX-109 leak area versus the tank SX-115 leak area also suggests accelerated migration of tank SX-115 waste. The tanks SX-107, SX-108, and SX-109 area shares a similar vadose zone stratigraphy with the tank SX-115 area, but is characterized by a drier soil column (e.g., soil moisture content in boreholes 41-09-39 and the SX-108 slant borehole versus borehole 299-W23-19) and the absence of both associated groundwater contamination and known anthropomorphic leakage or leak sources. Tank fluid mobile constituents technetium and nitrate in borehole 299-W23-19 are concentrated at lower depths compared to borehole 41-09-39 and the SX-108 slant borehole (e.g., maximum vadose zone concentrations in the Plio-Pleistocene unit versus the H2 subunit).

Collectively, these data support a hypothesis that contaminant migration in the tank SX-115 area of the vadose zone occurred rapidly in both the horizontal and vertical direction in the vadose zone and broke through to the unconfined aquifer somewhere upgradient (west) of borehole 299-W23-19. Circumstantial evidence of recent extensive waterline leaks near tank SX-115 could have provided the needed source of water that would explain the rapid contaminant migration rates and high concentrations for technetium-99, chromium, and nitrate in groundwater at borehole 299-W23-19. The minimum amount of contamination in the borehole 299-W23-19 soil column between the Plio-Pleistocene unit and the water table indicates that breakthrough did not occur at this borehole and that some lateral movement of tank fluid contaminants in the vadose zone is necessary if the groundwater contamination source is the tank SX-115 leak. Lateral movement may have occurred at one or more depths because of stratigraphic controls, one plausible unit being the Plio-Pleistocene unit, another being subunit H1. Both units predispose movement to the west, the general down-dip direction (Figure 3.3). This hypothesis also requires that a fairly extensive and multi-directional distribution in the vadose zone (e.g., tens of meters) of water from the water line leaks must have occurred to allow contact between water and contaminants and subsequent rapid migration. This mechanism is feasible because of the combination of stratigraphic controls promoting horizontal flow and high volume rapid fluid discharge into the vadose zone created by water line leak(s).

Figure 3.19. Technetium-99/Nitrate Ratios for Waste Management Area S-SX Network Wells



### 3.4.3 Conceptual Model of the Tank S-104 Area

Additional data that have been collected in the tank S-104 area are limited to the investigation of shallow soil contamination using a cone penetrometer and collection of groundwater monitoring samples downstream of the tank S-104 area. The cone penetrometer data provided minimal data relevant to the tank S-104 leak. The groundwater data consist of elevated levels of technetium-99 and nitrate, which are tentatively linked to the tank S-104 leak by relative location and historical knowledge. This suggests that the tank S-104 leak is the largest known plausible technetium-99 source in S tank farm. Technetium-99 concentrations at wells 299-W22-44 and 299-W22-48 currently appear to be going through a short-term spiking event in downstream wells at peak concentrations of the same order of magnitude as found at well 299-W22-46 attributed to the tank SX-115 leak. Also, technetium-99/nitrate ratios are elevated above background.

Given the limited amount of new data, the conceptual model of contamination genesis and migration remains unchanged. Environmental contamination indicators at this site resemble that of the tank SX-115 leak. First, vadose zone contamination began with a relatively large tank leak where highly reactive contaminants (e.g., cesium-137) dropped out of solution rapidly and mobile constituents continued to migrate with tank fluid. Second, at least one large pipe leak is known to have occurred in the region and the local topography has been conducive to collection of runoff and snowmelt. Accelerated recharge is plausible and mobile constituent contaminants (e.g., technetium-99) currently do appear in groundwater that may be attributed to this source. The timing of technetium-99 groundwater contamination that may be attributed to the tank S-104 leak is more or less concurrent with the technetium-99 groundwater contamination attributed to the tank SX-115 leak.

### 3.4.4 Representation of Conceptual Models in Contaminant Migration Modeling

Projection of future contaminant migration through modeling (see Section 4.0 and Appendix E) is necessary to make long-term waste management decisions where multi-generational environmental impact is a key concern of regulators and stakeholders. Frequently, as in the case of vadose zone contamination, the evolution of contaminant distribution into the natural environment is a slow process that can take many decades or longer to evolve. When waste management decisions are required in a shorter timeframe, modeling is the only tool available to estimate potential human health risk estimates needed to make near-term decisions. Modeling approaches that provide useful results must accommodate the uncertainties intrinsic to both the natural system being modeled and estimates of future events and outcomes.

Natural system heterogeneities, including those inherent in the environmental setting and those associated with physical and chemical processes controlling contaminant migration, cannot be truly simulated in real time and space because of an insufficient database and limited computational capabilities. Therefore, simplifying assumptions and representations of real conditions and events that provide a reasonably conservative (e.g., bounding) approximation rather than a true prediction of future environmental impact and associated risk must be selected. At the same time, the degree of conservatism must be selected carefully to avoid very large risk estimates that require costly and inefficient waste management actions.

Given this perspective, aspects of the conceptual model that have been incorporated into the base case numerical modeling configuration include the following:

- Two-dimensional modeling of contaminant transport through the vadose zone in representative cross-sections at each of the three high-contamination areas
- Placement of initial vadose zone inventory in a present-day configuration consistent with historical knowledge and field data
- Imposition of several steady state recharge rates that approximate average yearly recharge from natural precipitation, depending on the surface barrier characteristics as the hydraulic driver for contaminant transport to the underlying aquifer.

Having taken this approach, aspects of the conceptual model have not been simulated or are only simulated by the primary numerical model summarized in Section 4.0. A deliberate decision was made not to model the initial leak events but to model future contaminant migration beginning with current conditions. This decision allowed avoidance of extremely complex events for which only a fraction of the necessary data is available. The leak events were highly transient involving variable release rates, nonisothermal conditions (spatial and temporal), and variable tank leak chemistry as tank fluids migrated through the soil column, interacting with soils and soil water. Some aspects of these events have been modeled by the S&T activity (Appendix D).

The potential drawback of this decision was the chance that processes actively influencing contaminant migration during the initial leakage phase could still be affecting contaminant mobility such that modeling results do not account for still active primary driving forces. Chief among these potentially significant processes include the following:

- Heat effects on fluid migration and contaminant chemical reactivity
- Tank fluid chemistry effects on contaminant mobility.

The evolution of thermal gradients has been modeled by the S&T activity (Appendix D). Results indicate that current and future profiles are reaching a quasi steady state condition that leaves ambient temperatures not greatly above natural condition values, a condition that should not seriously affect future moisture movement. Lingering heat effects on moisture would likely retard moisture movement relative to that assumed in the modeling analysis. Thus, an isothermal modeling approach should provide a conservative result (faster travel time and higher contamination levels in the unconfined aquifer) and is used (Section 4.0).

Empirical desorption tests on soils have been used from the characterization boreholes (Appendix B) to estimate current in situ mobility. In particular, continuation of initially very high cesium-137 mobility in the tank SX-108 leak needed to be assessed. The results indicate that the mobility of contaminants of interest are now relatively similar to those observed in undisturbed Hanford Site soils. In essence, tank fluid chemistry has been buffered to the extent that it no longer dominates contaminant behavior compared to undisturbed soil conditions. Assumptions of normal retardation coefficients are adequate to represent likely future occurrence of contaminants in the unconfined aquifer. Realistically, only technetium-99, nitrate, and chromium—the constituents currently observed in groundwater and attributed to tank leak sources—are likely to reach groundwater from this source at other than negligible concentration

levels. Iodine-129 may also be of some concern but has only been measured in a small zone at the bottom of the SX-108 slant borehole. These contaminants are assumed to be completely mobile ( $K_d = 0$  mL/g) in the modeling analyses. This assumption maximizes aquifer concentration estimates and eliminates any relevance of geochemical conditions to the groundwater contamination estimate.

Heterogeneities in vadose zone hydrologic properties and recharge events are considered in the modeling analysis. Heterogeneities occur somewhat randomly over small regions that cannot be characterized. Geologic heterogeneities include stratigraphic controls that may induce lateral migration to occur. Clastic dike features may provide conduits for preferential flow. As noted above, particularly in the tank SX-115 area, the Plio-Pleistocene unit may have a variable capability to divert fluid migration. The modeling approach considers hydrologic properties and variable, moisture-dependent anisotropy for the major geologic strata in the vadose zone based on laboratory measurements of hydrologic properties for samples representative of each stratigraphic unit (Section 4.0 and Appendix E). Clastic dikes are known to occur in the vicinity of the WMA S-SX tank leaks and have been postulated as significant pathways for enhancing contaminant migration rates and groundwater concentrations. Because of this concern, a sensitivity case (Section 4.0) was considered to evaluate the influence of a clastic dike feature on contaminant migration, despite the fact that exact site-specific location and hydrologic properties of these features are not known.

Recharge events derived from natural processes (i.e., precipitation, snowmelt, and runoff) are transient, random events. Similarly, water-line leaks that are assumed to occur at various locations in WMA S-SX are unpredictable events. Neither of these types of processes are modeled in this analysis realistically. Recharge from precipitation and infiltration is modeled as a steady-state event that is correlated to a yearly average. This is a standard, well-accepted approach and quantification of recharge is based on lysimeter data of recharge through gravel materials that are similar to tank farm barriers. Events that have caused short-term, high volume water releases to the vadose zone (water-line leaks) are only evaluated in a few sensitivity cases for two reasons.

- The database that adequately quantifies water fluxes from these events does not exist and probably cannot be generated.
- The focus of the modeling analysis is long-term contaminant migration.

Steps already have been taken to eliminate the possibility of future high-volume discharge occurrences (e.g., underground water lines will be entirely capped off, surface covers will be engineered to minimize infiltration and prevent ponding of runoff or snowmelt) in FY 2001.

### 3.5 INTERIM MEASURES

The interim measures and ICMs that have been evaluated and/or implemented as they relate to WMA S-SX are described in this section. Interim measures are initial response actions that can be taken while characterization activities are underway and while long-term strategies are being developed to reduce the impacts of tank leaks on groundwater. Interim measures do not require comprehensive evaluation in a CMS. Interim measures identified to date for WMA S-SX focus

on actions to minimize infiltration and contaminant migration to groundwater. Four categories of interim measures have been implemented at WMA S-SX during the past three years (see Section 3.5.1).

ICMs are response actions with the objective of reducing contaminant migration to groundwater to acceptable regulatory levels and that require balancing risk, benefits, and costs. In general, ICMs involve a substantial commitment of resources, require a more thorough evaluation, and are intended to provide a more permanent solution to the long-term threats posed by a release. Detailed evaluation of the proposed WMA S-SX ICMs will be undertaken in a CMS or an accelerated CMS pending results of this FIR.

Detailed information on WMA S-SX interim measures and ICMs is contained in Appendix F.

### **3.5.1 Interim Measures Identification**

An engineering report (FFS 1999) was published November 1999 that assessed potential measures to limit infiltration through the vadose zone at the SST farms. That report was updated and revised in May 2001 (Anderson 2001). Anderson (2001) evaluates leaking water lines, wells within the SST farms, and surface water (both recharge and run-on). Updated rough order of magnitude cost estimates are also provided in Anderson (2001).

Included in Anderson (2001) are a number of interim measures that are 'good housekeeping' actions considered for implementation because they clearly would reduce water infiltration at the tank farms and limit the migration of contamination through the vadose zone.

**3.5.1.1 Abandonment of Active Water Lines.** Combined, the S and SX tank farms contain approximately 1,930 m (6,300 ft) of active water lines that could be or have been abandoned to eliminate persistent leaks and prevent future water line breaks. These lines were mainly installed during original tank farm construction in the 1950s and 1960s and have exceeded their design life of 20 years. Pipe breaks, failed leaded joints, and poorly functioning gate valves are common. The Hanford Site-wide failure rate appears to be increasing geometrically. Four pressurized water lines entering the S and SX tank farms from the east were identified as still potentially operational or pressurized.

**3.5.1.2 Decommissioning Unfit-for-Use Wells.** Wells and drywells identified as unfit-for-use in Anderson (2001) are potential preferential pathways for downward contaminant migration. It is important to note that many of the wells and boreholes do not extend to the groundwater. Anderson (2001) identifies six wells in the S and SX tank farms that are potential Priority 1 candidates for near-term decommissioning.

**3.5.1.3 Upgradient Surface Water Run-On Control Measures.** Upgradient surface water run-on control consists of some combination of regraded ground surfaces, gravel berms, asphalt pavement, and concrete curbs and valley drains constructed outside the SST farms to prevent surface water from pressurized water-line leaks and unusual meteorological events from flowing onto the tank farm areas. Photographic evidence shows that low areas of the SX tank farm were flooded in 1979 when rapid snowmelt occurred. Anderson (2001) recommends that run-on control be established to prevent surface water from entering the SST farms from outside sources even if no other interim measures are selected to reduce infiltration within each SST.

### 3.5.2 Interim Corrective Measures Identification

ICMs have the same overall purpose as interim measures. Because of size, complexity, or impact to operations, a more careful study must be performed before an ICM is implemented. Many potential ICMs for mitigation of potential impacts at WMA S-SX have been identified; however, some of these potential ICMs are likely to be implemented sooner than others.

**3.5.2.1 Identification of Potential Near-Term Interim Corrective Measures.** The activities that have been undertaken to identify potential ICMs for all of the WMAs are as follows.

- In 1992 an engineering study, documented in *Single-Shell Tank Interim Cover Engineering Study* (Young et al. 1992), evaluating 4 approaches for reducing surface infiltration at all of the WMAs was completed. The surface infiltration reduction approaches evaluated were (1) polymer-modified asphalt, (2) fine-soil cover, (3) buildings (structures), and (4) flexible membrane liners. The engineering study concluded that implementation of these approaches for all of the WMAs ranged from \$40 million to \$158 million. Cost and other factors were the reasons that none of the approaches were implemented.
- On May 4 through 6, 1999 a forum was held in Richland, Washington to discuss techniques for reducing and monitoring infiltration at the SST farms. DOE, Hanford Site contractors, and various vendors from throughout the United States and Canada attended. Pacific Northwest National Laboratory summarized this conference in "Reducing Water Infiltration Around Hanford Tanks" (Molton 1999). Four technical sessions were conducted to discuss (1) moisture monitoring and characterization, (2) structures or buildings to cover the WMAs, (3) surface modifications or covers, and (4) near-surface modifications (barriers and permeability reduction techniques). The forum concluded that existing commercial capabilities could be employed to reduce and monitor infiltration in the WMAs, but that no one technology was appropriate for all seven WMAs. Another conclusion of the forum was that the costs shown in Young et al. (1992) were 50% to 80% higher than those reflected by the vendors attending the forum. During the course of the forum a number of DOE officials and Hanford Site subcontractors addressed site-specific constraints that the vendors may not have taken into account before they submitted their estimated or typical-unit costs.
- In June 2000 DOE revised *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas* (DOE-RL 2000). Section 4.2 of that document identifies a number of general response actions and technology and process options associated with each general response action, and it screens each option based on effectiveness, ability to implement, worker safety, and cost.
- In November 1999 an engineering report by Fluor Federal Services (FFS 1999) was completed. This report was revised and updated in May 2001 (Anderson 2001). In addition to evaluating water lines and wells within the WMAs, the report also evaluated surface water both from natural causes and catastrophic events. Alternatives considered in that report include (1) no action, (2) site grading, (3) geo-fabric liners, (4) asphalt concrete paving, (5) building enclosure with asphalt apron, and (6) run-on

control. The report recommends that a combination of a building enclosure with asphalt apron and run-on control be implemented. While the building enclosure is not the preferred option (because of the cost) the report concludes that it provides the best operational and technical alternative.

Three potentially viable near-term ICMs are: near-surface barriers, surface barriers, and overhead structures. The following sections describe how each of those three near-term ICMs would apply to WMA S-SX.

**3.5.2.2 Near-Surface Barrier.** A near-surface barrier would consist of an impervious, geo-fabric (geomembrane liner or geosynthetic clay) system over the entire WMA S-SX to direct surface water to the outer boundaries of the tank farms. A run-off collection system consisting of ditches and pipes would be required to route collected surface water to existing drainage routes.

**3.5.2.2.1 Implementation at WMA S-SX.** Implementation of a near-surface barrier would be disruptive to other tank farm activities. The entire area, 18,000 m<sup>2</sup> (194,000 ft<sup>2</sup>) at the S tank farm and 20,500 m<sup>2</sup> (220,000 ft<sup>2</sup>) at the SX tank farm, would require hand excavation to remove 30 cm (12 in.) of existing soil and subsequent replacement of this soil as a cover over the liner to allow for traffic. The soil would have to be hand excavated because of the tank dome-loading restrictions and the many utilities within the tank farm. Some of those utilities may require support during construction or relocation to a depth below the liner. Installation of the near-surface barrier would require more time than a typical installation because of the many obstructions protruding above the ground surface. During the period that the near-surface barrier is required to control surface water, repairs would be required if any tank farm activities required work below the liner.

**3.5.2.2.2 Cost.** The estimated costs cited in the engineering study (Anderson 2001) for implementation of a subsurface barrier are \$7.1 million for the S tank farm and \$8.1 million for the SX tank farm.

**3.5.2.3 Surface Barrier.** The only surface barrier evaluated is a 6 cm (2.5 in.) layer of asphalt cement pavement. Surface barriers that were not evaluated but have been used successfully on other projects include various liquid and solid reagents that are applied and allowed to penetrate the surface materials or are mixed with the surface materials to form a crust. A run-off collection system comprised of ditches and pipes would be required to route collected surface water to existing drainage routes. It is recommended an engineering trade study be conducted to examine the impact an interim surface barrier on tank farm operations would create through the annual interim measures discussions between ORP and Ecology.

**3.5.2.3.1 Implementation at WMA S-SX.** Implementation of a surface barrier would be disruptive to other tank farm activities. The entire area, 18,000 m<sup>2</sup> (194,000 ft<sup>2</sup>) at the S tank farm and 20,500 m<sup>2</sup> (220,000 ft<sup>2</sup>) at the SX tank farm, would require hand excavation to remove 10 cm (4 in.) of existing gravel cover, which would be taken from the site and disposed of if contaminated or used in the production of the asphalt. The material would have to be hand excavated because of the tank dome-loading restrictions and the many utilities within the tank farm. Some of these utilities may require relocation if they are near the surface following

removal of the 10 cm (4 in.) of existing materials. Installation of the surface barrier would also take additional time from typical installations to seal the numerous obstructions protruding above the surface.

Adequate compaction of both the subgrade and the asphalt will not be obtained because of the obstructions within the tank farm and the tank dome-loading restrictions. During the period that the surface barrier is required to control surface water, traffic loading may do substantial damage to the surface barrier. The cost to repair the asphalt barrier using the special fine mix could be excessive.

**3.5.2.3.2 Cost.** The estimated costs cited in the engineering study (Anderson 2001) for implementation of a surface barrier are \$3.4 million for the S tank farm and \$3.9 million for the SX tank farm.

**3.5.2.4 Overhead Structure.** An overhead structure would consist of an enclosed shelter covering the majority of the surface water control area of WMA S-SX. An asphalt apron would be constructed around the perimeter of the structure to capture surface water and route that water to a run-off collection system.

**3.5.2.4.1 Implementation at WMA S-SX.** Erection of the overhead structure would be more complicated than typical erections because of tank dome-loading limitations. This option may require larger-than-normal cranes for erection of the structure and coverings. To span the entire width of the S or SX tank farm (104 m [340 ft] or 107 m [350 ft], respectively) would limit the weight of equipment that could be attached to the structure (e.g., monorails; lighting; heating, ventilation, and air conditioning). Engineers would have to determine if foundations could be constructed between the tanks at the S and SX tank farms to decrease the free-span distance and to allow greater auxiliary loading of the structure's supports.

The evaluation of which overhead structure to construct must take into account the free-span distances of 104 m (340 ft) and 107 m (350 ft). To provide a structure with this free span, a rigid-framed structure may be required. An evaluation should be made of intermediate supports to be located between the tanks. This would allow the structure to be equipped with accessories that may increase productivity of future tank farm operations (e.g., monorail; lighting; and heating, ventilation, and air conditioning). The use of intermediate supports would also allow the use of enclosure systems other than a rigid-framed structure.

The evaluation of overhead structures should also include recently emerging or advanced technologies (e.g., a domed structure). This technology is purported to provide greater strengths at less cost than conventional structures.

**3.5.2.4.2 Cost.** The estimated costs presented in the engineering study (Anderson 2001) for implementation of a building enclosure with an asphalt apron are \$18.3 million for the S tank farm and \$20.8 million for the SX tank farm. Depending on the closure technology used at WMA S-SX, a confinement facility would be required (DOE-RL 2000). If a confinement facility were not required, production would be increased 30% by working within an enclosure (Anderson 2001). Credit was not given to these items in determination of the costs.

**3.5.2.5 Recommendation.** The evaluation of three options in the engineering report (Anderson 2001) resulted in a recommendation to implement the overhead structure. This recommendation is based on the summary of the evaluation criteria that ranked the overhead structure lowest for both S and SX tank farms. The estimated cost for the overhead structure is considerably higher than the other options evaluated and this variation is not well captured. For example, the report did not provide credit for an estimated 30% productivity gain for tank farm operations within the enclosure or that enclosure would be required for certain tank farm closure alternatives.

### 3.5.3 Additional Potential Interim Corrective Measures

This section identifies additional potential ICMs for consideration at WMA S-SX. These ICMs generally involve a greater commitment of resources than the ICMs discussed in Section 3.5.2 and require a more thorough site-specific evaluation prior to selecting an ICM for implementation at WMA S-SX. Any evaluation of ICMs must include consideration of continued storage of waste in the tanks and future plans to retrieve waste from the tanks as well as cost versus benefits of the technologies in terms of reducing groundwater impacts. If warranted, detailed evaluation of ICMs for WMA S-SX would be conducted in a CMS. Additional potential ICMs are detailed in Appendix F.

### 3.5.4 Implemented Interim Measures at WMA S-SX

The Tank Farm Vadose Zone Project has implemented the following interim measures at WMA S-SX:

- Installation of water-tight drywell caps
- Abandonment and leak testing of pressurized water lines
- Construction of up-gradient surface water run-on control measures
- Updated and created water line status maps.

**3.5.4.1 Installation of Water-Tight Drywell Caps.** During the baseline spectral logging of tank farm drywells, the logging contractor, MACTEC-ERS, noted that many of the drywells contained standing water. Review of the well construction records revealed that there was no ready way for this water to enter the bores from the subsurface. Significantly, the drywells used caps that were flush with the ground surface so that would not create traffic obstacles. Consequently, some caps were apparently driven over. Leakage of water ponded on the ground surface within the tank farms into the drywells via broken or leaking surface caps appeared to be a likely cause of standing water in some drywells.

In FY 1999, 786 surface-located drywell caps in the SST farms were replaced with new water-tight surface caps, including those at the S and SX tank farms. These caps were obtained, installed, and inspected as the earliest of the tank farm interim measures. The cost of this activity was \$47,000.

**3.5.4.2 Abandonment and Leak Testing of Pressurized Water Lines.** The interim measures engineering report (Anderson 2001) identifies four water lines serving WMA S-SX that should be considered for abandonment. An 8-in. water line and a 6-in. raw water line serving the SX tank farm were determined to be unneeded by the CHG cognizant engineer for the SX tank

farm. These lines were cut and capped in April 2001. The CHG cognizant engineer for the S tank farm determined that a 14 in. raw water line and a 4-in. potable water line serving the S tank farm were needed. These lines were leaked tested in May 2001 and determined to not be leaking. These two lines remain in service. The cost of this activity was \$76,000.

**3.5.4.3 Construction of Upgradient Surface Water Run-On Control Measures.** The interim measures engineering report (Anderson 2001) identifies WMA S-SX as being susceptible to upgradient surface water run-on and ponding. There are two documented incidences of surface water run-on at WMA S-SX. Ponding at the S and SX tank farms was apparent in February 1979 photographs of the effects of rapid melting of snow cover by a Chinook wind. The area of the S and SY tank farms was flooded in 1996 with 2.2 million L (580,000 gal) of water when a 14 in. raw water line broke just east of the SY tank farm. Note that this water line was leak tested in May 2001 and determined not to be leaking.

Upgradient surface water run-on control measures for WMA S-SX were designed in March 2001 and constructed in July 2001. Camden Avenue and 16<sup>th</sup> Street are to become control measures to route surface water run-on around and down-slope of the farms. These measures consist of a combination of regraded and repaved road surfaces, new curbs and gutters, and a valley drain. The cost of this activity was \$265,000.

**3.5.4.4 Updated and Created Water Line Status Maps.** Sixteen water line sketch maps indicating the location, water type, pipe diameter, status, and date of installation were included in the interim measures engineering report (Anderson 2001). These maps were field checked and updated by the water purveyor and tank farm engineers and operators. Because an integrated current set of water-line maps for the 200 East and 200 West Areas does not exist, a set of 60 updated water line status maps, including the S and SX tank farms, was released in 2001. The cost of this activity was \$25,000.

**3.5.4.5 Decommissioned Unfit-for-Use Wells.** The interim measures engineering report (Anderson 2001) identified six wells in the S and SX tank farms that were potential Priority 1 unfit-for-use wells for near-term decommissioning. Priority 1 wells are those dry or abandoned groundwater wells that present the highest risks to groundwater. Many of these wells come into contact with groundwater or are in detrimental locations. Four Priority 1 wells was decommissioned during FY 2000; however, none of these wells were located in WMA S-SX.

**3.5.4.6 Technetium-99 in Groundwater.** An assessment is planned to determine the appropriateness of an interim measure addressing the elevated concentration of technetium-99 in well 299-W23-19. This assessment will be conducted early in FY 2002 and will consist of two phases.

- **Phase 1:** The well will be restored to its full depth configuration and an aquifer test will be performed to ascertain the aquifer properties at this site and sustainable yield of the well. This phase consists of conducting a step-drawdown test and a short-term (72 hour) active pumping aquifer test followed by a recovery test. The data derived from this test will be analyzed to determine how effective a pump and treat remediation system might be and to provide design input to such a system.

- **Phase 2:** Based on the analysis of Phase 1 data, a long-term (60 to 90 day) periodic (daily) pumping of the well with regular sampling may be carried out. This phase of the testing will be used to help determine the extent and sustainability of the high concentrations of technetium-99.

Based on the results of both Phase 1 and Phase 2, a recommendation will be made on whether or not to proceed with an interim remedial measure (pump and treat) at this site.

#### 4.0 SUMMARY AND CONCLUSIONS OF THE IMPACT (RISK) EVALUATION

An impact evaluation using a suite of numerical simulations was performed to predict long-term human health risks from potential groundwater contamination from WMA S-SX. The evaluation also predicted human health risk at four defined points of compliance using groundwater exposure scenarios. The base case assumes no interim barriers are placed on the WMA before a long-term closure barrier is installed at year 2040. The major sensitivity cases involve placement of an interim barrier over the WMA and the sensitivity of the results to inventory distribution and recharge rate assumptions. The scope and parametric data for these simulations were defined by a modeling data package (Khaleel et al. 2000). This section summarizes results for the 13 simulated cases involving two-dimensional cross-sections through WMA S-SX and one three-dimensional domain of a single tank (quarter symmetry) within the WMA. Risk and dose were evaluated using *Hanford Site Risk Assessment Methodology* (HSRAM) (DOE-RL 1995b) and "Model Toxics Control Act" (MTCA) Method B (unrestrictive) and Method C (industrial) exposure scenarios.

The major findings are described below.

- Predicted groundwater concentrations for technetium-99, nitrate, and chromium exceeded the drinking water standard (40 CFR 141) at the WMA S-SX boundary for all cases except for projected nitrate groundwater concentrations for the two low recharge cases (i.e., 30 and 10 mm/yr).
- Incremental lifetime cancer risk (ILCR) ranges from  $9.98 \times 10^{-3}$  to  $8.82 \times 10^{-5}$  at the WMA S-SX boundary for the industrial worker scenario. The hazard index ranges from  $3.0 \times 10^2$  to  $7.7 \times 10^{-1}$  at the WMA S-SX boundary for the industrial worker scenario. Technetium-99 is the key CoC for the ILCR, while chromium and nitrate is the key CoC for the hazard index. Regulatory exceedances are  $1.0 \times 10^{-5}$  for ILCR and 1.0 for hazard index.

Section 4.1 presents the numerical modeling approach. Section 4.2 discusses the numerical simulation results. Section 4.3 presents the human health risk and dose estimation approach. Section 4.4 presents the results of the human health risk and dose estimation evaluation and how these values compare to DQO for WMA S-SX and the regulatory standards. Details on the modeling approach, data used, and numerical simulations are presented in Appendix E.

#### 4.1 NUMERICAL MODELING APPROACH

The numerical simulations were performed with the STOMP (Subsurface Transport Over Multiple Phases) simulator (White and Oostrom 2000a, 2000b). The simulations consider the distribution of contaminants presently in the vadose zone and the migration of the contaminants through the vadose zone to groundwater and to points of compliance within the unconfined aquifer. Four contaminant species (cesium-137, technetium-99, chromium, and nitrate) representing the range of mobile and immobile constituents were considered in the migration and risk analyses. The suite of two-dimensional simulations were used to investigate the impact of the no action alternative (which includes a surface closure barrier); interim surface barriers; water-line leaks; clastic dikes; nonuniform inventories; concentration-dependent density and viscosity for the transporting fluid (i.e., water); and meteoric recharge. A three-dimensional simulation was used to investigate the impact of dimensionality on the numerical predictions.

The simulations do not attempt to model a tank leak itself but model the potential risk posed by past tank leaks, as quantified by existing contamination within the vadose zone. All simulations are composed of steady-flow and transient components, where flow fields developed from the steady-flow component were used to initialize the transient simulation. Steady-state initial conditions were developed by simulating from a prescribed unit hydraulic gradient condition to a steady-state condition, dictated by the initial meteoric recharge at the surface, water table elevation, water table gradient, no flux vertical boundaries, variation of hydrologic properties, and location of impermeable tanks. From the starting conditions, transient simulations of solute transport were conducted for a 1,000-year period (i.e., years 2000 to 3000) that involved changes in the flow fields in response to placement of surface barriers, water-line leaks, or solute-concentration-dependent density and viscosity. All simulations were run assuming isothermal conditions, an assumption supported by the Integration Project S&T activity modeling work (Appendix D). The vadose zone was modeled as an aqueous-gas porous media system, where transport through the gas phase was neglected. All but one simulation used the infinite dilution assumption for coupling fluid flow and contaminant transport. The solute-concentration-dependent density and viscosity run coupled aqueous-phase density with the concentration of a single contaminant, sodium nitrate.

Fluid flow within the vadose zone is described by Richards' equation, whereas the contaminant transport is described by the conventional advective-dispersive transport equation with an equilibrium linear sorption coefficient ( $K_d$ ) formulation. Detailed stratigraphic cross-sectional models are presented in Appendix E, Figures E.2 through E.4; the models include the effect of dipping strata. The enhanced spreading at the fine-grained/coarse-grained interfaces and the increased downdip movement of the plume along these interfaces are included in the model.

For two-dimensional cross-sectional models, three representative (west-east) cross-sectional models for the S and SX tank farms (Figure 1.2) are considered:

- Cross-section through tanks SX-107, SX-108, and SX-109
- Cross-section through tanks SX-113, SX-114, and SX-115
- Cross-section through tanks S-104, S-105, and S-106.

Note that, in the discussion below and elsewhere, the three cross-sections are labeled in two ways. For example, the cross-section containing tanks SX-107, SX-108, and SX-109 is often labeled as SX-DD'. Similarly, SX-FF' refers to the cross-section containing tanks SX-113, SX-114, and SX-115; and S-CC' refers to the cross-section containing tanks S-104, S-105, and S-106. Detailed descriptions of individual cases are included in Appendix E, Section E.2.1.

A principal objective of this investigation was to evaluate the effectiveness of interim barriers to the infiltration (recharge) of meteoric water (from winter precipitation and snowmelt) on the migration of contaminants from previous leak sources. The reference suite of simulations (base case) considered the migration of contaminants from field estimates of concentration distributions through the vadose zone and groundwater to the WMA S-SX boundary with no interim barriers but a closure barrier by the year 2040. The timeline for emplacement of the interim and closure barriers and the corresponding recharge estimates used in the base case simulation are indicated in Table 3.1 and also in Appendix E, Table E.1.

Inventory estimates are considered to be a critical factor in calculations, and uncertainties in inventories are considered. The postulated conceptual model uses the recently collected data on technetium-99 and other constituents from borehole 41-09-39, borehole 299-W23-19 near tank SX-115, and the MACTEC-ERS cesium-137 plume data (Appendix E). It is assumed that no tank leaks will occur in the future. Also, it is assumed that, as part of 'good housekeeping,' water-line leaks from existing piping are addressed and resolved. However, as part of sensitivity analysis, simulations are run to evaluate long-term effects of water-line leaks in the vicinity of tank SX-115. The umbrella-shaped dome structure of the tank and shedding of water are simulated. Sediments adjacent to the tanks attain elevated water contents and, while remaining unsaturated, they develop what is known as moisture-dependent anisotropy. Such effects are simulated in the model (Appendix E). Numerical results are obtained for compliance at the WMA boundary, 200 West fence boundary, 200 Area exclusion boundary, and the Columbia River. Except for the 200 West fence boundary, these boundaries are based on DOE-RL (2000). Instead of the 200 West fence boundary, DOE-RL (2000) refers to the 200 Areas boundary. However, since the 200 Areas and the exclusion boundaries are relatively close, the 200 Areas boundary is replaced by the 200 West fence boundary. The focus of the report is at the WMA boundary. Ecology through DOE-RL (2000) required that three additional points of compliance be examined.

Simulation of flow and transport through each cross-section generates a breakthrough curve (BTC) (Appendix E). The temporal and spatial distribution for each of these BTCs are recognized and the principle of superposition is used to generate a composite BTC at the compliance boundary. An analytical/streamline approach is used to route the BTCs through the unconfined aquifer to the compliance boundaries (Appendix E). The BTCs are converted into dose estimates using appropriate factors (Appendix E).

## 4.2 NUMERICAL SIMULATION RESULTS

A brief description of the simulation cases is provided in Table 4.1. The physical domains for the two-dimensional simulations were east-west sections across the WMA S-SX boundary. These domains were discretized with grid resolutions of 0.5334 m (1.75 ft) in the horizontal direction and 0.4572 m (1.5 ft) in the vertical direction, yielding 42,900- to 48,516-node grids. The simulations involving a clastic dike used grid refinement to include the clastic dike, yielding 50,232-node grids. The physical domain for the three-dimensional simulation was a quarter section of tank SX-108. This domain was modeled at the same grid resolution as the two-dimensional simulations, yielding a 119,422-node grid. Execution times for these simulations varied from 20 to 120 hours, with the longest executions occurring for the three-dimensional simulations and the density- and viscosity-dependent two-dimensional simulations. Mass balance errors over the 1,000-year simulation period for the solute species ranged between  $2.06 \times 10^{-7}\%$  to  $5.94 \times 10^{-5}\%$  for pressure- and temperature-dependent density and viscosity, and between  $2.19 \times 10^{-2}\%$  and  $9.83 \times 10^{-2}\%$  for those simulations involving nitrate-concentration-dependent density and viscosity.

**Table 4.1. Case Descriptions for the Two-Dimensional Simulations**

Case No.	Description*	Interim Barrier	Inventory Distribution	Meteoric Recharge mm/yr
1	Base case (no action alternative)	No	Uniform	100
2	Barrier alternative	Yes	Uniform	100
3	Water-line leak (25,000 gal)	No	Uniform	100
4	Clastic dike	No	Uniform	100
5	Nonuniform inventory	No	Nonuniform	100
6	Nonuniform inventory with barrier	Yes	Nonuniform	100
7	Displaced nonuniform inventory	No	Displaced	100
8	Density and viscosity effects	No	Uniform	100
9	Base case with 50% recharge	No	Uniform	50
10	Base case with 30% recharge	No	Uniform	30
11	Base case with 10% recharge	No	Uniform	10
12	Alternative inventory	No	Alternate	100
13	Water-line leak (200,000 gal)	No	Uniform	100

\*See Section E.2.1 of Appendix E for details on each case.

As indicated earlier, contaminant concentrations at the WMA S-SX boundary were translated to the other three compliance points (i.e., 200 West fence, 200 Area exclusion boundary, and Columbia River shoreline). Simulated results for the base case scenario predicted arrivals of peak concentrations for technetium-99 in the following sequence:

- WMA S-SX boundary, year 2046
- 200 West fence, year 2181
- 200 Area exclusion boundary, year 2344
- Columbia River shoreline, year 2545.

Arrival times for peak concentrations for chromium and nitrate were similar to those for technetium-99; the variations primarily resulted from the initial inventory distributions. Because of its retardation factor and radioactive decay, cesium-137 was undetected at the WMA S-SX boundary for all simulation runs.

Tables 4.2 through 4.4 provide a summary of the simulated peak time and concentration for each simulation case for the three species at various compliance points. As described in Appendix E, Tables 4.2 through 4.4 are obtained by combining releases from the three cross-sections using a weighted area approach. Table 4.5 shows the changes in peak concentrations for the three species compared to the base case. Base case area-weighted (Appendix E) BTCs for the three species are shown in Figures 4.1 through 4.3. Note that the slight increase in concentration toward the end of each simulation is due to the assumed increase in recharge rate for the degraded barrier.

**Table 4.2. Simulated Peak Concentrations and Arrival Times for Technetium-99  
(DWS 900 pCi/L) at Various Compliance Boundaries**

Tc-99 Conc. (pCi/L)	WMA S-SX		200 West Fence		Exclusion Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.	Time	Conc.
Case 1	2046	6.85E+04	2181	4.89E+03	2344	3.80E+02	2545	1.28E+02
Case 2	2030	2.90E+04	2179	1.91E+03	2341	1.47E+02	2543	5.11E+01
Case 3	2046	6.74E+04	2180	4.89E+03	2344	3.79E+02	2545	1.29E+02
Case 4	2046	6.83E+04	2181	4.89E+03	2344	3.79E+02	2545	1.28E+02
Case 5	2044	7.49E+04	2179	5.29E+03	2342	4.11E+02	2543	1.39E+02
Case 6	2029	3.44E+04	2178	2.09E+03	2340	1.62E+02	2542	5.61E+01
Case 7	2011	1.71E+05	2149	6.89E+03	2314	5.42E+02	2514	1.78E+02
Case 8	2046	6.92E+04	2180	4.96E+03	2344	3.85E+02	2545	1.30E+02
Case 9	2061	3.53E+04	2203	2.50E+03	2365	1.91E+02	2567	6.67E+01
Case 10	2075	1.74E+04	2223	1.32E+03	2384	9.97E+01	2586	3.54E+01
Case 11	3000*	4.34E+03	2312	3.08E+02	2471	2.26E+01	2673	8.28E+00
Case 12	2046	6.87E+04	2180	4.95E+03	2344	3.84E+02	2545	1.30E+02
Case 13	2047	6.31E+04	2179	4.76E+03	2342	3.68E+02	2543	1.25E+02

\*Peak concentrations continue to increase for a 1,000-year simulation period because of the long residence time within the vadose zone for the low recharge rate.

DWS = drinking water standard (40 CFR 141).

**Table 4.3. Simulated Peak Concentrations and Arrival Times for  
Chromium (DWS 50 µg/L) at Various Compliance Boundaries**

Cr Conc. (µg/L)	WMA S-SX		200 West Area Fence		Exclusion Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.	Time	Conc.
Case 1	2052	7.33E+03	2191	4.49E+02	2354	3.49E+01	2556	1.19E+01
Case 2	2057	1.02E+03	2210	8.55E+01	2370	6.44E+00	2573	2.31E+00
Case 3	2052	7.34E+03	2191	4.52E+02	2354	3.51E+01	2555	1.20E+01
Case 4	2052	7.30E+03	2191	4.47E+02	2354	3.48E+01	2556	1.18E+01
Case 5	2051	8.71E+03	2188	5.23E+02	2351	4.08E+01	2552	1.38E+01
Case 6	2051	1.29E+03	2205	1.03E+02	2365	7.76E+00	2568	2.77E+00
Case 7	2017	1.49E+04	2157	7.78E+02	2321	6.09E+01	2522	2.02E+01
Case 8	2052	7.42E+03	2191	4.55E+02	2354	3.54E+01	2555	1.20E+01
Case 9	2074	2.04E+03	2226	1.54E+02	2386	1.17E+01	2589	4.14E+00
Case 10	2119	6.38E+02	2272	5.55E+01	2430	4.11E+00	2632	1.50E+00
Case 11	3000*	3.86E+02	3000*	7.27E+00	2771	5.13E-01	2972	1.89E-01
Case 12	2052	7.28E+03	2191	4.51E+02	2354	3.51E+01	2555	1.19E+01
Case 13	2052	7.20E+03	2189	4.55E+02	2353	3.53E+01	2554	1.20E+01

\*Peak concentrations continue to increase for a 1,000-year simulation period because of the long residence time within the vadose zone for the low recharge rate.

DWS = drinking water standard (40 CFR 141).

**Table 4.4. Simulated Peak Concentrations and Arrival Times for Nitrate (DWS 45,000 µg/L) at Various Compliance Boundaries**

NO <sub>3</sub> Conc. (µg/L)	WMA S-SX		200 West Fence		Exclusion Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.	Time	Conc.
Case 1	2041	1.28E+05	2178	9.49E+03	2342	7.37E+02	2542	2.49E+02
Case 2	2029	6.88E+04	2177	4.31E+03	2339	3.34E+02	2541	1.15E+02
Case 3	2041	1.27E+05	2178	9.50E+03	2341	7.38E+02	2542	2.50E+02
Case 4	2041	1.28E+05	2178	9.46E+03	2342	7.35E+02	2542	2.49E+02
Case 5	2038	1.39E+05	2176	1.02E+04	2340	7.96E+02	2540	2.69E+02
Case 6	2027	8.41E+04	2175	4.81E+03	2337	3.73E+02	2539	1.29E+02
Case 7	2007	3.57E+05	2148	1.31E+04	2312	1.03E+03	2513	3.39E+02
Case 8	2041	1.29E+05	2178	9.61E+03	2341	7.47E+02	2542	2.52E+02
Case 9	2058	7.76E+04	2199	5.32E+03	2361	4.09E+02	2563	1.42E+02
Case 10	2074	4.12E+04	2221	3.04E+03	2382	2.31E+02	2584	8.17E+01
Case 11	2167	8.45E+03	2315	7.45E+02	2473	5.48E+01	2676	2.01E+01
Case 12	2039	1.28E+05	2177	9.63E+03	2340	7.48E+02	2541	2.53E+02
Case 13	2041	1.21E+05	2177	9.42E+03	2340	7.30E+02	2541	2.48E+02

\*Peak concentrations continue to increase for a 1,000-year simulation period because of the long residence time within the vadose zone for the low recharge rate.

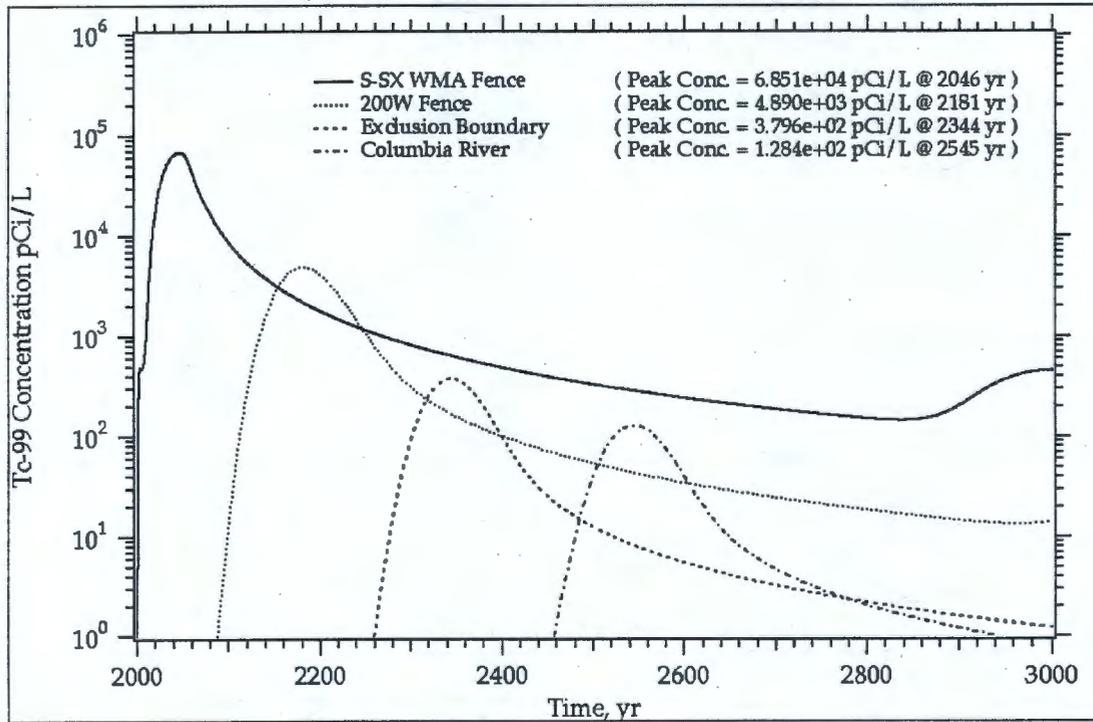
DWS = drinking water standard (40 CFR 141).

**Table 4.5. Percent Change in Technetium-99 Peak Concentration as a Percentage of the Base Case 1 (Recharge 100 mm/yr, interim barrier [recharge 0.5 mm/yr] by 2010, closure barrier [recharge 0.1 mm/yr] by 2040) Peak Concentration**

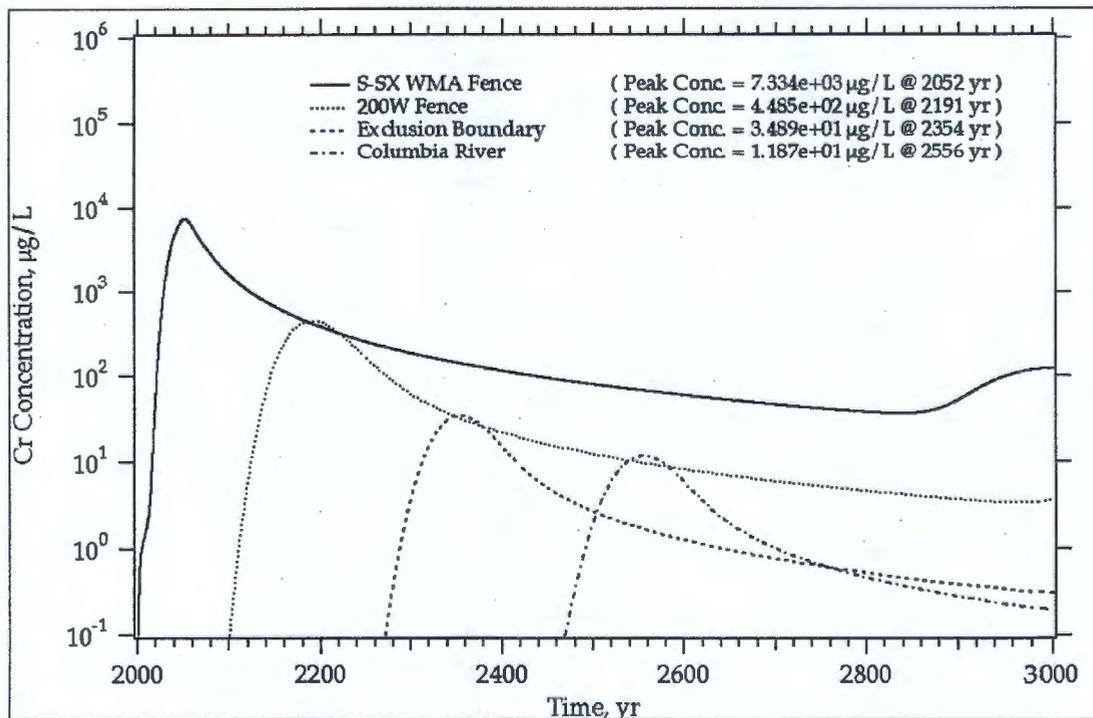
Case No.	Percent Change* in Peak Concentration from Base Case		
	Technetium-99	Chromium	Nitrate
1	100	100	100
<b>Variations in Inventory</b>			
5	109	119	109
7	249	203	279
12	100	99	100
<b>Variations in Recharge</b>			
9	52	28	61
10	25	9	32
11	6	5	7
<b>Barrier Effects with Uniform Inventory</b>			
2	42	14	54
<b>Barrier Effects with Nonuniform Inventory</b>			
6	50	18	66
<b>Water-Line Leak Effects</b>			
3	98	100	99
13	92	98	95
<b>Clastic Dike Effects</b>			
4	100	100	100
<b>Density and Viscosity Effects</b>			
8	101	101	101

\*Except for Case 6, percent changes for all cases were with respect to the base case. For Case 6, percent changes were with respect to Case 5.

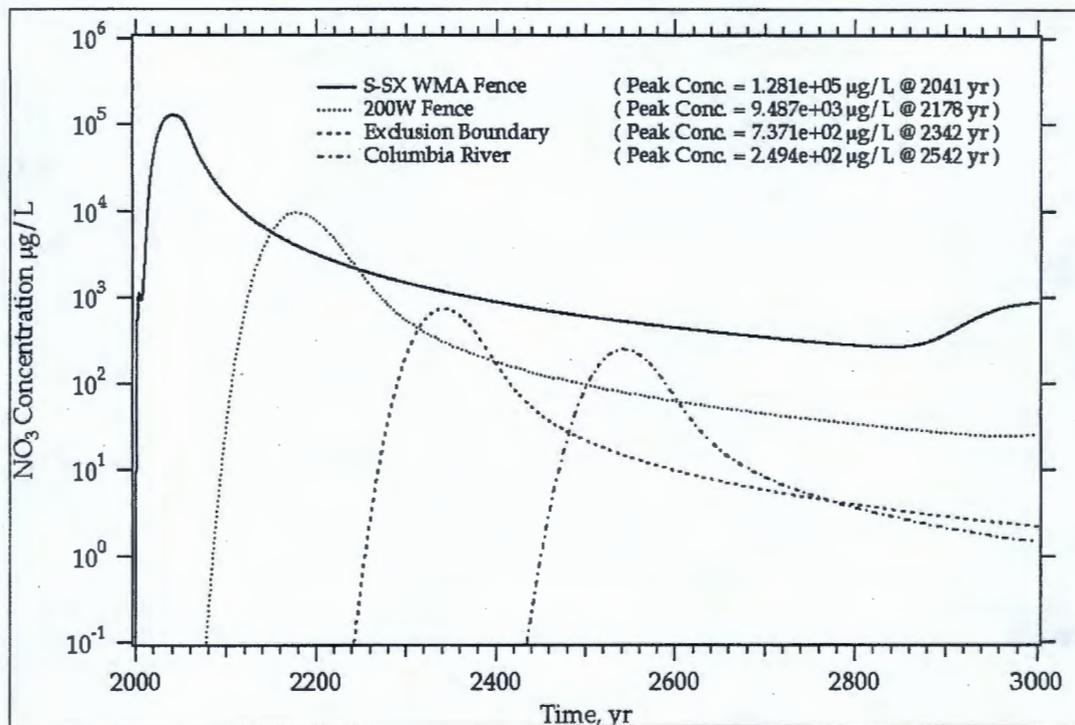
**Figure 4.1. Base Case Area-Weighted Average Technetium-99 Concentration and Dose versus Time at Compliance Points**



**Figure 4.2. Base Case Area-Weighted Average Chromium Concentration versus Time at Compliance Points**



**Figure 4.3. Base Case Area-Weighted Average Nitrate Concentration versus Time at Compliance Points**



The impact of an interim surface barrier was investigated by altering the base case (Case 1) simulation to include an interim barrier in place by the year 2010 (Case 2). Results showed that, with the interim barrier, the peak concentrations were reduced by 58, 86, and 46% for technetium-99, chromium, and nitrate, respectively (Table 4.5). Peak concentrations, translated to the remote compliance points, were similarly reduced. An earlier placement of the interim barrier will further delay arrival times and reduce the peak concentrations at the compliance points.

The effect of initial contaminant inventory distributions on BTCs was investigated by varying the base case contaminant inventory distributions. In each of these variations, the integrated quantity of contaminant mass (Ci or kg) was conserved (i.e., held equal to the values reported in Appendix E, Attachment E1). In the first variation (Case 5), the solute mass was concentrated in the region between tanks—the tank ‘umbrella-effect’ region. In the second variation (Case 7), the solute mass was concentrated in the region between tanks and displaced toward the water table. In the third variation (Case 12), the solute mass was uniformly distributed over a prescribed circular area below the tanks (i.e., tank diameter). When compared against the uniform distribution, the nonuniform distribution (Case 5) showed little change in peak arrival times and peak concentrations at the four compliance points, primarily because of the homogenizing effect of the Plio-Pleistocene unit. For example, peak concentrations of technetium-99 for the nonuniform distribution (Case 5) at the WMA S-SX boundary were only 9% higher than the base case estimate (Table 4.5). A similar trend was observed for other species (Table 4.5).

The displaced-nonuniform distribution (Case 7) is an extreme scenario that was used to evaluate the effect of the Plio-Pleistocene unit on the BTCs. In this scenario, unlike the nonuniform (Case 5) distribution, the solute mass was displaced well beyond the Plio-Pleistocene unit; the unit has high moisture-holding capacity and consequently a homogenizing effect on the solute front. As expected, the displaced-nonuniform inventory simulations showed markedly earlier peak arrival times and higher concentrations for technetium-99 at the four compliance points. Peak technetium-99 concentration at the WMA S-SX boundary was 149% higher than that for the base case uniform distribution (Table 4.5). For the alternate distribution (Case 12), peak technetium-99 concentration at the WMA S-SX boundary was nearly unchanged compared to the base case (Table 4.5).

To investigate the impact of meteoric recharge on contaminant transport, a series of simulations were performed, using uniform inventory distributions and no interim barriers but having different surface recharge for the first 40 years, compared to the base case (100 mm/yr). Case 9 had a 50 mm/yr recharge rate; Case 10 had a 30 mm/yr recharge rate; and Case 11 had a 10 mm/yr recharge rate. In all cases, the closure barrier was assumed to control recharge beyond the first 40 years. The initial flow field for these simulations was the steady-state condition for the prescribed meteoric recharge rate and fixed groundwater conditions (i.e., water table conditions and gradient). As expected, lowering meteoric recharge delayed peak arrival times and reduced peak concentrations at the compliance points (Table 4.5). The exception was the 10 mm/yr recharge case (Case 11), where arrival times were delayed beyond 1,000 years. However, because of the late arrival, the peak concentrations for the low-recharge case continued to increase for the 1,000-year simulation. Nonetheless, the concentration at the WMA boundary, after 1,000-year simulation, was still well below those for other recharge rates. Figures 4.4 through 4.7 show the recharge effects on technetium-99 BTCs at the first compliance point for various cross-sections. The BTCs followed the expected behavior, with differences among the cross-sections related primarily to how the initial inventories were distributed within the vadose zone. Figure 4.8 is an area-weighted BTC for technetium-99 at the WMA for different recharge cases.

A second suite of simulations was performed for Case 5 (nonuniform inventory) simulation having an interim barrier (Case 6). Results showed responses similar to those for uniform inventory cases with (Case 2) and without (Case 1) an interim barrier. Compared to that for Case 5, Case 6 peak technetium-99 concentration at the WMA S-SX boundary was lowered by about 50% (Table 4.5). Such a reduction was similar to that for uniform inventory cases with (Case 2) and without (Case 1) an interim barrier (Table 4.5).

Figure 4.4. Unaltered Breakthrough Curves for Technetium-99 at the WMA S-SX Boundary for the Three Simulated Cross-Sections (Recharge = 100 mm/yr)

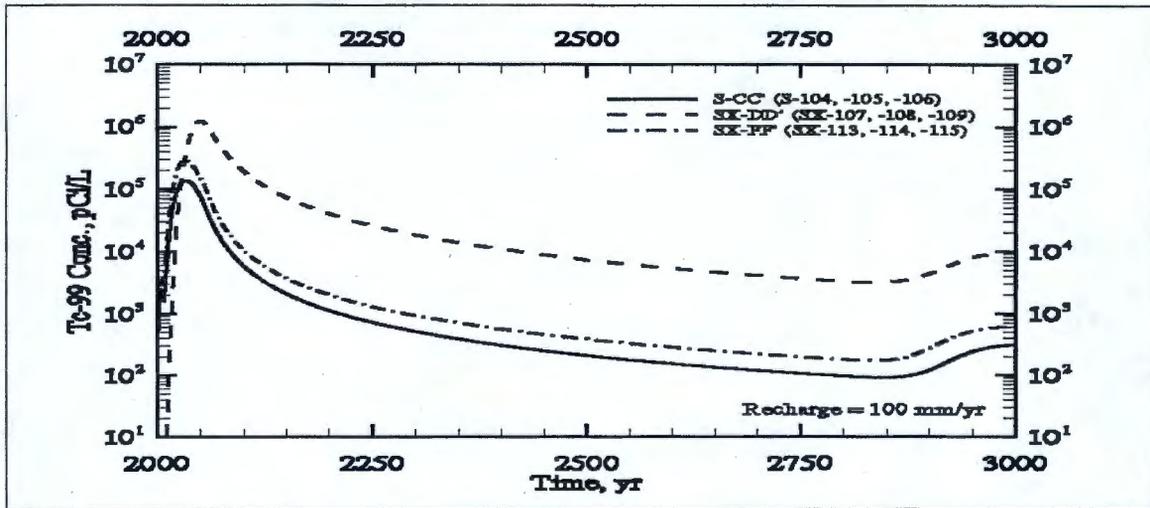


Figure 4.5. Unaltered Breakthrough Curves for Technetium-99 at the WMA S-SX Boundary for the Three Simulated Cross-Sections (Recharge = 50 mm/yr)

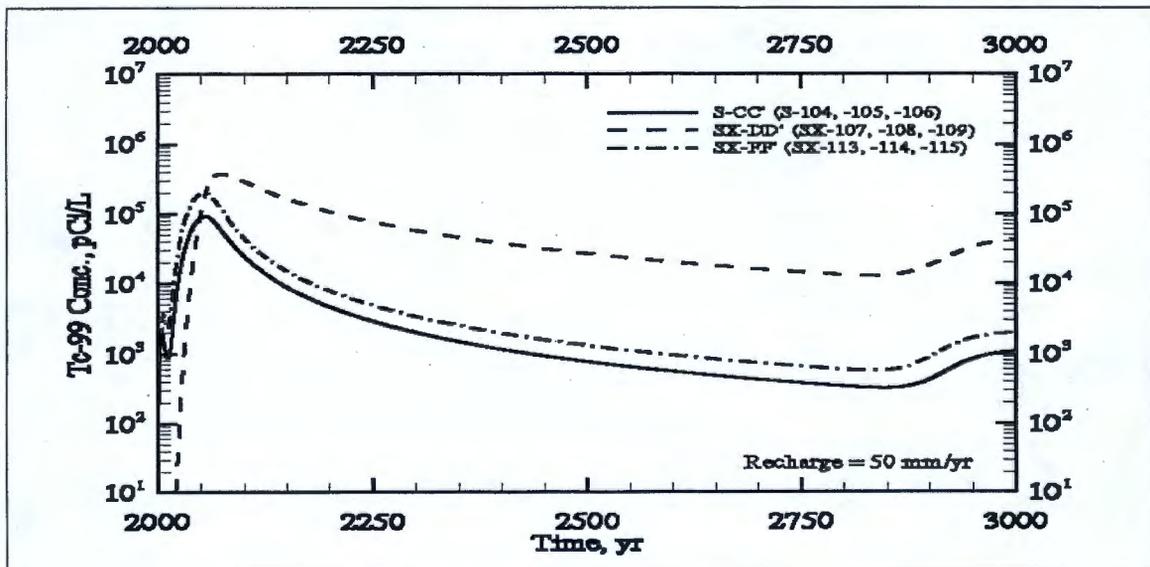


Figure 4.6. Unaltered Breakthrough Curves for Technetium-99 at the WMA S-SX Boundary for the Three Simulated Cross-Sections (Recharge = 30 mm/yr)

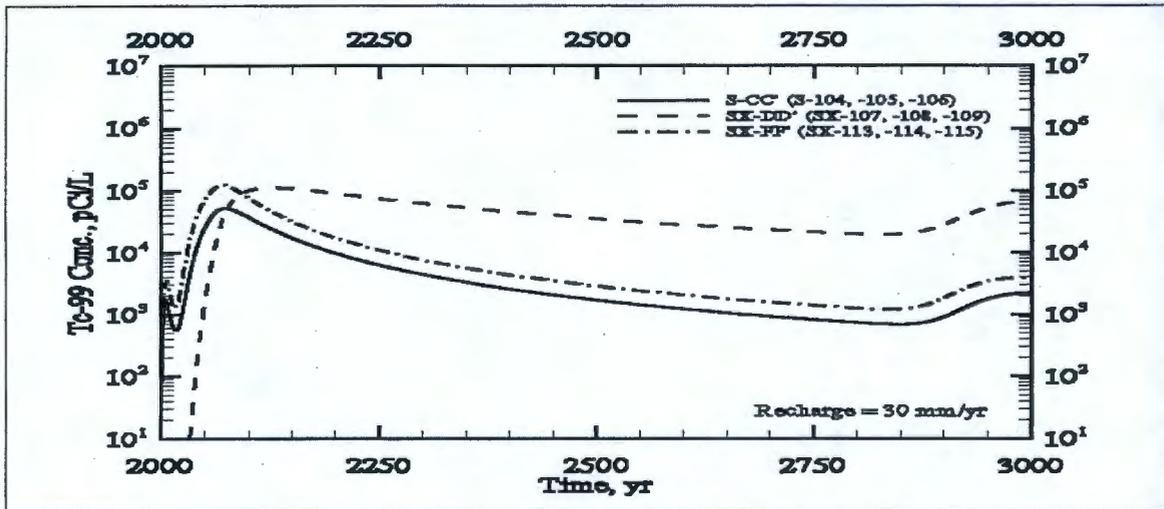
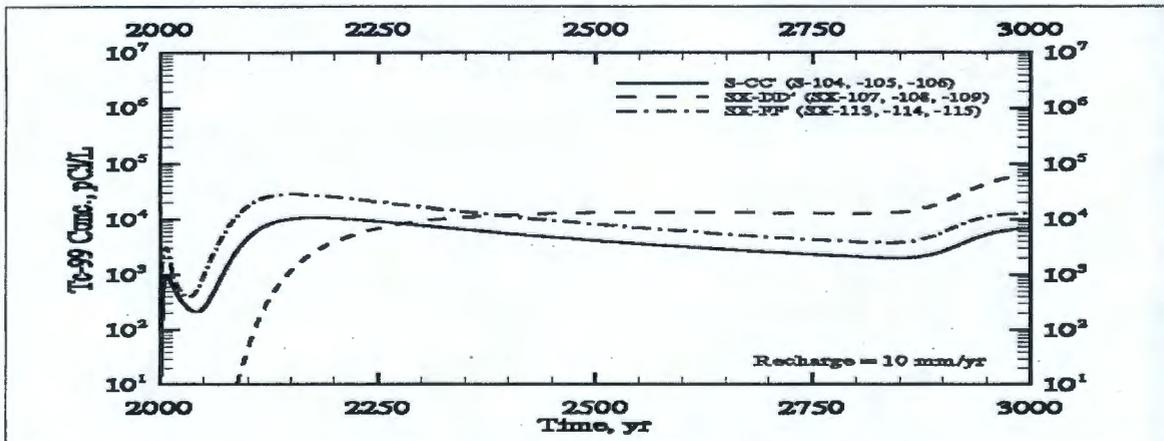
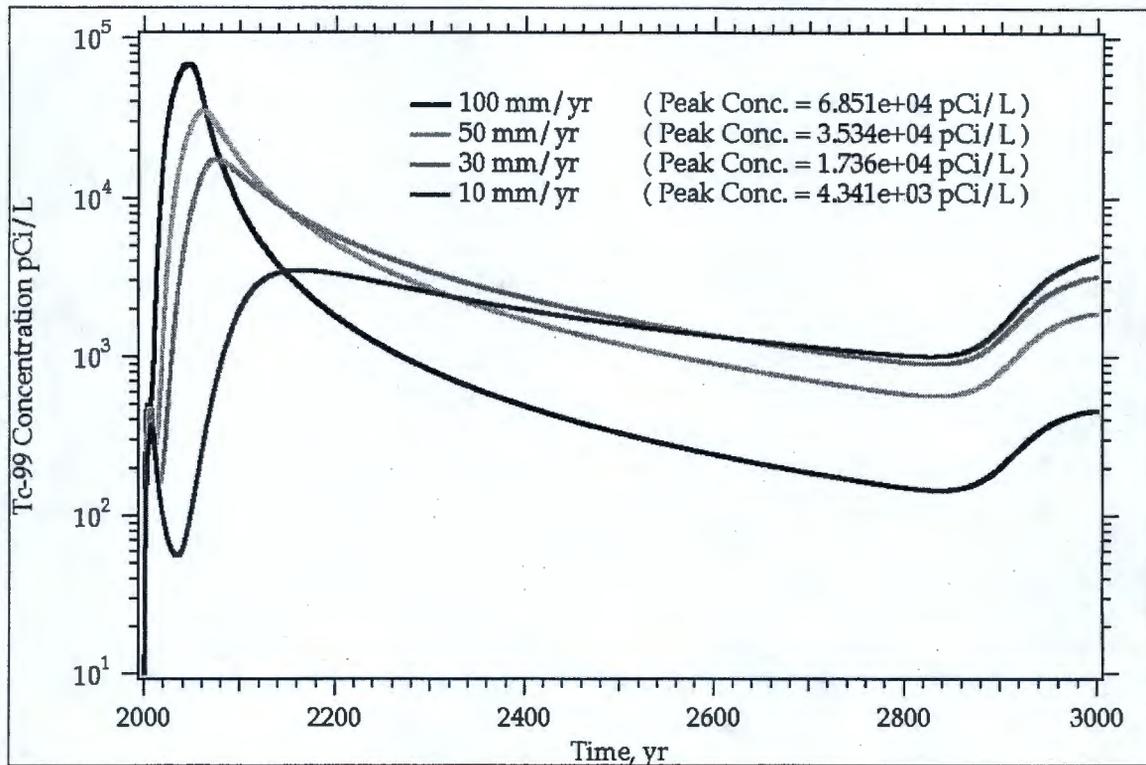


Figure 4.7. Unaltered Breakthrough Curves for Technetium-99 at the WMA S-SX Boundary for the Three Simulated Cross-Sections (Recharge = 10 mm/yr)



**Figure 4.8. Averaged Breakthrough Curves for Technetium-99 at the WMA S-SX Boundary for the Three Simulated Cross-Sections and for Various Recharge Rates**



The impact of a soil-saturating water-line leak was investigated by altering the base case simulation to include a water-line leak near the dome of tank SX-115. Note that the simulated water-line leak scenarios were not designed to be representative of the leak events that actually occurred near tank SX-115 and are discussed in Section 3.4.2. Two water-line leak cases were simulated: 25,000 gal over a 5-day period (Case 3) and 200,000 gal over a 5-day period (Case 13). For the 25,000 gal leak, simulation results showed that this quantity of water was sufficient to saturate the soil between tanks SX-114 and SX-115, but the plume rapidly diffused as it migrated down through the vadose zone, thus having negligible impact below the Plio-Pleistocene unit. Peak concentrations and arrival times at the four compliance points were essentially unchanged from the base case simulations, demonstrating that the single-event 25,000 gal leak had negligible impact on contaminant migration. For the 200,000 gal leak, leak water migrated over the tank domes and descended rapidly to the groundwater. For the 200,000 gal leak, arrival times were shortened but the shape of the BTCs and the peak concentrations (Table 4.5) were only slightly altered.

Clastic dikes, near-vertical geologic features filled with unconsolidated sediments, have been postulated to form a polygonal pattern in the vicinity of WMA S-SX. The influence of a single clastic dike (Case 4), situated between tanks SX-108 and SX-109, which extended vertically from the base of the tanks to the top of the Plio-Pleistocene unit, was investigated as an alteration to the base case simulation. This suite of simulations used an altered grid for cross-section SX-DD' compared with the base case simulation, where grid refinement was used to include the

clastic dike. Peak concentrations (Table 4.5) and arrival times for technetium-99 for the clastic dike simulations at the four compliance points were nearly identical to those for the base case, demonstrating the negligible influence of a single clastic dike situated outside the initial contaminant inventory domain. Such results for a simulated clastic dike are consistent with other Hanford Site impact assessments (Wood et al. 1995; Mann et al. 2001).

The base case simulations considered the concentration of transported solutes as having no influence on the properties of the carrier fluid (i.e., the infinitely dilute assumption). At the field-measured concentrations, however, the density and viscosity of water is dependent on the concentration of dissolved solutes, especially sodium nitrate. To investigate the influence of concentration-dependent fluid properties, a suite of simulations (Case 8) were performed that varied from the base case in that the aqueous-phase density and viscosity were considered to be a function of the sodium nitrate concentration, as determined by the concentration of dissolved nitrate. Results from these simulations showed nearly same earlier arrival time of the peak concentration and slightly higher peak concentration for technetium-99 at the WMA S-SX boundary (Table 4.5). The chromium and nitrate BTCs showed similar trends. These results indicate that density and viscosity effects have minimal impact on the migration of contaminants through the vadose zone beneath WMA S-SX, partially because of the influence of the Plio-Pleistocene unit.

A three-dimensional simulation of tank SX-108 (modeled in quarter symmetry) was performed to provide a quantitative comparison against the two-dimensional cross-section simulations. To isolate the influence of domain dimensionality, the geology of the three-dimensional domain was developed by extrapolating the east-west cross-section geology in the north-south direction. In addition, the horizontal and vertical grid spacings were unaltered from the base case simulations. The three-dimensional simulation was executed following the base case scenario (i.e., no interim barrier, no water-line leaks, and a closure barrier by 2040). The resulting flow fields and solute migration results at the water table show close agreement compared to the two-dimensional base case simulations (Appendix E). Three-dimensional simulation results indicate that errors associated with analyzing WMA S-SX using two-dimensional cross-sections are minimal for the base case.

The major observations and conclusions, based on the numerical modeling, are as follows.

- The contaminant inventories have a major influence on the peak concentrations and arrival times of long-lived mobile radionuclides and chemical species at the WMA S-SX boundary. Several variations of the inventory distributions were considered. A comparison of the unaltered (i.e., not averaged) BTCs at the first compliance boundary for the three cross-sections suggests that the inventory mass (i.e., Ci or kg) has a much more significant influence on the BTCs than the spatial distribution of the contaminants.
- Recharge estimates have a major influence on the peak concentrations and their arrival times. No tank farm-specific recharge estimates are presently available. The base case infiltration rate of 100 mm/yr was essentially based on lysimeter data for gravel-covered, nonvegetated surfaces that mimic tank farm conditions. Additional studies to better refine the infiltration rates at the tank farms should be considered. Also, because of its

importance, efforts at reducing the current infiltration rates at the tank farms prior to retrieval or closure should be explored.

- The Plio-Pleistocene unit, with its higher moisture-holding capacity and favorable hydraulic properties, can delay migration of contaminants to the water table. The homogenizing effect of the Plio-Pleistocene unit is evident from simulations that considered variations in spatial variability of the vadose zone contaminant inventory. BTCs for cases with nonuniform distribution were similar to those for cases with uniform distribution. While the Plio-Pleistocene unit can prolong the vadose zone residence time, contaminants do eventually break through the unit.
- Limited work on the effect of potential preferential flow paths resulting from clastic dikes suggests that these did not have a major influence on the long-term simulations and BTCs. Such results are consistent with other long-term impact assessments at the Hanford Site.
- The interim surface barriers, as expected, reduce fluxes to the water table. The technetium-99 peak concentrations were reduced by over a factor of two with placement of barriers. Numerical simulation results (Appendix E) suggest that the impact of the interim barrier on lowering peak concentrations is most affected by the location of the initial inventory distribution within the vadose zone.
- Simulated peak technetium-99 concentrations are considerably higher than those measured by the groundwater monitoring wells in the vicinity of the WMA. The measured technetium-99 concentrations for well 299-W23-19 directly east-southeast of tank SX-115 have shown a persistent upward trend (technetium-99 concentration in well 299-W23-19 increased from 39,000 pCi/L in October 1999 to 81,500 pCi/L in March 2001). Numerical simulations (Appendix E) for the base case suggest that peak technetium-99 concentrations for the unaltered (not averaged) BTCs were 4 times (for cross-section SX-FF') to 15 times (for cross-section SX-DD') larger than the highest measured technetium-99 in monitoring wells.

It should be noted that all simulations were run using an isothermal model. Such an assumption is supported by a comparison of simulation results for non-isothermal and isothermal runs (Appendix D). Non-isothermal model simulations indicate that during periods of high heat loads in the fifties and sixties the thermal load from the boiling waste tanks altered flow patterns and caused large-scale redistribution of moisture. As a result, fluid and vapor flow near the high-heat tanks was dominated by vapor-liquid counterflow. Therefore, to understand the historical behavior, it is important to consider the strong coupling between the thermal and hydrologic environments. However, for impact assessment, simulations of technetium-99 migration into the future, on the basis of the current thermal conditions in WMA S-SX, were not significantly different for isothermal and non-isothermal conditions (Appendix D). Nonetheless, for investigations of future tank leaks from retrieval activities (e.g., sluicing), the coupled nature of the thermal and hydrologic environments may have to be considered (Appendix D).

### 4.3 HUMAN HEALTH RISK AND DOSE ESTIMATION APPROACH

This section presents the approach used to estimate human health risk (risk) and dose associated with exposure to CoCs from past leaks and releases from WMA S-SX.

Risk is used herein to refer to the following:

- ILCR, which can occur from exposure to carcinogenic chemicals and radionuclides
- Hazard index, which is a measure of the potential for toxic health effects from exposure to noncarcinogenic chemicals.

Dose is the measure of radioactivity potentially received in a human body.

The interim measures under consideration for WMA S-SX address mitigation of groundwater impacts. The exposure pathways for this risk assessment therefore are based on the groundwater exposure medium. The exposure scenarios used for this assessment are as follows:

- Industrial
- Residential
- Industrial worker
- Residential farmer
- Recreational shoreline user.

Risk associated with the use of groundwater from a hypothetical water supply well was estimated at several downgradient points of compliance over a 1,000-year timeframe. Groundwater contaminant concentration estimates were based on the results of the contaminant transport analysis presented in Appendix E, Sections E.4.0 and E.5.0.

Based on DOE-RL (2000), the risk assessment for this WMA S-SX FIR is qualitative at this stage in the corrective action process even though substantial site-specific data have been generated. Qualitative WMA risk evaluations have been performed at the Hanford Site using historical process and characterization data (DOE-RL 1995c; DOE-RL 1996a). These qualitative risk evaluations have been used to initially evaluate the applicability and relative effectiveness of interim measures (e.g., eliminate leaking water lines and replace well caps). The risk assessment presented herein also relies on historical process and characterization data but is supplemented with additional site-specific data collected under the RCRA Corrective Action Program as described in Appendices A and B. The results of this risk assessment are used to support evaluation of potential interim measures or ICMs and to determine the need for additional WMA-specific characterization data.

Procedures for the approach and assumptions necessary to calculate human health risk are described in the following documents:

- "The Model Toxics Control Act Cleanup Regulation" (WAC 173-340), which implements MTCA requirements

- HSRAM (DOE-RL 1995b), which is the risk assessment methodology that DOE, Ecology, and EPA have agreed to use to support Hanford Site cleanup decisions.

The WAC 173-340 implementing regulations define exposure scenarios and input parameters for two types of site uses: unrestricted (MTCA Method B) and industrial (MTCA Method C). Both the Method B and C exposure scenarios include potential consumption of groundwater. The Method B exposure scenario essentially assumes residential use; the scenario has been used in risk assessments of the Hanford Site 100 Areas to represent unrestricted land use (DOE-RL 1995a). The Method C exposure scenario has not been applied for site-specific decisions at the Hanford Site.

Under MTCA, risk assessment requirements for nonradioactive contaminants stipulate that carcinogenic risks shall be less than  $10^{-6}$  ( $10^{-5}$  for multiple contaminants) for Method B and  $10^{-5}$  for Method C. Also, concentrations of individual noncarcinogenic contaminants that pose acute or chronic toxic effects to human health shall not exceed a hazard quotient of 1.0.

The MTCA risk criteria apply only to nonradioactive contaminants. The EPA guidance indicates that action is generally warranted when the cumulative carcinogenic risk is greater than  $10^{-4}$  or the cumulative noncarcinogenic hazard index exceeds 1.0. Carcinogenic risks below  $10^{-6}$  or hazard indices less than 1.0 are regarded as 'points of departure' below which no action is required. DOE orders require that groundwater protection standards be consistent with federal and Washington State requirements (i.e., EPA and Ecology requirements).

#### 4.3.1 Receptor Scenario Rationale

DOE and Ecology have agreed (DOE-RL 2000) to use MTCA Methods B and C in the Corrective Action Program. MTCA Methods B and C risks are calculated based on equations and parameters specified in the MTCA protocol for establishing groundwater cleanup levels (WAC 173-340-720). Risk is calculated for the residential farmer, industrial worker, and recreational shoreline user exposure scenarios based on the HSRAM. Estimates of risk based on the three HSRAM exposure scenarios are provided in this assessment to allow for comparison to risks cited in *Tank Waste Remediation System, Hanford Site, Richland, Washington, Final Environmental Impact Statement* (TWRS EIS; DOE and Ecology 1996) and *Retrieval Performance Evaluation Methodology for the AX Tank Farm* (DOE-RL 1999c). Risk calculations for the three HSRAM-based scenarios use groundwater pathway unit risk factors adapted without modification directly from the TWRS EIS.

Four hypothetical receptor locations identified by DOE and Ecology (DOE-RL 2000) as the points of compliance for which potential risk were calculated are as follows:

- Downgradient WMA boundary
- Downgradient boundary of the 200 West Area
- Downgradient boundary of the 200 Area exclusion zone as defined by the Hanford Future Site Uses Working Group (FSUWG 1992)
- Downgradient at the Columbia River shoreline.

For the WMA S-SX boundary, risk and dose is calculated at three separate locations corresponding to the three cross-sections (S-CC', SX-DD', SX-FF') considered in the contaminant transport analysis.

**4.3.1.1 Residential Exposure Scenario (MTCA Method B).** The MTCA cleanup standards are applicable only to nonradioactive constituents. Under the Method B groundwater cleanup level protocol, exposure to hazardous and carcinogenic chemicals is based solely on ingestion of drinking water (with an inhalation correction factor used for volatile chemicals). Method B risk exposure parameters are discussed in Appendix E, Section E.3.1.1. Method B risk is calculated for the four points of compliance as defined in Section 4.3.1.

**4.3.1.2 Industrial Exposure Scenario (MTCA Method C).** As in the MTCA Method B residential exposure scenario, the MTCA Method C industrial exposure scenario is applicable only to nonradioactive constituents. Under the Method C groundwater cleanup level protocol, exposure to hazardous and carcinogenic chemicals is based solely on ingestion of drinking water (with an inhalation correction factor used for volatile chemicals). Method C risk exposure parameters are discussed in Appendix E, Section E.3.1.2. Method C risk is calculated for the same four points of compliance as defined in Section 4.3.1.

**4.3.1.3 Industrial Worker Scenario.** An industrial worker scenario consistent with the scenario described in HSRAM is used to represent potential exposure to workers in a commercial or industrial setting. The receptors are adult employees assumed to work at a location for 20 years. The industrial worker scenario risk exposure parameters are discussed in Appendix E, Section E.3.1.3. The scenario is intended to represent nonremediation workers assumed to wear no protective clothing.

Industrial worker risk is evaluated using a unit risk factor approach consistent with that used for the TWRS EIS and DOE-RL (1999c) analyses. This approach involves calculating risk as the product of the groundwater concentration and the unit risk factor. The calculation equation and unit risk factors are provided in Appendix E, Section E.3.0.

These unit risk factors are for the groundwater pathway and are taken from the risk analysis presented in the TWRS EIS (DOE and Ecology 1996). These unit risk factors were also used in DOE-RL (1999c). Industrial worker risk is calculated for the same four points of compliance as defined in Section 4.3.1.

**4.3.1.4 Residential Farmer Scenario.** A residential farmer scenario is used to represent exposures associated with the use of the land for residential and agricultural purposes. This scenario is a slight modification to the residential scenario described in HSRAM; it includes all of the exposure pathways for the residential scenario plus most of the food ingestion pathways described in the HSRAM agriculture scenario. The residential farmer scenario includes using groundwater for drinking water (ingestion rate of 2 L/day [0.5 gal/day]) and other domestic uses as well as for irrigation to produce and consume animal, vegetable, and fruit products. The residential farmer exposure parameters are discussed in Appendix E, Section E.3.1.4.

Residential farmer risk is evaluated using a unit risk factor approach as discussed for the industrial worker scenario in Appendix E, Section E.3.1.3. Residential farmer risks are calculated for the same four points of compliance as defined in Section 4.3.1.

**4.3.1.5 Recreational Shoreline User Scenario.** A recreational shoreline user scenario consistent with the scenario described in HSRAM is used to represent exposure to contamination in groundwater seeps along the Columbia River shoreline from recreational swimming, boating, and other shoreline activities. The scenario involves outdoor activities and occurs only in an area within 400 m (0.25 mi) of the river shoreline. The recreational shoreline user scenario exposure parameters are provided in Appendix E, Section E.3.1.5.

Recreational shoreline user risk is evaluated using a unit risk factor approach as described in the industrial worker scenario in Appendix E, Section E.3.1.3. Recreational shoreline user risks are calculated only at the downgradient Columbia River shoreline point of compliance that is defined in Section 4.3.1. The recreational land user scenario is not included in the WMA S-SX risk assessment because this receptor does not have access to the groundwater pathways.

#### 4.3.2 Tank Waste Constituents of Potential Concern

Determination of the constituents of potential concern (CoPCs) to be used in the WMA S-SX risk assessment starts with the estimated inventory released from the tank farm system to the environment. That estimated inventory is provided in *Inventory Estimates for SST Leaks in S and SX Tank Farms* (Jones et al. 2000a). The CoPCs listed in the Jones et al. (2000a) estimate include the analytes listed in the model cited in *Hanford Defined Wastes: Chemical and Radionuclide Compositions* (Agnew 1997). The following sections provide the rationale used to exclude some of these CoPCs to calculate human health risk and dose in the WMA S-SX risk assessment. Because not all of the constituents associated with the released tank waste will migrate to the groundwater, the CoCs in a groundwater pathway must be selected. The rationale for making this constituents selection is provided in the following sections.

**4.3.2.1 Rationale for Excluding Constituents of Potential Concern.** Following are the criteria used to exclude CoPCs from consideration in the WMA S-SX risk assessment.

- Constituents with distribution coefficients ( $K_d$ ) equal to or greater than 0.6 mL/g. *Composite Analysis for Low-Level Waste disposal in the 200 Area Plateau of the Hanford Site* (Kincaid et al. 1998) provides reference to distribution coefficient selection used in previous studies and for past tank leaks. *Hanford Immobilized Low-Activity Tank Waste Disposal Performance Assessment* (DOE-RL 1999b), along with Kincaid et al. (1998), provides rationale for selection of CoPCs for risk calculations. Numerical modeling results provided in the TWRS EIS indicate that constituents with distribution coefficients equal to or greater than 1 take over 1,000 years to reach the vadose zone/saturated zone interface. Numerical modeling of past tank leaks for concurrent S tank farm retrieval performance evaluation (Thompson 2001) and for DOE-RL (1999c) indicate that within 1,000 years constituents with distribution coefficients equal to or greater than 0.6 would not reach the underlying aquifer or would reach the underlying aquifer at low concentrations (less than  $3.0 \times 10^{-2}$  pCi/L) that would

not contribute to significant human health risks (less than  $4.0 \times 10^{-8}$  ILCR for the residential farmer scenario) using base case recharge estimates as shown in Table 3.1.

CoPCs eliminated because of the distribution coefficient criterion are aluminum, iron, bismuth, lantharium, zirconium, lead, nickel, strontium, manganese, calcium, plutonium (total), nickel-59, nickel-63, cobalt-60, strontium-90, yttrium-90, zirconium-93, niobium-93m, cadmium-113m, antimony-125, tin-126, cesium-134, cesium-137, barium-137, samarium-151, europium-152, europium-154, and europium-155, radium-226, radium-228, plutonium series, americium series, curium series, uranium series, and thorium-232.

- Low-activity radionuclides present in low concentrations and with short half-lives if they have decayed for at least five half-lives. A decay time of 5 half-lives is sufficient for decay of 96.9% of the radionuclide activity and results in a reduced level of potential risk (EPA 1995). Based on numerical modeling results provided in the TWRS EIS, constituents with distribution coefficients of 0 take 150 years to reach the vadose zone/saturated zone interface.

CoPCs eliminated because of the half-life criterion are ruthenium-106 and tritium.

- Constituents without documented human health risk or toxicity factors. The basis for these factors is documented in the *Integrated Risk Information System* (EPA 2000a) or the *User's Guide: Radionuclide Carcinogenicity* (EPA 2000b) databases. A constituent lacking a toxicity reference dose or a carcinogenic slope factor is eliminated.

CoPCs eliminated because of the health effects criterion are carbonate, chloride, calcium, hydroxide, potassium, phosphate, sulfate, silica, and sodium.

Although several organic chemicals are listed in the Agnew (1997) model, only EDTA was carried forward because it is the only constituent that has a reference dose. All others were not listed in the Integrated Risk Information System.

In addition, field data were used for revising the risk-producing CoPC (Section 3.3.5) that met the criteria in Section 4.3.2.1, but were determined to have inventories associated with below background levels or very small inventories in the vadose zone. The field data assisted in eliminating the uranium series isotopes (see Section 3.3.5) that appear to be overestimated in Jones et al. (2000a).

**4.3.2.2 Constituents of Potential Concern for Risk Assessment.** The CoPCs to be used in the WMA S-SX risk assessment after applying the exclusion criteria described in Section 4.3.2.1 are:

- **Chemicals:** chromium, fluoride, mercury, nitrate, nitrite, and EDTA
- **Radionuclides:** carbon-14, selenium-79, technetium-99, and iodine-129.

### 4.3.3 Estimating Total Incremental Lifetime Cancer Risk and Hazard Index

The total ILCR for a particular receptor scenario at a particular point in time and space is expressed as the sum of the ILCR calculated for the individual carcinogenic chemical and

radionuclide CoPCs. Note that because none of the chemical CoPCs identified in Section 4.3.2.2 is classified as carcinogenic, ILCR values for this assessment are based only on radionuclide exposures. Although hexavalent chromium is classified as carcinogenic by inhalation, carcinogenic impacts from hexavalent chromium would apply only for airborne releases from a facility or for suspension of surface contamination. Because groundwater is the only exposure medium considered in this assessment, neither of these exposure routes applies and hexavalent chromium is treated as an ingestion toxicant. As for the total ILCR, the total hazard index is expressed as the sum of the hazard quotients calculated for the individual noncarcinogenic chemical CoPCs. Total ILCR and hazard index values are calculated for each receptor scenario and point of compliance for the 1,000-year period of analysis used in the contaminant transport simulations.

Risks for CoPCs included in the contaminant transport analysis (i.e., technetium-99, nitrate, and chromium) are based on the modeled groundwater concentrations. Risks for CoPCs not included in the contaminant transport analysis are based on scaled groundwater concentrations. Scaling is performed by multiplying the non-modeled CoPC source inventories (as reported in Jones et al. 2000a) by the ratio of the modeled groundwater concentration to source inventory for one of the modeled CoPCs. The basis for the scaling calculations is shown in Table 4.6.

**Table 4.6. Basis for Scaled Groundwater Concentrations**

Simulated CoPC	Non-simulated CoPC Ratioed from Simulated CoPC
Technetium-99	Carbon-14, Selenium-79, Iodine-129
Chromium	None
Nitrate	Nitrite, Mercury, Fluoride, EDTA

CoPC = constituent of potential concern.

#### 4.3.4 Dose Methodology

Radionuclide doses are calculated as the product of the groundwater concentration and a unit dose factor. The unit dose factors used are groundwater pathway unit dose factors provided in Kincaid et al. (1998). Unit dose factors are presented in Appendix E, Section E.3.4. Dose calculations are performed only for the industrial worker exposure scenario. Exposure pathways and parameters associated with this scenario are described in Appendix E, Section E.3.1.3. Industrial worker dose is calculated at the four points of compliance as defined in Section 4.3.1.

#### 4.4 HUMAN HEALTH RISK AND DOSE RESULTS

This section presents the results of the human health risk and dose assessment. The risk and dose values presented are based on the groundwater concentrations generated through contaminant transport modeling (Sections 4.1 and 4.2) and were calculated using the approach described in Section 4.3. Groundwater concentration values from cross-sections S-CC', SX-DD', and SX-FF' at the WMA S-SX boundary are used in Appendix E, Equation E.19 to calculate the risk and dose values with the methodology described in Section 4.3 and Appendix E, Section E.3.0.

Note that risk and dose results are presented only for a select group of simulation cases (Table 4.7). Results for these cases are representative of the larger set of cases considered in the contaminant transport analysis and include information on the impacts associated with existing conditions (Case 1); interim barrier use (Case 2); and variable meteoric recharge rates (Cases 9, 10, 11). The remaining cases generally represent variations around the existing conditions or interim barrier cases and are not specifically discussed in this section because their impacts are of similar magnitude to either Case 1 or 2.

**Table 4.7. Human Health Risk and Dose Assessment Cases**

Case	Description	Rationale
1	Base case (no action alternative)	Reference case. Estimation of impacts from past contaminant releases at WMA S-SX if no interim measures or interim corrective measures were implemented.
2	Barrier alternative and no water-line leaks	Interim corrective measure case. Estimation of degree to which implementation of an interim surface barrier would decrease impacts from past contaminant releases at WMA S-SX.
9	Base case with 50 mm/yr meteoric recharge	Meteoric recharge sensitivity cases. Estimation of degree to which meteoric recharge modeling assumptions affect estimated base case impacts from past contaminant releases at WMA S-SX.
10	Base case with 30 mm/yr meteoric recharge	
11	Base case with 10 mm/yr meteoric recharge	

WMA = waste management area.

Risk and dose results for the five cases shown in Table 4.7 are presented individually in Sections 4.4.1 to 4.4.5. As discussed in Section 4.3.1, multiple exposure scenarios are considered in this assessment to account for the uncertainty of long-term Hanford Site land use. To simplify the presentation, the individual case discussions focus on the results for the industrial worker scenario. Results for all the receptor scenarios are provided in table format for each case; however, for comparison purposes, a single scenario is sufficient because the relationship between the receptor scenarios remains relatively consistent within each case. For example, regardless of the case or compliance point, the peak residential farmer ILCR is always approximately 35 times higher than the peak industrial worker ILCR, and the MTCA Method B peak hazard index is always approximately 2.2 times higher than the MTCA Method C peak hazard index.

#### 4.4.1 Base Case, No Action Alternative (Case 1)

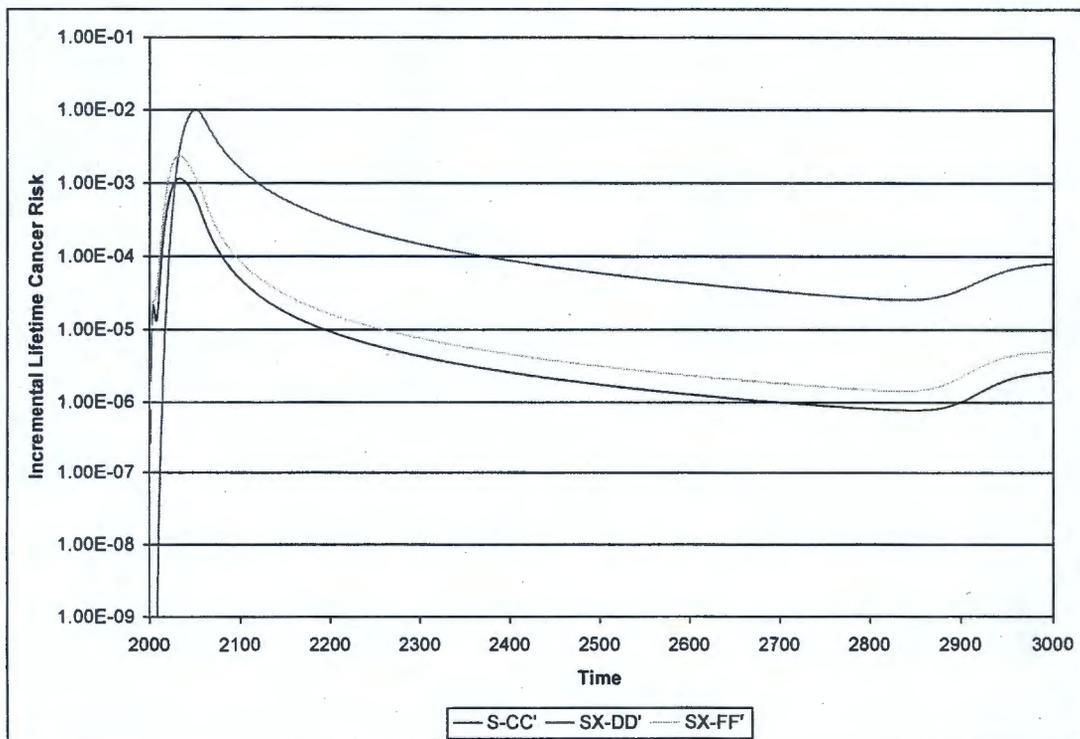
Results for the base case (Case 1) are summarized in Table 4.8. Results for Case 1 reveal three general trends that are also evident in the results for the other cases considered (Cases 2, 9, 10, 11). First, peak values for the cross-sections at the WMA S-SX boundary exceed the peak values for the downgradient compliance points. Second, peak values at the WMA S-SX boundary are

highest for cross-sections SX-DD' or SX-FF', followed by cross-section S-CC'. Third, peak values at the last compliance point (i.e., the Columbia River shoreline) are generally three to four orders of magnitude lower than the peak values at the WMA S-SX boundary.

Peak values for Case 1 are the highest of the five cases considered. Between the WMA S-SX boundary and the Columbia River shoreline compliance location, the peak industrial worker ILCR varies from  $9.98 \times 10^{-3}$  to  $1.33 \times 10^{-6}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index varies from  $3.00 \times 10^2$  to  $4.22 \times 10^{-2}$ . Peak hazard index values are driven by chromium. The peak dose varies from  $5.94 \times 10^2$  mrem/yr to  $7.94 \times 10^{-2}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for Case 1 are shown in Figure 4.9 for compliance points at the WMA S-SX boundary and in Figure 4.10 for compliance points between the WMA S-SX boundary and the Columbia River. Temporal variations in hazard index and dose for Case 1 are similar to those shown for ILCR. At the WMA S-SX boundary, peaks for the three cross-sections arrive within approximately the first 50 years and are all relatively sharp. Peaks at the 200 West fence, 200 Area exclusion boundary, and Columbia River shoreline compliance locations arrive after approximately 180, 350, and 550 years, respectively, and are broader than the peaks at the WMA S-SX boundary.

**Figure 4.9. Case 1 Industrial Worker ILCR Versus Time at WMA S-SX Boundary**



**Figure 4.10. Case 1 Industrial Worker ILCR Versus Time at Compliance Points Between the WMA S-SX Boundary and the Columbia River**

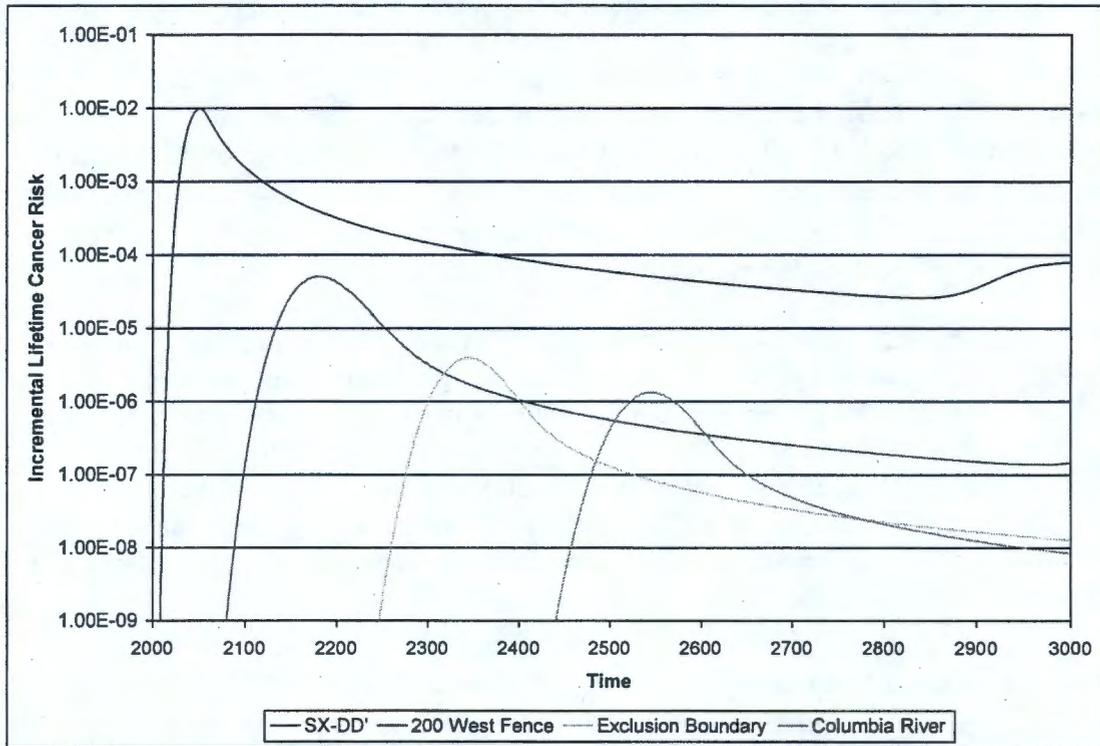


Table 4.8. Peak Long-Term Human Health Impacts for Case 1

Compliance Point		Residential Farmer		Industrial Worker		Recreational Shoreline User <sup>a</sup>		MTCA Method B <sup>b</sup>		MTCA Method C <sup>b</sup>		Dose to Worker
		ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	mrem/yr
S-SX WMA Boundary	S - CC'	4.13E-02	5.07E+03	1.15E-03	1.16E+01	N/A	N/A	N/A	2.13E+02	N/A	9.75E+01	6.91E+01
	SX - DD'	3.57E-01	2.09E+04	9.98E-03	3.00E+02	N/A	N/A	N/A	2.77E+03	N/A	1.26E+03	5.94E+02
	SX - FF'	8.39E-02	6.09E+03	2.34E-03	1.96E+01	N/A	N/A	N/A	5.20E+02	N/A	2.38E+02	1.40E+02
200 West Fence		1.82E-03	7.70E+01	5.07E-05	1.60E+00	N/A	N/A	N/A	1.32E+01	N/A	6.02E+00	3.02E+00
200 Area Exclusion Boundary		1.41E-04	5.98E+00	3.94E-06	1.24E-01	N/A	N/A	N/A	1.02E+00	N/A	4.67E-01	2.35E-01
Columbia River Shoreline		4.77E-05	2.02E+00	1.33E-06	4.22E-02	2.21E-07	4.52E-03	N/A	3.48E-01	N/A	1.59E-01	7.94E-02

<sup>a</sup>Exposures defined to occur only within 400 m (1,300 ft) of the Columbia River shoreline.

<sup>b</sup>Cancer risks not shown because MTCA addresses only nonradioactive contaminants and no nonradioactive carcinogenic chemicals were identified as contaminants of concern for WMA S-SX.

HI = hazard index.

ILCR = incremental lifetime cancer risk.

MTCA = Model Toxics Control Act.

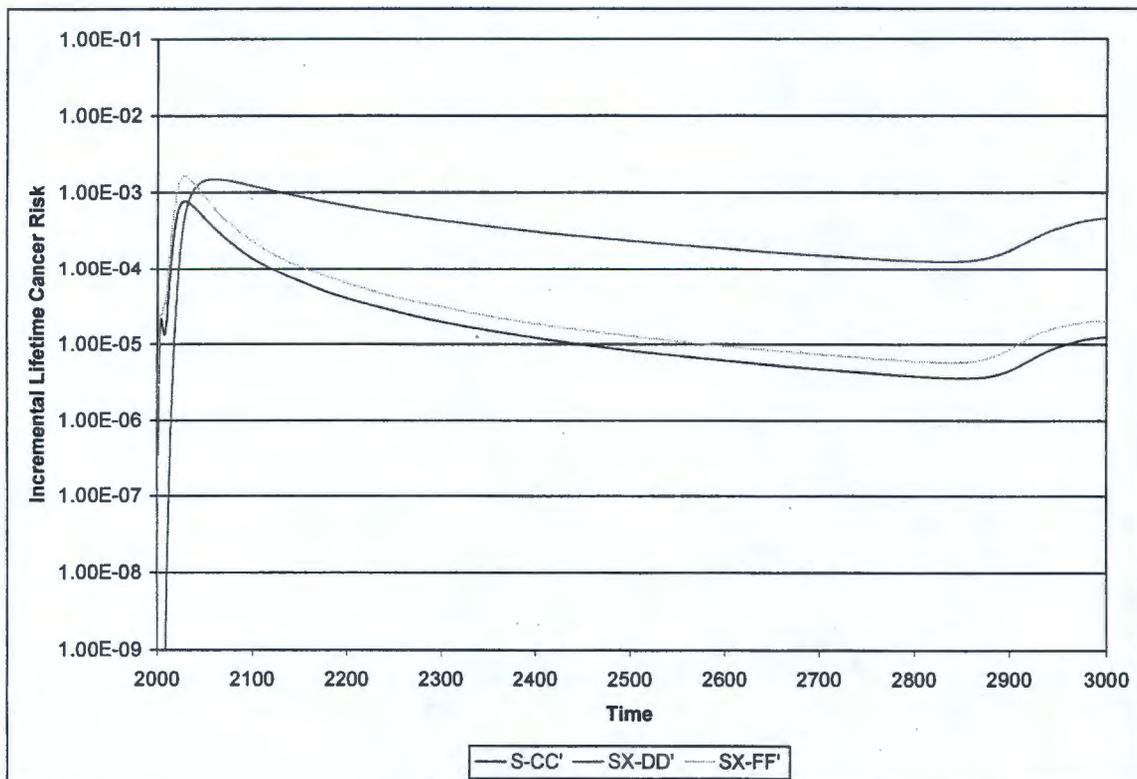
N/A = not applicable.

#### 4.4.2 Barrier Alternative and No Water-Line Leaks Case (Case 2)

Results for Case 2, barrier alternative and no water-line leaks, are summarized in Table 4.9. Results for Case 2 show the same general trends regarding the compliance points as discussed above for Case 1. Peak values for Case 2 are generally a factor of 2 to 10 lower than the corresponding values for Case 1. Between the WMA S-SX boundary and the Columbia River shoreline, the peak industrial worker ILCR varies from  $1.65 \times 10^{-3}$  to  $5.30 \times 10^{-7}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index varies from  $2.99 \times 10^1$  to  $8.79 \times 10^{-3}$ . Peak hazard index values are driven by chromium and nitrate. The peak dose ranges from  $9.85 \times 10^1$  mrem/yr to  $3.16 \times 10^{-2}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for Case 2 are shown in Figure 4.11 for compliance points at the WMA S-SX boundary and in Figure 4.12 for compliance points between the WMA S-SX boundary and the Columbia River. Temporal variations in hazard index and dose for Case 2 are similar to those shown for ILCR. At the WMA S-SX boundary, peak arrival times for the three cross-sections are similar to Case 1 but the peaks are broader in shape. All three peaks arrive within approximately the first 60 years. Peaks at the 200 West fence, 200 Area exclusion boundary, and Columbia River shoreline compliance locations are also similar to and slightly broader than Case 1 and arrive after approximately 180, 350, and 550 years, respectively.

Figure 4.11. Case 2 Industrial Worker ILCR Versus Time at WMA S-SX Boundary



**Figure 4.12. Case 2 Industrial Worker ILCR Versus Time at Compliance Points Between the WMA S-SX Boundary and the Columbia River**

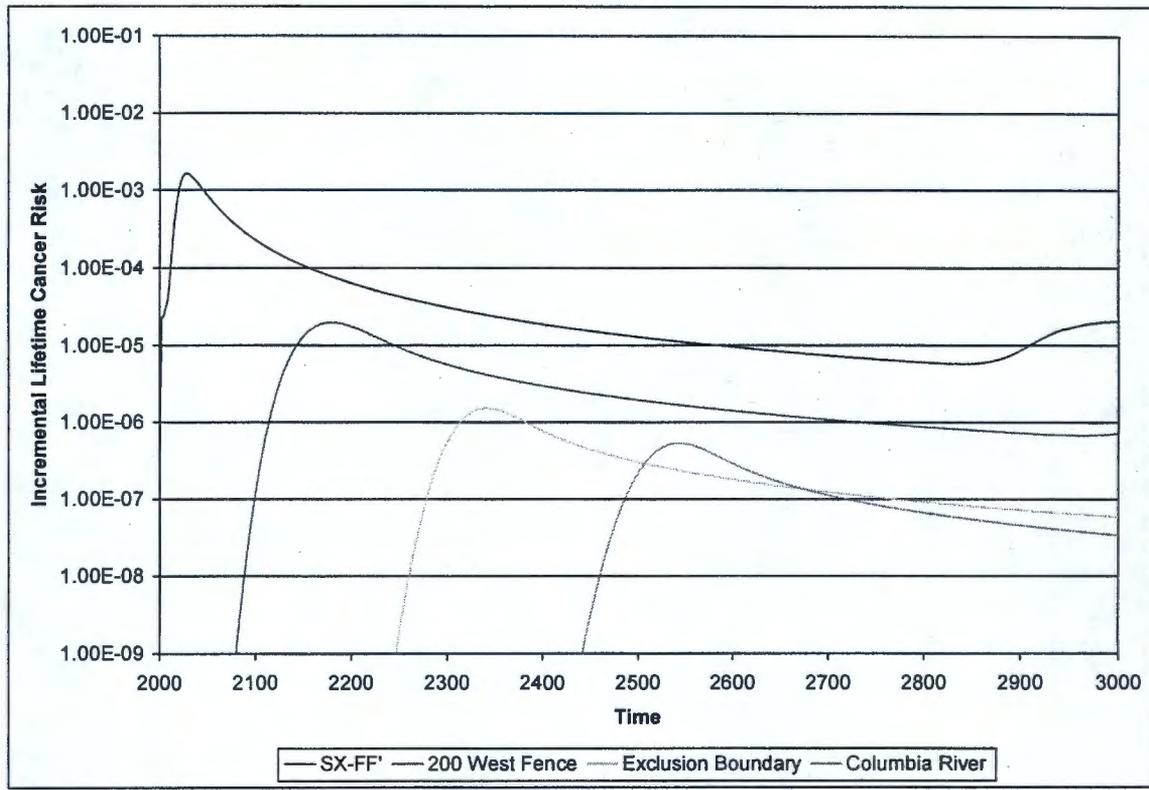


Table 4.9. Peak Long-Term Human Health Impacts for Case 2

Compliance Point		Residential Farmer		Industrial Worker		Recreational Shoreline User <sup>a</sup>		MTCA Method B <sup>b</sup>		MTCA Method C <sup>b</sup>		Dose to Worker
		ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	mrem/yr
S-SX WMA Boundary	S - CC'	2.76E-02	3.43E+03	7.68E-04	5.35E+00	N/A	N/A	N/A	1.36E+02	N/A	6.20E+01	4.61E+01
	SX - DD'	5.32E-02	3.35E+03	1.49E-03	2.99E+01	N/A	N/A	N/A	3.28E+02	N/A	1.57E+02	8.86E+01
	SX - FF'	5.91E-02	4.11E+03	1.65E-03	9.77E+00	N/A	N/A	N/A	3.39E+02	N/A	1.55E+02	9.85E+01
200 West Fence		7.08E-04	3.36E+01	1.98E-05	3.25E-01	N/A	N/A	N/A	3.38E+00	N/A	1.55E+00	1.18E+00
200 Area Exclusion Boundary		5.46E-05	2.60E+00	1.53E-06	2.45E-02	N/A	N/A	N/A	2.58E-01	N/A	1.18E-01	9.10E-02
Columbia River Shoreline		1.90E-05	9.00E-01	5.30E-07	8.79E-03	8.81E-08	9.60E-04	N/A	9.14E-02	N/A	4.18E-02	3.16E-02

<sup>a</sup>Exposures defined to occur only within 400 m (1,300 ft) of the Columbia River shoreline.

<sup>b</sup>Cancer risks not shown because MTCA addresses only nonradioactive contaminants and no nonradioactive carcinogenic chemicals were identified as contaminants of concern for WMA S-SX.

HI = hazard index.

ILCR = incremental lifetime cancer risk.

MTCA = Model Toxics Control Act.

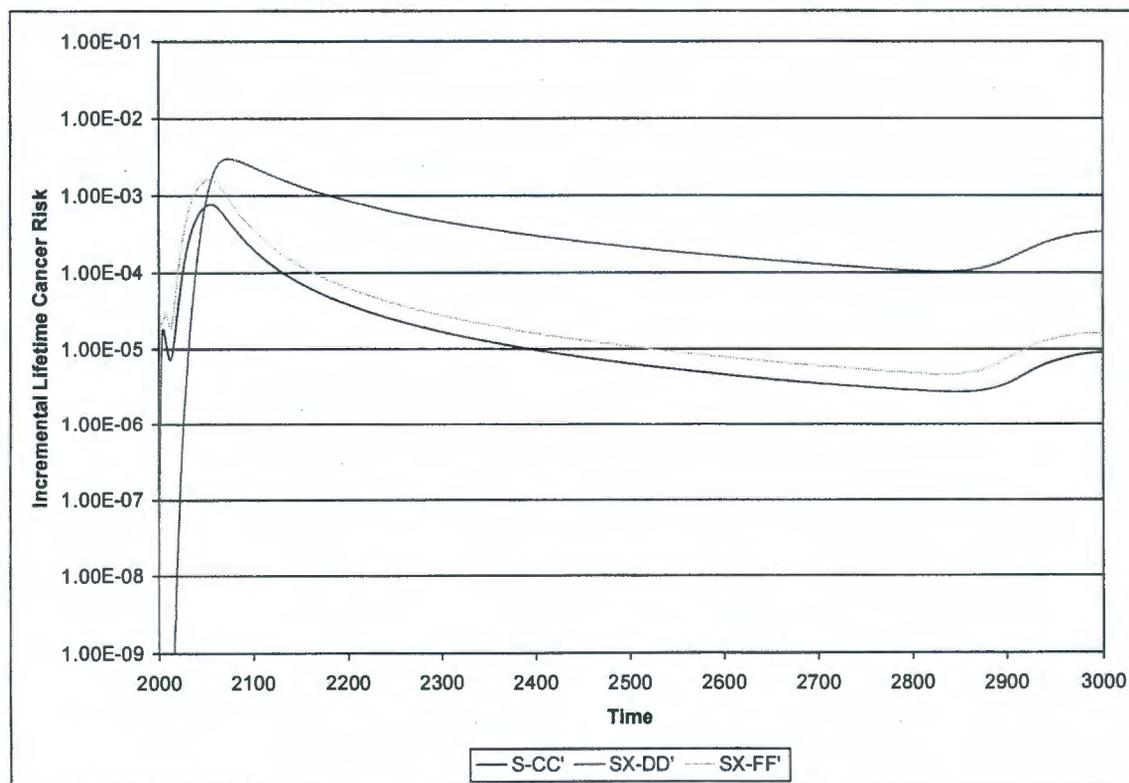
N/A = not applicable.

#### 4.4.3 Base Case with 50 mm/yr Meteoric Recharge (Case 9)

Results for Case 9, base case with 50 mm/yr meteoric recharge, are summarized in Table 4.10. Results for Case 9 show the same general trends regarding the compliance points as discussed above for Case 1. Peak values for Case 9 are generally a factor of 2 to 4 lower than the corresponding values for Case 1. Between the WMA S-SX boundary and the Columbia River shoreline, the peak industrial worker ILCR varies from  $3.03 \times 10^{-3}$  to  $6.92 \times 10^{-7}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index varies from  $6.73 \times 10^1$  to  $1.52 \times 10^2$ . Peak hazard index values are driven by chromium and nitrate. The peak dose varies from  $1.80 \times 10^2$  mrem/yr to  $4.13 \times 10^2$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for Case 9 are shown in Figure 4.13 for compliance points at the WMA S-SX boundary and in Figure 4.14 for compliance points between the WMA S-SX boundary and the Columbia River. Temporal variations in hazard index and dose for Case 9 are similar to those shown for ILCR. Overall, the temporal variations for Case 9 resemble those for Case 2. At the WMA S-SX boundary, peaks for the three cross-sections have slightly delayed arrival times and broader shapes compared to Case 1. All three peaks arrive within the first 75 years. Peaks at the 200 West fence, 200 Area exclusion boundary, and Columbia River shoreline compliance locations are also slightly delayed and broadened compared to Case 1.

**Figure 4.13. Case 9 Industrial Worker ILCR Versus Time at WMA S-SX Boundary**



**Figure 4.14. Case 9 Industrial Worker ILCR Versus Time at Compliance Points Between the WMA S-SX Boundary and the Columbia River**

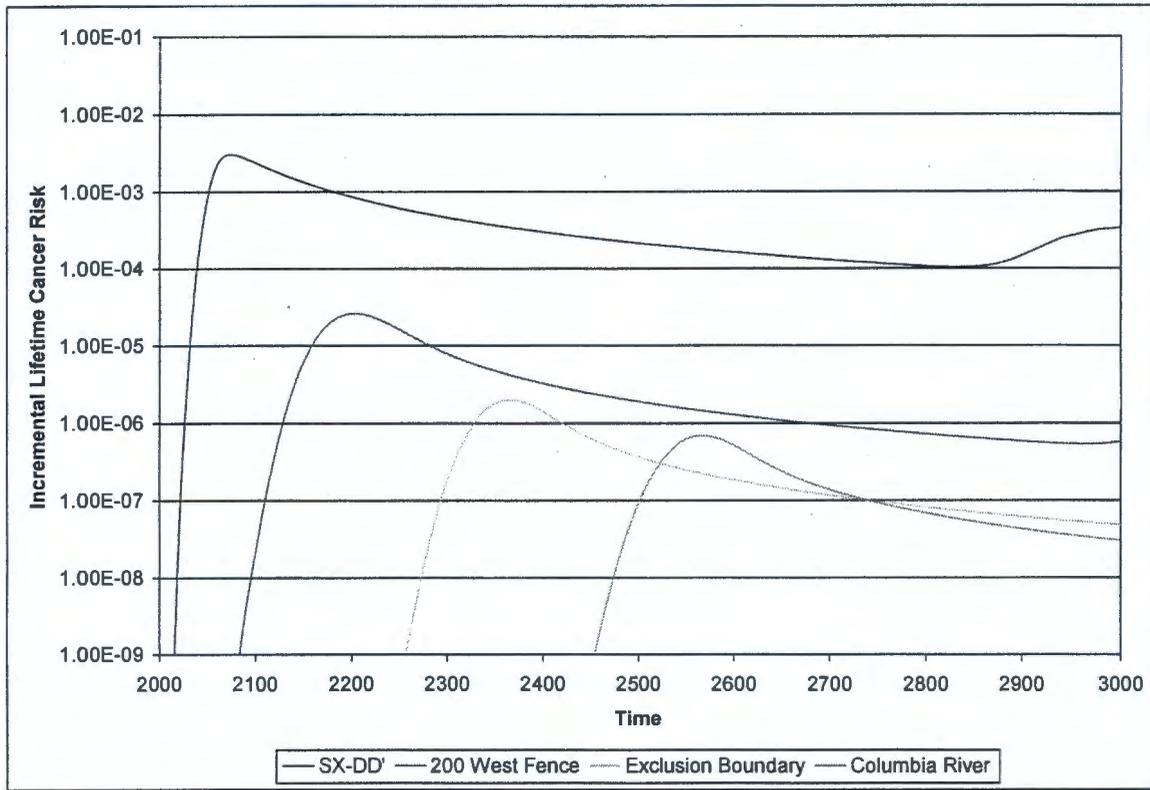


Table 4.10. Peak Long-Term Human Health Impacts for Case 9

Compliance Point		Residential Farmer		Industrial Worker		Recreational Shoreline User <sup>a</sup>		MTCA Method B <sup>b</sup>		MTCA Method C <sup>b</sup>		Dose to Worker
		ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	mrem/yr
S-SX WMA Boundary	S - CC'	2.76E-02	3.40E+03	7.70E-04	6.29E+00	N/A	N/A	N/A	1.40E+02	N/A	6.39E+01	4.63E+01
	SX - DD'	1.08E-01	6.45E+03	3.03E-03	6.73E+01	N/A	N/A	N/A	6.95E+02	N/A	3.18E+02	1.80E+02
	SX - FF'	5.81E-02	4.23E+03	1.62E-03	1.19E+01	N/A	N/A	N/A	3.58E+02	N/A	1.64E+02	9.69E+01
200 West Fence		9.27E-04	4.20E+01	2.59E-05	5.63E-01	N/A	N/A	N/A	5.21E+00	N/A	2.38E+00	1.54E+00
200 Area Exclusion Boundary		7.10E-05	3.22E+00	1.99E-06	4.29E-02	N/A	N/A	N/A	3.97E-01	N/A	1.81E-01	1.18E-01
Columbia River Shoreline		2.48E-05	1.12E+00	6.92E-07	1.52E-02	1.15E-07	1.64E-03	N/A	1.40E-01	N/A	6.40E-02	4.13E-02

<sup>a</sup>Exposures defined to occur only within 400 m (1,300 ft) of the Columbia River shoreline.

<sup>b</sup>Cancer risks not shown because MTCA addresses only nonradioactive contaminants and no nonradioactive carcinogenic chemicals were identified as contaminants of concern for WMA S-SX.

HI = hazard index.

ILCR = incremental lifetime cancer risk.

MTCA - Model Toxics Control Act.

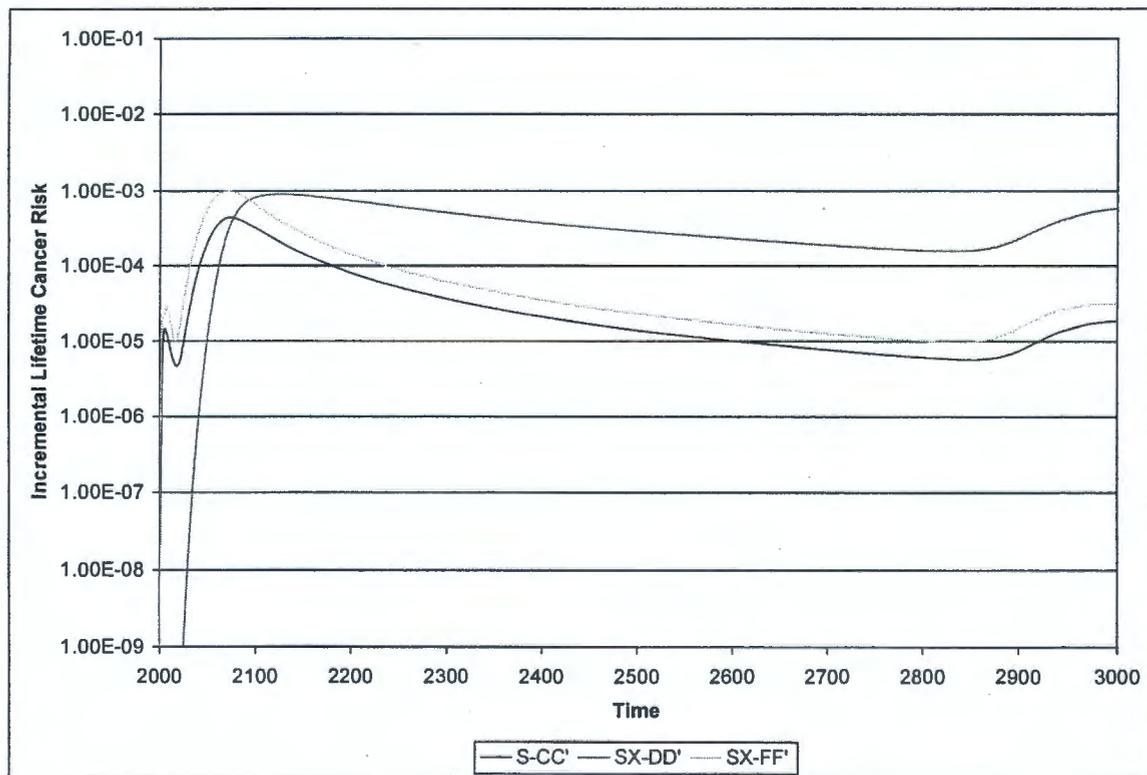
N/A = not applicable.

#### 4.4.4 Base Case with 30 mm/yr Meteoric Recharge (Case 10)

Results for Case 10, base case with 30 mm/yr meteoric recharge, are summarized in Table 4.11. Results for Case 10 show the same general trends regarding the compliance points as discussed above for Case 1. Peak values for Case 10 are generally a factor of 2 to 15 lower than the corresponding values for Case 1. Between the WMA S-SX boundary and the Columbia River shoreline, the peak industrial worker ILCR varies from  $1.01 \times 10^{-3}$  to  $3.67 \times 10^{-7}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index varies from  $2.07 \times 10^1$  to  $5.69 \times 10^{-3}$ . Peak hazard index values are driven by chromium and nitrate. The peak dose ranges from  $6.01 \times 10^1$  mrem/yr to  $2.19 \times 10^{-2}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for Case 10 are shown in Figure 4.15 for compliance points at the WMA S-SX boundary and in Figure 4.16 for compliance points between the WMA S-SX boundary and the Columbia River. Temporal variations in hazard index and dose for Case 10 are similar to those shown for ILCR. At the WMA S-SX boundary, peaks for the three cross-sections are further delayed in arrival times and have even broader shapes compared to Case 9. The three peaks arrive within approximately 125 years. The curves for the three cross-sections begin to rise again after approximately 900 years and are still rising at the end of the 1,000-year analysis period. Peaks at the 200 West fence, 200 Area exclusion boundary, and Columbia River shoreline compliance locations are also further delayed and broadened compared to Case 9.

Figure 4.15. Case 10 Industrial Worker ILCR Versus Time at WMA S-SX Boundary



**Figure 4.16. Case 10 Industrial Worker ILCR Versus Time at Compliance Points Between the WMA S-SX Boundary and the Columbia River**

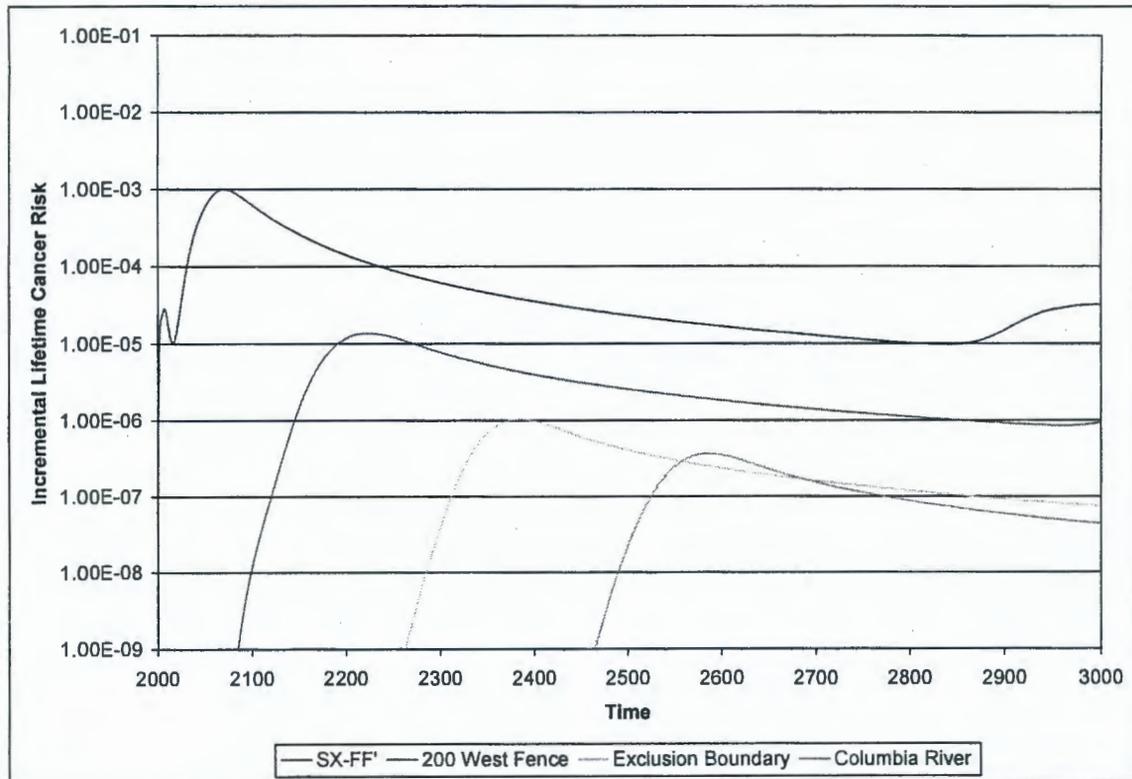


Table 4.11. Peak Long-Term Human Health Impacts for Case 10

Compliance Point		Residential Farmer		Industrial Worker		Recreational Shoreline User <sup>a</sup>		MTCA Method B <sup>b</sup>		MTCA Method C <sup>b</sup>		Dose to Worker
		ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	mrem/yr
S-SX WMA Boundary	S - CC'	1.56E-02	1.95E+03	4.36E-04	3.08E+00	N/A	N/A	N/A	7.75E+01	N/A	3.54E+01	2.61E+01
	SX - DD'	3.23E-02	1.98E+03	9.02E-04	2.07E+01	N/A	N/A	N/A	1.98E+02	N/A	9.03E+01	5.37E+01
	SX - FF'	3.61E-02	2.60E+03	1.01E-03	6.30E+00	N/A	N/A	N/A	2.15E+02	N/A	9.82E+01	6.01E+01
200 West Fence		4.88E-04	2.36E+01	1.36E-05	2.11E-01	N/A	N/A	N/A	2.23E+00	N/A	1.02E+00	8.14E-01
200 Area Exclusion Boundary		3.70E-05	1.79E+00	1.03E-06	1.57E-02	N/A	N/A	N/A	1.67E-01	N/A	7.63E-02	6.17E-02
Columbia River Shoreline		1.31E-05	6.34E-01	3.67E-07	5.69E-03	6.10E-08	6.22E-04	N/A	6.02E-02	N/A	2.75E-02	2.19E-02

<sup>a</sup>Exposures defined to occur only within 400 m (1,300 ft) of the Columbia River shoreline.

<sup>b</sup>Cancer risks not shown because MTCA addresses only nonradioactive contaminants and no nonradioactive carcinogenic chemicals were identified as contaminants of concern for WMA S-SX.

HI = hazard index.

ILCR = incremental lifetime cancer risk.

MTCA - Model Toxics Control Act.

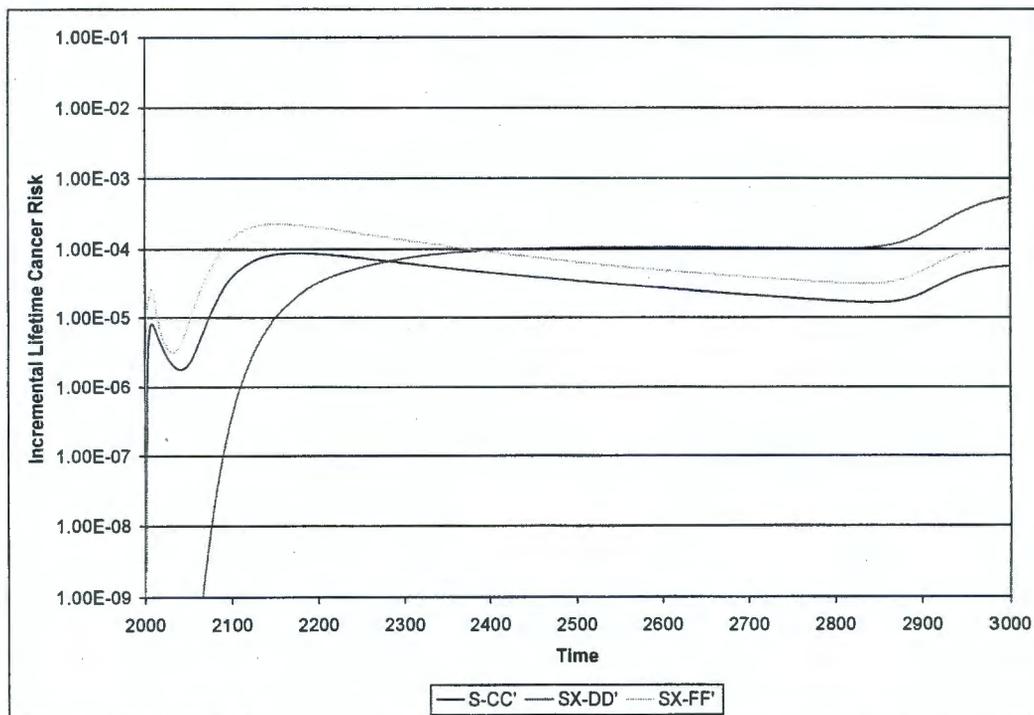
N/A = not applicable.

#### 4.4.5 Base Case with 10 mm/yr Meteoric Recharge (Case 11)

Results for Case 11, base case with 10 mm/yr meteoric recharge, are summarized in Table 4.12. Results for Case 11 show the same general trends regarding the compliance points as discussed above for Case 1. Peak values for Case 11 are generally a factor of 15 to 50 lower than the corresponding values for Case 1. Between the WMA S-SX boundary and the Columbia River shoreline, the peak industrial worker ILCR varies from  $5.94 \times 10^{-4}$  to  $8.59 \times 10^{-8}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index varies from  $1.25 \times 10^1$  to  $7.54 \times 10^{-4}$ . Peak hazard index values are driven by chromium. The peak dose varies from  $3.26 \times 10^1$  mrem/yr to  $5.12 \times 10^{-3}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for Case 11 are shown in Figure 4.17 for compliance points at the WMA S-SX boundary and in Figure 4.18 for compliance points between the WMA S-SX boundary and the Columbia River. Temporal variations in hazard index and dose for Case 11 are similar to those shown for ILCR. At the WMA S-SX boundary, peaks for the three cross-sections are even further delayed in arrival times and have even broader shapes compared to Case 10. The secondary elevation in ILCR values observed for Case 10 at the end of the 1,000-year analysis period is also observed for Case 11 but is more pronounced. For cross-section SX-DD', the late ILCR peak actually exceeds the earlier peak. Peaks at the 200 West Fence, 200 Area exclusion boundary, and Columbia River shoreline compliance locations are also even further delayed and broadened compared to Case 10 and arrive after approximately 300, 480, and 680 years, respectively.

Figure 4.17. Case 11 Industrial Worker ILCR Versus Time at WMA S-SX Boundary



**Figure 4.18. Case 11 Industrial Worker ILCR Versus Time at Compliance Points Between the WMA S-SX Boundary and the Columbia River**

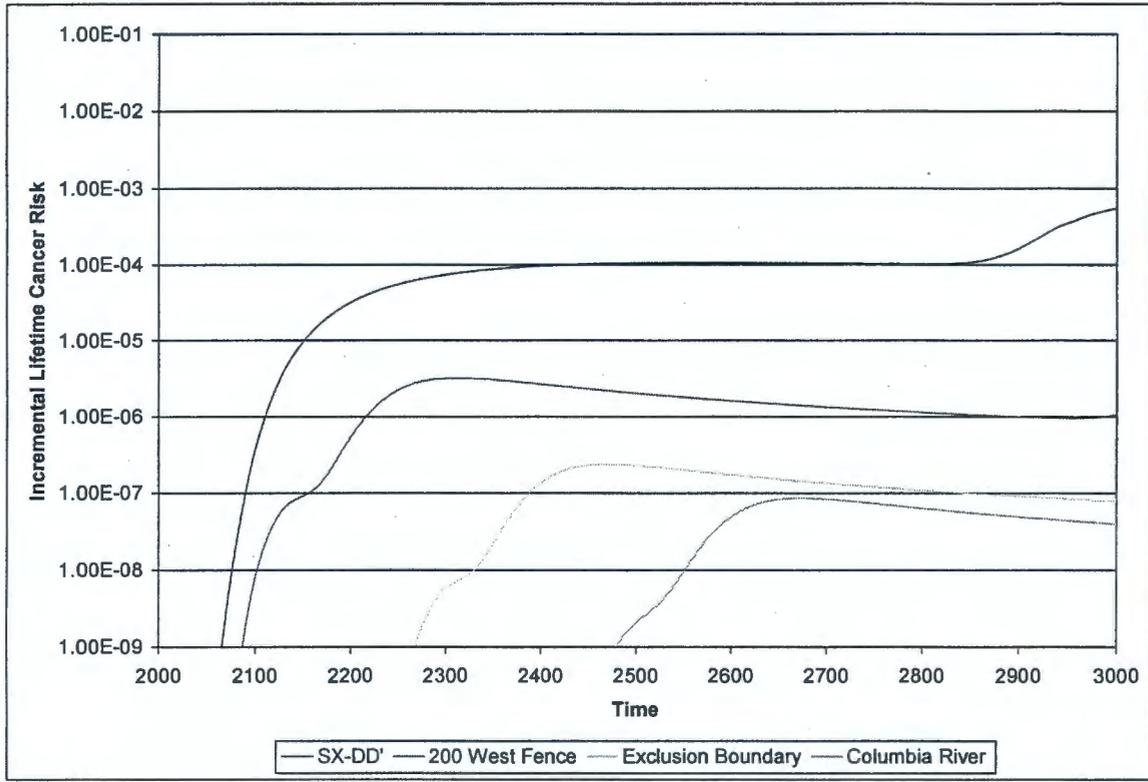


Table 4.12. Peak Long-Term Human Health Impacts for Case 11

Compliance Point		Residential Farmer		Industrial Worker		Recreational Shoreline User <sup>a</sup>		MTCA Method B <sup>b</sup>		MTCA Method C <sup>b</sup>		Dose to Worker
		ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	mrem/yr
S-SX WMA Boundary	S - CC'	3.16E-03	4.08E+02	8.82E-05	7.67E-01	N/A	N/A	N/A	1.59E+01	N/A	7.25E+00	5.29E+00
	SX - DD'	1.96E-02	1.12E+03	5.49E-04	1.25E+01	N/A	N/A	N/A	1.27E+02	N/A	5.82E+01	3.26E+01
	SX - FF'	8.14E-03	5.94E+02	2.27E-04	1.43E+00	N/A	N/A	N/A	4.84E+01	N/A	2.21E+01	1.36E+01
200 West Fence		1.14E-04	5.70E+00	3.19E-06	2.81E-02	N/A	N/A	N/A	3.85E-01	N/A	1.76E-01	1.90E-01
200 Area Exclusion Boundary		8.40E-06	4.19E-01	2.35E-07	2.04E-03	N/A	N/A	N/A	2.81E-02	N/A	1.28E-02	1.40E-02
Columbia River Shoreline		3.07E-06	1.54E-01	8.59E-08	7.54E-04	1.43E-08	8.38E-05	N/A	1.03E-02	N/A	4.73E-03	5.12E-03

<sup>a</sup>Exposures defined to occur only within 400 m (1,300 ft) of the Columbia River shoreline.

<sup>b</sup>Cancer risks not shown because MTCA addresses only nonradioactive contaminants and no nonradioactive carcinogenic chemicals were identified as contaminants of concern for WMA S-SX.

HI = hazard index.

ILCR = incremental lifetime cancer risk.

MTCA = Model Toxics Control Act.

N/A = not applicable.

#### 4.4.6 Use of Assessment Results for Data Quality Objectives Decisions

Six principle study questions constituting four decision statements are provided in Section 2.0 of Ovink (1999). Those principle study questions are evaluated against the results of the potential risk from Section 4.4.5.

**Principal Study Question No. 1** – Do current shallow (less than 4.6 m [15 ft]) soil radionuclide and chemical concentrations resulting from releases within the WMA achieve preliminary corrective measure performance standards for direct exposure in the vicinity of the WMA boundary?

**Principal Study Question No. 2** – Do current vadose zone (surface to water table) soil radionuclide and chemical concentrations resulting from releases within the WMA achieve preliminary corrective measure performance standards for groundwater protection in the vicinity of the four potential boundaries (i.e., WMA boundary, 200 Area exclusion boundary, 200 Area buffer zone, Columbia River)?

**Principal Study Question No. 3** – Do current groundwater CoC concentrations resulting from releases within the WMA comply with preliminary corrective measure performance standards in the vicinity of the four potential boundaries?

**Principal Study Question No. 4** – Is there shallow soil, deep soil, or groundwater information pertinent to ICM technology evaluations that can be collected concurrent with WMA characterization (i.e., opportunities for project integration)?

**Principal Study Question No. 5** – Will shallow soil (less than 4.6 m [15 ft]), vadose zone soil (surface to water table), or groundwater radionuclide and chemical concentrations resulting from releases and potential retrieval leak losses achieve closure performance standards in the vicinity of the WMA boundary, 200 Area exclusion boundary, 200 Area buffer zone boundary, and the Columbia River?

**Principal Study Question No. 6** – Will shallow soil (less than 4.6 m [15 ft]), vadose zone soil (surface to water table), or groundwater radionuclide and chemical concentrations resulting from releases, potential retrieval leak losses, residual waste, and remaining structures achieve closure performance standards in the vicinity of the WMA boundary, 200 Area exclusion boundary, 200 Area buffer zone boundary, and the Columbia River?

The 200 Area buffer zone was replaced with the 200 Area fence boundary. The shallow soil, vadose zone soil (surface to water table), or groundwater radionuclide and chemical concentrations resulting from releases are above the preliminary performance standards. The current groundwater concentration for technetium-99 is 81,500 pCi/L in well 299-W23-19. The soil concentrations were used as input for the numerical simulation of flow and solute transport modeling. The results of the numerical simulations indicate that the groundwater concentrations would exceed the maximum contaminant levels, and thereby are not protective of groundwater.

The answer to principal study questions 1, 2, 3, 5, and 6 is 'no' at the WMA boundary and 200 West fence; soil and groundwater concentrations would exceed the preliminary performance

standards. The 200 Area exclusion zone boundary and Columbia River would be 'yes.' For principal study question 4, ongoing interim measures and a CMS are proposed for the RCRA groundwater well 299-W23-19 to treat the groundwater for the removal of technetium-99.

#### 4.4.7 Conclusions of Risk and Dose

Table 4.13 presents the peak ILCR, hazard index, and dose for the industrial worker scenario for the five cases analyzed. This comparison indicates the following ranking from the highest risk to lowest risk:

- Case 1 (no action alternative)
- Case 9 (base case with 50 mm/yr recharge)
- Case 2 (barrier case with no water lines)
- Case 10 (base case with 30 mm/yr recharge)
- Case 11 (base case with 10 mm/yr recharge).

**Table 4.13. Comparison of Peak Incremental Lifetime Cancer Risk, Hazard Index, and Dose for the Industrial Worker Scenario**

Case	WMA S-SX Boundary			200 West Fence	200 Area Exclusion Boundary	Columbia River Shoreline
	S-CC'	SX-DD'	SX-FF'			
<b>Industrial Worker Peak Incremental Lifetime Cancer Risk</b>						
1	1.15E-03	9.98E-03	2.34E-03	5.07E-05	3.94E-06	1.33E-06
2	7.68E-04	1.49E-03	1.65E-03	1.98E-05	1.53E-06	5.30E-07
9	7.70E-04	3.03E-03	1.62E-03	2.59E-05	1.99E-06	6.92E-07
10	4.36E-04	9.02E-04	1.01E-03	1.36E-05	1.03E-06	3.67E-07
11	8.82E-05	5.49E-04	2.27E-04	3.19E-06	2.35E-07	8.59E-08
<b>Industrial Worker Peak Hazard Index</b>						
1	1.16E+01	3.00E+02	1.96E+01	1.60E+00	1.24E-01	4.22E-02
2	5.35E+00	2.99E+01	9.77E+00	3.25E-01	2.45E-02	8.79E-03
9	6.29E+00	6.73E+01	1.19E+01	5.63E-01	4.29E-02	1.52E-02
10	3.08E+00	2.07E+01	6.30E+00	2.11E-01	1.57E-02	5.69E-03
11	7.67E-01	1.25E+01	1.43E+00	2.81E-02	2.04E-03	7.54E-04
<b>Industrial Worker Peak Dose (mrem/yr)</b>						
1	6.91E+01	5.94E+02	1.40E+02	3.02E+00	2.35E-01	7.94E-02
2	4.61E+01	8.86E+01	9.85E+01	1.18E+00	9.10E-02	3.16E-02
9	4.63E+01	1.80E+02	9.69E+01	1.54E+00	1.18E-01	4.13E-02
10	2.61E+01	5.37E+01	6.01E+01	8.14E-01	6.17E-02	2.19E-02
11	5.29E+00	3.26E+01	1.36E+01	1.90E-01	1.40E-02	5.12E-03

Rankings by compliance points indicate the following ranking usually occurs (from highest to lowest risk):

- Cross-section SX-DD' at WMA S-SX boundary
- Cross-section SX-FF' at WMA S-SX boundary
- Cross-section SX-CC' at WMA S-SX boundary
- 200 West fence
- 200 Area exclusion boundary
- Columbia River shoreline.

The CoC driver for risk and dose is technetium-99. For the hazard index, the principle CoC drivers are chromium and nitrate.

## 5.0 CONCLUSIONS

This section summarizes the major findings and conclusions for this report. Areas covered include the overview of the process (Section 5.1), a description of the characterization approach (Section 5.2), a summary of the additions to the characterization database (Section 5.3), a discussion of the affirmation and refinement of the conceptual model for WMA S-SX (Section 5.4), a summary of the simulations and associated impacts analysis (Section 5.5), and a summary of the interim measures already in place.

### 5.1 OVERVIEW

An extensive characterization and analysis program that evaluates current vadose zone contamination in WMA S-SX has been completed and is described in this document. This work is the culmination of an orderly investigation process that includes the following steps.

1. Collect and interpret available data pertinent to tank leaks and vadose zone contamination.
2. Determine missing information and plan to collect new data and complete analyses.
3. Collect new data through the development of improved sediment collection methods that reduce dose to the workers and improve data quality.
4. Integrate new and old data with numerical modeling of future contamination and associated risk evaluation.
5. Integrate the DOE national laboratories into the effort to better examine the potential for radionuclide transport under the harsh conditions imposed by tank waste leaks.
6. Implement interim measures and/or additional data collection and analysis.

Eight major outcomes have resulted from this work.

- A workable, effective approach has been developed to improve the characterization of vadose zone contamination in the tank farm WMAs, to interpret past contamination events, and to estimate future contaminant migration.
- A set of data collection activities has been completed to fill major data gaps that quantify the nature, extent, and mobility of contamination in the vadose zone. From these data, a conceptualization of contaminant migration events has evolved.
- Through cooperation with the S&T activity of the Hanford Groundwater/Vadose Zone Integration Project and other Hanford Site projects, resources normally unavailable to the RCRA Corrective Action Program were put to use on soil and groundwater issues. These activities provided significant insight into their resolution.
- The insertion of DOE national laboratory and university laboratory expertise was directed at important issues and yielded significant results over a very short time period.

- Future migration patterns and associated risk from groundwater contamination have been projected for the next 1,000 years.
- A series of interim measures have been identified and implemented that immediately reduce the potential of accelerated contaminant migration.
- The approach used by the RCRA Corrective Action Program is successful and should be used for future efforts. The approach of the RCRA Corrective Action Program (gather existing data, identify gaps, collect new data based on gaps, analyze the consequence of the data obtained, and document all the efforts) worked extremely well.
- The current conceptual model should be the basis for further RCRA Corrective Action Program activities and modeling.

In addition, some more general conclusions can be reached. These conclusions involve the approach taken by the program itself and the conceptual models used.

The approach, data collection, and analyses also were performed to support other SST programs, specifically the SST Waste Retrieval Program.

Prior to the initiation of the WMA S-SX characterization effort, a conceptual model was developed from the existing data to explain contamination events that lead to the current state of contamination in the WMA S-SX vadose zone and nearby unconfined aquifer. This conceptual model pictured the contaminant transport having two stages (an early stage driven by the chemical constituents of the leak including enhanced moisture flow, followed by a second stage where the natural systems of the vadose zone reasserted themselves). In general, this conceptual model has been strengthened by the new information gathered (Section 5.4).

A second phase of field investigation is not deemed necessary except for the purpose of reducing inventory and migration uncertainty at specific locations identified in Section 6.0. Interim corrective measures related to well 299-W23-19 are ongoing as are interim measures that have been identified by Ecology and DOE. This alleviates the need for an accelerated CMS.

Interim measures that have been implemented will require various monitoring efforts to ensure they are effective. Section 6.0 recommends that the effectiveness of the interim measures that have been performed be monitored and evaluated.

## 5.2 CHARACTERIZATION APPROACH

The characterization approach to quantify vadose zone soil contamination is identified by three principal factors:

- Collection of field data in areas of known tank leaks
- A tiered sample analysis approach directed at samples affected by tank waste
- Use of laboratory and modeling analyses focused on site-specific processes controlling contaminant movement.

In WMA S-SX, three deep boreholes were completed: two to interrogate the vadose zone area contaminated by the tank SX-108 leak (borehole 41-09-39 and SX-108 slant borehole) and one to interrogate contamination from the tank SX-115 leak (borehole 299-W23-19). Innovative techniques were developed to provide minimum disturbance of the soil samples (particularly cross-contamination from other soil depths when attempting to collect from a representative zone), collect highly radioactive samples in a safe manner, and maximize drilling and sampling efficiency. In the SX-108 slant borehole, effective techniques were developed for drilling at an angle and accurately tracking the borehole position to avoid contact with the tank and ancillary equipment. Numerous new procedures were developed to accomplish these tasks because they were new to tank farm operations, and demonstration of worker safety was of paramount concern.

A tiered analysis approach was developed and applied to the collected soil samples with the goal being to locate and characterize contaminant zones containing tank fluid constituents. Sampling sites were selected such that all geologic units and high gamma zones were sampled and the sampling intervals were no more than 3 m (10 ft). Recognizing that the most important data involved the identification and location of tank fluid contaminants in the borehole soil column and that not all samples were going to be contaminated, a core suite of initial screening analyses were performed on all samples. These analyses were convenient and helpful for identification of in situ contamination. These analyses included geologic logging; gamma logging; and water extract chemistry (nitrate concentration, pH, electrical conductivity, total organic carbon/total carbon). If positive results occurred (e.g., high values of chemical constituents), additional analyses were performed to identify specific constituents (e.g., technetium-99). In addition to constituent measurements, some samples were evaluated to elucidate constituent mobility (e.g., cation exchange capacity, distribution coefficient measurements) or hydrologic properties (matric potential, moisture retention curves, saturated hydraulic conductivity).

Laboratory experiments and modeling analyses were conducted that were focused on mechanistic and theoretical explanations of site-specific physical and chemical processes controlling contaminant behavior in the vadose zone. Experimental and modeling results from these studies provided considerable enhancement in the understanding of contaminant behavior and increased confidence in the evaluation of future contaminant behavior and associated risk. This work has been completed by a consortium of researchers from national laboratories and universities organized through the S&T activity that is conducted by Pacific Northwest National Laboratory staff and associated with the Hanford Groundwater/Vadose Zone Integration Project and the Environmental Management Sciences Program. Selection of specific research projects was a joint decision resulting from coordination between S&T and Tank Farm Vadose Zone Project staff scientists. The results of these projects for the WMA S-SX characterization effort are provided in Appendix D, with summaries in Sections 3.0 and 4.0 as appropriate.

### **5.3 PRIMARY ADDITIONS TO THE CHARACTERIZATION DATABASE**

A fundamental conclusion from the initial data collection and conceptualization of the current vadose zone contamination was that several aspects of contaminant distribution and mobility in the vadose zone are critical to the successful evaluation of future risk. Furthermore, confidence in the risk evaluation would be greatly enhanced by key additions to the existing database. To improve understanding of contaminant characteristics in the vadose zone, data collection and

various analyses have focused on several key tasks. These tasks include completion of improved total inventory estimates of major tank leak fluids (radionuclides and chemicals), identification of tank leak fluid constituents present in measurable quantities in the vadose zone, and measurements/estimates of contaminant distribution and current mobility in the vadose zone. Given this information and recharge estimates, input parameters to flow and transport models were developed and future groundwater contamination and associated risk estimates were completed.

Inventory estimates of the major tank leaks have been enhanced in two ways.

- Improved inventory estimates were derived from the HDW model providing inventory estimates as a function of time (Section 3.3.1 and Appendix D, Section D.7.3).
- Additional kriging analysis was completed using all of the available cesium-137 concentration data (Section 3.3.1.3). The cesium-137 data included all gamma data from drywells and laterals and all cesium-137 soil sample data from the new characterization boreholes in the SX tank farm.

From this exercise a more refined range of vadose zone cesium-137 inventory, volume discharge, and other contaminants-of-concern estimates has been derived.

Borehole soils analysis data (Section 3.3 and Appendix B, Sections B.2.0, B.3.0, and B.4.0) have clearly identified particular constituents present in the vadose zone from tank leaks and in concentrations large enough to be of concern as future groundwater contaminants. These include technetium-99, chromium, nitrate, and sodium. Comparison of actual cesium-137 concentration measurements with gamma logging data in the SX-108 slant borehole correlate very well (within an order of magnitude), lending confidence to all recent gamma logging measurements. Also, qualitative indications of long-term contaminant mobility were provided by their distribution with depth (e.g., higher concentration zones at greater depth indicate greater relative mobility) and empirical desorption data (e.g., a greater fraction of total contaminant removed by water extraction indicates greater relative mobility). These data indicate which of these constituents are essentially mobile at this time (technetium-99, nitrate); moderately mobile (sodium, chromium); and essentially immobile (cesium-137).

More mechanistically oriented laboratory experiments were conducted to determine the chemical reactions affecting mobility of cesium-137 (and sodium by association) and chromium (Section 3.2 and Appendix D, Sections D.3.0 and D.4.0, respectively). The cesium-137 experiments completed over a range of sodium and cesium-137 concentrations, illustrated that sodium effectively competes for sorption sites with cesium-137 at sufficiently high sodium concentrations. These data, combined with inventory estimates (Section 3.3) and speciation studies (Section 3.3.2 and Appendix D, Section D.7.3), indicate that the initial tank leak composition could have imposed a local chemical environment sufficient to prevent cesium-137 sorption, at least temporarily. Conversely, as sodium concentrations diminish, cesium-137 sorption increases. Soils analyses from the SX-108 slant borehole show a separation of high sodium and cesium-137 concentration zones. These data provide a plausible explanation for the apparently variable cesium-137 mobility in tank SX-108 fluid as it migrated in the vadose zone and the lack of a high cesium-137 mobility period associated with the tank SX-115 leak.

These data also suggest that cesium-137 presently is sufficiently immobile to remain trapped in the vadose zone until radioactive decay reduces the inventory to negligible quantities and should remain so unless some very high-sodium-bearing liquids pass through the contamination zone.

Laboratory experiments and chromium species characterization (Section 3.2 and Appendix D, Section D.4.0) indicate that limited retardation of chromium in the soil column has occurred because iron(II)-bearing minerals reduce chromium from the VI to the III valence state allowing sorption or coprecipitation to occur. Chromium(III) was also measured in soil samples. Laboratory data also indicate that highly caustic solutions dissolved iron(II)-bearing minerals, thereby facilitating the kinetics of chromium reduction.

#### **5.4 AFFIRMATION AND REFINEMENT OF THE CONCEPTUAL MODEL**

Before initiation of the WMA S-SX characterization effort, a conceptual model was developed from existing data to explain contamination events that lead to the current state of contamination in the WMA S-SX vadose zone and the underlying unconfined aquifer (Section 2.1.1). The conceptual model aided the selection of field investigations (defined in the workplans) and other pertinent analyses. Additional characterization work and analyses presented in this report affirm the basic tenants of the conceptual model, these being that contaminant migration originating with tank leaks is a two-stage process largely controlled by several key factors including tank waste solution chemistry, vadose zone stratigraphic controls on contaminant movement, natural recharge, and humanmade water discharges (e.g., water-line leaks) to the soil column (Section 2.1.2). During the first stage, now completed, physical and chemical conditions, modified by the leak event were primary drivers on contaminant migration in the vadose zone. In the second and ongoing stage, the tank leak effects have ceased and contaminant migration is controlled by natural processes and, in some cases, accelerated by other manmade events (i.e., leaking water lines).

##### **5.4.1 First-Stage Contaminant Migration**

In the area contaminated by the tank SX-108 leak, an outstanding feature of the contamination zone is the extensive distribution of cesium-137 in both the lateral and vertical directions. The additional soil sample analyses from borehole 41-09-39 and the SX-108 slant borehole (Appendix B, Sections B.2.0 and B.4.0, respectively) confirm the occurrence of high cesium-137 concentration zones in the Hanford formation subunit H1 and upper parts of subunit H2 beneath tank SX-108 and extending westward toward tank SX-109. Inventory estimates (Section 3.3; Appendix C, Section C.6.0; Appendix D, Section D.7.3) and geochemical laboratory experiments (Appendix D, Section D.3.0) indicate that local soil chemical conditions imposed by tank fluid chemistry during the first stage created a temporary environment that strongly increased cesium-137 mobility such that it became poorly reactive and migrated with the tank fluid. The primary mechanism for enhanced mobility is the presence of very high sodium concentrations that successfully competed for sorption sites normally occupied by cesium-137. Consequently, cesium-137 is considered to be a marker for tank SX-108 leak migration in the first stage. Also, zones of elevated pH (greater than 8.5) soil water remain that coincide with the high cesium-137 concentration zones and indicate the remnant of high pH tank fluid mixing with moderately alkaline vadose zone soil water. The correlation between the high cesium-137 concentration zone distribution and the distinctive subunit H1 layer indicates the influence of in

situ stratigraphic controls that promote lateral migration, particularly under conditions where high-volume, short-term fluid releases contact horizontal stratigraphic units with contrasting hydrologic properties.

Thermal modeling analyses (Appendix D, Sections D.7.1 and D.7.2) estimate that a high temperature zone area for tanks SX-107, SX-108, and SX-109 existed during the first stage. This zone extended well into the vadose zone below the high cesium-137 contamination zone because of radiogenic heat loading provided by tank waste. The impact of this zone would have been to create an essentially dry zone (ambient temperatures above 100 °C [212 °F]) next to the tank such that local recharge and contaminant migration would have been delayed until the late 1960s.

First stage tank fluid migration is not as clearly defined at the tank SX-115 leak site. Cesium-137 is observed to concentrate under and near the edge of tank SX-115 very close to the assumed leak locations. This distribution indicates that cesium-137 mobility was not enhanced during the first stage and dropped out of solution quickly after tank fluid contacted vadose zone soil. A mechanistic explanation of this observation is provided by inventory estimates of a more dilute solution and the geochemical experimental data suggesting that tank SX-115 fluid chemistry was not sufficient to enhance cesium-137 mobility (i.e., insufficiently high sodium concentrations). Because cesium-137 never experienced a period of high mobility in this area, it does not provide a chemical marker for first stage tank leak migration in the vadose zone. However, the other system components, including a high-volume leak and the underlying subunit H1, are in place to permit large-scale lateral contaminant movement as seen in the vicinity of tank SX-108. Unlike the tank SX-108 site with two boreholes, only one borehole very near the tank is available, preventing evaluation of lateral migration. Given the tank SX-115 waste inventory estimates, a high temperature thermal zone probably occurred near tank SX-115 but should not have been as long-lasting nor extensive as near tank SX-108.

#### **5.4.2 Second-Stage Contaminant Migration**

Second-stage contaminant migration is assumed to begin when the physical and chemical effects of a tank leak have dissipated and migration responds to natural environmental or other manmade conditions. In the tank SX-108 area, the tank-leak effects have dissipated, the soil temperatures have reduced sufficiently to allow recharge, and the chemical conditions affecting tank fluid constituents are controlled primarily by ambient soil-water reactions.

Migration is indicated by the variable distribution of tank fluid constituents in the soil samples from both boreholes (Appendix B, Sections B.2.0 and B.4.0). Tank fluid constituents are identified in the borehole soils simply by their presence (e.g., technetium-99 does not occur naturally) or by their presence over some depth interval at elevated concentrations relative to natural levels (e.g., sodium). In the boreholes contaminated by the tank SX-108 leak, the distance between the high cesium-137 versus the high technetium-99/nitrate concentration zones shows second stage contaminant migration. This conclusion presumes that cesium-137 has been essentially immobile during the second stage migration and that technetium-99 and nitrate are chemically nonreactive and moving with the tank fluid. Cesium-137 immobility is indicated by long-term gross gamma logging measurements since 1974 that show only isolated spatial and temporal changes in gamma profiles. Also, current high sodium and cesium-137 concentration

zones are separated by depth and water extraction analyses of borehole soils remove only a small fraction of cesium-137 activity from the soil. Conversely, technetium-99 and nitrate are extracted almost completely from soil by water.

In the tank SX-108 area second stage migration appears to be largely vertical and controlled, in the absence of water-line leaks, by natural recharge. However, several factors hinder quantitative estimates of contaminant migration in this area. These include historical influences of soil heating from high heat tanks, a lack of site-specific recharge rate measurements, and the potential that the Plio-Pleistocene unit is acting as a retarding barrier to vertical migration and enhancing lateral movement. Currently, there is no indication that in the absence of water-line leaks, contaminant migration from tank leaks has extended below the Plio-Pleistocene unit, although eventual migration to the unconfined aquifer is expected (see Section 4.0).

Second stage migration in the area contaminated by the tank SX-115 leak has had a substantially different and more complex history than that in the tank SX-108 area. Elevated pH levels and trace concentrations of cesium-137 in subunit H1 at borehole 299-W23-19 (Section 3.4 and Appendix B, Section B.3.0) suggest that subunit H1 is a plausible starting location for second stage migration at this location.

Subsequently, contaminant migration proceeded at an accelerated rate as indicated by several pieces of data. Most importantly, circumstantial evidence of extensive water-line leakage in the late 1980s to early 1990s, and the continuing occurrence of very large technetium-99 and nitrate concentrations in recent borehole 299-W23-19 groundwater samples (Johnson and Chou 2001; Section 3.1.2.1 and Appendix C, Section C.7.0) suggests that these water-line leaks near tank SX-115 could provide the needed source of water that would explain the rapid contaminant migration rates and high concentration levels for technetium-99, nitrate, and chromium in groundwater at borehole 299-W23-19. Other data indicating enhanced moisture movement in well 299-W23-19 are high moisture contents in borehole soils and matric potential measurements indicating ongoing drainage in the entire soil column. Also, a more pronounced chromatographic separation between chromium and technetium-99/nitrate high concentration zones is observed in borehole 299-W23-19 compared to the tank SX-108 boreholes, suggesting longer recharge times and/or faster recharge rates.

Technetium-99 and nitrate distribution in borehole 299-W23-19 and unconfined aquifer samples also indicate a complex tank fluid migration pattern in the vadose zone. Outstanding features are as follows:

- Maximum technetium-99 and nitrate concentration zones within the Plio-Pleistocene unit
- Much smaller, but still elevated, technetium-99 and nitrate concentrations between the Plio-Pleistocene and the water table.

The obvious discontinuity between technetium-99 and nitrate concentration levels at the bottom of the vadose zone and in the unconfined aquifer show that vertical migration at the location of this borehole (299-W23-19) is not the major contributing pathway. Lateral migration of the primary technetium-99 and nitrate concentration zones to the west of borehole 299-W23-19 is

indicated, with the Plio-Pleistocene unit and perhaps subunit H1 providing stratigraphic control over fluid migration at different times.

## 5.5 IMPACTS ANALYSIS

In determining potential impacts from soil contamination from past releases, a suite of numerical simulations of flow and solute transport were performed to predict the performance of surface barriers for reducing long-term human health risk from potential groundwater contamination at WMA S-SX. Thirteen simulated cases involving two-dimensional cross-sections through WMA S-SX and one three-dimensional domain of a single tank (quarter symmetry) within the WMA were conducted. The suite of two-dimensional simulations were used to investigate the impact of no action alternative, surface barriers, water-line leaks, clastic dikes, nonuniform inventories, concentration dependent density and viscosity for the transporting fluid (i.e., water), and meteoric recharge. The three-dimensional simulation was used to investigate the impact of dimensionality on the numerical predictions. From the starting conditions, transient simulations of solute transport were conducted for a 1,000-year period (i.e., years 2000 to 3000) that involved changes in the flow fields in response to placement of surface barriers, water-line leaks, or solute-concentration dependent density and viscosity. All simulations were run assuming isothermal conditions. This assumption is supported by the S&T modeling work (see Section 4.2 and Appendix D, Section D.7.2). The vadose zone was modeled as an aqueous-gas porous media system, where transport through the gas phase was neglected. All but one simulation used the infinite dilution assumption for coupling fluid flow and contaminant transport. The solute-concentration dependent density and viscosity run coupled aqueous phase density with the concentration of a single contaminant, sodium nitrate.

Contaminant concentrations at the WMA S-SX boundary were translated to the other three compliance points (i.e., 200 West fence, 200 Area exclusion boundary, and Columbia River shoreline). Simulated results for the base case (no action alternative) scenario predicted arrivals of peak concentrations for technetium-99 in the following sequence:

- WMA S-SX boundary, year 2046
- 200 West fence, year 2181
- 200 Area exclusion boundary, year 2344
- Columbia River, year 2545.

Arrival times for peak concentrations of chromium and nitrate were similar to those for technetium-99, with the variations being primarily due to the initial inventory distributions. Because of its retardation factor and radioactive decay, cesium-137 was undetected at the WMA S-SX boundary for all simulation runs.

Simulation results suggest that two key factors affecting the prediction of contaminant migration are vadose zone contaminant inventory and recharge. The contaminant inventories have a major influence on the peak concentrations and arrival times of long-lived mobile radionuclides and chemical species at the WMA S-SX boundary. A comparison of the simulated BTCs at the first compliance boundary for the three cross-sections suggests that the inventory mass (i.e., Ci or kg) has a much more significant influence on the BTCs than the spatial distribution of the contaminants. Sensitivity analyses indicate that recharge estimates have a major influence on the

peak concentrations and their arrival times. No tank farm-specific recharge estimates are presently available. The base case infiltration rate of 100 mm/yr was essentially based on lysimeter data for gravel-covered, non-vegetated surfaces that mimic tank farm conditions.

The interim surface barriers, as expected, reduce fluxes to the water table. The technetium-99 peak concentrations were reduced by over a factor of two with placement of barriers. Numerical simulation results suggest that the impact of the interim barrier on reducing peak concentrations is most affected by the location of the initial inventory distribution within the vadose zone. Clastic dikes and enhanced fluid properties had negligible impact on simulated peak concentrations.

Overall, modeled peak concentrations exceed the drinking water standards (40 CFR 141) for the mobile constituents (i.e., technetium-99, nitrate, chromium) at WMA S-SX boundary. Exceptions are when recharge is only 30 mm/yr (Case 10) and 10 mm/yr (Case 11) where nitrate values do not exceed drinking water standards. However, tank farm recharges are not expected to be this low. At 200 West Fence, technetium-99 exceeds drinking water standards (40 CFR 141) for all cases, except Case 11 and chromium exceeds drinking water standards for all cases except Cases 10 and 11. Chromium exceeds the drinking water standard for Case 7 (displaced nonuniform inventory) at the 200 Area exclusion zone boundary.

The numerical simulation groundwater concentrations were used to evaluate the human health risk and dose (Section 4.4 and Appendix E, Section E.6.0) at each point of compliance. Five numerical simulation cases were evaluated using five groundwater exposure scenarios. The exposure pathways for this risk evaluation therefore are based on the groundwater exposure medium. The exposure scenarios used for this assessment are as follows:

- Industrial (MTCA C)
- Residential (MTCA B)
- Industrial worker (HSRAM)
- Residential farmer (HSRAM)
- Recreational shoreline user (HSRAM).

The compliance period, exposure scenarios, and compliance points were all established by Ecology and DOE during RFI/CMS workshop negotiations in March 1999 (DOE-RL 2000). Risk associated with the use of groundwater from a hypothetical water supply well was estimated at several downgradient points of compliance over a 1,000-year timeframe. Groundwater contaminant concentration estimates were based on the results of the contaminant transport analysis presented in Section 4.3 and Appendix E, Sections E.4.0 and E.5.0.

Based on DOE-RL (2000), the risk assessment for this WMA S-SX FIR is qualitative at this stage in the corrective action process even though substantial site-specific data have been generated. The results of this risk assessment are used to support evaluation of potential interim measures or ICMs and to determine the need for additional WMA-specific characterization data.

Risks due to contaminants included in the contaminant transport analysis (i.e., cesium-137, technetium-99, nitrate, and chromium) are based on the modeled groundwater concentrations. Risks due to other contaminants are based on scaled groundwater concentrations. Scaling is

performed by multiplying the non-modeled contaminant source inventories (as reported in Jones et al. 2000a) by the ratio of the modeled groundwater concentration to source inventory for one of the modeled contaminants. Because of the suspect amount of tank waste uranium found in the characterization efforts (see Section 3.3.5) and because of the limited mobility of uranium (solubility constraints and the positive distribution coefficient [0.6 mL/g per Kincaid et al. 1998]), uranium was not considered in the risk evaluation.

This impact evaluation indicates that technetium-99 is the key constituent driver for risk and dose, which represents current groundwater impact conditions (see Section 3.3 and Appendix E, Section E.6.0) and chromium and nitrate for the hazard index. For the evaluation between the WMA S-SX boundary and the Columbia River shoreline, the peak industrial worker ILCR varies from  $9.98 \times 10^{-3}$  to  $1.33 \times 10^{-6}$  for the no action base case compared to  $1.65 \times 10^{-3}$  to  $5.30 \times 10^{-7}$  for the barrier case. If the recharge rate is 50 mm/yr, rather than the 100 mm/yr assumed in the no action base case, the peak industrial worker ILCR varies from  $3.03 \times 10^{-3}$  at the WMA boundary to  $6.92 \times 10^{-7}$  at the Columbia River shoreline.

## 5.6 INTERIM MEASURES SUMMARY

Interim measures are initial response actions that can be taken while characterization activities are underway and long-term strategies are being developed to reduce the impacts of tank leaks on groundwater. Interim measures do not require comprehensive evaluation in a CMS. The ORP and the RPP have actively implemented various interim measures during the time this FIR was being prepared.

The following interim measures have been implemented.

- **Abandon Approximately 1,930 m (6,300 ft) of Active Water Lines.** Pipe breaks, failed leaded joints and poorly functioning gate valves are common. The sitewide failure rate appears to be increasing geometrically. Four pressurized water lines entering the S and SX tank farms from the east were identified and either leak tested or abandoned.
- **Decommission Unfit-For-Use Wells.** Wells and drywells that were identified as unfit-for-use are potential preferential pathways for downward contaminant migration. (Note that many of the wells and boreholes do not extend to the groundwater.) *Engineering Report, Single-Shell Tank Farms Interim Measures to Limit Infiltration through the Vadose Zone* (Anderson 2001) identifies six wells in the S and SX tank farms that are potential Priority 1 candidates for near-term decommissioning.
- **Implement Up-Gradient Surface Water Run-On Control Measures.** Up-gradient surface water run-on control consists of some combination of re-graded ground surfaces, gravel berms, asphalt pavement, and concrete curbs and valley drains constructed outside the SST farms to prevent surface water from pressurized water-line leaks and unusual meteorological events from flowing onto the tank farm areas. The report recommends that run-on control be established to prevent surface water from entering the SST farms from outside sources, even if no other interim measures are selected to reduce infiltration within each SST.

## 6.0 RECOMMENDATIONS

This section provides recommendations for further investigations and decisions based on findings from the WMA S-SX vadose zone and groundwater characterization activities. Recommendations for further investigations and decisions are provided for the following:

- Interim measures
- Accelerated CMSs
- Future tank farm operations
- Collection of additional data and information
- Lessons learned
- Restructuring of the RCRA Corrective Action Program.

### 6.1 RECOMMENDATIONS FOR INTERIM MEASURES

As discussed in Section 3.1.2, artificial recharge sources can have an important impact on contaminant transport. Interim measures are already being implemented at WMA S-SX (see Section 3.5):

- Groundwater wells have been capped and some decommissioned
- Water lines into the S and SX tank farms have been either cut or leaked tested
- Berms and gutters are being constructed around the S, SX, T, TX, TY, and U tank farms to lessen potential water run-on.

Other interim measures are planned (e.g., well decommissioning) to mitigate the artificial recharge. These interim measures should be incorporated throughout the tank farms to ensure that best management practices are incorporated to prevent run-on and run-off water and reduce potential driving forces that cause contaminants to migrate downward to the groundwater. In addition, waterlines that are deemed necessary should be leak tested on a periodic (i.e., annual) basis.

### 6.2 ACCELERATED CORRECTIVE MEASURE STUDIES

According to HFFACO Milestone M-45-58 (Ecology et al. 2001), a CMS could be conducted after the RFI report is written if determined to be needed by Ecology. The date for issuance of the CMS is to be determined.

The major potential corrective measures are the removal of waste, thus eliminating the source, and the mitigation of artificial recharge through run-on controls and leaking water lines (Sections 3.5 and 6.1). As proposed in HFFACO Change Package M-45-00-01A (Ecology et al. 1989), waste from two tanks in the S farm (i.e., tanks S-102 and S-112) will be retrieved and sent to double-shell tanks in 2006 thus beginning the process of waste removal.

Corrective measures to remove soil or piping are not recommended even though surface contamination (less the 4.6 m [15 ft] bgs) is widespread. Because of concerns for tank structural integrity, load limits exist for any operations inside the tank farms. Such load restrictions greatly

limit options for removing soil. In addition, soil removal could not be conducted without considering removal of the ancillary equipment piping systems throughout the tank farms that connect the tanks. Removal of these pipes would have to be conducted in unison with soil removal activities. The removal of the ancillary equipment piping would expose workers to significant radiation.

Water lines serving WMA S-SX are being cut and capped. Run-on and run-off controls have been implemented. Construction of long-term surface barriers is planned at the time of tank farm closure, depending on the closure strategy chosen.

A possible accelerated interim measure would be the placement of interim barriers. Numerical simulation results summarized in Section 4.2 suggest that compared to the no action alternative, placement of an interim surface barrier provides very little reduction in peak concentrations for mobile contaminants. It is premature to implement additional interim measures such as an interim surface barrier until the impact of capping water lines and run-on and run-off barriers can be ascertained and documented. If closure of the tank farms is delayed, safety issues associated with an interim barrier that could increase exposure to workers during waste retrieval efforts must be balanced against long-term environmental concerns. An engineering study for placing an interim surface barrier on tank farms should be conducted to determine the costs and impacts on tank farm operations and waste retrieval actions. Thus, an accelerated CMS is not recommended at this time.

### 6.3 FUTURE TANK FARMS OPERATIONS

Future tank operations (i.e., those at WMA S-SX and other tank farm WMAs) can benefit from the information gained from the WMA S-SX waste characterization studies in the following areas:

- Storage operations (e.g., waste transfers)
- Integration among waste retrieval, tank farm closure, and RCRA Corrective Action Program activities
- Matric potential and moisture content measurements in other SST farms.

Numerous tank waste leaks have occurred in the SST farms through overfilling of tanks or through leaks in ancillary equipment (e.g., piping) during transfers of waste from one tank to another. This characterization program has shown how important the effects of anthropomorphic type leaks from tank infrastructure have been in the migration history of tank leaks. Therefore, aboveground piping and similar types of best management practices should be used during waste retrieval activities to minimize potential releases to the environment in the future during waste retrieval activities.

Tank waste retrieval and tank farm closure decisions are partially based on information obtained from past leaks that occurred in the SST farm system. The RCRA Corrective Action Program characterization activities quantify vadose zone contaminant characteristics caused by past leaks and provide a better understanding of the environmental parameters (both human-made and natural) affecting contaminant migration. This information provides a means of estimating the

consequences of other leaks that may occur during retrieval and after closure. This capability is useful for determining the best approaches for waste retrieval and closure that satisfy regulatory requirements and are cost effective. Already, the Retrieval Program is using the data (particularly the data modeling package) from the Characterization Program in analysis of the impacts from potential leak losses in tanks S-102 and S-112. Greater integration is projected for the future as waste retrieval activities increase.

The new enhanced understanding of cesium migration implies that new sodium sources should not be applied to the vadose zone. Without such sources, the cesium-137 is not expected to move significant distances. Thus, future liquid waste retrieval activities should evaluate the use of either limited water-based or dry waste retrieval methods instead of sodium-rich supernate as the waste retrieval media to ensure cesium does not migrate further downward, especially on known past leaking tanks like tank SX-115.

#### 6.4 COLLECTION OF ADDITIONAL WMA S-SX DATA AND INFORMATION

Additional data collection is warranted only if the data collected are anticipated to have a significant impact on the findings presented in this report. Additional data do not appear to be necessary to support interim action decisions.

To reduce uncertainty, additional data could be obtained in WMA S-SX:

- Quantify gamma activity directly beneath the tanks through the use of the laterals located beneath SX farm tanks
- Quantify recharge rates for tank farm sediments
- Obtain vadose zone samples near tanks SX-107, S-104, and SX-115 and analyze those samples for important contaminants.

Horizontal access tubes (laterals) that were used for gross gamma and moisture measurements exist approximately 3 m (10 ft) beneath 10 of the SX farm tanks (tanks SX-105, SX-107, SX-108, SX-109, SX-110, SX-111, SX-112, SX-113, SX-114, SX-115). These laterals should be re-used for spectral gamma, moisture, and temperature measurements. If possible, contaminated soil samples may be retrieved.

The matric potential and moisture content measurements for sediment samples in WMA S-SX are valuable in determining the tank farm soil moisture regime and potential for contaminant migration (see Section 3.1.2 and Appendix C). These measurements can and should be extended to other tank farms. In FY 2001, a plan similar to that used for analyses of gross gamma measurements was developed to analyze previously collected moisture content measurements. Such analyses should be performed for all SST farms to aid in identifying preferred migration pathways.

Tank SX-107 may have leaked about 24,000 L (6,350 gal), about 40% of the amount that leaked from tank SX-108. However, most of these contaminants are thought to have moved almost vertically, not extending much beyond the edge of the tank. Tank SX-107 is a candidate for further investigation.

The only new characterization performed in the S tank farm was that using a cone penetrometer to detect gamma radiation and the retrieval of a few soil samples. Given the presumed leak volume of 90,800 L (24,000 gal), additional soil sample gathering at depth is indicated with subsequent contaminant analysis to provide data to support future waste retrieval activities (see Section 3.3 and Appendix B, Section B.6.0).

Technetium-99 concentrations in groundwater at well 299-W23-19 near tank SX-115 (the greatest manifestation of contamination in groundwater due to a tank waste source) are much higher than supported by a vertical pathway through the vadose zone. The groundwater data, stratigraphic conditions, leak characteristics, and current aquifer gradient all point toward a contaminated vadose zone in the Ringold Formation west of well 299-W23-19. In addition, a second characterization borehole would provide information on contaminant transport, similar to the pair of holes near tank SX-108.

## 6.5 LESSONS LEARNED

Much has been learned from the characterization, laboratory analyses, and modeling done for WMA S-SX. For example, the drilling techniques developed from the SX-108 slant borehole may be applied to characterization of the TX tank farm. The use of a tiered analysis approach has greatly decreased costs while prioritizing areas of greatest interests. Finally, non-isothermal and isothermal modeling (Appendices D and E) have improved the assessment of future releases to the groundwater and an understanding of thermal effects for contaminant migration through the vadose zone.

The main lesson learned is that the approach used in creating this FIR was successful and should be repeated for other FIR efforts. The FIRs will provide the baseline information to support tank waste retrieval and tank farm closure. The steps used in the approach are as follows:

- Collect geophysical data from previously published reports
- Collect and document construction and operational history
- Document the state of knowledge through a subsurface conditions description report (Johnson et al. 1999)
- Perform and document a DQO process (Ovink 1999) to prioritize new data collection activities
- Document the new work to be done in a work plan addendum (Henderson 1999; Rogers and Knepp 2000)
- Implement and document the work plan addendum (drilling, sample collection, geophysical logging, and laboratory analyses) (Henderson 1999; Rogers and Knepp 2000)
- Perform and document additional data gathering and analysis activities

- Work with others (e.g., Integration Project S&T activity) to gather and document additional data gathering and analyses activities
- Plan, perform, and document computer modeling (Khaleel et al. 2000; White et al. 2001)
- Integrate and document the preceding activities in a FIR.

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**APPENDIX A**  
**WORK PLAN INVESTIGATIVE APPROACH**

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## LIST OF TERMS

bgs	below ground surface
CHG	CH2M HILL Hanford Group, Inc.
DQO	data quality objectives
Ecology	Washington State Department of Ecology
PNNL	Pacific Northwest National Laboratory
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
WMA	waste management area

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## A.1.0 INTRODUCTION

This appendix summarizes the two work plans for waste management area (WMA) S-SX: *Preliminary Site-Specific SST Phase 1 RFI-CMS Work Plan Addendum for WMA S-SX* (Henderson 1999) and *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA S-SX* (Rogers and Knepp 2000). The activities defined in the two work plans have been completed.

Both Henderson (1999) and Rogers and Knepp (2000) are intended to serve as guidelines for the work described and are designed to allow for changes depending on conditions encountered in the field. Any changes were recorded on the appropriate field documentation, memoranda, or letters. Any modifications that did occur are addressed in Appendix B.

The activities performed in accordance with the work plans were as follows:

- Borehole 41-09-39 sampling and decommissioning
- *Resource Conservation and Recovery Act of 1976* (RCRA) groundwater monitoring well sediment sampling and analyses
- Installation of new borehole (299-W23-19) at tank SX-115
- Installation and decommissioning of new slant borehole at tank SX-108
- Near-surface characterization in the S tank farm.

The following sections discuss these activities.

## A.2.0 BOREHOLE 41-09-39 DECOMMISSIONING

Borehole 41-09-39 was driven to 40.1 m (131.5 ft) below ground surface (bgs) in December 1996 in the SX tank farm. A 17.8 cm (7 in.) outside diameter by 16.5 cm (6.5 in.) inside diameter well casing was placed from ground surface to 39.8 m (130.5 ft) bgs. The casing was initially closed at the bottom with a steel plug. The bottom plug was milled out and borehole 41-09-39 was extended to 69 m (225.3 ft) bgs in September 1997. A second 11.4 cm (4.5 in.) outside diameter by 9.8 cm (3.8 in.) inside diameter casing string was installed inside the 17.8 cm (7 in.) casing. The casing is 65 m (214 ft) in length by 11.4 cm (4.5 in.) outside diameter steel pipe, with a 3 m by 8.9 cm (10 ft by 3.5 in.) 0.010 slot stainless steel screen with a 0.3 m by 8.9 cm (1 ft by 3.5 in.) blank for a total length of 69 m (225 ft). There is no annular seal in either section of casing strings.

Borehole 41-09-39 decommissioning activities included sidewall sampling in the upper portion of the borehole; that is, 39.6 m (103 ft) bgs to surface. The lower portion of borehole 41-09-39 was sampled in 1997 and 1998. The following are the field activities executed as part of borehole 41-09-39 decommissioning:

- Removed Kabis sampler to support decommissioning
- Performed groundwater sampling and analysis before decommissioning
- Performed a tracer test that might clarify path, direction, and rate of groundwater flow
- Measured formation in the open borehole face as the casing is removed and measured temperature in the casing prior to removal to correlate sediment temperatures for future investigations
- Conducted borehole geophysical logging and analysis (moisture, neutron spectral gamma, and high-purity germanium analysis) to find indicated zones of contamination and stratigraphic correlation
- Sampled at intervals in the driven portion of the borehole to try to determine if drag-down from original drilling may be the cause of contamination found during geophysical analysis
- Obtained sediment samples to analyze for presence and concentration of contaminants and to evaluate alterations of the sediments from waste chemistry effects
- Obtained sediment samples to support preparation of the borehole geologic logs and stratigraphic and lithologic contact correlation with other boreholes
- Respond to the Washington State Department of Ecology (Ecology) and *Washington Administrative Code* requirements to decommission the borehole in a compliant manner.

The way some or all of the work was executed may have been modified because of field conditions; such modifications are acceptable per Henderson (1999). Any changes will be recorded on the appropriate field documentation, memoranda, or letters.

### A.2.1 REMOVAL OF KABIS SAMPLER

The Kabis sampler is 10.2 cm (4 in.) in diameter and stuck at the top of the 7.6 cm (3 in.) well screen section (Johnson and Chou 1999). The sampler was removed using appropriate techniques. After removing the sampler; the 11.43 cm (4.5 in.) borehole casing was brushed and swabbed to improve the ability to gather high-purity germanium logging runs.

### A.2.2 GROUNDWATER ANALYSES

The collection and analysis of groundwater samples from borehole 41-09-39 was completed before initiating the decommissioning activities described in Henderson (1999). Therefore, details of the groundwater analyses work are not addressed in this appendix. Information regarding groundwater analyses may be found in *RCRA Assessment Plan for Single-Shell Tank Waste Management Area at the Hanford Site* (Johnson and Chou 1999).

### A.2.3 TRACER INJECTION TEST

The purpose of the tracer injection test was to measure direction and flow rate of the groundwater from the center of the SX tank farm to monitoring wells surrounding the tank farm. The tracer medium was sodium bromide powder dissolved in 15,140 L (4,000 gal) of water to obtain a 50 parts per million bromide solution. The well screen sections remain in the borehole to ensure that the hole stays open and to provide better control over the injection zone and the rate of injection for the tracer test. Removal of the screen could create downhole conditions that could prevent completion of tracer testing and complicate the decommissioning process. A variance request to leave the screen in the borehole was approved by Ecology.

### A.2.4 BOREHOLE GEOPHYSICAL SURVEYING ACTIVITIES

Borehole 41-09-39 was geophysically surveyed in the lower portion prior to removal of the 11.43 cm (4 in.) casing and in the upper portion of the borehole prior to removal of the 17.8 cm (7 in.) casing to provide additional characterization information to supplement the sediment sampling data for the entire borehole. The following geophysical surveying techniques were used during borehole 41-09-39 decommissioning:

- Gross gamma logging to identify confining layers and for stratigraphic correlation
- Spectral gamma logging for measuring the distribution of selected radionuclides
- Neutron log for measuring the saturation distribution
- Neutron-enhanced spectral gamma logging for correlation of high-salt tank waste and moisture content with spectral gamma and neutron probes, respectively
- Infrared temperature gauge for measuring sediment temperature (this logging will be conducted both inside and outside the conductor casing for future correlation analysis).

The existing equipment and procedures for gross gamma and spectral gamma logging in use at the Hanford Site provide acceptable data through the various quality assurance measurements.

## A.2.5 SIDEWALL SAMPLING BOREHOLE SEDIMENTS

Sixteen sidewall sample locations have been identified in accordance with the data quality objectives (DQO) process. Prior to sample collection, comparison of the geophysical surveys obtained from activities specified in Section A.2.4 to the surveys utilized in the DQO meeting was done to verify sample locations. If the geophysical surveys indicated movement of the gamma contamination or changes in moisture content, the sample horizons were adjusted with the concurrence of the CH2M HILL Hanford Group, Inc. (CHG) technical representative. The sample locations are identified in Table A.1. Three samples were taken in a 120° radial pattern at each sample horizon at the bottom of the 11.43 cm (4.5 in.) casing for a total of 48 aliquots. Samples were retrieved using a sidewall sampler.

**Table A.1. Sample Number, Sample Interval, and Geologic Medium for Sampling During Decommissioning of Borehole 41-09-39 as Determined in the Data Quality Objectives Process**

Sample Number	Sample Interval Below Ground Surface (ft) <sup>a</sup>	Geologic Medium
1	39.9 – 40.2 m (131 – 132)	Silt – Plio-Pleistocene unit
2	35.7 – 36.0 m (117 – 118)	Silty sand – Hanford formation
3	34.1 – 34.4 m (112 – 113)	Silty sand – Hanford formation
4	32.9 – 33.2 m (108 – 109)	Silty sand – Hanford formation
5	31.1 – 31.4 m (102 – 103)	Silty sand – Hanford formation
6	29.0 – 29.3 m (95 – 96)	Sandy gravel – Hanford formation
7	27.1 – 27.4 m (89 – 90)	Sandy gravel – Hanford formation
8	25.0 – 25.3 m (82 – 83)	Gravelly sand – Hanford formation
9	24.1 – 24.4 m (79 – 80)	Gravelly sand – Hanford formation
10	22.6 – 22.9 m (74 – 75)	Gravelly sand – Hanford formation
11	21.0 – 21.3 m (69 – 70)	Gravelly sand – Hanford formation
12	19.8 – 20.1 m (65 – 66)	Slightly silty sand – Hanford formation
13	18.6 – 18.9 m (61 – 62)	Slightly silty sand – Hanford formation
14	17.4 – 17.7 m (57 – 58)	Slightly silty sand – Hanford formation
15	13.7 – 14.0 m (45 – 46)	Gravelly sand – original backfill <sup>b</sup>
16	7.6 – 7.9 m (25 – 26)	Gravelly sand – original backfill <sup>b</sup>

<sup>a</sup>Subject to change based on new geophysical surveying.

<sup>b</sup>Sample will be as a clean control.

If sampling the sidewall produced no sample or a limited sample collection as a result of sidewall collapse or poor retrieval as a result of field conditions, a split-spoon sample was to be collected if sidewall collapse occurs. If corrected sample volumes were small, another sample was to be attempted at an appropriate location above the first attempted sample location, unless interference for the next specified sample was a concern. See Appendix B for discussion of the events.

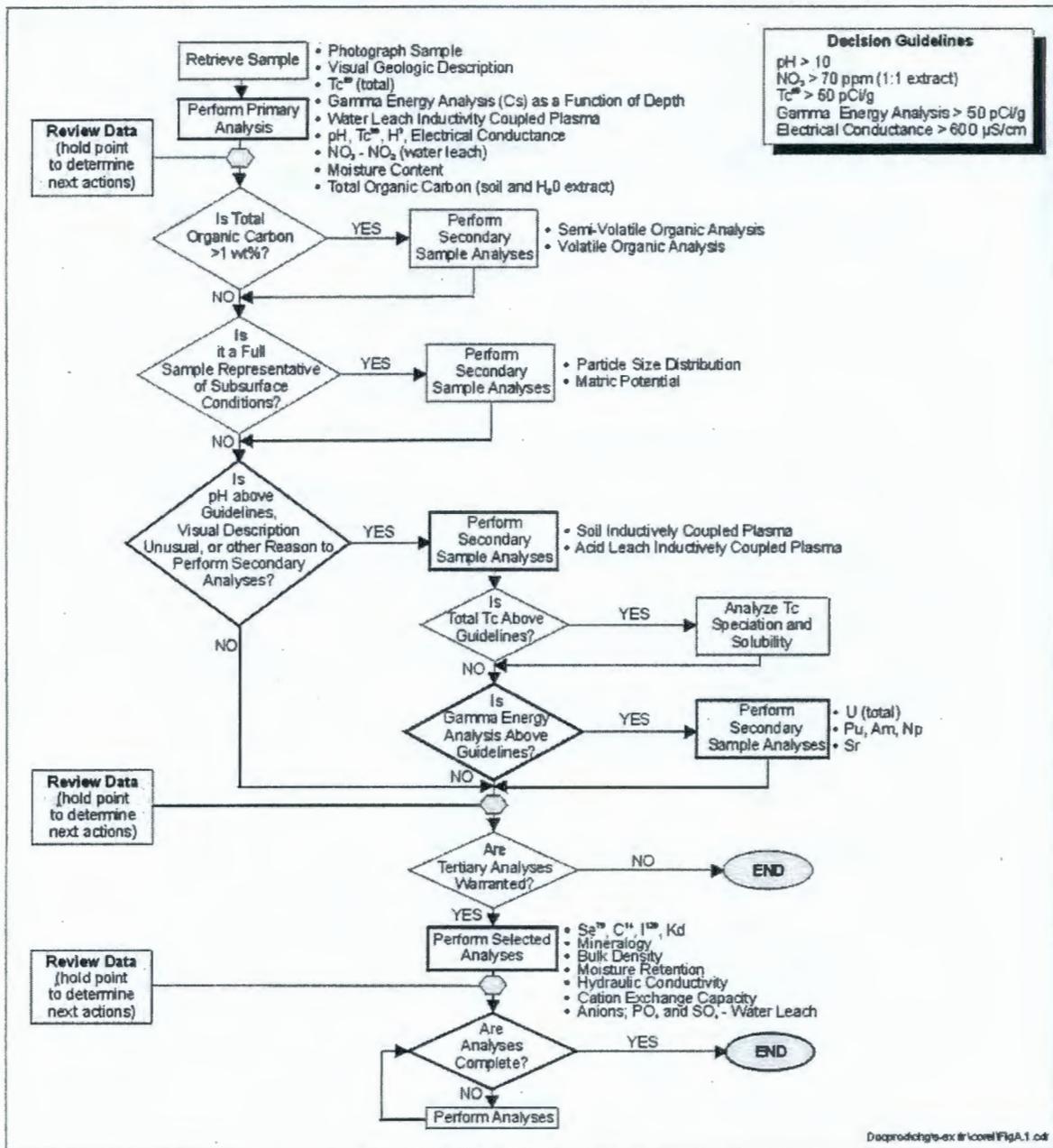
Once received at the laboratory, the samples underwent the analysis scheme identified in Figure A.1, using the analytical methods listed in Henderson (1999). This analysis event produced few samples with limited sample volume. Therefore, hold points were inserted into the process to allow the laboratory and CHG technical staff to collaborate and review data before each new round of analyses. See Appendix B for reports of the data review activities.

Based on the results of the primary analyses, spectral gamma surveys, and moisture content measurements performed during the field geophysical surveys and the geologic logging and field notes, geological technical experts, CHG technical staff, the laboratory technical staff, and decision-makers (Ecology and the U.S. Department of Energy) convened to determine what additional analyses should be conducted. Some of the determining criteria were to be the amount and integrity of the remaining sample, primary analytical results, and regulatory requirements. Based on these decisions, the secondary and tertiary analyses were to be performed. See Appendix B for report of the analyses performed.

#### **A.2.6 REMOVAL OF THE OUTER TEMPORARY CASING**

The total length of the 11.43 cm (4.5 in.) outside diameter casing removed is 63.4 m (208 ft). The casing shoe has a 13 cm (5 in.) outside diameter. Sediment sampling was conducted in 1997 from 39.6 m to 68.9 m (130 ft to 225 ft) bgs; therefore, no sampling was required in this interval. Abandonment of the interval is in compliance with "Minimum Standards for the Construction and Maintenance of Wells" (WAC 173-160) requirements. After the decommissioning, all steel casing in the borehole was removed and transferred to an appropriate disposal facility or a controlled decontamination facility.

Figure A.1. Analytical Scheme for Analysis of Borehole 41-09-39 Samples

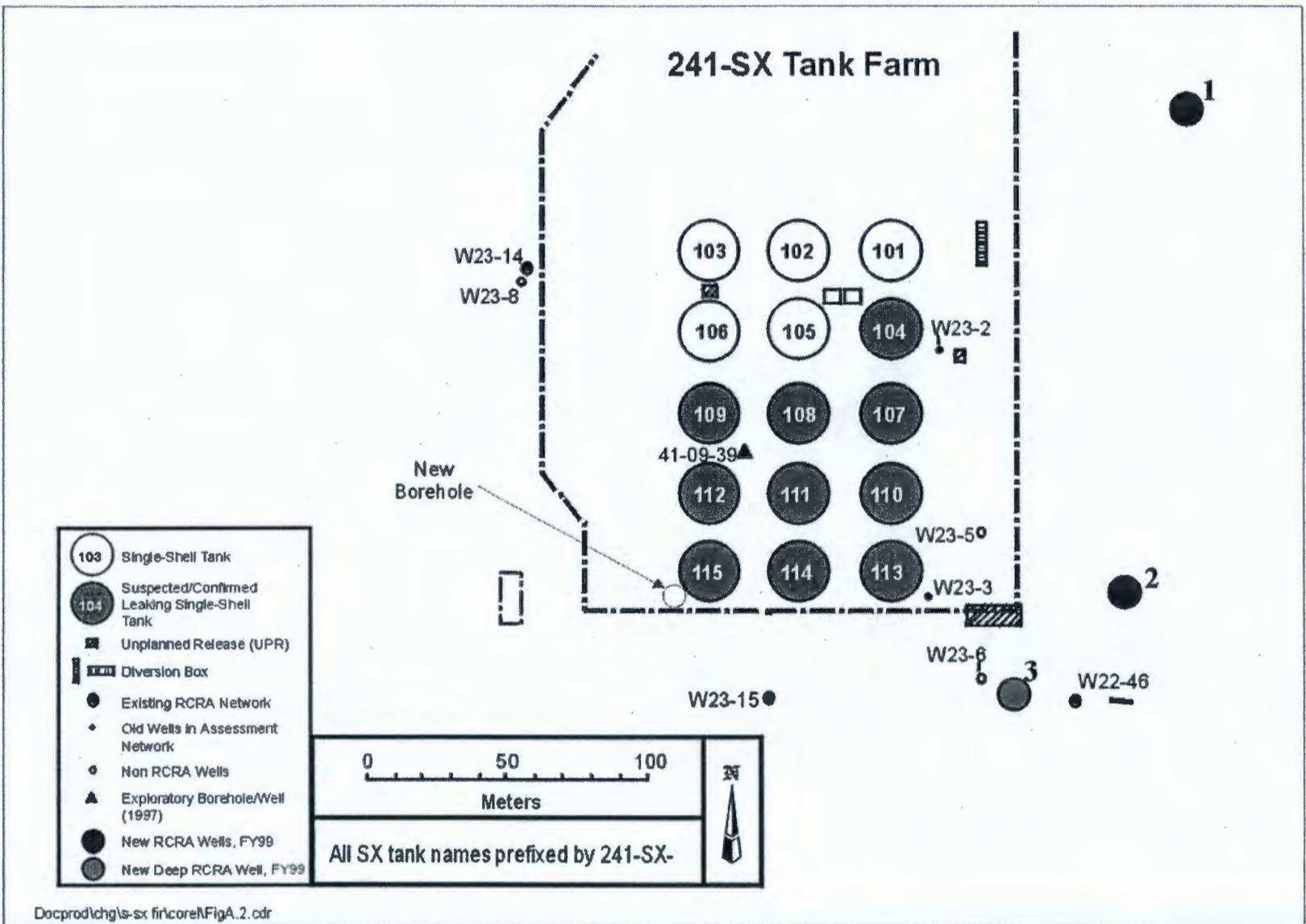


### **A.3.0 RESOURCE CONSERVATION AND RECOVERY ACT GROUNDWATER MONITORING WELL SEDIMENT SAMPLE ANALYSIS**

Continuous split-spoon driven samples and drill cutting samples were collected in conjunction with the installation of three RCRA groundwater monitoring wells. The southern-most monitoring well is located about 50 m (164 ft) southeast of tank SX-113 (Figure A.2). From this well, continuous sediment split-spoon driven samples from about 6 m (20 ft) bgs to refusal (anticipated to be near the top of the Ringold Formation) were collected. Drill cuttings were collected from refusal to the total depth of the water table. The other two RCRA groundwater monitoring wells are located east of the S and SX tank farms. Drill cuttings were collected from these two wells. Selected portions of the driven samples and cuttings were analyzed for chemical and physical characteristics. A detailed description of the work associated with the installation of these monitoring wells has been developed and, once Ecology comments are incorporated, will supercede Johnson and Chou (1999). Only details associated with analysis of sediment split-spoon driven samples and cuttings are addressed in this appendix.

Continuous driven samples taken from the vadose zone during construction of one well (well 3 of Figure A.2), and the samples were made available for hydrologic properties analysis. The analyses required for this sample are listed in Table A.2. Samples for analysis were from each stratigraphic unit, stratigraphic contacts, weathered bedding structures, and lithologic facies changes.

Figure A.2. Locations for the New Borehole and Resource Conservation and Recovery Act Groundwater Monitoring Wells



**Table A.2. Required Analyses on Resource Conservation  
and Recovery Act Well Sediment Samples**

Analysis/ Constituent	Preparation Method	Preparation Procedure Number	Analytical Method	Analytical Procedure Number*
PH	Water extract	Methods of Soil Analysis, Part 2; 62-1.3.2.2	Electrometric	Methods of Soil Analysis; 60-3.4
Particle size distribution	Bulk sediment	NA	Particle size distribution	ASTM D 422-63 ASTM D 854-83
Moisture content	Gravimetric	NA	Moisture content	PNL-MA-567-SA-7
Matric potential	Filter paper suction	NA	Matric potential	PNL-MA-567-SA-10
Bulk density	Gravimetric/volume	NA	Bulk density	PNL-MA-567-SA-8
Moisture retention	Bulk sediment	NA	Moisture retention	ASTM D 2325-68
Saturated hydraulic conductivity	Bulk sediment	NA	Saturated hydraulic conductivity	ASTM D 18.21 (draft in review) Methods of Soil Analysis, Part 2; 13-3.2 and 13-3.3
Anions	Water extract	Methods of Soil Analysis, Part 2; 62-1.3.2.2	IC  ISE Colorimetric	PNL-ALO-212 US EPA Method 300.0A Orion-720a Hach procedure
Metals	Water extract  Acid leach  Fusion	Method of Soil Analysis, Part 2; 62-1.3.2.2  PNL-ALO-106  PNL-ALO-235	ICPMS	PNL-ALO-211
Cation exchange capacity	Bulk sediment	NA	Cation exchange capacity	Methods of Soil Analysis Part 2; 9-3.1

\*The procedures are addressed in EPA (1983), EPA (1986), and ASTM (1998).

IC = ion chromatography.

ICPMS = inductively coupled plasma mass spectrometry.

ISE = ion selective electrode.

NA = not applicable.

#### A.4.0 INSTALLATION OF NEW BOREHOLE AT TANK SX-115

A new borehole labeled 299-W23-19 (well number B8809) was installed at tank SX-115. The following activities were conducted at the new borehole.

- Measured formation and casing temperature in the open borehole face after the casing was advanced and after cleaning the borehole during drilling for future correlation analysis.
- Conducted borehole geophysical surveying and analysis (moisture, neutron, gross gamma, spectral gamma and enhanced neutron spectral gamma analysis) for stratigraphic correlation and selected contaminant distribution.
- Performed spectral gamma logging and evaluated the potential use of microspheres to support attempt to determine the occurrence of dragdown during drilling.
- Obtained sediment samples to analyze for the presence and concentration of contaminants and to evaluate alterations of the sediments from waste chemistry effects.
- Obtained sediment samples to support preparation of the borehole geologic logs and stratigraphic and lithologic contact correlation with other boreholes in the WMA S-SX vicinity.

#### A.4.1 NEW BOREHOLE LOCATION

A new vertical borehole was drilled southwest of tank SX-115 within the SX tank farm. The location of the borehole is 3 m (10 ft) south of drywell 41-15-09 at coordinates Northing 134166.72 and Easting 566759.19, as is shown in Figure A.3. The boring extends from the surface to just below the water table, approximately 64 m (210 ft) bgs, to allow for groundwater sampling.

#### A.4.2 DRILLING AND SEDIMENT SAMPLING METHODS AND INTERVALS

The new borehole was advanced in conjunction with split-spoon sampling techniques through regions of interest with samples acquired in advance of the conductor casing installation. Then, the boring was cleaned out (i.e., drilled to expand the borehole diameter to approximately the drill pipe and conductor casing diameter while the conductor casing was being driven downward to the bottom of the last sample interval). The reverse-air circulation drill and drive method was used for this task because of the ease of drilling through gravels, cobbles, and boulders common to the area geology. Also, the quantity of drilling residuals (cuttings) is minimal with this technique, washout zones are significantly reduced or eliminated, and more representative formation and water samples can be obtained (Driscoll 1986) compared to previously used methods.



Air used in the drilling process had to be contained per the Washington State Department of Health. A Notice of Construction permit (DOE-RL 1999a) were acquired before drilling operations inside the tank farm. The drilling method complies with the requirements of the Washington State Department of Health for the Notice of Construction permit and other pertinent requirements and appropriate engineering systems to prevent the potentially contaminated air from being released to the environment.

Drilling was conducted using specifications and guidance in accordance with WAC 173-160. All waste was handled in accordance with the requirements of "Dangerous Waste Regulations" (WAC 173-303). The drilling and sampling techniques are based on minimizing the exposure of field personnel to both radiation and chemical pollutants, which is the application of as low as reasonably achievable principles in compliance with regulatory requirements.

The new borehole was completed as a RCRA-compliant groundwater monitoring well after completion of the geophysical surveying. All temporary steel casing removed from the boring was surveyed and either decontaminated and released or transferred to an appropriate disposal facility. A 4-in. stainless steel casing and screen was permanently installed, and a flush mount surface protection/well seal was constructed. The well was completed in accordance with WAC 173-160 requirements to meet groundwater protection goals. Specific work steps for well completion were documented in the tank farm work package.

Borehole sampling was performed to define the depth of contamination. The borehole serves to establish the general lithology of the sediments lying below the site and to give indications of how radionuclides and other contaminants have migrated. It also provides sediment samples for determination of sediment chemistry and vadose zone properties.

There is some question as to the geographical extent of the effect of the Hanford Site operations on sediment quality. There are uncertainties as to the extent of the effect of the site activities; therefore, a background sample (i.e., above the base of the tank) was obtained from the drilling of the borehole at SX tank farm. As with all samples, this sample was field screened using alpha, beta, gross gamma, and spectral gamma scans. The results from this sample were evaluated and compared to data from onsite borings to determine whether there has been any significant impact on the sediment below WMA S-SX from the Hanford Site operations. Because the background sample was taken 9 m (30 ft) bgs, any surface contamination present in the drilling location is not expected to have altered the constituent results.

For the new borehole, split-spoon drive sampling began at 3 m (10 ft) bgs to allow for a limited open borehole and placement of a sealed surface casing to prevent air contamination from occurring. Drilling and sampling continued until groundwater was reached. Figure A.4 shows the sampling strategy for the new borehole. The boring extends to just below the water table to permit installation of the Kabis sampler for groundwater sampling in accordance with guidance from the Hanford Groundwater Program (Stewart 1997).

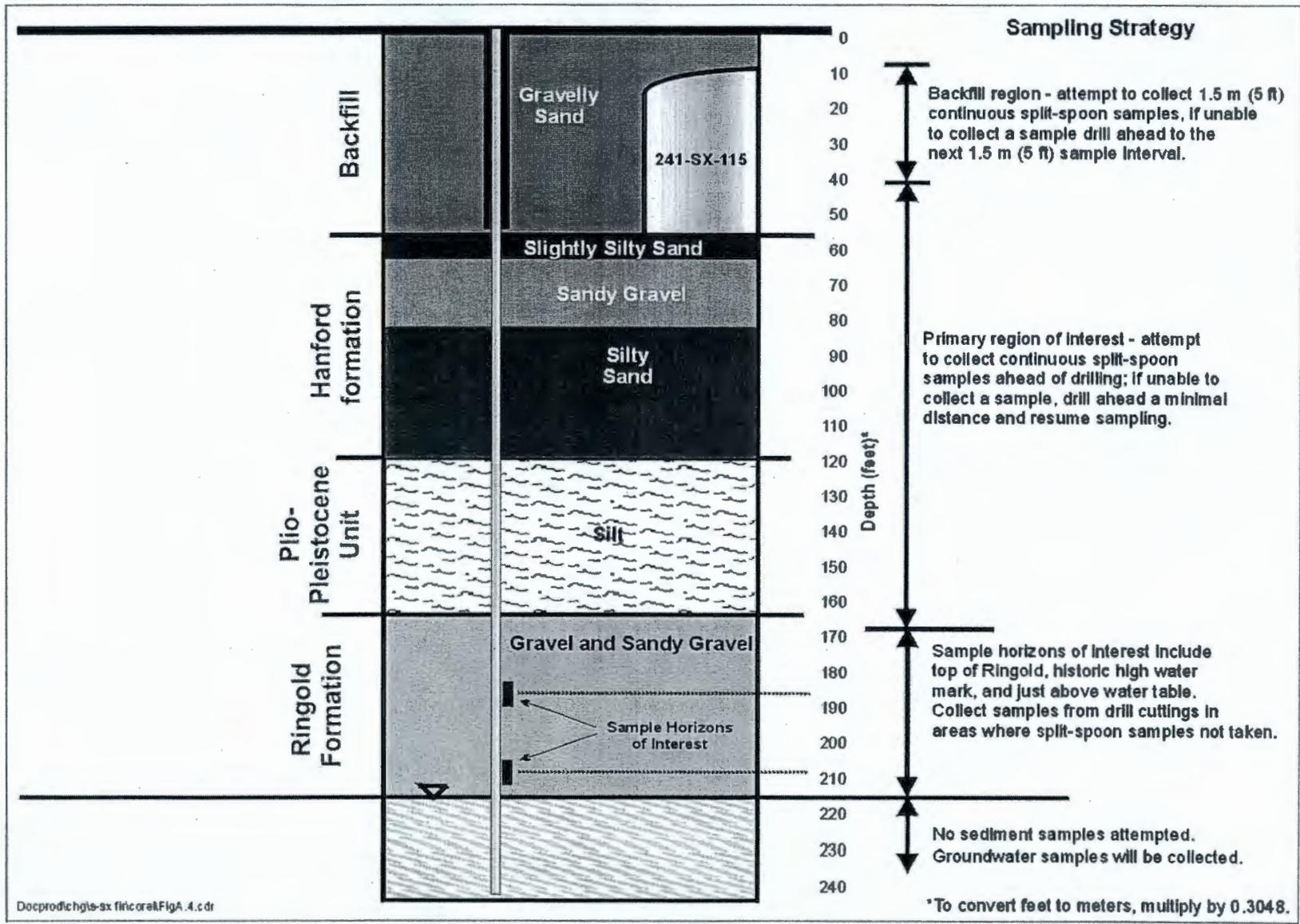


Figure A.4. New Borehole Sampling Strategy

### **A.4.3 BOREHOLE GEOPHYSICAL SURVEYING ACTIVITIES**

Downhole spectral gamma or gross gamma geophysical logging was conducted to ascertain the gamma-emitting radionuclide concentrations and assess contaminant drag-down during advancement of the casing. The spectral gamma or gross gamma logging frequency was directed by CHG. The planning basis for spectral gamma or gross gamma logging frequency included logging every 6.1 to 9.2 m (20 to 30 ft) that the borehole was advanced. If the radiological screening performed by the site health physics technician indicated a zone of high contamination was penetrated, a log was to be run within 4.6 m (15 ft) of passing through that zone.

A full suite of geophysical logs was run any time the casing size was changed and at the completion of the borehole. This provided some flexibility and provided for logging on average every 2 days following Waste Management Northwest's planning basis of advancing the hole 3 m (10 ft) per day.

The following logging techniques were used for the new borehole:

- Gross gamma logging to support correlation of confining layers and stratigraphy
- Spectral gamma logging for measuring the distribution of selected radionuclides
- Neutron log for measuring the degree of saturation distribution
- Neutron-enhanced spectral gamma logging for correlation of high-salt tank waste and moisture content with spectral gamma and neutron probes, respectively
- Infrared temperature gauge for measuring sediment temperature.

The existing equipment and procedures for gross gamma and spectral gamma logging in use at the Hanford Site provide acceptable data (DOE-GJO 1995).

The borehole was decommissioned following completion of the groundwater sampling described in Section A.3.4. All steel casing was removed and transferred to an appropriate disposal facility or controlled decontamination facility, and each boring was pressure-grouted from the bottom up, using a Portland cement/bentonite slurry. The procedures comply with U.S. Environmental Protection Agency requirements and WAC 173-160.

### **A.4.4 GROUNDWATER SAMPLING ACTIVITIES**

The sampling and analyses of groundwater was conducted by the Hanford Groundwater Program as described in Johnson and Chou (1999). The new borehole penetrated the groundwater table; therefore, samples of groundwater were collected and analyzed in accordance with guidance provided in the sampling plan for borehole 41-09-39 (Stewart 1997).

### **A.4.5 LABORATORY ANALYSIS**

The following sections describe the laboratory analyses required for the samples collected from the new borehole. Samples for laboratory analysis were placed in appropriate containers and

properly preserved. All samples for laboratory analysis were transported under chain of custody in accordance with Henderson (1999).

### **Sediment Sample Analysis**

After the split-spoon sediment samples and drill cutting samples were screened, these samples were transported to the Pacific Northwest National Laboratory (PNNL) Applied Geology and Geochemistry group for analysis. All material removed from the borehole was sent to the laboratory for possible future analysis. Samples are contained in airtight sample containers after their initial screening by the health physics technician and are kept under refrigeration. This process is used to retain sediment moisture in as close to field condition as possible. All samples were transported to the laboratory under refrigeration to further limit alteration of sediment moisture.

Sediment subsamples for laboratory analysis were defined by location in the sample after the field screening and geologic logging were completed and indication of contamination locations were identified. Approximately 22 sediment subsamples from the borehole were chosen for screening analysis. The following criteria were used to identify subsamples for laboratory analysis based on concurrence with Ecology.

- One background subsample taken at 9 m (30 ft) bgs.
- One subsample taken at 17 m (55 ft) bgs, at the level of the tank bottom.
- Two subsamples taken at the major lithology changes in the Hanford formation.
- One subsample taken at the Plio-Pleistocene unit and Hanford formation contact, and one subsample obtained at the Ringold Formation and Plio-Pleistocene unit contact.
- One subsample taken just above the water table in the capillary fringe zone.
- One subsample taken at the historic high water table at approximately 56 m (185 ft) bgs.
- Subsamples taken of any paleosols seen in the split-spoon drive samples.
- Subsamples taken in locations where elevated or altered gamma surveying or moisture content was measured during the geological and geophysical borehole logging process.
- At least one subsample taken every 3 m (10 ft) if samples have not already been taken, based on the above criteria to ensure continuous distribution and lithologic completeness.

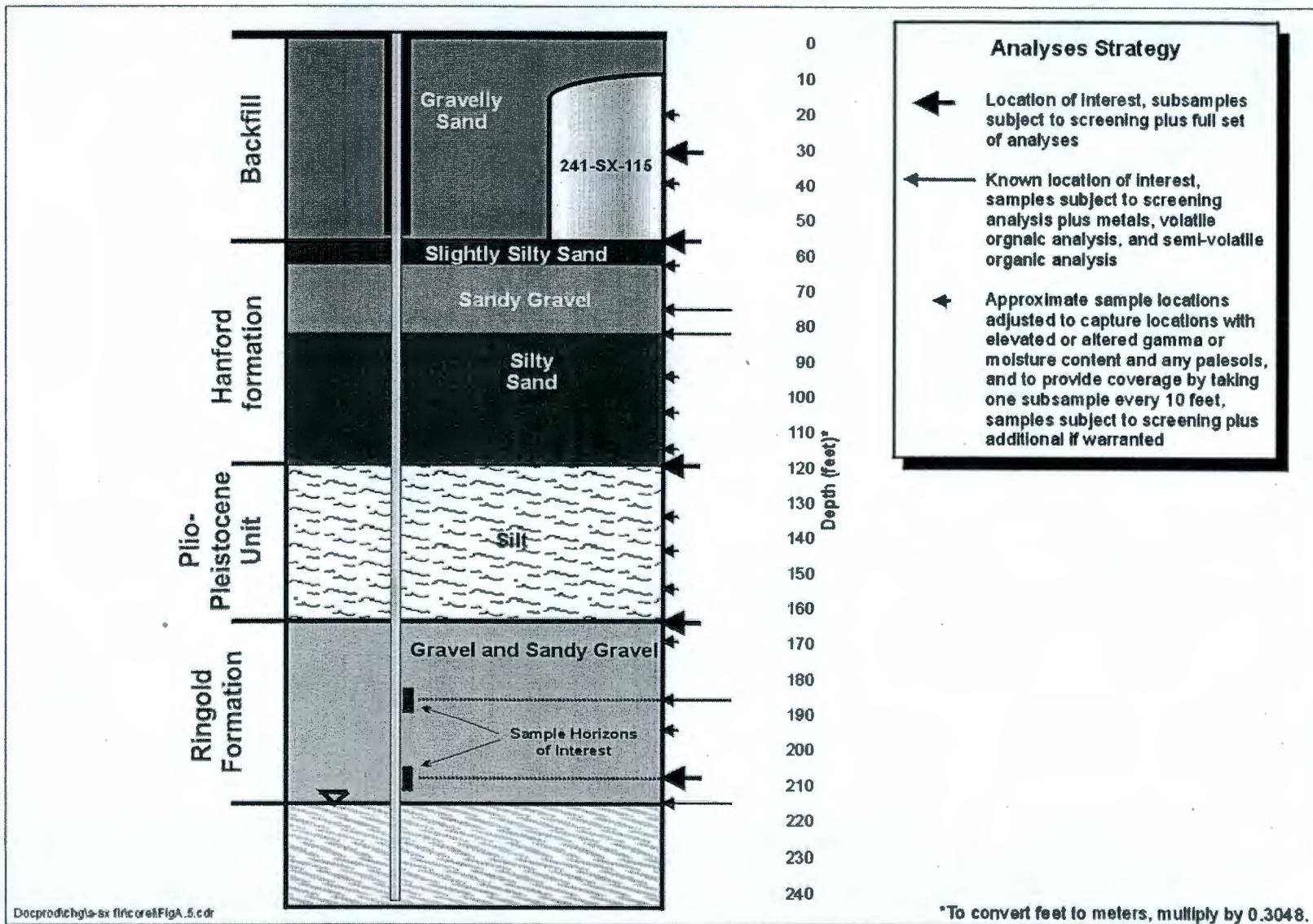
Figure A.5 shows the subsamples identified for laboratory analyses. All subsamples underwent screening analyses, which consist of nitrate analysis by the colorimetric method, pH measurement, electrical conductance measurement, and gamma energy analysis. These analyses, along with the gamma surveying and moisture content measurements performed during the field geophysical surveys and the laboratory geologic logging, were used to determine the extent of further subsample analysis. Table A.3 identifies the full complement of analyses and their respective laboratory preparation and analytical methods. This paragraph and the remainder of

this section identifies which analyses were conducted on which subsample. If more than one preparation or analytical method is listed, the laboratory geochemistry staff determined which methods would produce the best results and provide the best understanding of the chemistry involved. For those methods that produce multiple constituents (i.e., inductively coupled plasma or volatile organic analysis), all constituents identified were reported. Regulatory hold times were met where appropriate.

Because the purpose of the new borehole analysis is to both gain an understanding of the nature and extent of contamination, the fate and transport of the contaminants in the vadose zone, and to produce RCRA-compliant data, the analysis of these subsamples consisted of two levels. The baseline level involved analysis of organic, inorganic, and radiochemical constituents in full conformance with *Hanford Analytical Services Quality Assurance Requirements Document* (DOE-RL 1998) and with no modifications to methods (as defined in DOE-RL 1998) without concurrence from the CHG technical representative and from Ecology. Substitutions and deviations to methods as defined in DOE-RL (1998) did not require concurrence from Ecology. The second level involved a research-type approach to the analyses. In this level, procedures could be modified or developed to gain a more comprehensive understanding of the dynamics involved. Although specific quality control criteria did not apply to this level, compliance with the other quality assurance requirements of DOE-RL (1998) still had to be met and research analysis had to be initiated only following review and approval of the activities by the CHG technical representative.

The background subsample, backfill – Hanford formation contact subsample, the two subsamples obtained at the Hanford formation and Plio-Pleistocene unit contact and the Plio-Pleistocene unit and Ringold Formation contact, and the subsample obtained just above the water table in the capillary fringe zone were analyzed for the constituents and properties identified in Table A.3. It was recognized before analysis that conditions could occur in which all of the analyses identified in Table A.3 are not warranted (e.g., limited potential for data). These occurrences were to be evaluated on a case-by-case basis. See Appendix B for discussion of what did occur.

The remaining subsamples were analyzed for specific constituents listed in Table A.3 depending on the results of the nitrate, electrical conductivity, and pH screening analyses. A review of the screening analyses results with technical representatives along with Ecology was conducted prior to performing additional analyses. Screening analysis may have been used to determine whether alternative analytical techniques with lower detection limits should be used for specific radionuclides of concern. The screening criteria and associated analytical requirements are identified as follows:



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Figure A.5. Tank SX-115 Borehole Subsample Analyses Strategy

**Table A.3. Constituents and Methods for New Borehole Sediment Sample and Borehole 41-09-39 Decommissioning Sample Analyses (2 Sheets)**

Analysis/ Constituent	Preparation Method	Preparation Procedure Number	Analytical Method	Analytical Procedure Number <sup>a</sup>
Cesium-137	Bulk sediment	NA	GEA	PNL-RRL-001
Carbon-14	Bulk sediment Water extract	NA Methods of Soil Analysis, Part 2; 62-1.3.2.2	Total combustion LSC method in review based on:	ASTM D 4129-82 PNL-ALO-476
Europium-152	Bulk sediment	NA	GEA	PNL-RRL-001
Neptunium-237 Plutonium-239 Plutonium-240 Americium-241	Acid leach Fusion	PNL-ALO-106 PNL-ALO-235	ICP-MS	PNL-ALO-211
Strontium-90	Acid leach Fusion	PNL-ALO-106 PNL-ALO-235	LSC	PNL-ALO-476
Cobalt-60	Bulk sediment	NA	GEA	PNL-RRL-001
Technetium-99	Acid leach Fusion	PNL-ALO-106 PNL-ALO-235	ICP-MS LSC	PNL-ALO-211 PNL-ALO-476
Hydrogen-3	Water extract	Methods of Soil Analysis, Part 2; 62-1.3.2.2	LSC	PNL-ALO-476
Iodine-129	Acid leach	PNL-ALO-106	ICP-MS	PNL-ALO-211
Selenium-79	b	b	b	b
Total uranium	Water extract  Fusion	Methods of Soil Analysis, Part 2; 62-1.3.2.2 PNL-ALO-235	ICP-MS	PNL-ALO-211
Metals	Water extract  Acid leach Fusion	Methods of Soil Analysis, Part 2; 62-1.3.2.2 PNL-ALO-106 PNL-ALO-235	ICP-MS	PNL-ALO-211
VOA	Bulk sediment	c	GC/MS	SW846-8260
SVOAs with TICs	Bulk sediment	c	CG/MS	SW846-8270
pH	Water extract	Methods of Soil Analysis, Part 2; 62-1.3.2.2	Electrometric	Methods of Soil Analysis; 60-3.4
Anions	Water extract	Methods of Soil Analysis, Part 2; 62-1.3.2.2	IC  ISE Colorimetric	PNL-ALO-212 US EPA Method 300.0A Orion-720a Hach procedure
Cation exchange capacity	Bulk sediment	NA	Cation exchange capacity	Methods of Soil Analysis Part 2; 9-3.1

**Table A.3. Constituents and Methods for New Borehole Sediment Sample and Borehole 41-09-39 Decommissioning Sample Analyses (2 Sheets)**

Analysis/ Constituent	Preparation Method	Preparation Procedure Number	Analytical Method	Analytical Procedure Number <sup>a</sup>
Particle size distribution	Bulk sediment	NA	Particle size distribution	ASTM D 422-63 ASTM D 854-83
Mineralogy	Bulk powder/clay	JEA-2, Rev. 0	XRD/SEM/TEM	JEA-3, Rev. 0
Electrical conductance	Water extract	Methods of Soil Analysis, Part 2; 62-1.3.2.2	Electrometric	PNL-MA-567-FA-2
Moisture content	Gravimetric	NA	Moisture content	PNL-MA-567-SA-7
Matric potential	Filter paper suction	N/A	Matric potential	PNL-MA-567-SA-10
Distribution coefficient	Bulk sediment	NA	Methods for determining radionuclide retardation factors, 1980	PNL-3349 USC-70
Bulk density	Gravimetric/volume	NA	Bulk density	PNL-MA-567-SA-8
Moisture retention	Bulk sediment	NA	Moisture retention	ASTM D 2325-68
Saturated hydraulic conductivity	Bulk sediment	NA	Saturated hydraulic conductivity	ASTM D18.21 (draft in review) Methods of Soil Analysis, Part 2; 13-3.2 and 13-3.3

<sup>a</sup>The procedures are addressed in EPA (1983), EPA (1986), and ASTM (1998).

<sup>b</sup>Procedures for analysis of selenium-79 are being prepared; this analysis does not apply to the new borehole.

<sup>c</sup>Preparation/extraction procedures for VOA and SVOA analysis will depend on the types of organic compounds present in the sediment.

GEA = gamma energy analysis.

IC = ion chromatography.

ISE = ion selective electrode.

LSC = liquid scintillation.

NA = not applicable.

SEM = scanning electron microscopy.

SVOA = semi-volatile organic analysis.

TEM = transmission electron microscopy.

TIC = tentatively identified compound.

TOC = total organic carbon.

VOA = volatile organic analysis.

XRD = x-ray diffraction.

- Gamma-emitting radioisotopes by gamma energy analysis
- Carbon-14
- Metals and radioisotopes by inductively coupled plasma mass spectrometry
- Tritium and strontium-90 by the liquid scintillation method
- Particle size distribution
- Volatile and semi-volatile organic analysis, including tentatively identified compounds.

A minimum of two subsamples collected within the Hanford formation were to be analyzed for volatile and semi-volatile organic compounds, including tentatively identified compounds and metals.

The data obtained from the above analyses were used to evaluate the location of contamination plumes in the sediment column. If isolated peaks or unusual results were found, additional subsamples from the archived drive sample may have been obtained and analyzed. The results of the above analyses were also used to determine if additional analyses are warranted. Additional analyses were performed based on the judgement and expertise of the responsible PNNL geochemist, with concurrence from the CHG technical representative and Ecology. The following analyses were considered for additional analyses:

- Cation exchange capacity
- Mineralogy
- Matric potential
- Distribution coefficient
- Bulk density
- Moisture retention
- Saturated hydraulic conductivity.

Table A.3 identifies the analyses and laboratory methods used for the sample analyses. For the chemical and radiological constituents, the preferred methods are those listed in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (EPA 1986) or the American Society for Testing and Materials standards (ASTM 1998). The requested constituents may have been analyzed by laboratory-specific procedures, provided that the procedures were validated and conform to DOE-RL (1998). Appendix B discusses the laboratory-specific procedures used. Both the EPA (1986) methods and the PNNL methods listed in Table A.3 are based on techniques from "Methods of Soil Analysis" (ASTM 1998). Therefore, these procedures should be comparable.

## A.5.0 INSTALLATION OF SLANT BOREHOLE AT TANK SX-108

The following activities were conducted during installation of a slant borehole at tank SX-108.

- Conduct borehole geophysical surveying and analysis (moisture, neutron, gross gamma, spectral gamma and neutron-enhanced spectral gamma analysis).
- Obtain sediment samples to analyze for the presence and concentration of contaminants and to evaluate alterations of the sediments from waste chemistry effects.
- Obtain sediment samples to support preparation of the borehole geologic logs and stratigraphic and lithologic contact correlation with other boreholes/wells in the WMA S-SX vicinity.

### A.5.1 SLANT BOREHOLE LOCATION

The slant borehole is located northwest of tank SX-108 extending under tank SX-108 within the SX tank farm. The location of the borehole is shown in Figure A.6.

### A.5.2 DRILLING AND SEDIMENT SAMPLING METHODS AND INTERVALS

One of the primary constraints on sample collection from the 'hot' zone under tank SX-108 was the potential radiation level (greater than 500 mrem/h), which may have limited the sample volumes that could be brought to the surface. To reduce the uncertainties associated with placing a slant borehole beneath tank SX-108, a demonstration was conducted outside of the tank farms to evaluate the techniques for installing the borehole and collecting samples. This demonstration helped refine the borehole angle and the sample collection methods. The planning basis for the SX-108 slant borehole included the following.

- The borehole enters the ground at approximately the 11 o'clock position 12.2 m (40 ft) from the edge of the tank nominally 30° off vertical, heading directly underneath the center of the tank (toward the 5 o'clock position). A preliminary investigation of surface and subsurface interference identified this as a potentially viable location. The borehole depth was to be limited to the Plio-Pleistocene unit or to the maximum depth of contamination, whichever is greater.
- Driven samples were collected ahead of the casing. The samples were transported to the laboratory and analyzed for the contaminants of concern identified in Table A.4. Nominally, 10 horizons would be sampled based on the geophysical surveys or the need to provide depth coverage.

Figure A.6. Tank SX-108 Soil Sampling Location

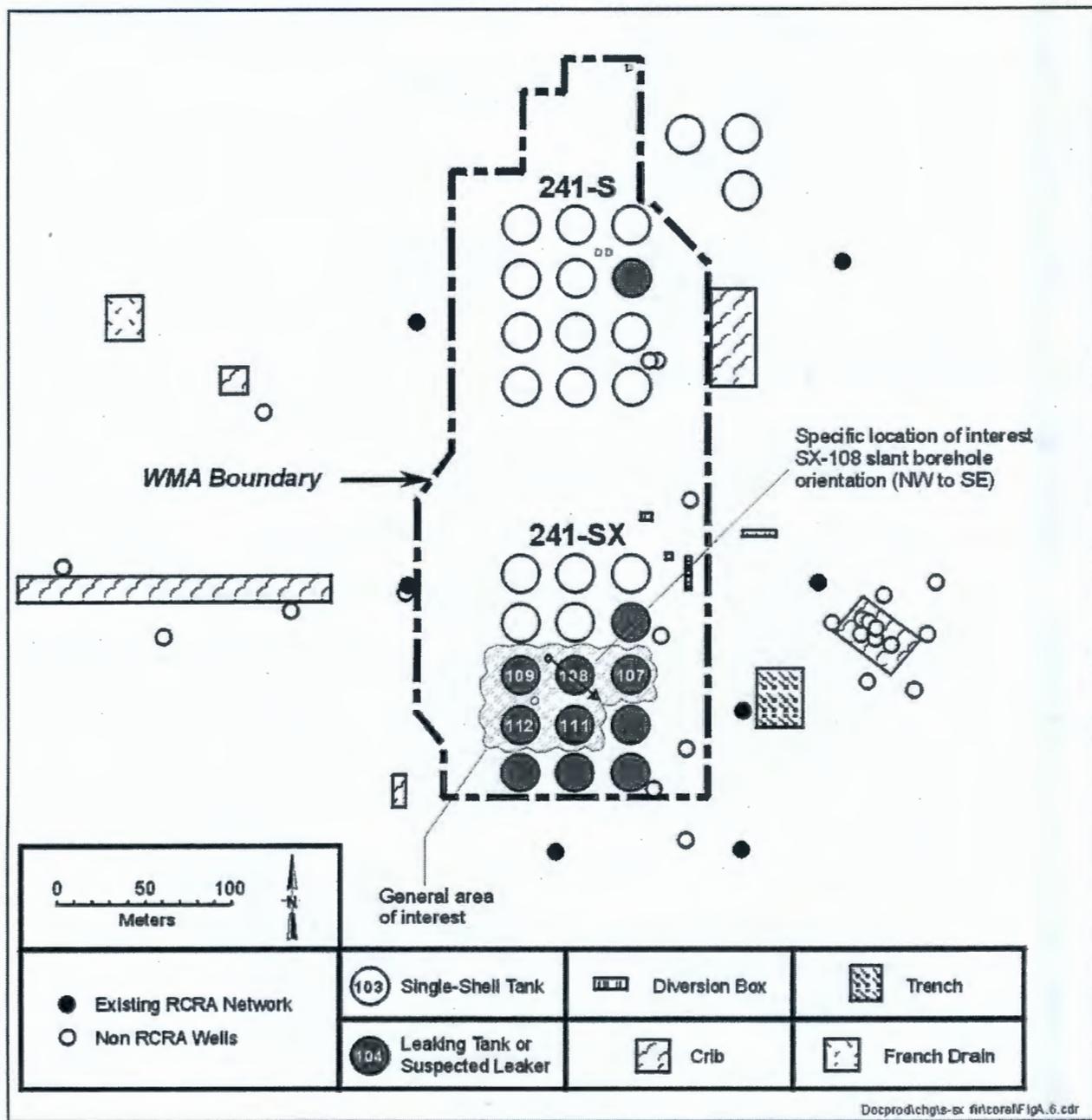


Table A.4. Constituents and Methods for SX-108 Slant Borehole Sediment Sample Analyses and Near-Surface Characterization Samples (4 Sheets)

Contaminants of Potential Concern	CAS #	Action Levels		Name/Analytical Technology <sup>a</sup>	Target Required Quantitation Limits				Precision Water (%)	Accuracy Water (%)	Precision Soil (%)	Accuracy Soil (%)
		RR <sup>b</sup> (pCi/g)	CI <sup>c</sup> (pCi/g)		Water <sup>b</sup> Low Level (pCi/L)	Water <sup>b</sup> High Level (pCi/L)	Soil Other Low Level (pCi/g)	Soil Other High Level (pCi/g)				
Radionuclide												
Americium-241	14596-10-2	3.10E+01	2.10E+02	Americium isotopic - AEA	1	400	1	4,000	+20	70-130	-35	70-130
Carbon-14	14762-75-5	5.20E+00	3.31E+04	Carbon-14 - liquid scintillation	200		50	NA	+20	70-130	+35	70-130
Cesium-137	10045-97-3	6.20E+00	2.50E+01	Gamma energy analysis	15	200	0.1	2,000	+20	70-130	+35	70-130
Cobalt-60	10198-40-0	1.40E+00	5.20E+00	Gamma energy analysis	25	200	0.05	2,000	+20	70-130	+35	70-130
Europium-152	14683-23-9	3.30E+00	1.20E+01	Gamma energy analysis	50	200	0.1	2,000	+20	70-130	+35	70-130
Europium-154	15585-10-1	3.00E+00	1.10E+01	Gamma energy analysis	50	200	0.1	2,000	+20	70-130	+35	70-130
Europium-155	14391-16-3	1.25E+02	4.49E+02	Gamma energy analysis	50	200	0.1	2,000	+20	70-130	+35	70-130
Neptunium-237	13994-20-2	2.50E+00	6.22E+01	Neptunium-237 - AEA	1		1	8,000	+20	70-130	+35	70-130
Nickel-63	13981-37-8	4.03E+03	3.01E+06	Nickel-63 - liquid scintillation	15	NA	30	NA	+20	70-130	+35	70-130
Plutonium-238	13981-16-3	3.74E+01	4.73E+01	Plutonium isotopic - AEA	1	130	1	1,300	+20	70-130	+35	70-130
Plutonium-239/240	PU-239/240	3.39E+01	4.37E+02	Plutonium isotopic - AEA	1	130	1	1,300	+20	70-130	+35	70-130
Total radioactive strontium or strontium-90	SR-RAD or 10098-97-2	4.50E+00	2.50E+03	Total radioactive strontium or strontium isotopic - GPC	2	80	1	800	+20	70-130	+35	70-130
Technetium-99	14133-76-7	5.70E+00	4.10E+05	Technetium-99 - liquid scintillation	15	400	15	4,000	+20	70-130	+35	70-130
Thorium-232	TH-232	1.00E+00	5.10E+00	Thorium isotopic - AEA (pCi) ICPMS (mg)	1	0.002 mg/L	1	0.02 mg/Kg	+20	70-130	+35	70-130
Uranium-234	13966-29-5	1.60E+02	1.20E+03	Uranium isotopic - AEA (pCi) ICPMS (mg)	1	0.002 mg/L	1	0.02 mg/Kg	+20	70-130	+35	70-130
Uranium-235	15117-96-1	2.60E+01	1.00E+02	Uranium isotopic - AEA (pCi) ICPMS (mg)	1	0.002 mg/L	1	0.02 mg/Kg	+20	70-130	+35	70-130
Uranium-238	U-238	8.50E+01	4.20E+02	Uranium isotopic - AEA (pCi) ICPMS (mg)	1	0.002 mg/L	1	0.02 mg/Kg	+20	70-130	+35	70-130

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Table A.4. Constituents and Methods for Slant Borehole Sediment Sample Analyses and Near-Surface Characterization Samples (4 Sheets)

Contaminants of Potential Concern	CAS #	Action Levels		Name/Analytical Technology <sup>a</sup>	Target Required Quantitation Limits				Precision Water (%)	Accuracy Water (%)	Precision Soil (%)	Accuracy Soil (%)
		Method B (ug/Kg)	Method C (ug/Kg)		Water <sup>b</sup> Low Level (ug/L)	Water <sup>b</sup> High Level (ug/L)	Soil Other Low Level (ug/Kg)	Soil Other High Level (ug/Kg)				
Chemical												
PCBs	1336-36-3	5.00E+02	6.50E+04	PCBs - 808 <sup>b</sup> - GC	0.5	5	16.5	100	e	e	e	e
Cyanide	57-12-5	2.00E+04	2.00E+04	Total cyanide - 9010 - colorimetric	5	5	500	500	e	e	e	e
Lead	7439-92-1	3.53E+05	3.53E+05	Metals - 6010 - ICP	100	200	10,000	20,000	e	e	e	e
Lead	7439-92-1	3.53E+05	3.53E+05	Metals - 6010 - ICP(TRACE)	10	NA	1,000	NA	e	e	e	e
Mercury	7439-97-6	N/A	N/A	Mercury - 7470 - CVAA	0.5	5	N/A	N/A	e	e	e	e
Mercury	7439-97-6	3.30E+02	3.30E+02	Mercury - 7471 - CVAA	N/A	N/A	200	200	e	e	e	e
Nickel	7440-02-0	3.20E+04	7.00E+04	Metals - 6010 - ICP	40	40	4,000	4,000	e	e	e	e
Silver	7440-22-4	8.00E+03	1.00E+04	Metals - 6010 - ICP	20	20	2,000	2,000	e	e	e	e
Silver	7440-22-4	8.00E+03	1.00E+04	Metals - 6010 - ICP(TRACE)	5	NA	500	NA	e	e	e	e
Antimony	7440-36-0	3.20E+04	1.40E+06	Metals - 6010 - ICP	60	120	6,000	12,000	e	e	e	e
Antimony	7440-36-0	3.20E+04	1.40E+06	Metals - 6010 - ICP(TRACE)	10	NA	1,000	NA	e	e	e	e
Arsenic	7440-38-2	6.50E+03	6.50E+03	Metals - 6010 - ICP	100	200	10,000	20,000	e	e	e	e
Arsenic	7440-38-2	6.50E+03	6.50E+03	Metals - 6010 - ICP(TRACE)	10	NA	1,000	NA	e	e	e	e
Barium	7440-39-3	1.32E+05	2.45E+05	Metals - 6010 - ICP	200	200	20,000	20,000	e	e	e	e
Barium	7440-39-3	1.32E+05	2.45E+05	Metals - 6010 - ICP(TRACE)	5	NA	500	NA	e	e	e	e
Beryllium	7440-41-7	1.51E+03	1.51E+03	Metals - 6010 - ICP	5	10	500	1,000	e	e	e	e
Cadmium	7440-43-9	5.00E+02	5.00E+02	Metals - 6010 - ICP	5	10	500	1,000	e	e	e	e
Cadmium	7440-43-9	5.00E+02	5.00E+02	Metals - 6010 - ICP(TRACE)	5	NA	500	NA	e	e	e	e
Chromium (total)	7440-47-3	1.60E+06	3.50E+06	Metals - 6010 - ICP	10	10	1,000	2,000	e	e	e	e
Chromium (total)	7440-47-3	1.60E+06	3.50E+06	Metals - 6010 - ICP(TRACE)	10	NA	1,000	NA	e	e	e	e
Chromium VI	18540-29-9	8.00E+03	1.75E+04	Chromium (hex) - 7196 - colorimetric	10	4,000	500	200,000	e	e	e	e
Copper	7440-50-8	5.92E+04	1.30E+05	Metals - 6010 - ICP	25	25	2,500	2,500	e	e	e	e
Selenium	7782-49-2	5.00E+03	5.00E+03	Metals - 6010 - ICP	100	200	10,000	20,000	e	e	e	e
Selenium	7782-49-2	5.00E+03	5.00E+03	Metals - 6010 - ICP(TRACE)	10	NA	1,000	NA	e	e	e	e
Uranium (total)	7440-61-1	2.40E+05	1.05E+07	Uranium total - kinetic phosphorescence analysis	0.1	20	1,000	200	+20	70-130	+35	70-130

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Table A.4. Constituents and Methods for Slant Borehole Sediment Sample Analyses and Near-Surface Characterization Samples (4 Sheets)

Contaminants of Potential Concern	CAS #	Action Levels		Name/Analytical Technology <sup>a</sup>	Target Required Quantitation Limits				Precision Water (%)	Accuracy Water (%)	Precision Soil (%)	Accuracy Soil (%)
		Method B (ug/Kg)	Method C (ug/Kg)		Water <sup>b</sup> Low Level (ug/L)	Water <sup>b</sup> High Level (ug/L)	Soil Other Low Level (ug/Kg)	Soil Other High Level (ug/Kg)				
Chemical												
Ammonia-ammonium	7664-41-7	2.72E+07	5.95E+07	Ammonia - 350 N <sup>d</sup>	50	300,000	500	3,000,000	e	e	e	e
Phosphate	14265-44-2	N/A	N/A	Anions - 9056 - IC	500	15,000	5,000	40,000	e	e	e	e
Nitrate	14797-55-8	4.40E+06	4.40E+06	Anions - 9056 - IC	250	10,000	2,500	40,000	e	e	e	e
Nitrite	14797-65-0	3.30E+05	3.30E+05	Anions - 9056 - IC	250	15,000	2,500	20,000	e	e	e	e
Nitrate/nitrite as N	NO <sub>3</sub> +NO <sub>2</sub> -N	3.30E+05	3.30E+05	Nitrate/nitrite - 353 N <sup>d</sup>	75	NA	750	NA	e	e	e	e
Sulfate	14808-79-8	2.50E+07	2.50E+07	Anions - 9056 - IC	500	15,000	5,000	40,000	e	e	e	e
Chloride	16837-00-6	2.50E+07	2.50E+07	Anions - 9056 - IC	200	5,000	2,000	5,000	e	e	e	e
Fluoride	16984-48-8	9.60E+04	2.00E+05	Anions - 9056 - IC	500	5,000	5,000	5,000	e	e	e	e
Sulfides	18496-25-8	N/A	N/A	Sulfide - 9030 - colorimetric	500	NA	5,000	NA	e	e	e	e
Bromide	34959-67-9	N/A	N/A	Anions - 9056 - IC	250	NA	2,500	NA	e	e	e	e
pH	pH	N/A	N/A	pH - 9045 - electrode	N/A	N/A	N/A	N/A	e	e	e	e
Total organic carbon/ total carbon	TOC/TC	N/A	N/A	ASTM D4129-82 - total combustion/colorimetric	1 ppm	1 ppm	1 ppm	1 ppm	e	e	e	e
Cation exchange capacity	CEC	N/A	N/A	Cation exchange capacity/Methods of Soil Analysis Part 2, 9-3.1.	N/A	N/A	N/A	N/A	f	f	f	f
Particle size distribution	N/A	N/A	N/A	Particle size distribution/ ASTM D 422-63, ASTM D 854-83	N/A	N/A	N/A	N/A	f	f	f	f
Minerology	N/A	N/A	N/A	XRD/SEM/TEM/JEA-3, Rev. 0	N/A	N/A	N/A	N/A	f	f	f	f
Electrical conductance	EC	N/A	N/A	Electrometric/ PNL-MA-567-FA-2	N/A	N/A	N/A	N/A	f	f	f	f
Moisture content	N/A	N/A	N/A	Moisture content/ PNL-MA-567-SA-7	N/A	N/A	N/A	N/A	f	f	f	f
Matric potential	N/A	N/A	N/A	Matric potential/ PNL-MA-567-SA-10	N/A	N/A	N/A	N/A	f	f	f	f
Distribution coefficient	K <sub>d</sub>	N/A	N/A	Methods for determining radionuclide retardation factors, 1980/PNL-3349 USC-70	N/A	N/A	N/A	N/A	f	f	f	f
Bulk density	N/A	N/A	N/A	Bulk density/ PNL-MA-567-SA-8	N/A	N/A	N/A	N/A	f	f	f	f

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Table A.4. Constituents and Methods for Slant Borehole Sediment Sample Analyses and Near-Surface Characterization Samples (4 Sheets)

Contaminants of Potential Concern	CAS #	Action Levels		Name/Analytical Technology <sup>a</sup>	Target Required Quantitation Limits				Precision Water (%)	Accuracy Water (%)	Precision Soil (%)	Accuracy Soil (%)
		Method B (ug/Kg)	Method C (ug/Kg)		Water <sup>b</sup> Low Level (ug/L)	Water <sup>b</sup> High Level (ug/L)	Soil Other Low Level (ug/Kg)	Soil Other High Level (ug/Kg)				
Chemical												
Moisture retention	q <sub>s</sub>	N/A	N/A	Moisture retention/ ASTM D 2325-68	N/A	N/A	N/A	N/A	f	f	f	f
Saturated hydraulic conductivity	K <sub>s</sub>	N/A	N/A	Saturated hydraulic conductivity/ASTM D 18.21 (draft in review) Methods of Soil Analysis, Part 2, 13-3.2 and 13-3.3	N/A	N/A	N/A	N/A	f	f	f	f

Note: For the chemical and radiological constituents the preferred methods are those listed in *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (EPA 1986) or *Standard Test Methods for Materials* (ASTM 1998).

<sup>a</sup>Water values for sampling quality control (e.g. equipment blanks/rinses) or drainable liquid (if recovered).

<sup>b</sup>All four digit numbers refer to *Test Methods for Evaluating Solid Waste* (EPA 1986).

<sup>c</sup>Values from *Hanford Guidance for Radiological Cleanup* (WDOH 1997). Italicized values are calculated using the same parameters as the WDOH guidance.

<sup>d</sup>*Methods for Chemical Analysis of Water and Wastes* (EPA 1983).

<sup>e</sup>Precision and accuracy requirements as identified and defined in the referenced U.S. Environmental Protection Agency procedures.

<sup>f</sup>Precision and accuracy for these measurements are not required because of the nature of the measurement.

AEA = alpha energy analysis.

ASTM = American Society for Testing and Materials.

CI = commercial industrial.

CAS = chemical abstracts service.

CVAA = cold vapor atomic absorption.

GC = gas chromatography.

GPC = gas proportional counting.

IC = ion chromatography.

ICP = inductively coupled plasma.

ICPMS = inductively coupled plasma mass spectrometry.

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N/A = not applicable.

NA = not available.

PCB = polychlorinated biphenyl.

ppm = parts per million.

RR = rural residential.

SEM = scanning electron microscopy.

TEM = transmission electron microscopy.

TOC/TC = total organic carbon/total carbon.

WDOH = Washington Department of Health.

XRD = x-ray diffraction.

Appropriate permits and compliance with the Notice of Construction permit (DOE-RL 1999a) were maintained during the drilling operations for inside the tank farm. The selected drilling method complies with the requirements of the Washington State Department of Health for the Notice of Construction permit and other pertinent requirements and appropriate engineering systems to prevent the possible contaminated air from being released to the environment.

Drilling was conducted using specifications and guidance in accordance with WAC 173-160. The technique for collecting sediment samples was a removable tip in conjunction with a split-spoon sampler that allowed driven samples to be collected ahead of the casing. The removable tip concept may have led to contamination problems on the inside of the borehole casing and required the tip to be replaced with a new one each time it was removed and limited the ability to geophysical log the borehole. The split-spoon sampler that used was approximately 5 cm (2 in.) in diameter by 0.6 m (2 ft) long with a 10 cm (4 in.) diameter shielded lead casing around the sampler. The hole was 10 cm (4 in.) in diameter after the sample was collected, but only a 5 cm (2 in.) sample was collected and brought to the surface. The 0.6 m (2 ft) sample allowed for the depth of penetration to be beyond potential disturbed sediments below the end of the hole and brought sediments unable to be handled to the surface. This approach was demonstrated outside the tank farms prior to implementation inside the tank farms. This method collected enough sediment sample to be analyzed and provided the least amount of disturbance, therefore providing a sample that was as close as possible to being a representative sample.

There are backup approaches that could have been taken to collect sediment samples during casing extraction if collecting a split-spoon sample was found to be impractical. These options include using a sidewall sampling tool and scraping or under-reaming the hole and collecting the material with a split-spoon sampler. These backup approaches were not needed.

Contaminant dragdown during drilling and sampling activities is unavoidable and has been observed in recent sampling activities. Different drilling/sampling techniques impact dragdown to varying degrees. Because the objective of the characterization activities identified in the DQO is to safely sample in and below the 'hot' zone in a region of known leakage and not to tag the leading edge of a contaminant plume, the dragdown issue was a secondary concern.

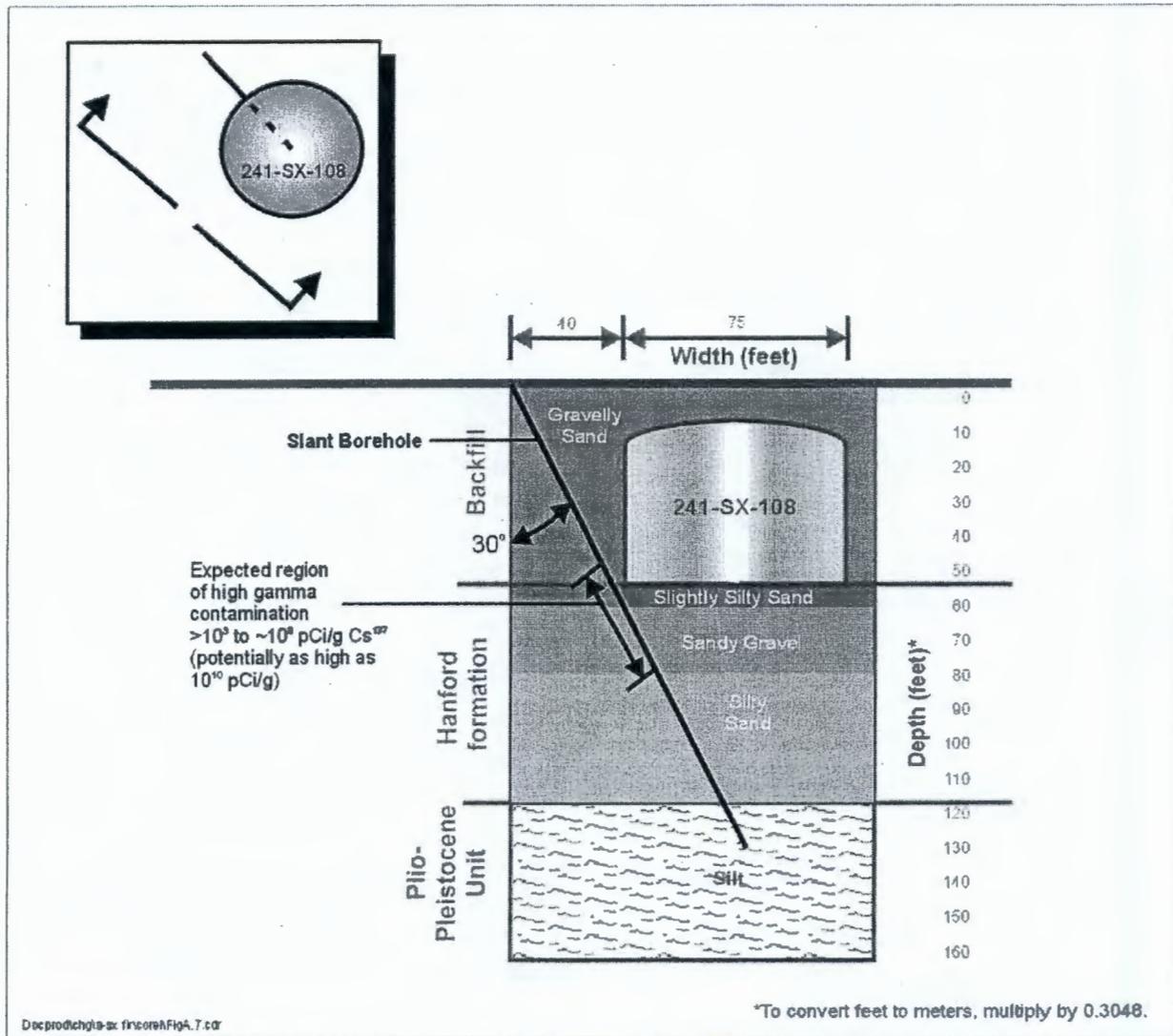
The depth of the vadose zone boring was to the maximum depth of contamination.

### **Sediment Sampling Activities**

For the SX-108 slant borehole, sediment sampling was conducted beginning at 16.7 m (55 ft) bgs and continued at discreet intervals of approximately 1.5 m (5 ft) until maximum depth of contamination or the Plio-Pleistocene unit was reached. Figures A.7 and A.8 show the slant borehole location and sampling strategy.

After the sediment samples were screened, these samples were transported to the PNNL Applied Geology and Geochemistry group for analysis. All material removed from the borehole was sent to the laboratory for possible future analysis. Samples were contained in airtight sample containers after their initial screening by the health physics technician and kept under refrigeration. This process is used to retain sediment moisture in as close to field condition as possible. All samples were transported to the laboratory under refrigeration to further limit alteration of sediment moisture.

Figure A.7. Tank SX-108 Slant Borehole



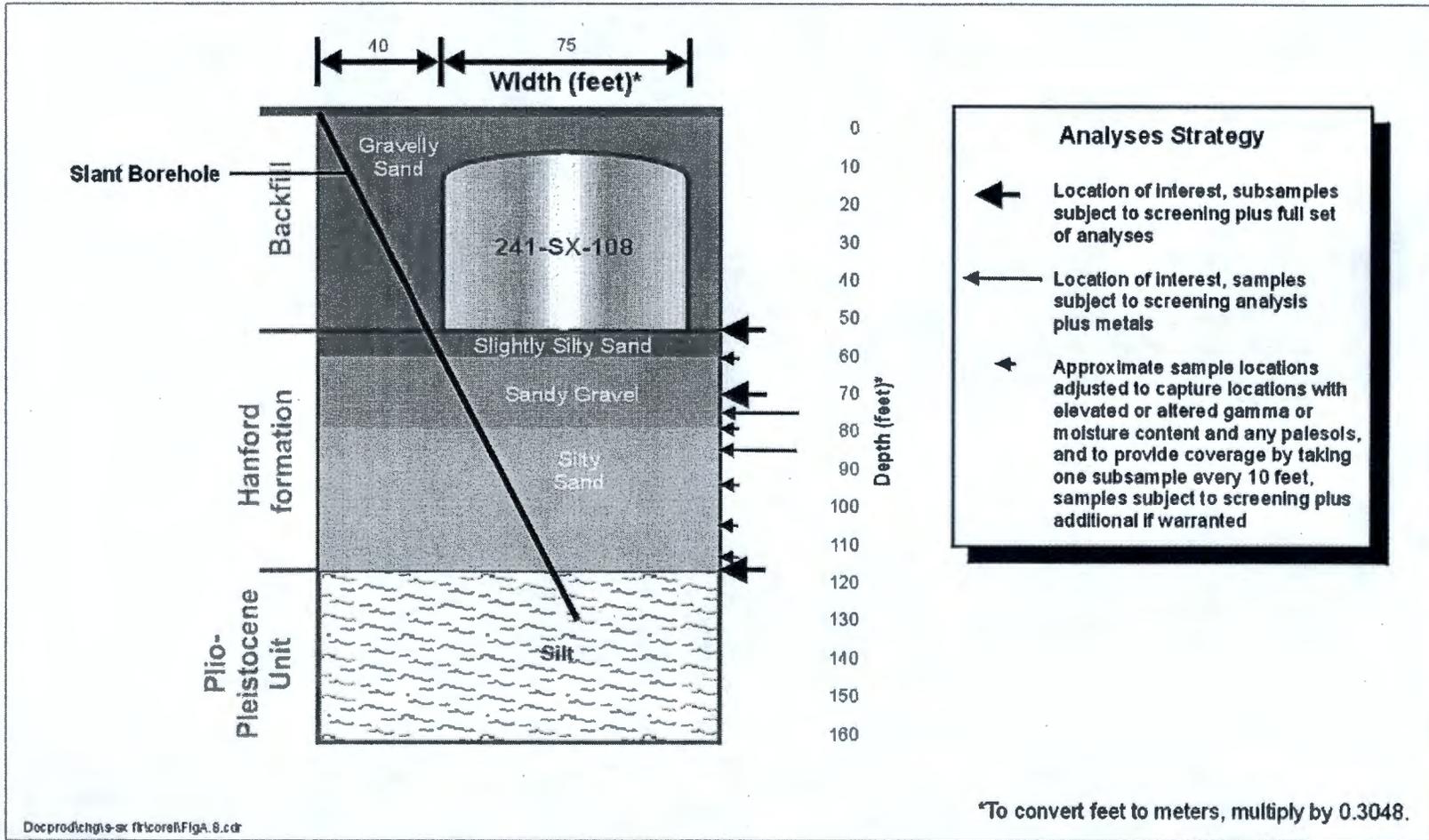


Figure A.8. Tank SX-108 Slant Borehole Subsample Analyses Strategy

Waste containing unknown, low-level mixed radioactive waste and/or hazardous waste contained, stored, and disposed of according with Appendix D of *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas* (DOE-RL 1999b) and specified in the quality assurance project plan (Appendix A of DOE-RL 1999b) and is documented in the field activity reports. Waste was disposed of in accordance with Appendix D of DOE-RL (1999b) and the waste acceptance criteria for the Mixed Waste Burial Grounds. All important information was recorded on field activity report forms per approved procedures. A field activity report form includes borehole number, site location drawings, drawing of the downhole tool strings, site personnel, sampling types and intervals, zones noted by the health physics technician as elevated in radiological contaminants, instrument readings and the depth represented by those readings, and specific information concerning borehole completion.

The SX-108 slant borehole was abandoned following completion of the geophysical surveying. All steel casing was removed and transferred to an appropriate disposal facility or controlled decontamination facility. The borehole was pressure-grouted from the bottom up, using a Portland cement/bentonite slurry or other appropriate material in accordance with WAC 173-160. Specific procedures for borehole abandonment were documented in the field work package. These procedures comply with U.S. Environmental Protection Agency requirements and WAC 173-160.

### **A.5.3 BOREHOLE GEOPHYSICAL SURVEYING**

Based on sampling and construction methods, downhole spectral gamma or gross gamma geophysical logging was conducted to ascertain the gamma-emitting radionuclide concentrations. The spectral gamma or gross gamma logging frequency was directed by CHG.

A full suite of geophysical logs was run any time the casing size was changed and at the completion of the borehole. Because the sampling method involves pulling split-spoon samples up through the borehole, there was a high probability that the inner bore of the casing would become contaminated. Following completion of the sampling, the contamination levels were evaluated and a determination was made on the utility of geophysically logging the borehole.

The following logging techniques may have been used for the slant borehole:

- Gross gamma logging to support correlation of confining layers and stratigraphy
- Spectral gamma logging for measuring the distribution of selected radionuclides
- Neutron log for measuring the relative moisture content
- Neutron-enhanced spectral gamma logging for correlation of high-salt tank waste and moisture content with spectral gamma and neutron probes, respectively.

The existing equipment and procedures for gross gamma and spectral gamma logging in use at the Hanford Site provide acceptable data (DOE-GJO 1995).

#### A.5.4 GROUNDWATER SAMPLING AND ANALYSIS

No sampling of groundwater was conducted for the SX-108 slant borehole characterization effort.

#### A.5.5 LABORATORY ANALYSES OF SX-108 SLANT BOREHOLE

##### Sediment Sample Analysis

Geologic logging for the SX-108 slant borehole was conducted as it was for the borehole 41-09-39 extension. Specifically, once sample material from the slant borehole was received at the laboratory, it was geologically logged by an assigned geologist in general conformance with standard procedures. The assigned geologist photographed the samples and described the geologic structure, texture, and lithology of the recovered samples. Special attention was paid to the presence of contaminant alteration. If such a phenomenon were noted, that sample was noted; preserved for more detailed physical, chemical, and mineralogic analyses; and recorded in the laboratory notebook.

Sediment samples for laboratory analysis were defined by location in the sample after the field screening and geologic logging were completed, and indication of contamination locations were identified. Approximately 10 sediment samples from the borehole were chosen for screening analysis. Screening analyses consisted of the following:

- Nitrate
- Electrical conductivity
- Total organic carbon/total carbon
- pH.

The following criteria were used to identify samples for laboratory analysis based on concurrence with Ecology.

- One subsample was taken at approximately 17 m (55 ft) bgs, at or near the base of the tank.
- Subsamples were taken at the major lithology changes in the Hanford formation.
- One subsample was taken at the Plio-Pleistocene unit and Hanford formation contact.
- Subsamples were taken in locations where elevated or altered gamma surveying was measured during the geological and geophysical borehole logging process based on nearby geophysical drywell logging.
- At least one subsample was taken every 3 m (10 ft) if samples were not already taken, based on the above criteria to ensure continuous distribution and lithologic completeness.

Worker safety considerations have limited the collection of samples at certain intervals. Figure A.8 shows the subsamples identified for laboratory analyses. A 1:1 water extract of all subsamples underwent screening analyses, which consist of nitrate analysis by the colorimetric

method, pH measurement, and electrical conductance measurement. In addition each subsample was directly measured for gamma emitters by gamma energy analysis. These analyses, along with the gamma surveying and moisture content measurements performed during the field geophysical surveys and the geologic logging, were used to determine the extent of further subsample analysis. Table A.4 identifies the full complement of analyses and their respective laboratory preparation and analytical methods. This paragraph and the remainder of this section identify which analysis was conducted on which sample. If more than one preparation or analytical method is listed, the laboratory geochemistry staff determined which methods would produce the best results and provide the best understanding of the chemistry involved. For those methods that produce multiple constituents (i.e., inductively coupled plasma), all constituents identified were reported. Every effort was made to meet regulatory holding times where appropriate.

Because the purpose of the slant borehole analysis was to gain an understanding of the nature and extent of contamination, the fate and transport of the contaminants in the vadose zone, and to produce RCRA-compliant data, the analysis of these subsamples consisted of two levels. The baseline level involved analysis of inorganic and radiochemical constituents in full conformance with DOE-RL (1998) and with no modifications to methods (as defined in DOE-RL 1998) without concurrence from the CHG technical representative and from Ecology. Substitutions and deviations to methods as defined by DOE-RL (1998) did not require concurrence from Ecology. The second level involved a research-type approach to the analyses. In this level, procedures may have been modified or developed to gain a more comprehensive understanding of the dynamics involved. Although specific quality control criteria do not apply to this level, compliance with an approved quality assurance plan provided by the primary laboratory was performed and research analysis was initiated following notification and approval of the activities by the CHG technical representative.

The backfill – Hanford formation contact sample, peak gamma concentration sample, and the sample obtained at the Hanford formation and Plio-Pleistocene unit contact were analyzed for the constituents and properties identified in Table A.4. It was recognized that conditions could occur when all of the analyses identified in Table A.4 were not warranted (e.g., limited potential for data). These occurrences were evaluated on a case-by-case basis.

One sample from at or near the base of the tank was analyzed for volatile organics identified in Table A.5.

**Table A.5. Constituents and Methods for Organic Analysis  
of Borehole Sediment Samples**

Analysis/Constituent	Preparation Method	Preparation Procedure Number	Analytical Method	Analytical Procedure Number
VOA	Bulk Sediment	<sup>a</sup>	GC/MS	SW846-8260
SVOAs with TICs	Bulk Sediment	<sup>a</sup>	GC/MS	SW846-8270
PCBs <sup>b</sup>	Bulk Sediment	<sup>a</sup>	GC	GW846-8082

<sup>a</sup> Preparation/extraction procedures for VOA and SVOA analysis will depend on the types of organic compounds present in the sediment.

<sup>b</sup> Analyzed on selected samples collected from the near-surface characterization effort.

GC = gas chromatography.

MS = mass spectrometry.

PCB = polychlorinated biphenyl.

SVOA = semi-volatile organic analysis.

TIC = tentatively identified compounds.

VOA = volatile organic analysis.

The remaining samples were analyzed for specific constituents listed in Table A.4 depending on the results of the nitrate, electrical conductivity, total organic carbon/total carbon, and pH screening analyses. A review of the screening analyses results with technical representatives and Ecology was conducted prior to performing additional analyses. Screening analysis may have been used to determine whether alternative analytical techniques with lower detection limits were to be used for specific radionuclides of concern. The screening criteria and associated analytical requirements were identified as follows:

- Gamma-emitting radioisotopes by gamma energy analysis
- Metals and radioisotopes by inductively coupled plasma-mass spectrometry
- Tritium and strontium-90 by the liquid scintillation method
- Particle size distribution
- Carbon 14.

A minimum of two samples collected within the Hanford formation were analyzed for metals as identified in Table A.4.

The data obtained from the above analyses were used to evaluate the location of contamination plumes in the sediment column. The results of the above analyses were also used to determine if additional analyses are warranted. Additional analyses were performed based on the judgement and expertise of the responsible PNNL geochemist, with concurrence from the CHG technical representative and Ecology. The following analyses were performed as additional analyses:

- Cation exchange capacity
- Mineralogy
- Matric potential
- Distribution coefficient
- Bulk density

- Moisture retention
- Saturated hydraulic conductivity.

Tables A.4 and A.5 identify the analyses and laboratory methods used for the sample analyses. For the chemical and radiological constituents, the preferred methods are those listed in EPA (1986) or American Society for Testing and Materials standards (ASTM 1998). The requested constituents may have been analyzed by laboratory-specific procedures, provided that the procedures were validated and conform to DOE-RL (1998). Both the EPA (1986) methods and the PNNL methods listed in Tables A.4 and A.5 are based on techniques from "Methods of Soil Analysis" (ASTM 1998). Therefore, these procedures should be comparable. The detection limit, precision, and accuracy guidelines for the parameters of interest are listed in the DQO workbook for WMA S-SX (Ovink 1999).

## A.6.0 NEAR-SURFACE CHARACTERIZATION

The following sections describe the near-surface characterization conducted in the S tank farm. These activities involved deployment of a truck-mounted, direct-push vehicle to collect the data.

### A.6.1 LOCATION

Two areas have been identified as regions of interest for the Phase 1 characterization of the shallow vadose zone soil. These areas are within the north end of the S tank farm. The S tank farm areas of interest include:

- Unplanned release near diversion box 241-S-B
- East of tank S-104 near the fence (in the drainage path of the unplanned release that occurred in the SY tank farm and flowed into the S tank farm).

### A.6.2 INVESTIGATIVE AND SAMPLING METHODS AND INTERVALS

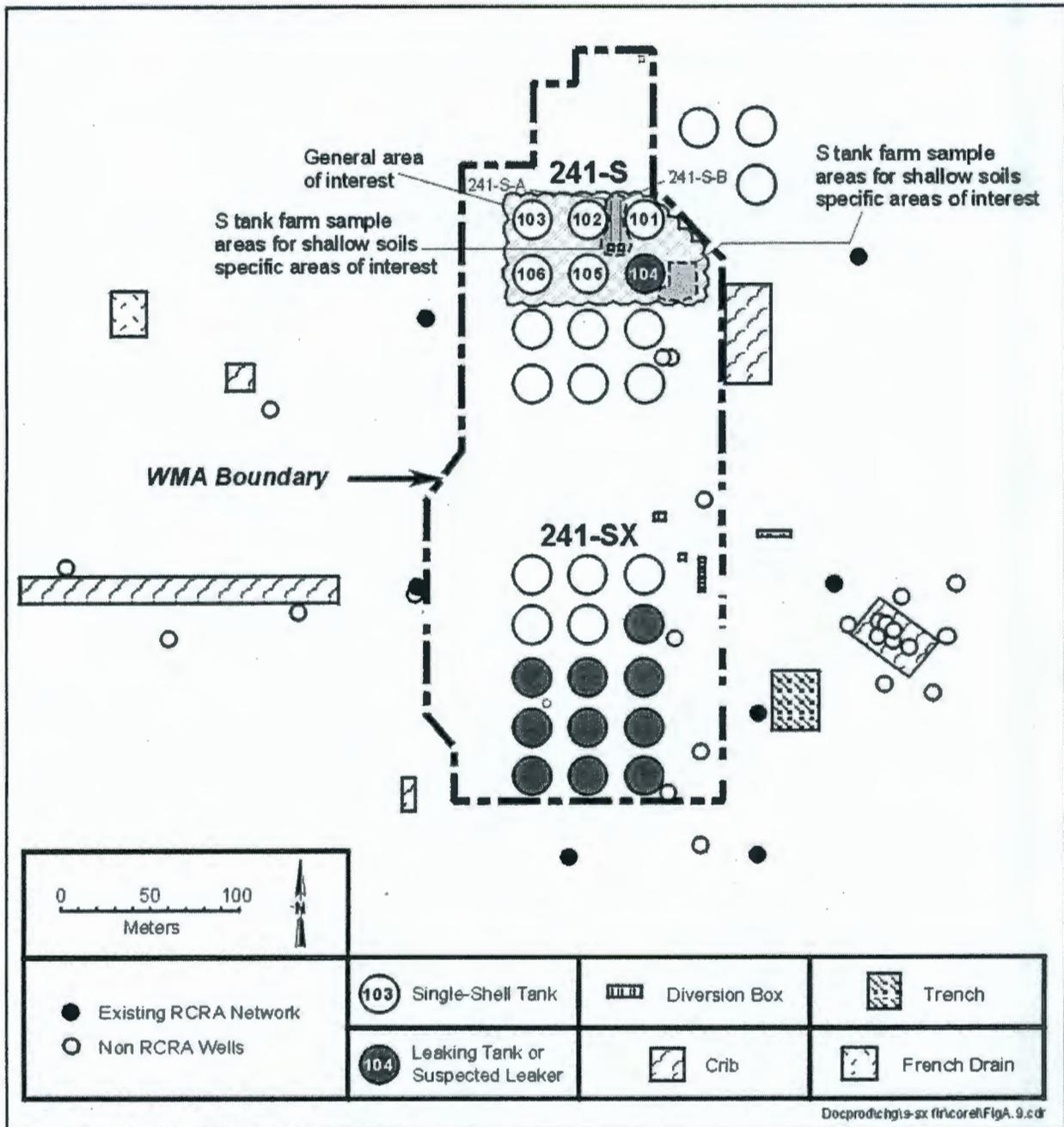
For the purpose of the DQO, the shallow investigation of 2 areas comprised collecting samples between the tank farm surface and approximately 16.7 m (55 ft) bgs using direct-push technology at 9 locations within either or both of these 2 areas (Figure A.9).

Shallow soil characterization was carried out using a truck-mounted cone penetrometer-based system. Specific sites cleared for access (underground piping and electrical services identified) and with an approved excavation permit were interrogated with a gross gamma/spectral gamma cone penetrometer probe. The depth of investigation was determined by the depth to which the probe could be advanced using a standard deployment truck. The probe was deployed using the gross gamma mode with the tool advanced at approximately 2 cm/sec (0.8 in./sec). If in the upper 5 m (15 ft) the downhole instrument indicated a potential cesium-137 concentration of 3.7 pCi/g or greater, logging was shifted to the spectral mode to determine the presence and level of concentration of cesium-137; below 5 m (15 ft) the threshold limit for spectral gamma determinations was 20 pCi/g. In zones where cesium-137 is present at concentrations greater than 20 pCi/g, spectral gamma readings were taken at 0.5 m (1.5 ft) intervals. In all cases, gross gamma measurements were to be taken while the probe was advanced.

The graphical log developed using the gross and spectral gamma measurements was used to select intervals to be sampled. The sampling push was made in a location no more than 0.7 m (2 ft) from the site of the gamma push. A single point sampler will be used to collect the required samples. Sampling intervals were selected from those horizons with a cesium-137 concentration of 20 pCi/g or greater. In the event that horizons were penetrated that would yield samples having a greater than 50 mrem/h dose rate at 30 cm (12 in.) (based on calculations using sampler size and cesium-137 concentration), a sample was collected from the first interval below the high rate zone having a dose rate of less than 50 mrem/h.

Two separate areas were characterized: the vicinity of tank S-102 and the vicinity of tank S-104. These two sites exhibit separate instances of cesium-137 in vadose zone drywells that may be indicative of near-surface sources. In addition, the region to the east of tank S-104 has potentially been impacted by a tank overflow event in the 241-SY double-shell tank farm. A total of nine push sites were identified. An average of four samples per site were collected.

Figure A.9. Waste Management Area S-SX Shallow Soil Sampling Locations



### A.6.2.1 Tank S-104 Site

The highest recorded levels of cesium-137 contamination associated with the tank S-104 site are in borehole 40-04-05 in the southeast quadrant of the tank. Contamination was estimated at about  $10^6$  pCi/g at a depth of about 14 m (48 ft) bgs. Up to five sets of gamma probe and sampling pushes were conducted to investigate this site. The pushes included the following.

- Adjacent to the 40-04-05 drywell, between the drywell and the tank. This location was to ascertain if there is a vertical gradient between the push location and the identified elevation of contamination in 40-04-05 and to collect a sample from below the contaminated zone to determine if mobile contaminants are moving ahead of the cesium-137 hot spot.
- Adjacent to tank S-104 at the 5 o'clock position. This location was as close to the tank as the push-truck could be positioned within dome-load restrictions. The S tank farm tanks are constructed with a spare inlet port at this point. Experience in other farms has shown that these spare inlet ports are subject to failure if a tank is overfilled. This push tested the hypothesis that the contamination adjacent to the tank is due to an overfill event.
- Adjacent to the normal fill line at the 3 o'clock position. This location was within 3 to 4.5 m (10 to 15 ft) of the tank and as close to the fill line as safety considerations allow. This location was used to determine the horizontal and vertical extent of the contamination found in the 40-04-05 borehole.
- Adjacent to the S tank farm fence. This location was used to determine the impact to shallow soils due to the surface release and subsequent ponding that occurred in the SY tank farm.
- Midway between the previous two pushes. This location was only to be interrogated if positive determinations of contamination were found in one of the two previous pushes.

### A.6.2.2 Tank S-102 Site

The highest recorded levels of cesium-137 contamination associated with the 241-S-102 site are in borehole 40-02-03 in the northeast quadrant of the tank. Contamination was estimated at about  $10^6$  pCi/g at a depth of about 6 m (20 ft) bgs. Four sets of gamma probe and sampling pushes were conducted to investigate this site. The pushes included the following.

- Adjacent to tank S-102, northwest of drywell 40-02-03. Because no contamination is detected in drywell 40-02-01, this push was used to determine the extent of contamination in a northwesterly direction from borehole 40-02-03. The push was situated about midway between the boreholes and as near the tank as safety considerations allow.
- Along the line projected between 40-02-01 and 40-02-03, north of the cascade line between tanks S-101 and S-102. This location provided information on the extent of contamination known to exist at 40-02-03 and assess the depth of movement of that contamination.

- Along the line projected between 40-02-01 and 40-02-03, south of the cascade line between tanks S-101 and S-102, and near the 241-S-A diversion box. This location provided information as to the extent and general direction of movement of contaminants for this site. In addition, the accumulation pit associated with the 241-S-A was assessed as a possible contributor to the contamination.
- Adjacent to the 241-S-B diversion box. The potential for contamination in this region related to operation of the 241-S-B accumulation pit was assessed.

### **A.6.2.3 Additional Pushes**

Additional pushes have been made based on the information developed during the initial campaign or decisions of the River Protection Project Vadose Zone Project management. These additional pushes were determined based on the determined extent of contamination and (1) the availability of both the push truck and crew and (2) availability of budget and support personnel.

Any samples were transported to the laboratory and analyzed for the contaminants of concern identified in Table A.4. A detailed field work plan was prepared to identify the number and location of samples to be collected.

### **A.6.3 GEOPHYSICAL SURVEYING ACTIVITIES**

Prior to sediment sampling using the direct push, downhole gross gamma and spectral gamma geophysical surveying was conducted to ascertain the gamma-emitting radionuclide concentration in the surrounding sediments. After each push with the direct-push or each borehole with the hollow-stem auger, decommissioning occurred.

### **A.6.4 LABORATORY ANALYSES**

Laboratory analyses included radiological and chemical analyses of selected sediment samples. Physical and hydrologic analyses of selected sediment samples was performed.

Once received at the laboratory, these samples underwent analysis using the analytical methods listed in Table A.4. These analyses are sample-limited. Therefore, hold points were inserted into the process to allow the laboratory and CHG technical staff to collaborate and review data before each new round of analyses. Analyses were reprioritized based on the results of other measurements. See Appendix B for discussion of the analyses conducted.

Based on the results of the screening analyses identified in the SX-108 slant borehole, spectral gamma surveys performed during the field geophysical surveys, and the geologic logging and field notes, geological technical experts, CHG technical staff, the laboratory technical staff, and decision makers (Ecology and the U.S. Department of Energy) convened to determine what, if any, additional analyses were to be conducted. Some of the determining criteria were the amount and integrity of the remaining sample, screening analytical results, and regulatory requirements. Based on these decisions, additional analyses were performed.

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**APPENDIX B**  
**RESULTS FROM WORK PLAN ACTIVITIES**

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**LIST OF TERMS**

bgs	below ground surface
PPlc	lower Plio-Pleistocene
PPlz	upper Plio-Pleistocene
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
S&T	Science and Technology
WMA	waste management area

## B.1.0 INTRODUCTION

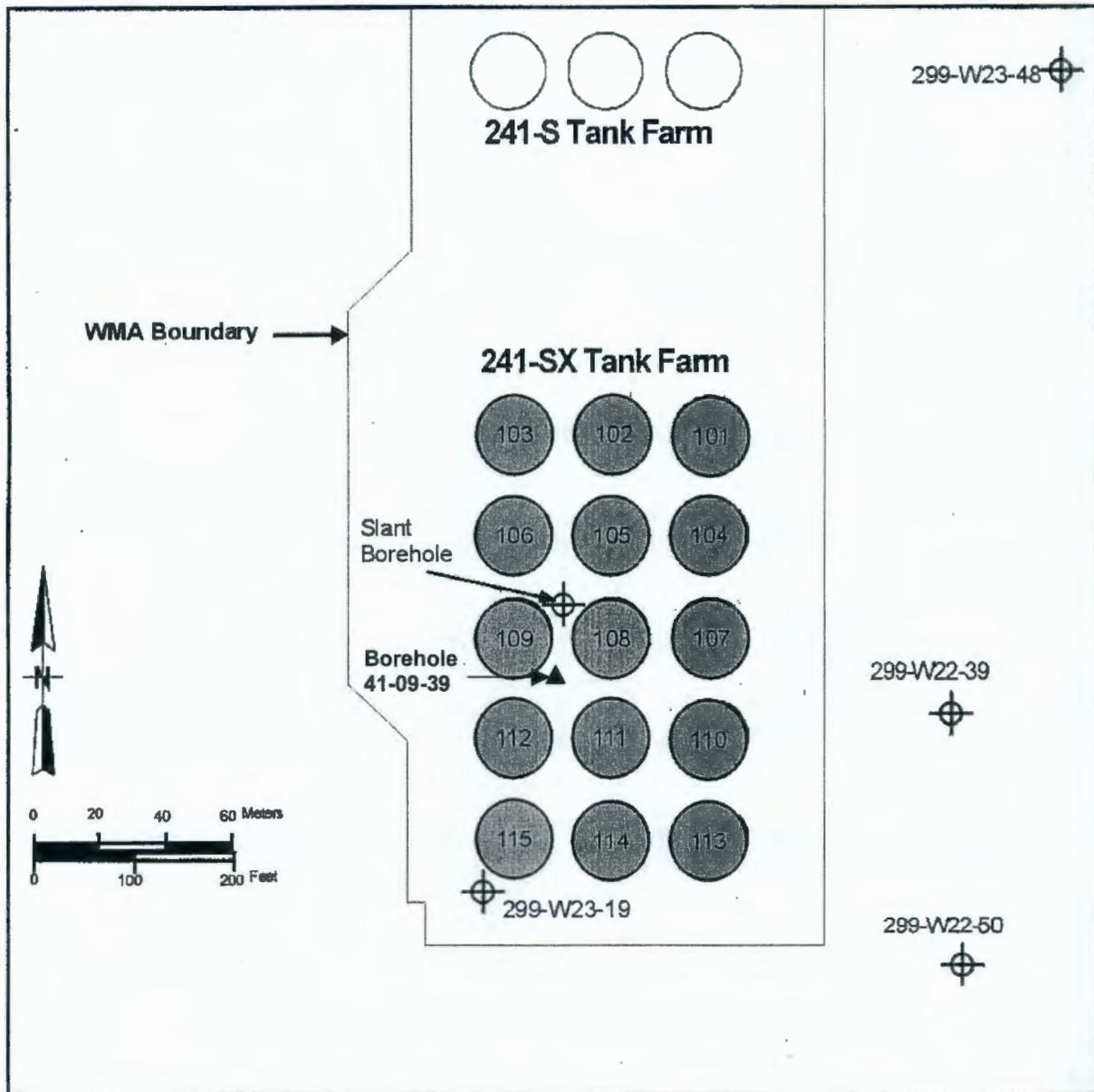
Several field characterization studies were completed to increase understanding of the vadose zone contamination as it presently exists in waste management area (WMA) S-SX. The results of those studies are summarized in this appendix. The primary information obtained from those activities was that resulting from extensive analyses of soil samples taken from several boreholes in the WMA (Figure B.1). Those boreholes were as follows.

- **Borehole 41-09-39** – Lies southwest of tank SX-108 and was extended from 40 m (130 ft) below ground surface (bgs) to groundwater. This borehole was extended to further characterize soil contamination caused by a tank SX-108 leak. It was extended from the depth it was drilled to support a previous characterization effort to determine the extent of tank fluid migration in that location and to determine groundwater impacts. Further discussion of borehole 41-09-39 soil sampling and analyses is provided in Section B.2.0.
- **Borehole 299-W23-19** – Lies just southwest of tank SX-115. This borehole was drilled from the surface to groundwater to further characterize vadose zone contamination caused by a SX-115 leak and to determine groundwater impacts from the leak. Further discussion of borehole 299-W23-19 soil sampling and analyses is provided in Section B.3.0.
- **Tank SX-108 Slant Borehole** – A slanted hole was driven underneath tank SX-108. This borehole was drilled into the Plio-Pleistocene unit to characterize soils as near to the source of the tank SX-108 leak as possible and to investigate contaminant behavior underneath that tank. Further discussion of borehole SX-108 soil sampling and analyses is provided in Section B.4.0.
- **Boreholes 299-W22-48 and 299-W22-50** – Borehole 299-W22-48, located east of S tank farm, and borehole 299-W22-50, located southeast of SX tank farm, are *Resource Conservation and Recovery Act of 1976* (RCRA) groundwater monitoring wells. These boreholes are close enough to the tank farms to be considered representative of tank farm vadose zone soils. Because the soils have not come into contact with tank fluids, their characteristics provide a means of defining tank farm vadose zone soil characteristics prior to tank leaks. Further discussion of boreholes 299-W22-48 and 299-W22-50 soil sampling and analyses is provided in Section B.5.0.

The characterization information summarized in this appendix includes brief descriptions of borehole geology, geophysical logs, moisture contents, soil suction data, soil water chemistry, and groundwater contamination data, if appropriate. In the interest of brevity, data reported here are those which have the most direct bearing on potential contaminant characteristics and migration. More background information is available in the referenced documents (Serne et al. 2001a,b,c,d).

In addition to the boreholes drilled and characterization of borehole samples, a shallow soils cone penetrometer study was completed around tank S-104 in the S tank farm to characterize near-surface contamination in that area. Further discussion of that study is provided in Section B.6.0.

**Figure B.1. Locations of Boreholes Sampled in Waste Management Area S-SX Characterization Studies**



## B.2.0 BOREHOLE 41-09-39 CHARACTERIZATION

This section summarizes data reported in *Geologic and Geochemical Data Collected from Vadose Zone Sediments from Borehole SX 41-09-39 in the S/SX Waste Management Area and Preliminary Interpretations* (Serne et al. 2001b) except for the groundwater sample data which are reported in *RCRA Groundwater Quality Assessment Report for Waste Management Area S-SX (November 1997 through April 2000)* (Johnson and Chou 2001). Borehole 41-09-39 was completed to further characterize the nature and extent of vadose zone contamination from the tank SX-108 leak. The data reported here are a follow-on from a previous drilling and sampling program (Myers et al. 1998) in which the borehole was drilled down to 40 m (130 ft) bgs. In the recent study the borehole was extended to groundwater, and soil samples were taken and analyzed from 40 m (130 ft) bgs to 68.6 m (225 ft) bgs. Also, sidewall coring samples were collected between 8 and 40 m (25 and 130 ft) bgs as the borehole was being decommissioned. Extensive analyses of these sediment samples were also completed. The method used to advance and sample this borehole may have contributed to cross-contamination of portions of each sample interval. Core was taken to recognize and minimize the impact of these occurrences for this field investigation report.

The most significant data provided by this characterization effort were measurements on sediment samples for radionuclides and chemicals attributed to the tank SX-108 leak. Elevated concentrations of several constituents were primarily measured in soils between 19 and 40 m (61 and 130 ft) bgs. This depth interval includes the Hanford formation H1 and H2 subunits. The primary radionuclides present in this zone are cesium-137 and technetium-99. Maximum cesium-137 concentrations are present in subunit H1 between 20 and 25 m (65 and 83 ft) and at lesser amounts in subunit H2 between 25 and 30 m (83 and 108 ft). The presence of high levels of cesium-137 at borehole 41-09-39 is indicative of strong lateral movement of tank fluid and attributed to unusually high cesium-137 mobility shortly after release from tank SX-108. Maximum technetium-99 concentrations are present in the subunit H2 between 24 and 39 m (79 and 129 ft). The primary chemical characteristics attributed to tank fluid-soil interaction within this zone are elevated pH, sodium, chromium, and nitrate. The depth of maximum technetium-99 concentration coincides with high nitrate concentrations and marks the leading edge of vertical tank fluid migration in the direction measurable in this borehole.

The measured moisture contents are somewhat dry relative to undisturbed Hanford formation soils. Soil suction measurements suggest that drainage is occurring in the soil column but the measured soil suction variability is too high to quantify rate of drainage. The lack of tank fluid contaminants below the Plio-Pleistocene unit and the low concentrations of technetium-99, and nitrate in groundwater samples from borehole 41-09-39 supports the hypothesis that contaminants from this area may not have reached the unconfined aquifer.

### B.2.1 GEOLOGY AT BOREHOLE 41-09-39

Borehole 41-09-39 was originally installed to a depth of 39.8 m (130.5 ft) bgs in December 1996. The borehole was installed by advancing a thick-walled casing with a sealed, hardened drive point using a pile driver. No samples could be collected or analyzed due to the nature of this original construction. Subsequently, the drive point was milled-off and the borehole deepened to groundwater. A cable-tool drilling rig was used to deepen and collect

samples to 68.6 m (225 ft) bgs. Split-spoon samples were collected whenever possible. Borehole decommissioning was subsequently completed in 1999 by grouting the void space to eliminate a potential preferential pathway for contaminant migration. During decommissioning of this borehole, side-wall sediment samples were collected from preselected horizons in the upper, previously unsampled portion of the bore. The nature of the side-wall sampler precluded collection of any coarse grained materials during decommissioning.

#### **B.2.1.1 Hanford formation**

No Hanford formation samples were collected during the original construction of borehole 41-09-39. In addition, the sediment samples collected using the side-wall sampler during decommissioning were unsuitable for geologic interpretation. Samples that were collected were biased toward fine-grained materials due to the nature of the sampling device.

#### **B.2.1.2 Plio-Pleistocene Unit**

The top of the Plio-Pleistocene unit is not identified in this borehole. The first samples collected during the extension were from the upper Plio-Pleistocene (PPlz) subunit. The lower Plio-Pleistocene (PPlc) subunit was also present.

- **Subunit PPlz** – Subunit PPlz is interpreted to be present from the start of sampling at 39.8 m (130.5 ft) bgs to about 47.5 m (155.8 ft) bgs. The upper sampled sediments consist of a very fine-grained sequence that is a thin-bedded, up to 0.3 m (1 ft) thick, silty very fine-grained sand to silt. The graded silty sand to silt beds appear to become thicker and more massive with depth. Beds in the middle portion of the sequence are on the order of 1 m (3 ft) thick and about 1.5 m (5 ft) thick at the bottom. The sand ranges from moist to dry and friable. Some silt stringers up to 1 cm (0.4 in.) thick were observed. Two massively bedded silt to clayey silt units are present; one from 43.5 to 44.2 m (142.8 to 144.9 ft) bgs and a second from 46 to 47.3 m (151 to 155 ft) bgs. The upper unit is described as moist with a strong to weak reaction to hydrogen chloride. It is a massively bedded clayey silt to silt at the base, grading upward to a silty sand, then back to a silt at the top. The lower silt to clayey silt layer is described as very compacted. Some small stratifications of very fine-grained sand with limonitic staining are present. The base of the PPlz subunit is dominated by a well-sorted 20 cm (8 in.) thick fine sand.
- **Subunit PPlc** – Subunit PPlc is approximately 1.3 m (4.3 ft) thick extending to approximately 48.6 m (160 ft) bgs. This horizon ranges in grain size from sandy silt to sandy gravel. It is moderately to strongly cemented with pinkish to whitish calcium carbonate. In places the calcium carbonate cement is massive, forming a calcrete layer that was broken up during drilling. In other places the calcium carbonate appears disseminated into the sand or silt matrix or as coatings on the gravel clasts.

#### **B.2.1.3 Ringold Formation**

The Ringold Formation consists predominately of weakly cemented sandy gravel to strongly cemented matrix-supported conglomerate and is correlated with the member of Wooded Island unit E.

The gravel-conglomeritic facies is both clast supported and matrix supported. The matrix ranges from a sandy mud to muddy fine sand to well-sorted quartz-rich fine or medium sand to very

coarse sand. Gravel clasts are subrounded to rounded and range up to 70 mm (2.8 in.). The clasts are predominately composed of quartzite, basalt, and granite. In places the basalt and granitic clasts are highly weathered and limonitic staining is common.

Intercalated sand and silt-mud lenses are common. These minor strata range in thickness from a few centimeters to nearly 1 m (3 ft). The sand units range from silty fine to very fine sand to clean, well-sorted fine or medium quartz sand to poorly sorted, gravelly, muddy, coarse- to fine-grained sand.

Silty and muddy units are generally poorly sorted and consist of slightly gravelly sandy silt to gravelly mud. Two thin (6 to 24 cm [2 to 9 in]), clean mud units were observed at 61.6 m (202.2 ft) bgs and 63.3 m (207.5 ft) bgs.

## **B.2.2 GEOPHYSICAL AND PHYSICAL PROPERTY MEASUREMENTS AT BOREHOLE 41-09-39**

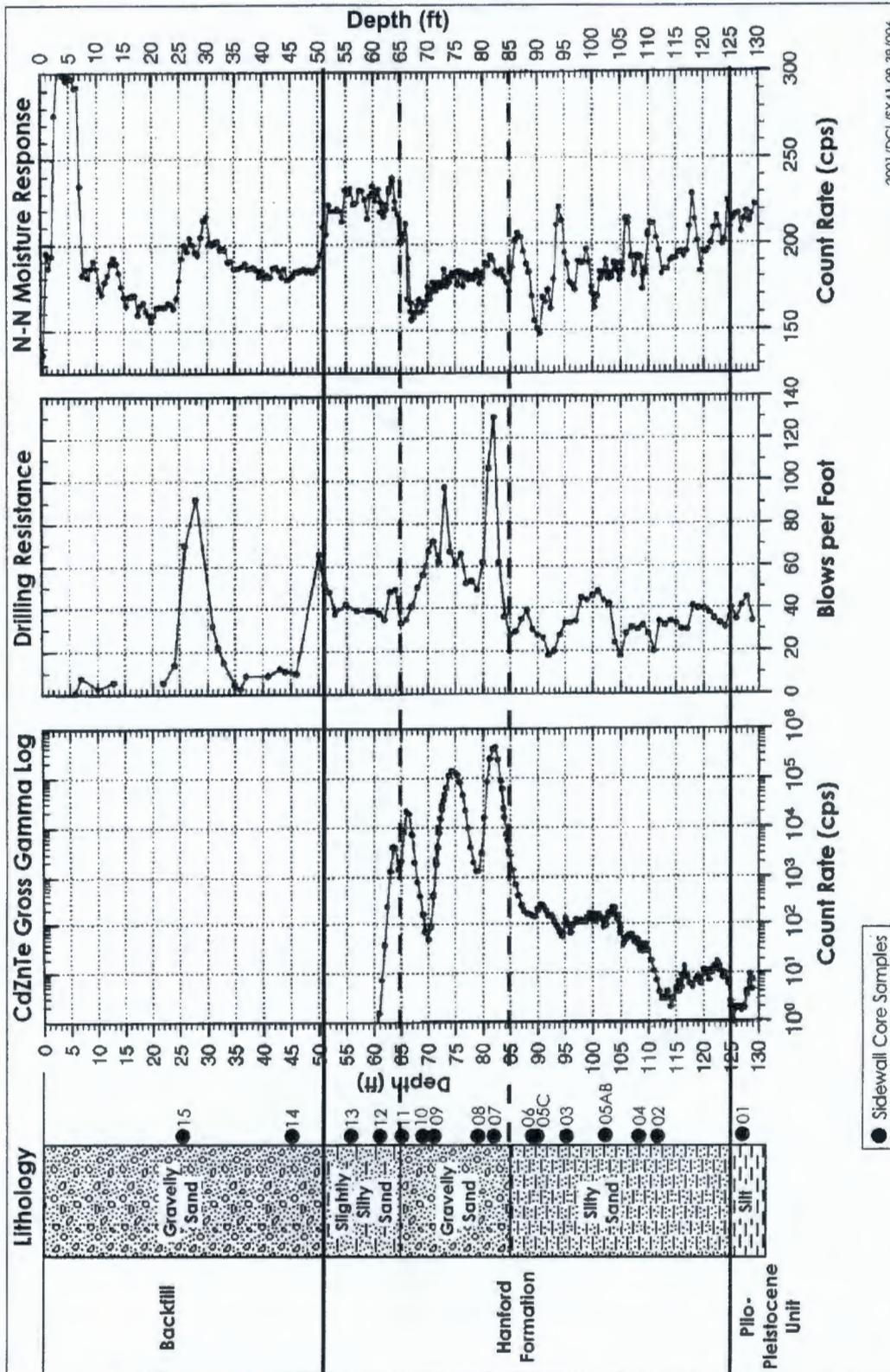
Downhole geophysical measurements at borehole 41-09-39 included a cadmium zinc tellurium gross gamma log and a drilling resistance log down to 40 m (130 ft) bgs, high-purity germanium spectral gamma logs from 40 m (130 ft) bgs to groundwater (about 65 m [214 ft] bgs), and neutron-neutron logs over the entire depth. Geophysical data for between 8 and 40 m (25 and 130 ft) bgs and between 40 and 65 m (130 and 214 ft) bgs are shown in Figures B.2 and B.3, respectively. The geophysical data provide features that distinguish stratigraphic units in the vadose zone. Subunit H1 shows a high gross gamma count because of the high cesium-137 content and a high drilling resistance because of the high gravel content. The Plio-Pleistocene unit shows relatively high natural thorium-232 and uranium-238 levels and moisture content.

Laboratory measurements of soil moisture content (Table B.1 and Figure B.4) show similar trends in relative concentrations as the neutron-neutron moisture measurements. Matric potential values were also measured (Figure B.5). While the majority of the data are indicative of a draining profile, a number of measurements suggest upward flow. Serne et al. (2000b) attributes this to the drying effect resulting from the head loading imposed by the contents of tank SX-108. The data variability is not indicative of unit gradient conditions nor does it provide any indication of deep drainage.

## **B.2.3 SOIL WATER CHEMISTRY MEASUREMENTS**

In addition to soil physical property measurements (Section B.2.2), an extensive water chemistry analysis has been completed for borehole 41-09-39 samples collected between 8 and 65 m (25 and 215 ft) bgs. The primary means of measuring porewater composition was to add deionized water to soil samples to generate enough water for performing analyses. By back-calculating for the dilution introduced by the added water, 'true' concentrations were derived. For a few samples porewater was directly separated from the same soil sample or one nearby and analyzed directly. By comparing the dilution-corrected water extract data with the porewater data in these few samples, an indication of the closeness of the water extract chemistry to original water chemistry was determined. In general, comparisons were not exact but concentration values were generally within a factor of two or better, agreement improved with increasing constituent concentration, and both sets of data showed similar concentrations versus soil depth correlations. Thus, the water extract method is an effective tool for evaluating tank fluid interactions with vadose zone soil.

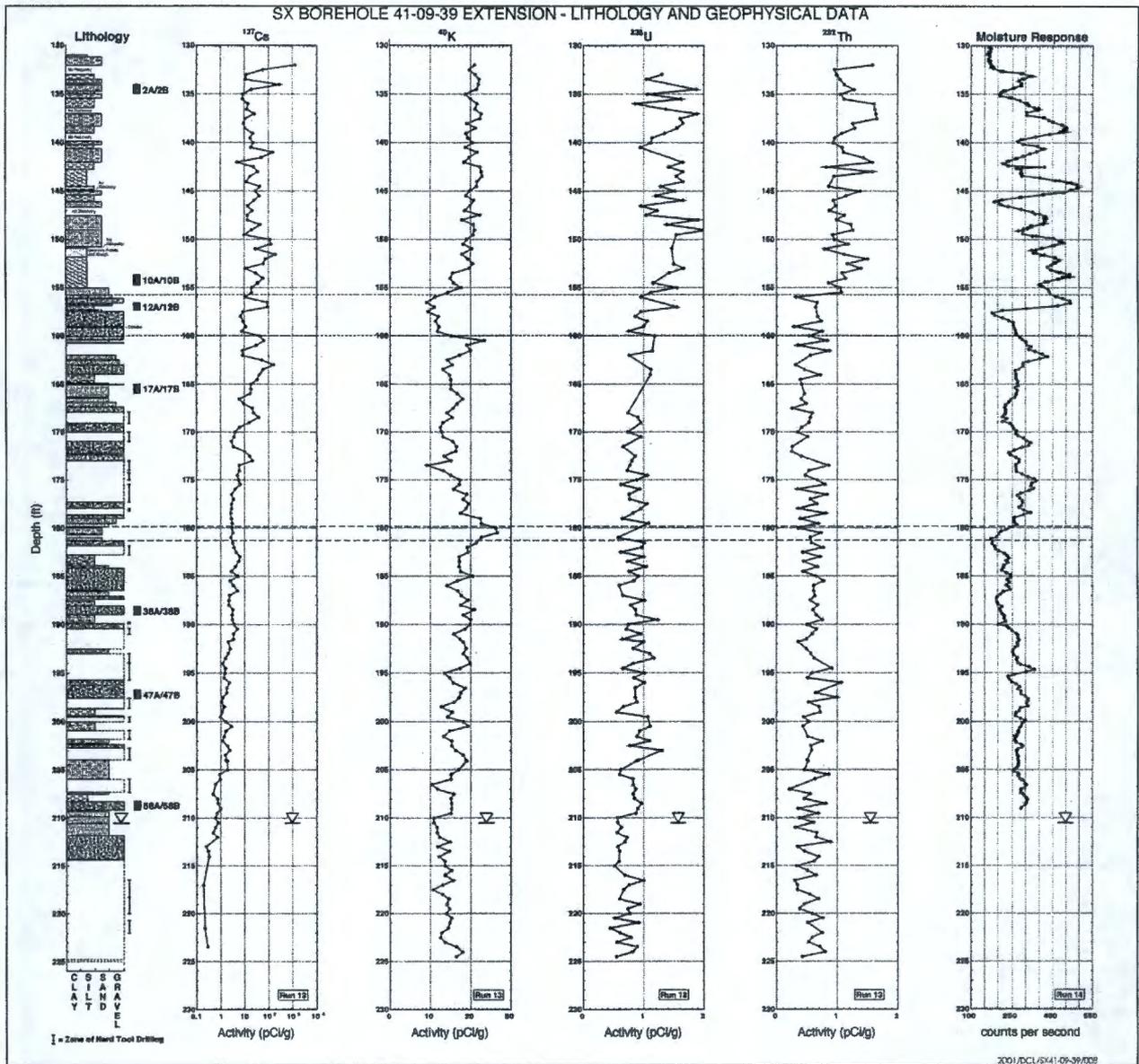
Figure B.2. Gamma-Ray, Drilling Resistance, and Moisture Logs for the Upper Portion of Borehole 41-09-39



2001/DCL/SX41-09-39/006

Source: MACTEC-ERS 1997.

**Figure B.3. Detailed Lithology and Analytical Values of Split-Spoon Samples from the Lower Portion of Borehole 41-09-39**



**Table B.1. Moisture Content (wt%) of Borehole 41-09-39  
Sidewall Cores and Extension Sleeves (2 Sheets)**

Depth (ft bgs)	Sample ID	Moisture Content (%)	Depth (ft bgs)	Sample ID	Moisture Content (%)	Depth (ft bgs)	Sample ID	Moisture Content (%)
<b>Sidewall</b>			149.9	8B	9.7	183.9	36C	3.37
25.5	15A/B/C	8.12	151.1	9C	12.8	184.6	36B	2.06
44.5	14A/B/C	8.57	151.8	9B	NM	185.8	37D	1.39
56.5	13A/B/C	16.27	152.8	9A	13.9	186.2	37C	2.6
61.5	12A/B/C	12.84	153.4	10C	13.6	186.8	37B	2.35
65.5	11A/B	4.71	153.9	10B	14.7	187.2	37A	2.09
66	11C	5.29	154.5	10A	19.6	187.8	38C	2.87
69.5	10A/B/C	4.36	155.1	11D	5.4	188.3	38B	1.9
74.5	9A/B/C	5.17	155.4	11C	4.3	188.7	38A	1.8
79.5	8A/B/C	10.71	155.9	11B	3.5	189.2	39B	1.54
82.5	7A/B/C	8.41	156.4	11A	4.5	189.5	39A	1.93
90	6A/B	10.25	156.8	12B	6.9	190.7	40A	5.13
95.5	3A/B/C	7.83	157.1	12A	6.6	193.3	45A	5.28
102.5	5A/B/C *	10.4	157.2	13D	6.4	195.9	47D	8.84
108.5	4A/B/C	12.01	157.7	13C	4	196.4	47C	6.62
112	2B/C	8.17	158.2	13B	5.3	196.9	47B	5.74
127.4	1A/B/C	12.66	159.4	14C	5.9	197.4	47A	4.94
<b>Extension</b>			160	14B	5.8	199.1	49B	8.25
131.1	1C	NM	160.6	14A	7.6	199.1	49A	9.53
131.7	1B	13	162.3	16D	13.3	199.4	50B	6.83
133.2	2D	35.6	162.8	16C	13.5	199.4	50A	3.89
133.7	2C	18.3	163.3	16B	4.1	200.2	52B	5.47
133.7	2C-2	26.7	163.8	16A	4.4	200.7	52A	8.15
134.2	2B	14.5	164.3	17D	4.91	202.5	54B	6.58
134.7	2A	16	164.8	17C	3.56	202.5	54A	5.44
135.9	3A	13.1	165.3	17B	5.27	204.3	56C	7.74
137.4	4C	10.9	165.8	17A	4.91	205	56B	6.58
138	4B	11.7	166.6	18C	9.7	205.6	56A	5.44
138.7	4A	16.1	167.1	18B	4.7	207.6	58D	9.4
139.9	5D	14.1	167.7	18A	4.7	208.1	58C	10.18
140.3	5C	14.5	169.9	20A	4.3	208.6	58B	10.57

**Table B.1. Moisture Content (wt%) of Borehole 41-09-39  
Sidewall Cores and Extension Sleeves (2 Sheets)**

Depth (ft bgs)	Sample ID	Moisture Content (%)	Depth (ft bgs)	Sample ID	Moisture Content (%)	Depth (ft bgs)	Sample ID	Moisture Content (%)
140.9	5B	12.6	171.3	22C	5.8	209	58A	8.16
141.5	5A	9.4	172	22B	5.2	209.4	59D	10.1
141.9	6F	11	178.2	28A	7.94	209.8	59C	12.49
142.4	6E	9.6	178.8	30C	6.9	210.4	59B	17.5
143.3	6D	21.8	179.2	30B	3.35	210.9	59A	24.97
144.1	6C	26	179.7	30A	3.11	211.7	62B	8.15
144.7	6B	22.9	180.2	31B	4.36	212.1	62A	10.03
145.2	7E	8.7	180.5	31A	3.72	212.9	64B	12.58
145.8	7D	9.5	181.1	32B	5.31	213.3	64A	13.19
146.4	7C	11.2	181.5	32A	3.15	214.1	65B	7.76
146.4	7C-R	11.2	183	35B	3.56	214.3	65A	8.6
148.3	8C	7.4	183.3	35A	2.84			

\* One of the three cores may be different depth at 5A/B/C.

NM = not measured.

**Figure B.4. Moisture Content (wt%) versus Depth for Vadose Sediments from Borehole 41-09-39**

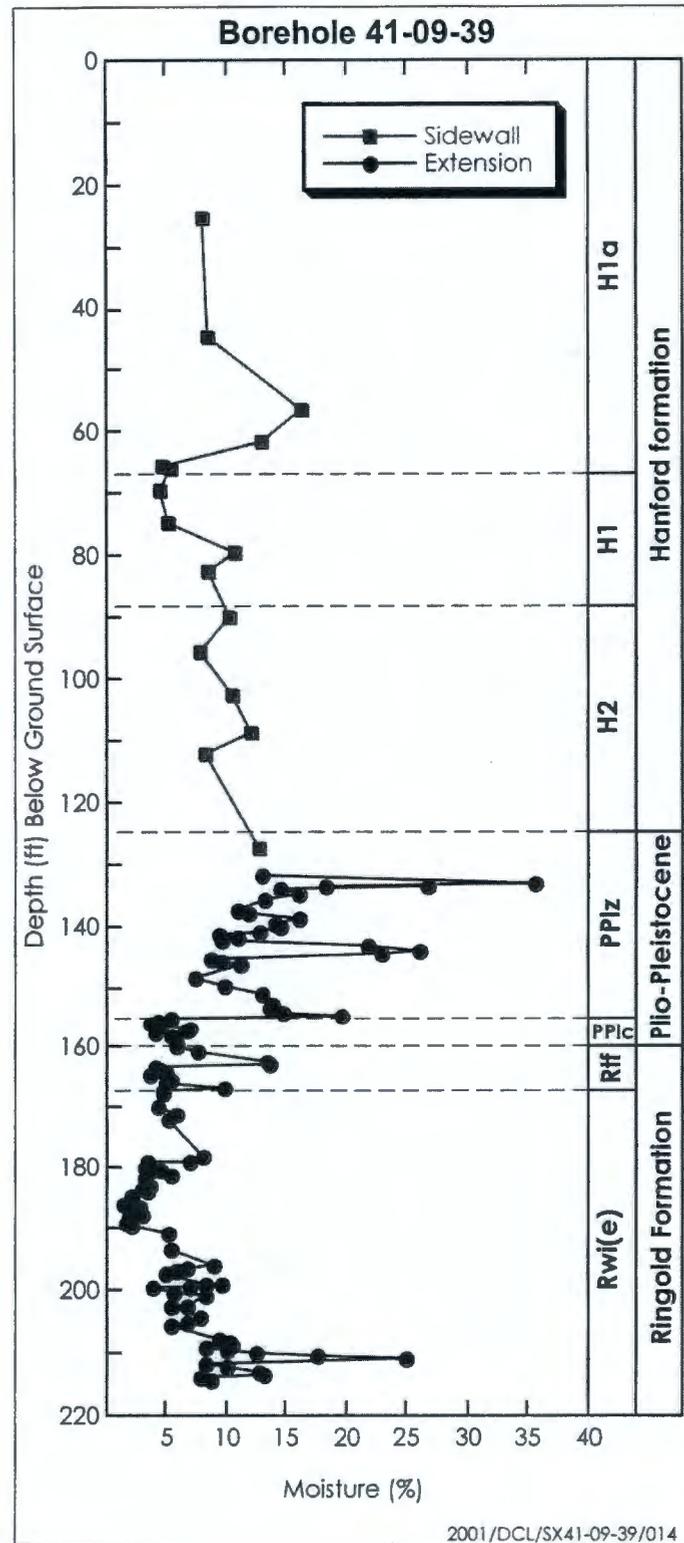
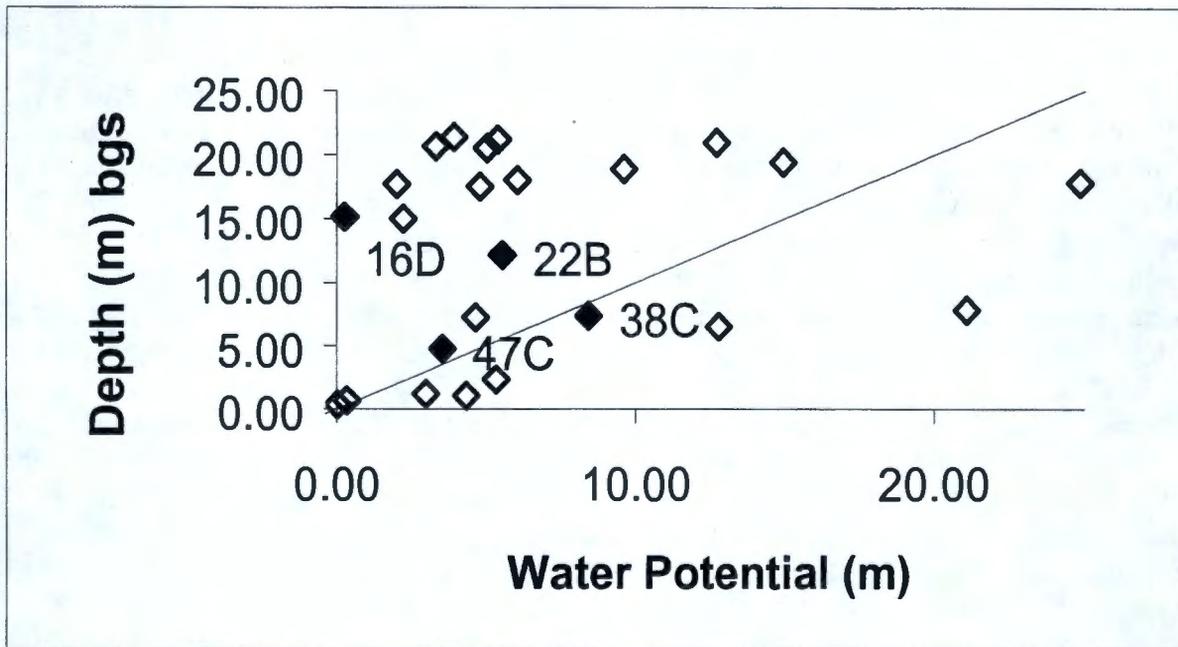


Figure B.5. Soil Suction Profile for Samples Taken from Borehole 41-09-39



Water extract pH and electrical conductivity measurements with depth are listed in Table B.2 and graphed in Figure B.6. Elevated pH values (8.5 to 9.7) are measured between 20 and 25 m (65 and 83 ft) bgs primarily in subunit H1 of the Hanford formation. Because pH values are expected to decrease as increasing interaction with soil and soil water occurs, the location of maximum pH values suggests the approximate initial depth of tank fluid interaction with the vadose zone at this location. Increases in electrical conductivity values compared to undisturbed soil water values are also an indicator of tank fluid occurrence in soil. Substantive increases are measured between 20 and 40 m (65 and 132 ft) bgs with maximum values (approximately 98,000 to 524,000  $\mu\text{S}/\text{cm}$ ) between 25 and 39 m (83 and 127 ft) bgs, primarily in subunit H2. Maximum electrical conductivity values are an indicator of location for mobile tank fluid constituents and maximum vertical penetration of tank fluids along the pathway sampled at this location.

Water extract anion concentrations as a function of depth are listed in Table B.3. Nitrate, chloride, and sulfate concentrations with depth are shown in Figure B.7. The primary indicator of tank fluid occurrence is elevated nitrate concentrations which is measured in this borehole between 20 and 41 m (65 and 136 ft) bgs with maximum values between 25 and 39 m (83 and 127 ft) bgs. Elevated levels of chloride (between 25 and 39 m [83 and 127 ft] bgs) and sulfate (between [20 and 39 m [65 and 127 ft] bgs) are also observed. Chloride maximum concentrations (between 27 and 34 m [90 and 112 ft] bgs) track closely with nitrate in subunit H2. An isolated chloride peak occurs at 60 m (197 ft) bgs, which may be a residual from groundwater present when the water table was elevated and has since drained. The sulfate peak occurs between 25 and 34 m (83 and 112 ft) bgs. The sulfate peak occurs between 25 and 34 m (83 and 112 ft) bgs, a maximum concentration depth interval that also coincides with chloride and nitrate. Also, sulfate shows a slight increase in concentration at 56 and 58 m (185 and 189 ft) bgs where the isolated chloride peak occurred in the Ringold Formation. Between 56 and 58 m (185 and 189 ft) bgs represents the high groundwater elevation.

Water extract cation concentrations as a function of depth are listed in Table B.4 and graphed in Figure B.8. Among the cations, elevated sodium concentrations are the primary tank fluid indicator. Maximum values begin abruptly at 25 m (83 ft) bgs and remain elevated above 10,000 mg/L until 34 m (112 ft) bgs. Calcium, magnesium, potassium, and natural strontium show depleted concentrations at 19 to 24 m (61 to 80 ft) bgs and above the high sodium zone and show elevated concentrations between 27 and 39 m (90 and 127 ft) bgs, a depth range coincident and perhaps slightly ahead of the high sodium range. The relative positioning of sodium concentration ranges versus that of the other cations supports the hypothesis that sodium preferentially replaces these cations in sorption sites as it migrates vertically and pushes them ahead to the leading edge of a leak plume.

The last group of constituents analyzed included radionuclides and trace metals. Of these, cesium-137, technetium-99, and chromium (Tables B.5 and B.6) are clearly present in concentrations above background and are attributed to have originated in the tank fluid. Water extract concentrations of cesium-137 are listed in Table B.5 and distribution is shown in Figure B.9. Above-background cesium-137 concentrations are measured between 8 and 42 m (25 and 137 ft) bgs.

**Table B.2. Measurements of pH and Electrical Conductivity for 1:1 Water Extracts of Borehole 41-09-39 Sidewall and Extension Sleeves (3 Sheets)**

Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S}/\text{cm}$ )	Corrected ( $\mu\text{S}/\text{c}$ )m	Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S}/\text{cm}$ )	Corrected ( $\mu\text{S}/\text{cm}$ )	Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S}/\text{cm}$ )	Corrected ( $\mu\text{S}/\text{cm}$ )
<b>Sidewall</b>														
25.5	15A/B/C	8.39	188	2317	141.9	6F	8.49	255	4886	165.3	17B	7.77	149	2828
44.5	14A/B/C	8.52	226	2638	142.4	6E	8.36	203	4389	165.8	17A	7.78	93.0	2031
56.5	13A/B/C	8.31	287	1790	143.3	6D	8.46	300	3033	166.6	18C	8.10	181	1861
61.5	12A/B/C	8.61	355	2767	144.1	6C	8.29	353	3057	167.1	18B	7.85	99.0	2100
65.5	11A/B	9.18	899	19092	144.7	6B	8.5	314	3036	167.7	18A	7.94	105	2246
66	11C	9.76	504	9535	145.2	7E	8.75	194	2328	169.9	20A	8.35	216	5033
69.5	10A/B/C	9.18	752	17248	145.8	7D	8.7	212	2209	171.3	22C	8.43	250	4295
74.5	9A/B/C	9.60	719	13928	146.4	7C	8.41	237	2097	172.0	22B	8.33	180	3433
79.5	8A/B/C	9.55	1722	16090	148.3	8C	8.71	236	3160	178.2	28A	8.46	231	2897
82.5	7A/B/C	8.70	8293	98684	149.9	8B	8.71	200	2032	178.8	30C	8.36	183	2637
90	6A/B	8.33	41820	408017	152.8	9A	8.91	210	1489	179.2	30B	7.62	67.0	2000
95.5	3A/B/C	7.93	41010	521060	153.4	10C	8.75	277	1997	179.7	30A	7.72	74.0	2375
102.5	5A/B/C	8.01	41910	402855	153.9	10B	8.7	254	2085	180.2	31B	8.42	214	4892
108.5	4A/B/C	8.07	56480	470722	154.5	10A	8.75	221	1085	180.5	31A	8.39	201	5395
112	2B/C	8.12	42770	524413	155.4	11C	8.62	163	3736	181.1	32B	8.51	267	5044
127.4	1A/B/C	7.92	16550	130789	155.9	11B	8.64	155	4431	181.5	32A	8.30	151	4793
<b>Extension</b>					156.4	11A	8.67	114	4788	183.0	35B	8.50	261	7334
131.1	1C	8.52	382	N/A	156.8	12B	8.64	379	5435	183.3	35A	8.32	190	6680
131.7	1B	8.06	4858	36192	157.1	12A	8.63	317	4761	183.9	36C	8.18	137	4052
133.2	2D	8.26	865	1817	157.2	13D	8.55	289	4471	184.6	36B	7.85	67.0	3247

**Table B.2. Measurements of pH and Electrical Conductivity for 1:1 Water Extracts of Borehole 41-09-39 Sidewall and Extension Sleeves (3 Sheets)**

Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S/cm}$ )	Corrected ( $\mu\text{S/cm}$ )	Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S/cm}$ )	Corrected ( $\mu\text{S/cm}$ )	Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S/cm}$ )	Corrected ( $\mu\text{S/cm}$ )
133.7	2C	8.28	413	1648	157.7	13C	8.8	311	7731	185.0	36A	7.96	94.0	5493
134.2	2B	8.36	658	4363	158.2	13B	8.7	190	3576	185.8	37D	7.87	68.0	4891
134.7	2A	8.25	611	3629	158.7	13A	7.21	207	3912	186.2	37C	7.48	49.0	1886
135.2	3B	8.25	831	5618	159.4	14C	8.5	270	4552	186.8	37B	7.66	40.0	1699
135.9	3A	8.34	442	3266	160	14B	8.46	215	3726	187.2	37A	7.57	45.0	2155
137	4D	8.29	387	3150	160.6	14A	8.38	189	2482	187.8	38C	8.16	121	4201
137.4	4C	8.78	172	1538	162.3	16D	8.28	245	1813	188.3	38B	7.75	58.0	3046
138	4B	8.61	223	1846	162.8	16C	8.52	319	2313	188.7	38A	7.35	24.0	1337
138.7	4A	8.63	193	1141	163.3	16B	8.02	117	2828	189.2	39B	7.95	79.0	5131
140.3	5C	8.57	230	1520	163.8	16A	7.79	92	2112	189.5	39A	8.11	123	6379
140.9	5B	8.92	184	1417	164.3	17D	8.36	268	5435	190.7	40A	7.77	59.0	1147
141.5	5A	8.97	167	1737	164.8	17C	8.31	322	9000	193.3	45A	8.79	275	5239
195.9	47D	8.23	93.0	1048										
196.4	47C	8.16	101	1523										
196.9	47B	7.40	71.0	1243										
197.4	47A	7.70	76.0	1546										
198.8	49C	8.22	165	1838										
199.1	49B	8.17	149	1803										
199.1	49A	8.13	152	1605										
199.4	50B	8.22	165	2412										
199.4	50A	7.81	102	2631										

**Table B.2. Measurements of pH and Electrical Conductivity for 1:1 Water Extracts of Borehole 41-09-39 Sidewall and Extension Sleeves (3 Sheets)**

Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S/cm}$ )	Corrected ( $\mu\text{S/cm}$ )	Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S/cm}$ )	Corrected ( $\mu\text{S/cm}$ )	Depth (ft bgs)	Sample ID	1:1 extract pH	1:1 extract ( $\mu\text{S/cm}$ )	Corrected ( $\mu\text{S/cm}$ )
200.2	52B	8.45	160	2928										
200.7	52A	8.33	148	1814										
202.5	54B	8.08	135	2067										
202.5	54A	7.96	93.0	1721										
204.3	56C	7.94	86.0	1082										
205	56B	8.16	122	1479										
205.6	56A	8.07	94.0	1208										
207.6	58D	8.26	191	2034										
208.1	58C	8.30	160	1576										
208.6	58B	7.87	60.0	569										
209	58A	7.56	42.0	513										
209.4	59D	8.06	103	1017										
209.8	59C	7.72	56.0	452										
210.4	59B	7.72	55.0	316										
210.9	59A	8.80	710.	284										
211.7	62B	7.81	50.0	610										
212.1	62A	7.73	51.0	512										
212.9	64B	8.04	92.0	1122										
213.3	64A	7.99	76.0	762										
214.1	65B	7.85	87.0	1124										
214.3	65A	7.93	72.0	838										

**Figure B.6. Concentrations of pH, Electrical Conductivity, and Nitrate in Dilution-Corrected Water Extract**

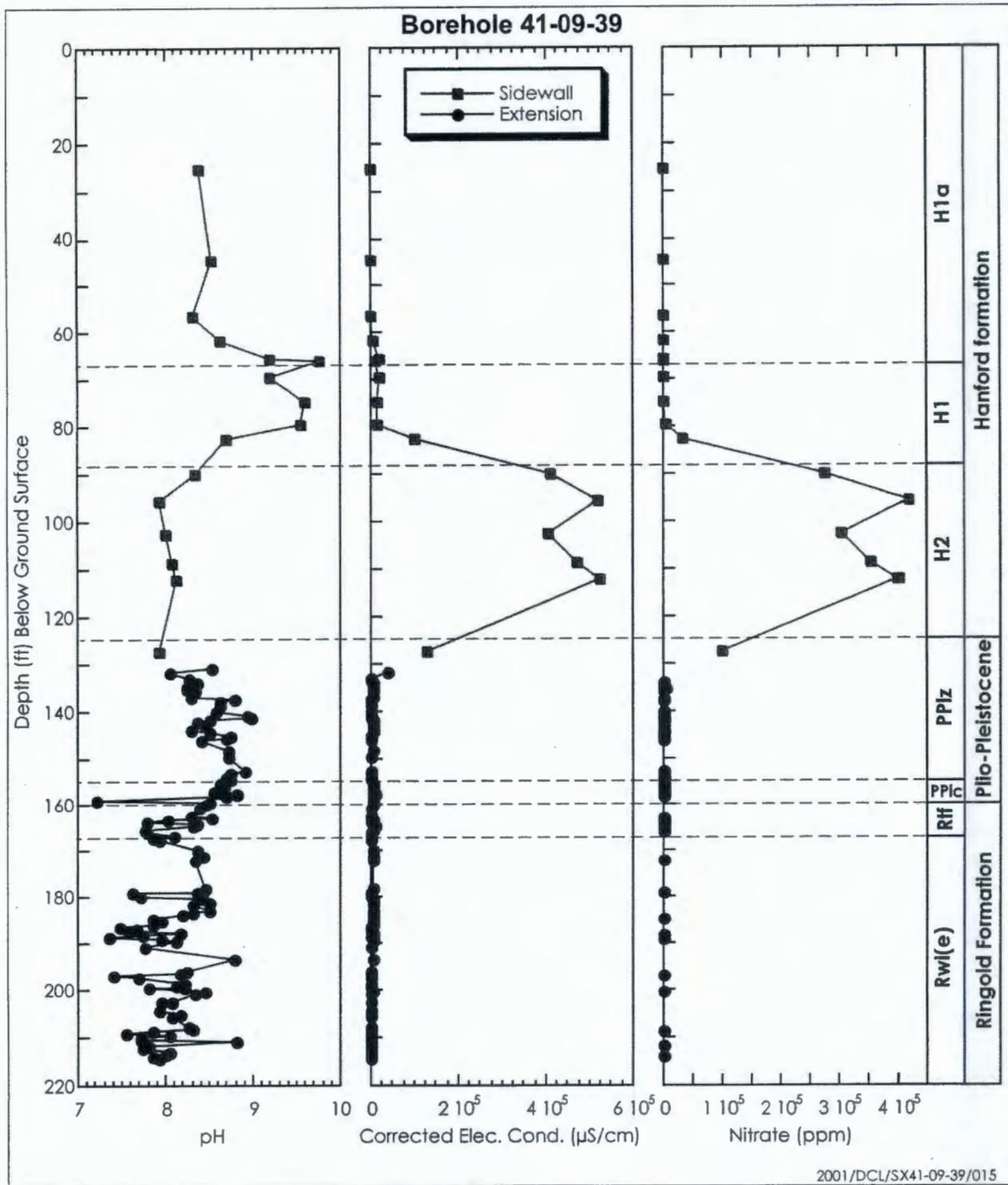


Table B.3. Anion Concentrations at Borehole 41-09-39 in 1:1 Water Extracts (3 Sheets)

Depth (ft bgs)	Sample ID	1:1 Extracts					Dilution Factor	Dilution Ratio Corrected				
		Nitrate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrite (ppm)	Sulfate (ppm)		Nitrate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrite (ppm)	Sulfate (ppm)
<b>Sidewall</b>												
25.5	15A/B/C	13.0	<0.3	NM	0.26	1.70	12.3	161	<4.0	NM	3.18	20.9
44.5	14A/B/C	13.0	0.92	NM	0.26	16.4	11.7	152	10.7	NM	3.01	191
56.5	13A/B/C	13.0	0.84	NM	0.26	<2.8	6.24	81.0	5.22	NM	1.61	<17.2
61.5	12A/B/C	13.0	0.81	NM	0.26	5.13	7.79	102	6.34	NM	2.01	40.0
65.5	11A/B	29.1	0.52	NM	0.26	11.5	21.2	618	10.9	NM	5.48	244
66.0	11C	17.6	0.26	NM	0.26	6.45	18.9	333	4.89	NM	4.88	122
69.5	10A/B/C	33.5	0.38	NM	0.26	8.66	22.9	767	8.80	NM	5.91	199
74.5	09A/B/C	44.3	0.54	NM	0.26	18.1	19.4	857	10.5	NM	5.00	351
79.5	08A/B/C	371	3.34	NM	1.40	51.7	9.34	3464	31.3	NM	13.1	483
82.5	07A/B/C	2836	30.1	NM	82.1	336	11.9	33746	358	NM	976	3999
90.0	06A/B	28044	307	NM	139	271	9.76	273614	2992	NM	1355	2642
95.5	03A/B/C	32767	321	NM	28.6	260	12.7	416332	4074	NM	364	3308
102.5	05A/B/C	31666	198	NM	133	198	9.61	304385	1903	NM	1279	1904
108.5	04A/B/C	42448	359	NM	130	386	8.33	353773	2990	NM	1084	3215
112.0	02B/C	32764	344	NM	106	373	12.3	401733	4212	NM	1297	4576
127.4	01A/B/C	12808	77.5	NM	28.6	73.3	7.90	101213	613	NM	226	579
<b>Extension</b>												
134.2	2B	291	NM	NM	NM	NM	6.63	1929	NM	NM	NM	NM
134.7	2A	268	NM	NM	NM	NM	5.94	1592	NM	NM	NM	NM
135.2	3B	362	NM	NM	NM	NM	6.76	2447	NM	NM	NM	NM
135.9	3A	165	NM	NM	NM	NM	7.39	1219	NM	NM	NM	NM

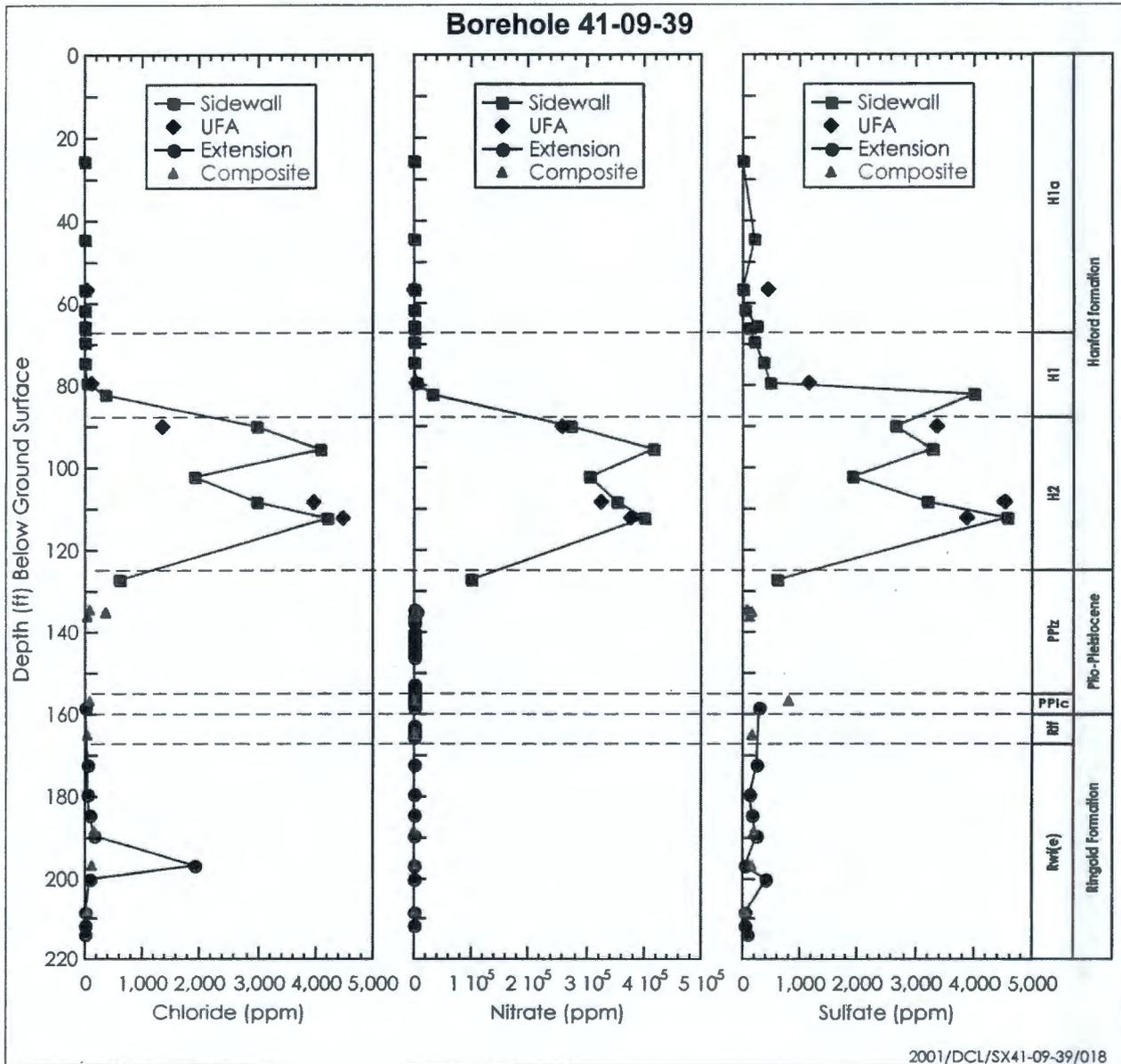
Table B.3. Anion Concentrations at Borehole 41-09-39 in 1:1 Water Extracts (3 Sheets)

Depth (ft bgs)	Sample ID	1:1 Extracts					Dilution Factor	Dilution Ratio Corrected				
		Nitrate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrite (ppm)	Sulfate (ppm)		Nitrate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrite (ppm)	Sulfate (ppm)
Extension (Cont'd)												
137.4	4C	12.0	NM	NM	NM	NM	8.94	107	NM	NM	NM	NM
138	4B	24.0	NM	NM	NM	NM	8.28	199	NM	NM	NM	NM
140.3	5C	9.90	NM	NM	NM	NM	6.61	65.4	NM	NM	NM	NM
140.9	5B	3.70	NM	NM	NM	NM	7.70	28.5	NM	NM	NM	NM
141.5	5A	9.80	NM	NM	NM	NM	10.4	102	NM	NM	NM	NM
141.9	6F	9.10	NM	NM	NM	NM	19.2	174	NM	NM	NM	NM
142.4	6E	14.0	NM	NM	NM	NM	21.6	303	NM	NM	NM	NM
143.3	6D	42.0	NM	NM	NM	NM	10.1	425	NM	NM	NM	NM
144.1	6C	58.0	NM	NM	NM	NM	8.66	502	NM	NM	NM	NM
144.7	6B	48.0	NM	NM	NM	NM	9.67	464	NM	NM	NM	NM
145.2	7E	18.0	NM	NM	NM	NM	12.0	216	NM	NM	NM	NM
145.8	7D	32.0	NM	NM	NM	NM	10.4	333	NM	NM	NM	NM
146.4	7C	36.0	NM	NM	NM	NM	8.85	319	NM	NM	NM	NM
152.8	9A	24.0	NM	NM	NM	NM	7.09	170	NM	NM	NM	NM
153.4	10C	48.0	NM	NM	NM	NM	7.21	346	NM	NM	NM	NM
153.9	10B	49.0	NM	NM	NM	NM	8.21	402	NM	NM	NM	NM
154.5	10A	33.0	NM	NM	NM	NM	4.91	162	NM	NM	NM	NM
155.4	11C	9.80	NM	NM	NM	NM	22.9	225	NM	NM	NM	NM
155.9	11B	8.40	NM	NM	NM	NM	28.6	240	NM	NM	NM	NM
156.4	11A	5.30	NM	NM	NM	NM	42.0	223	NM	NM	NM	NM
156.8	12B	10.5	NM	NM	NM	NM	14.3	151	NM	NM	NM	NM

Table B.3. Anion Concentrations at Borehole 41-09-39 in 1:1 Water Extracts (3 Sheets)

Depth (ft bgs)	Sample ID	1:1 Extracts					Dilution Factor	Dilution Ratio Corrected				
		Nitrate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrite (ppm)	Sulfate (ppm)		Nitrate (ppm)	Chloride (ppm)	Fluoride (ppm)	Nitrite (ppm)	Sulfate (ppm)
Extension (Cont'd)												
157.1	12A	7.50	NM	NM	NM	NM	15.0	112	NM	NM	NM	NM
157.2	13D	2.00	NM	NM	NM	NM	15.5	30.9	NM	NM	NM	NM
157.7	13C	6.20	NM	NM	NM	NM	24.9	154	NM	NM	NM	NM
158.2	13B	6.80	1.00	0.45	<0.06	14.5	18.8	128	18.8	8.50	<1.1	273
162.8	16C	1.90	NM	NM	NM	NM	7.25	13.8	NM	NM	NM	NM
163.3	16B	4.60	NM	NM	NM	NM	24.2	111	NM	NM	NM	NM
163.8	16A	6.70	NM	NM	NM	NM	23.0	153	NM	NM	NM	NM
164.8	17C	0.30	NM	NM	NM	NM	28.0	8.4	NM	NM	NM	NM
165.3	17B	7.60	NM	NM	NM	NM	19.0	144	NM	NM	NM	NM
165.8	17A	10.8	NM	NM	NM	NM	21.8	236	NM	NM	NM	NM
172	22B	5.00	3.00	1.40	<0.06	13.0	19.1	95.4	57.2	26.7	1.10	248
179.2	30B	4.70	1.30	0.38	<0.04	4.70	29.9	140.	38.8	11.3	1.20	140
184.6	36B	3.00	1.60	0.52	<0.06	3.70	48.5	145.	77.5	25.2	<2.9	179
189.2	39B	0.80	2.40	0.56	<0.06	3.40	65.0	51.3	155	36.4	<3.9	221
196.9	47B	18.0	110	0.21	<0.06	2.50	17.5	315.	1926	3.70	<0.5	43.8
200.2	52B	<0.10	3.70	0.81	<0.06	22.0	18.3	<1.8	67.7	14.8	<1.1	403
208.6	58B	0.60	1.50	0.48	<0.06	2.50	9.49	5.20	14.2	4.6	<0.6	23.7
211.7	62B	0.60	1.00	0.48	<0.06	2.70	12.2	7.70	12.2	5.9	<0.7	32.9
214.1	65B	<0.10	1.50	0.45	<0.06	5.50	12.9	<1.29	19.4	5.8	<0.8	71.1

**Figure B.7. Dilution-Corrected 1:1 Sediment to Water Extract Anions and Actual Porewater Anion Concentrations versus Lithology and Depth**



**Table B.4. Major Cation Composition of 1:1 Water Extracts from Borehole 41-09-39 Sidewall Cores and Extension Sleeves (3 Sheets)**

Depth (ft bgs)	Sample ID	Calcium (ppm)	Potassium (ppm)	Magnesium (ppm)	Sodium (ppm)	Strontium (ppm)	Aluminum (ppm)	Boron (ppm)	Iron (ppm)	Manganese (ppm)	Silicon (ppm)
<b>Sidewall</b>											
25.5	15A/B/C	9.30	6.40	1.10	29.5	(0.053)	0.84	5.20	0.51	(0.01)	21.5
44.5	14A/B/C	6.00	6.90	0.70	41.8	(0.049)	0.59	15.9	0.14	(0.01)	14.8
56.5	13A/B/C	22.4	7.40	2.00	43.2	(0.036)	0.51	5.30	<0.25	<0.05	9.30
61.5	12A/B/C	3.60	2.60	0.30	80.7	(0.042)	0.56	31.0	(0.05)	(0.01)	7.50
65.5	11A/B	1.10	(1.70)	0.40	121	(0.035)	1.48	9.00	2.03	(0.04)	14.2
66.0	11C	0.90	2.60	1.90	212	(0.051)	5.72	10.5	8.97	0.13	37.0
69.5	10A/B/C	0.80	3.60	1.00	176	(0.035)	3.08	4.50	4.27	0.08	24.0
74.5	9A/B/C	0.50	(2.40)	(0.10)	168	(0.047)	0.65	10.3	(0.11)	<0.05	12.5
79.5	8A/B/C	0.70	4.20	(0.10)	423	(0.057)	0.75	35.6	(0.02)	<0.05	5.30
82.5	7A/B/C	22.1	16.0	2.20	2041	0.46	(0.48)	16.9	(0.02)	<0.05	7.00
90.0	6A/B	142	209	7.20	11270	2.68	(0.37)	26.6	(0.04)	<0.05	3.00
95.5	3A/B/C	975	129	19.8	10209	15.1	(0.22)	12.4	(0.06)	<0.05	3.60
102.5	5A/B/C	563	128	24.1	10753	10.1	(0.20)	14.0	(0.08)	<0.05	3.70
108.5	4A/B/C	449	117	17.3	15256	8.76	(0.26)	8.30	(0.08)	<0.05	4.80
112.0	2B/C	453	81.2	23.7	11344	8.56	<0.50	30.2	(0.06)	<0.05	4.90
127.4	1A/B/C	1705	76.7	186	1921	13.6	<0.50	15.7	(0.04)	0.10	5.10
<b>Extension</b>											
134.2	2B	49.3	5.38	12.9	31.3	0.22	<0.05	1.82	<0.05	<0.05	4.60
134.7	2A	57.4	4.29	13.8	22.5	0.26	<0.05	0.45	<0.05	<0.05	6.00
135.2	3B	57.3	22.4	15.0	53.6	0.26	<0.05	1.86	<0.05	0.06	7.90
135.9	3A	39.2	(10.7)	8.18	23.4	0.14	<0.05	0.77	<0.05	0.06	4.20

**Table B.4. Major Cation Composition of 1:1 Water Extracts from Borehole 41-09-39 Sidewall Cores and Extension Sleeves (3 Sheets)**

Depth (ft bgs)	Sample ID	Calcium (ppm)	Potassium (ppm)	Magnesium (ppm)	Sodium (ppm)	Strontium (ppm)	Aluminum (ppm)	Boron (ppm)	Iron (ppm)	Manganese (ppm)	Silicon (ppm)
Extension (Cont'd)											
137.4	4C	19.7	(1.60)	3.13	10.8	0.06	<0.05	0.29	<0.05	<0.05	5.00
138.0	4B	20.0	(8.10)	3.98	14.8	0.06	<0.05	0.37	<0.05	<0.05	5.40
140.3	5C	16.0	(3.20)	3.62	19.0	0.06	<0.05	0.50	<0.05	<0.05	6.60
140.9	5B	21.8	(6.60)	3.21	14.2	0.07	<0.05	0.41	<0.05	<0.05	4.70
141.5	5A	17.8	(2.40)	3.24	(13.5)	0.07	<0.05	0.34	<0.05	<0.05	6.30
141.9	6F	19.7	4.07	6.07	19.3	0.09	<0.05	1.45	<0.05	<0.05	9.70
142.4	6E	13.4	4.83	4.18	15.0	0.07	-0.06	0.99	<0.05	<0.05	10.0
143.3	6D	20.3	5.08	7.21	19.9	0.09	<0.05	0.54	<0.05	<0.05	10.7
144.1	6C	25.3	7.24	9.17	25.2	0.13	(0.07)	0.67	<0.05	<0.05	12.3
144.7	6B	22.4	5.15	8.09	22.0	0.1	<0.05	0.72	<0.05	<0.05	11.3
145.2	7E	12.1	(2.50)	3.88	17.5	0.05	(0.08)	1.23	<0.05	<0.05	11.2
145.8	7D	13.1	(2.90)	4.26	18.9	0.06	(0.14)	1.98	<0.05	<0.05	13.5
146.4	7C	15.3	(3.80)	5.53	20.1	0.08	(0.06)	1.26	<0.05	<0.05	14.3
151.1	9C	15.0	5.02	4.94	16.1	0.07	(0.07)	1.29	<0.05	<0.02	9.90
151.8	9B	13.2	4.63	4.45	15.6	0.06	<0.05	0.93	<0.05	<0.05	10.4
152.8	9A	10.5	4.62	3.63	16.3	0.05	0.17	1.09	<0.05	<0.01	9.80
153.4	10C	13.4	7.14	5.70	20.0	0.07	<0.05	0.84	<0.05	<0.05	10.1
153.9	10B	13.7	4.22	6.36	17.6	0.06	0.18	1.42	(0.07)	<0.01	16.4
154.5	10A	13.0	5.64	5.06	16.3	0.06	0.19	1.20	<0.05	<0.05	14.7
155.4	11C	12.5	(4.60)	3.60	12.1	0.04	<0.05	0.79	(0.04)	<0.01	15.1
155.9	11B	12.9	(3.60)	3.5	10.9	0.05	<0.05	0.94	<0.05	<0.05	14.9

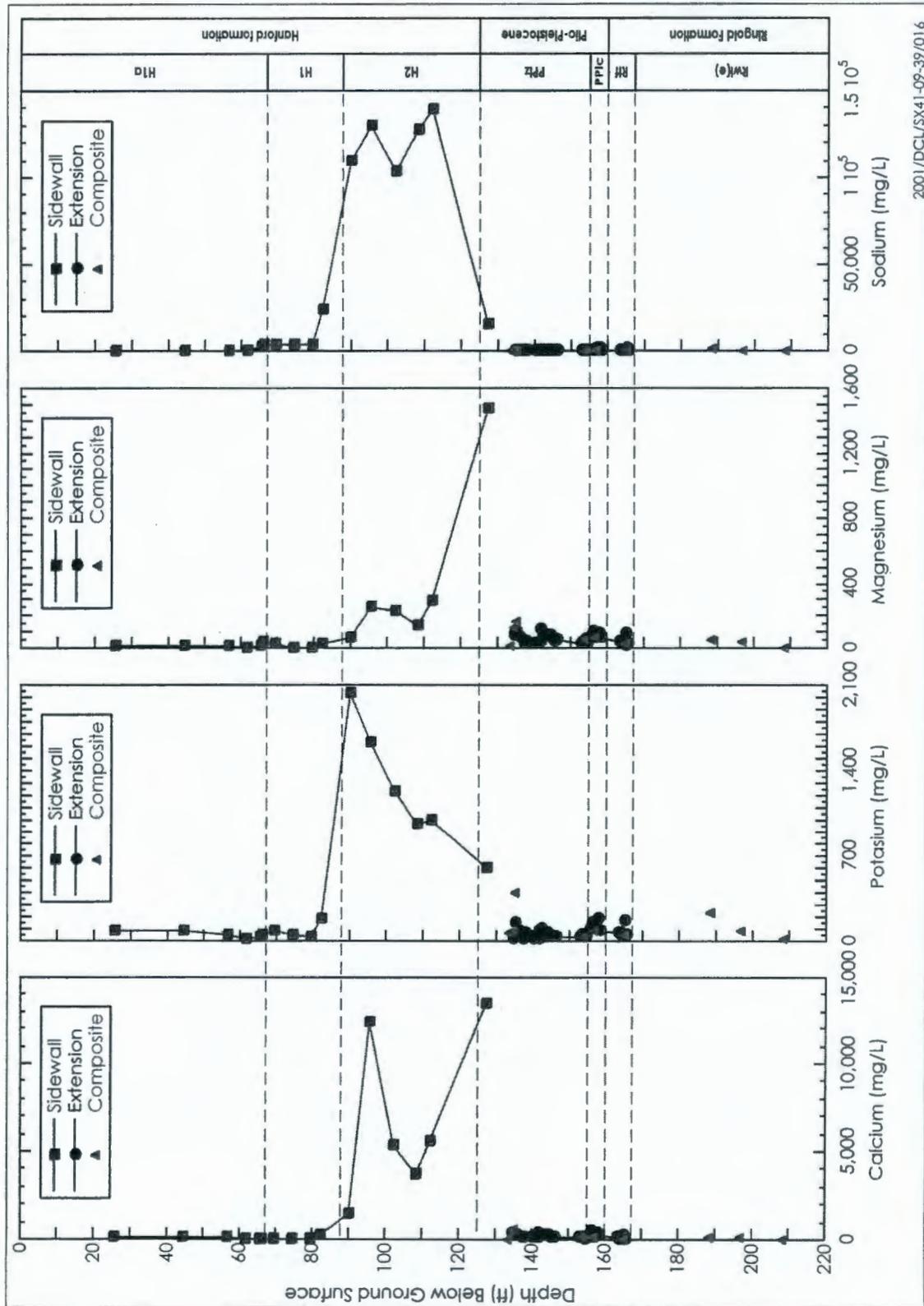
**Table B.4. Major Cation Composition of 1:1 Water Extracts from Borehole 41-09-39 Sidewall Cores and Extension Sleeves (3 Sheets)**

Depth (ft bgs)	Sample ID	Calcium (ppm)	Potassium (ppm)	Magnesium (ppm)	Sodium (ppm)	Strontium (ppm)	Aluminum (ppm)	Boron (ppm)	Iron (ppm)	Manganese (ppm)	Silicon (ppm)
Extension (Cont'd)											
156.4	11A	11.3	(3.40)	2.51	6.63	0.04	0.01	0.96	<0.05	<0.05	10.9
156.8	12B	12.1	8.16	4.43	49.6	0.06	<0.05	0.92	<0.05	<0.05	14.0
157.1	12A	11.2	6.89	4.11	40.3	0.06	<0.05	1.12	<0.05	<0.05	13.1
157.2	13D	13.4	11.2	4.74	50.8	0.06	<0.05	0.62	<0.05	<0.05	12.5
157.7	13C	12.6	7.34	3.73	35.1	0.06	(0.08)	0.99	(0.06)	<0.05	13.8
158.2	13B	11.3	(4.30)	3.63	16.7	0.05	0.13	0.93	(0.09)	<0.05	15.9
162.3	16D	5.77	5.94	2.14	33.8	(0.03)	(0.08)	1.26	0.07	0.07	7.60
163.3	16B	5.40	3.14	1.60	7.58	(0.03)	0.08	0.81	0.08	(0.01)	11.1
163.8	16A	2.83	1.97	0.97	7.53	(0.01)	0.35	1.37	0.33	(0.03)	15.2
164.3	17D	9.52	6.00	3.02	29.3	0.05	(0.12)	0.93	0.14	(0.04)	11.3
165.3	17B	2.53	(2.00)	0.92	9.35	(0.01)	0.35	1.39	0.45	(0.02)	16.6
165.8	17A	2.75	2.00	0.92	7.72	(0.01)	0.60	1.28	0.71	(0.03)	16.6

Note: Values in parenthesis are near the detection limit but are considered good values.

NM = not measured.

**Figure B.8. Dilution-Corrected Cation Concentrations at Borehole 41-09-39 in 1:1 Sediment to Water Extracts**



2001/DCL/SX41-09-39/016

Table B.5. Cesium-137 Activity in Borehole 41-09-39 Sidewall Cores and Extension Sleeves (2 Sheets)

Depth (ft bgs)	Sample ID	Cesium-137 (pCi/g)	Cesium-137 (+/- pCi/g)	Cesium-137 (pCi/g)	Depth (ft bgs)	Sample ID	Cesium-137 (pCi/g)	Cesium-137 (+/- pCi/g)	Cesium-137 (pCi/g)	Depth (ft bgs)	Sample ID	Cesium-137 (pCi/g)	Cesium-137 (+/- pCi/g)	Cesium-137 (pCi/g)
		Wet Wt.	Error	Dry Wt.			Wet Wt.	Error	Dry Wt.			Wet Wt.	Error	Dry Wt.
Sidewall					151.8	9B	9.54E+01	1.83E+00	NM	183	35B	3.21E-01	5.49E-02	3.32E-01
25.5	15A/B/C	5.50E+02	9.70E+00	6.06E+02	152.8	9A	1.67E-01	1.24E-01	1.82E-01	183.3	35A	<MDA		<MDA
44.5	14A/B/C	1.01E+03	1.83E+01	1.11E+03	152.9	10D	1.12E+02	2.57E+00	NM	183.9	36C	1.75E-01	3.95E-02	1.81E-01
56.5	13A/B/C	2.36E+04	5.27E+02	2.60E+04	153.4	10C	7.13E-02	2.33E-02	7.95E-02	184.6	36B	4.89E-01	4.97E-02	4.99E-01
61.5	12A/B/C	1.13E+05	2.19E+03	1.25E+05	153.9	10B	<MDA		<MDA	185	36A	<MDA		NM
65.5	11A/B	5.68E+05	1.06E+04	6.26E+05	154.5	10A	1.98E-02	3.67E-02	2.39E-02	185.8	37D	1.57E-01	3.51E-02	1.59E-01
66	11C	3.71E+06	6.89E+04	4.09E+06	155.1	11D	1.75E+00	1.70E-01	1.84E+00	186.2	37C	<MDA		<MDA
69.5	10A/B/C	8.61E+03	1.10E+02	9.49E+03	155.4	11C	<MDA		<MDA	186.8	37B	<MDA		<MDA
74.5	9A/B/C	2.13E+06	3.94E+04	2.34E+06	155.9	11B	<MDA		<MDA	187.2	37A	<MDA		<MDA
79.5	8A/B/C	2.32E+06	4.54E+04	2.56E+06	156.4	11A	9.82E+00	2.94E-01	1.03E+01	187.8	38C	2.91E-01	3.23E-02	2.99E-01
82.5	7A/B/C	1.60E+07	4.31E+05	1.76E+07	156.8	12B	7.38E+01	1.16E-01	7.89E+01	188.3	38B	<MDA		<MDA
90	6A/B	3.97E+04	5.32E+02	4.38E+04	157.1	12A	7.31E+01	9.69E-01	7.79E+01	188.7	38A	<MDA		<MDA
95.5	3A/B/C	3.40E+04	4.66E+02	3.82E+04	157.2	13D	5.56E+01	7.80E-01	5.92E+01	189.2	39B	3.72E-01	4.12E-02	3.78E-01
102.5	5A/B/C	1.44E+06	2.83E+04	1.62E+06	157.7	13C	1.02E+01	2.45E-01	1.06E+01	189.5	39A	2.84E-01	3.72E-02	2.89E-01
108.5	4A/B/C	3.00E+05	7.54E+03	3.37E+05	158.2	13B	1.15E+00	7.46E-02	1.21E+00	190.7	40A	<MDA		<MDA
112	2B/C	1.32E+03	2.35E+01	1.49E+03	158.7	13A	3.13E-01	3.83E-02	NM	193.3	45A	4.40E-01	4.72E-02	4.63E-01
127.4	1A/B/C	3.73E+03	6.40E+01	4.20E+03	159	14D	NM		NM	195.9	47D	6.34E-02	1.87E-02	6.90E-02
Extension					159.4	14C	2.68E+00	1.08E-01	2.84E+00	196.4	47C	<MDA		<MDA
131.1	1C-L	3.24E+05	4.79E+03	NM	160	14B	<MDA		<MDA	196.9	47B	<MDA		<MDA
131.1	1C-D	7.96E+04	1.21E+03	NM	160.6	14A	<MDA		<MDA	197.4	47A	1.92E-02	6.11E-03	2.01E-02
131.7	1B-1	2.08E+06	3.58E+04	2.35E+06	162.3	16D	2.24E+00	8.25E-02	2.49E+00	198.8	49C	<MDA		NM
131.7	1B-2	9.29E+02	1.41E+01	NM	162.8	16C	2.28E+00	1.04E-01	2.61E+00	199.1	49B	1.65E-01	3.23E-02	1.79E-01
133.2	2D	4.80E+04	6.44E+02	6.50E+04	163.3	16B	4.56E+00	3.03E-02	4.75E+00	199.1	49A	9.66E-02	2.60E-02	1.06E-01
133.7	2C	2.66E+04	4.09E+02	3.15E+04	163.8	16A	<MDA		<MDA	199.4	50B	2.49E-01	6.19E-02	2.66E-01
133.7	2C-2	1.16E+06	1.70E+04	1.47E+06	164.3	17D	1.86E+00	8.63E-02	1.95E+00	199.4	50A	<MDA		<MDA
134.2	2B	2.27E+03	3.25E+01	2.60E+03	164.8	17C	9.31E-01	6.17E-02	9.63E-01	200.2	52B	<MDA		<MDA
134.7	2A	5.73E+01	1.14E+00	6.65E+01	165.3	17B	6.46E-02	2.98E-02	6.32E-02	200.7	52A	2.06E-01	3.55E-02	2.23E-01

Table B.5. Cesium-137 Activity in Borehole 41-09-39 Sidewall Cores and Extension Sleeves (2 Sheets)

Depth (ft bgs)	Sample ID	Cesium-137 (pCi/g)	Cesium-137 (+/- pCi/g)	Cesium-137 (pCi/g)	Depth (ft bgs)	Sample ID	Cesium-137 (pCi/g)	Cesium-137 (+/- pCi/g)	Cesium-137 (pCi/g)	Depth (ft bgs)	Sample ID	Cesium-137 (pCi/g)	Cesium-137 (+/- pCi/g)	Cesium-137 (pCi/g)
		Wet Wt.	Error	Dry Wt.			Wet Wt.	Error	Dry Wt.			Wet Wt.	Error	Dry Wt.
135.2	3B	2.29E+03	4.04E+01	NM	165.8	17A	<MDA		<MDA	202.5	54B	4.85E-02	3.93E-02	5.17E-02
135.9	3A	2.93E+03	3.79E+01	3.31E+03	166.1	18D	3.42E-01	8.96E-02	NM	202.5	54A	2.18E-02	1.27E-02	2.30E-02
137.0	4D	NM		NM	166.6	18C	<MDA		<MDA	204.3	56C	<MDA		<MDA
137.4	4C	<MDA		<MDA	167.1	18B	<MDA		<MDA	205	56B	1.04E-01	5.05E-02	1.11E-01
138.0	4B	4.31E+01	6.62E-01	4.81E+01	167.7	18A	5.12E-02	6.11E-02	5.24E-01	205.6	56A	3.45E-02	1.31E-02	3.64E-02
138.7	4A	4.76E-01	6.19E-02	5.86E-01	169.2	20D	1.60E+00	7.94E-02	NM	207.6	58D	5.27E-02	2.07E-02	5.77E-02
139.9	5D	3.63E+01	5.34E-01	4.14E+01	169.4	20C	1.42E+00	1.14E-01	NM	208.1	58C	1.03E-01	3.93E-02	1.13E-01
140.3	5C	1.54E+01	3.11E-01	1.76E+01	169.7	20B	1.75E+00	8.73E-02	NM	208.6	58B	<MDA		<MDA
140.9	5B	6.93E+01	1.06E+00	7.81E+01	169.9	20A	2.94E-01	3.37E-02	3.02E-01	209	58A	<MDA		<MDA
141.5	5A	3.61E+00	1.50E-01	3.97E+00	171.3	22C	4.81E-01	7.19E-02	5.08E-01	209.4	59D	<MDA		<MDA
141.9	6F	1.39E+02	2.92E+00	1.54E+02	172	22B	4.19E-01	3.98E-02	4.42E-01	209.8	59C	<MDA		<MDA
142.4	6E	2.69E+00	1.57E-01	2.96E+00	172.7	22A	<MDA		NM	210.4	59B	<MDA		<MDA
143.3	6D	1.10E-01	3.69E-02	1.34E-01	178.2	28A	5.78E-01	6.25E-02	6.24E-01	210.9	59A	<MDA		<MDA
144.1	6C	1.38E+02	2.99E+00	1.74E+02	178.8	30C	5.39E-01	8.53E-02	5.76E-01	211.7	62B	2.87E-02		3.10E-02
144.7	6B	<MDA		<MDA	179.2	30B	<MDA		<MDA	212.1	62A	<MDA		<MDA
145.2	7E	4.21E+00	1.48E-01	4.57E+00	179.7	30A	<MDA		<MDA	212.9	64B	4.01E-02	3.37E-02	4.51E-02
145.8	7D	2.06E-01	2.05E-01	2.19E-01	180.2	31B	6.53E-01	8.02E+00	6.81E-01	213.3	64A	2.39E-02	1.18E-02	2.71E-02
146.4	7C	<MDA		<MDA	180.5	31A	5.18E-01	7.34E-02	5.37E-01	214.1	65B	2.31E-01	3.52E-02	2.49E-01
148.3	8C	2.04E+01	3.96E+00	2.19E+01	181.1	32B	6.25E-01	1.07E-01	6.58E-01	214.3	65A	9.05E-02	2.62E-02	9.83E-02
149.9	8B	1.27E+01	2.99E-01	1.39E+01	181.5	32A	1.53E-01	2.87E-02	1.58E-01	215	67*	1.13E-01	9.25E-02	NM
151.1	9C	1.09E+03	2.17E+01	1.23E+03										

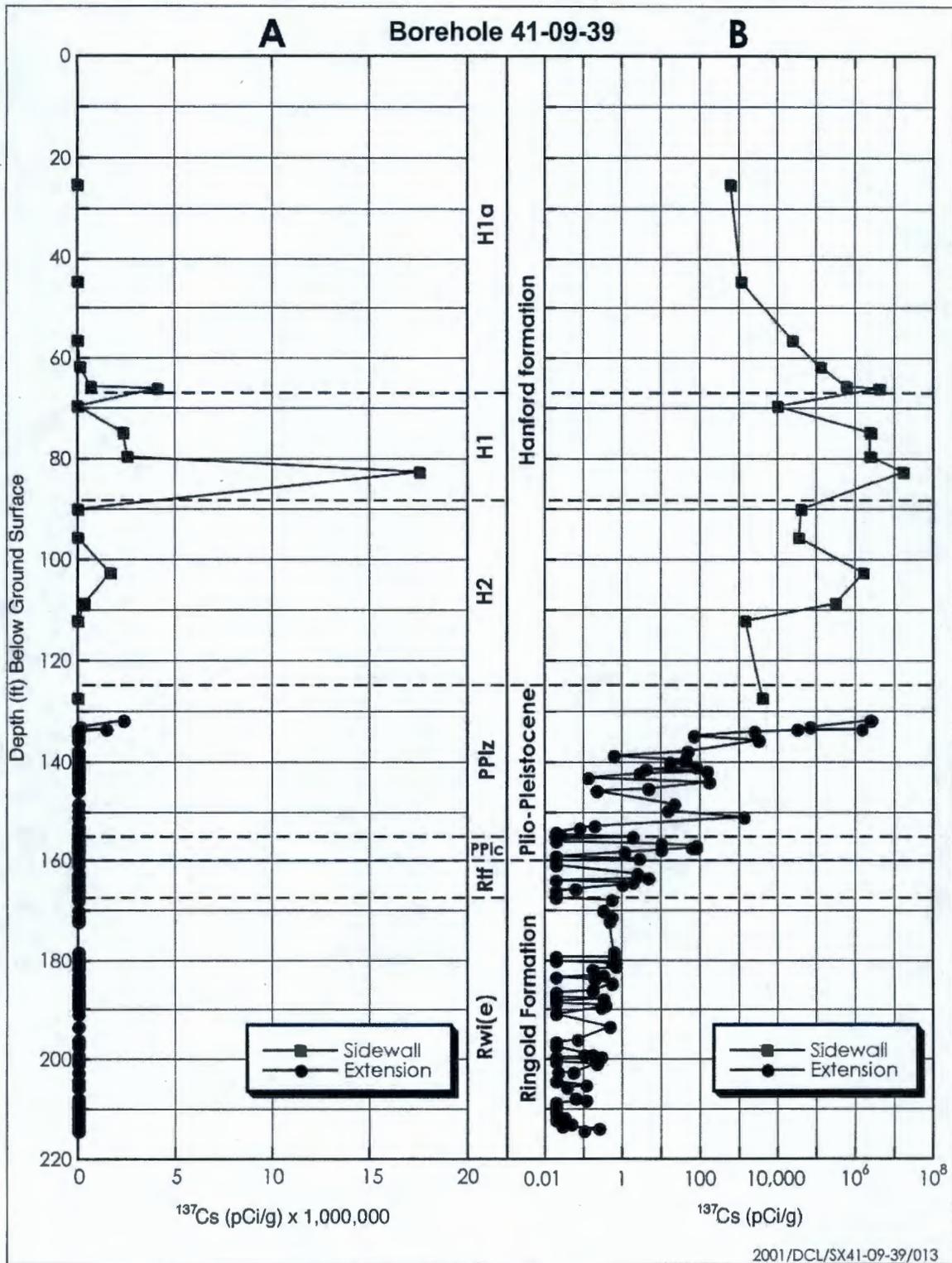
Note: Sleeves 1C and 1B were partially filled and were compressed materials from the pile driving of the original casing. 1C-L and 1C-D represent light and dark compressed sediments. 1B-1 and 1B-2 were two distinctly different grain-sized compressed materials. 2C-2 was a fine-grained lens of silt within a fine sand matrix.

67\* = clean out material in saturated sediments.

MDA = Minimum detectable cesium-137 activity; less than 2.00E-02 pCi/g.

NM = not measured.

Figure B.9. Cesium-137 Activity in Sediment versus Lithology and Depth



Note: A shows linear scale and B shows log scale.

**Table B.6. Trace Metal Composition of 1:1 Water Extracts and Porewaters from Borehole 41-09-39 Sidewall Cores and Extension Composites (2 Sheets)**

Composite Depth (ft bgs)	1:1 Extract ID	ICP-MS							
		Technetium-99 (pCi/L)	Chromium (ppb)	Cobalt (ppb)	Nickel (ppb)	Zinc (ppb)	Arsenic (ppb)	Selenium (ppb)	Molybdenum (ppb)
<b>Sidewall</b>									
25.5	15A/B/C	<1.0E+03	<0.5	(3.00)	<100	(68.0)	26.0	<5	14.0
44.5	14A/B/C	<1.0E+03	(2.89)	(1.00)	<100	(65.0)	14.9	<5	74.6
56.5	13A/B/C	<1.0E+03	(3.47)	<50	<100	(53.0)	0.77	<5	62.6
	13 UFA	2.88E+05	6463	<83	(9.00)	109	(4.33)	44.7	104
61.5	12A/B/C	7.0E+02	(8.15)	(3.00)	<100	(56.0)	4.00	<5	24.9
65.5	11A/B	4.1E+03	344	(2.00)	(4.00)	(104)	24.3	<5	304
66	11C	7.8E+03	342	(1.00)	(2.00)	(102)	15.8	<5	93.4
69.5	10A/B/C	5.5E+03	5070	(7.00)	<100	(86.0)	30.0	<5	516
74.5	09A/B/C	7.7E+03	4091	(5.00)	(4.00)	(51.0)	24.3	<5	552
79.5	08A/B/C	1.8E+04	718	(1.00)	(2.00)	(49.0)	7.84	(4.86)	1003
	8 UFA	5.17E+05	20850	<156	(11.0)	1848	(8.13)	(74.2)	2596
82.5	07A/B/C	3.9E+05	745753	96.0	(6.0)	(66.0)	7.63	85.7	6378
90	06A/B	2.7E+06	711595	86.0	(6.0)	(88.0)	<5	135	2911
	6 UFA	2.48E+07	5627500	<453	(41.0)	944	264	1218	5032
95.5	03A/B/C	7.1E+06	260333	(30.0)	<100	(83)	<5	219	427
102.5	05A/B/C	6.1E+06	527799	60.0	<100	(112)	<5	228	1575
108.5	04A/B/C	1.2E+07	481344	63.0	(5.00)	(60)	<5	388	604
	4 UFA	9.40E+07	3183229±23128	259±17	29±13	235±9	628±19	2836±62	943±27
112	02B/C	8.6E+06	175630	25.0	<100	(50)	<5	288	17.0
	2 UFA	1.23E+08	1795521	(157)	(41.0)	(332)	685	3074	(102)

**Table B.6. Trace Metal Composition of 1:1 Water Extracts and Porewaters from Borehole 41-09-39 Sidewall Cores and Extension Composites (2 Sheets)**

Composite Depth (ft bgs)	1:1 Extract ID	ICP-MS							
		Technetium-99 (pCi/L)	Chromium (ppb)	Cobalt (ppb)	Nickel (ppb)	Zinc (ppb)	Arsenic (ppb)	Selenium (ppb)	Molybdenum (ppb)
127.4	01A/B/C	3.3E+05	11.47	(0)	<100	(89)	1.05	31.5	167
Extension*									
133.2	2C/D	1000± 2500	3.00	6.86	<5	32.0	NA	<10	121
134.2	2A/B	5650±2200	<0.5	<0.5	<5	7.00	NA	<10	15.2
135.2	3A/B	2720±2500	<0.5	<0.5	<5	22.0	NA	<10	58.0
153.9	10A/B	3900±5200	<0.5	<0.5	<5	11.0	NA	<10	31.1
156.8	12A/B	380±2900	<0.5	<0.5	<5	7.00	NA	<10	87.1
165.3	17A/B	9320±12800	<0.5	<0.5	<5	14.0	NA	<10	13.0
188.3	38A/B	50±2800	<0.5	<0.5	<5	6.00	NA	<10	22.0
196.9	47A/B	(-190)±4700	<0.5	<0.5	<5	13.5	NA	<10	11.7
208.6	58A/B	(-470)±3800	<0.5	<0.5	<5	10.2	NA	<10	9.80

\*For technetium-99 the borehole extension samples were analyzed by wet chemical separations and liquid scintillation counting. Samples were analyzed in duplicate and mean and uncertainty are presented. The deepest two composites yielded negative values. The technique is not as sensitive as the ICP-MS data. Units for technetium-99 are pCi/L and not mass units.

Highlighted pairs are chemical analyses of soil water derived from a common soil in two ways, by 1:1 water extraction and by direct removal of porewater by centrifugation using the unsaturated flow apparatus (UFA).

ICP = inductively coupled plasma.

MS = mass spectrometer.

NA = not analyzed.

The primary zone of true contamination is considered to be in subunit H1 and the upper half of subunit H2 between 18 and 39 m (60 and 127 ft) bgs. In this zone three peaks occur at 20, 25, and 31 m (66, 82.5, and 102 ft) bgs at concentration levels of  $4 \times 10^6$ ,  $2 \times 10^7$ , and  $2 \times 10^6$  pCi/g. Overall, the vast majority of cesium-137 mass resides in subunit H1 between 20 and 26 m (66 and 84 ft) bgs. Just below these peaks, cesium-137 concentrations drop by orders of magnitude.

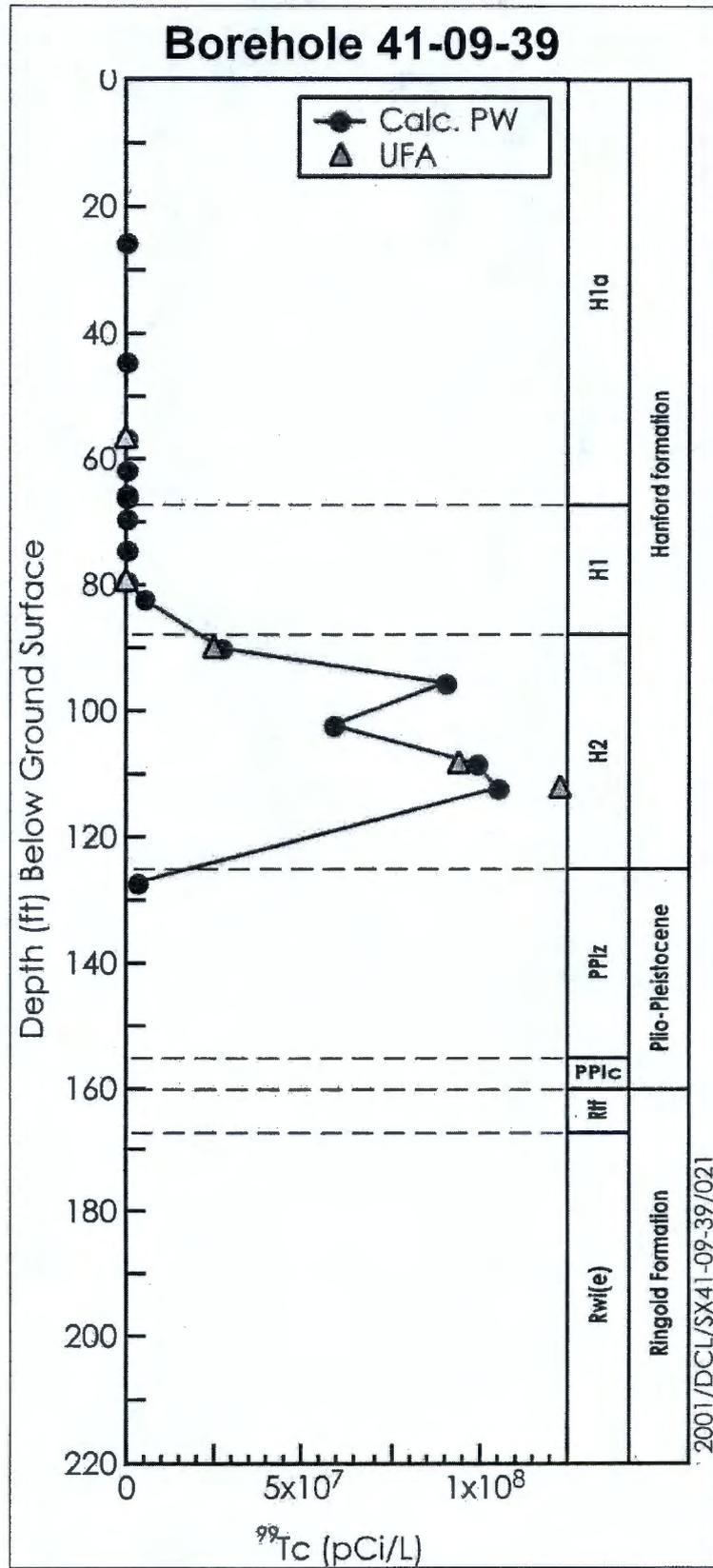
The primary zone of elevated technetium-99 concentration (listed as pCi/L in Table B.6) lies between 24 and 39 m (79 and 127 ft) bgs, where maximum concentrations of greater than  $1 \times 10^7$  pCi/L are measured at 33 m (108 ft) bgs. Water extract concentrations of technetium-99 with depth are shown in Figure B.10. This pattern closely mimics the nitrate concentration distribution. Chromium concentration values increase above background beginning at 20 m (66 ft) bgs and reach maximum concentrations of greater than 100,000  $\mu\text{g/L}$  between 22 and 38 m (82 and 112 ft) bgs. The occurrence of the maximum chromium range slightly higher in the soil column relative to technetium-99 indicates some retarding chemical mechanism has slowed chromium migration relative to technetium-99. Work completed by the Hanford Science and Technology (S&T) Program (Appendix D, Section D.4.1) indicates that iron(II)-rich minerals in the vadose zone soil reduce the oxidation state of a fraction of the chromium in solution from +6 to +3. In the +3 state, chromium is removed from solution by sorption or co-precipitation in iron(II)-rich minerals.

#### B.2.4 CHEMICAL INTERACTIONS

No specific experiments were completed on soils from borehole 41-09-39 to quantify geochemical reactions influencing contaminant migration. Dominant chemical reactions affecting radionuclides and tank fluid chemicals are inferred from the relative location of these constituents in the soil column, comparison of acid-leachable versus water-leachable concentrations for specific contaminants, and general knowledge of the tank fluid chemistry. Greater contaminant mobility is inferred from the occurrence of high concentration zones deeper in the vadose zone and smaller differences in dissolved concentrations leached by water versus acid.

Generally speaking, the data suggest that tank SX-108 fluid chemistry had a substantial but limited effect on contamination behavior at borehole 41-09-39. Given the distance between borehole 41-09-39 and the tank SX-108 bottom, the presence of very high concentrations of cesium-137 in subunit H1 in this borehole shows that cesium-137 was initially highly mobile in the leaked tank fluid. Various types of sorption experiments completed by the S&T activity (Appendix D, Section D.3.0) shows that the very high concentrations of cesium-137, sodium and to a lesser extent potassium in the tank SX-108 fluid created local conditions where sodium preferentially occupied soil sorption sites in soils and preventing cesium-137 sorption. These conditions were short-lived and confined to subunit H1 and the top part of subunit H2 as shown by the current limited distribution of cesium-137. Over time natural infiltration and recharge subsequently separated sodium from cesium-137, permitting cesium-137 to sorb in situ. The current degree of cesium-137 mobility was determined by comparing the amount of cesium-137 removed by water versus total activity measured by gamma. The in situ distribution coefficient for cesium-137 varies from 4 to 25 mL/g in the sediments between 27 and 34 m (90 and 112 ft) bgs where the bulk of the tank fluid with high salinity resides. Above and below this depth range cesium-137 in situ distribution coefficient values are usually much larger (greater than 1000 mL/g) because the pore fluids do not contain high sodium concentrations that compete for adsorption sites.

Figure B.10. Technetium-99 Activity in Porewater in Borehole 41-09-39



Tank fluids also increased amounts of other constituents to the soil column but had little effect on the chemical behavior of contaminants other than cesium-137 in the sense that chemical reactions between tank fluid constituents and the soil column environment were largely controlled by soil-soil water reactions. Constituent anions (e.g., nitrate and technetium-99) have migrated the most rapidly and mark the leading edge of vertical tank fluid migration. The technetium-99 in situ distribution coefficient was determined by comparing acid versus water leached concentrations and varies from 0.01 to about 5 mL/g over the whole zone of contamination. Chromium was slightly retarded relative to technetium-99 and nitrate, presumably because of oxidation reduction, allowing fixation on soil. Generally, the in situ distribution coefficient values were negative except for the soil sample at 24 m (80 ft) bgs where the distribution coefficient value greater than 20 mL/g was estimated.

Other constituent cations have migrated varying distances depending on the strength of retardation mechanisms. Sodium concentrations, being relatively high, successfully competed for sorption sites in vadose zone soils, were somewhat retarded. Calcium, magnesium, and indigenous strontium were displaced by sodium and pushed ahead of sodium during migration.

### **B.2.5 GROUNDWATER MEASUREMENTS**

One sample of groundwater was taken from borehole 41-09-39 prior to decommissioning. Small concentrations of technetium-99, tritium, and nitrate are present in the water. There is no indication of a tank waste source. A more likely source is the upgradient crib 216-S-25.

### B.3.0 BOREHOLE 299-W23-19

This section summarizes data reported in *Geologic and Geochemical Data Collected from Vadose Zone Sediments from Borehole 299-W23-19 [SX-115] in the S/SX Waste Management Area and Preliminary Interpretations* (Serne et al. 2001c) except for the groundwater sample data, which are reported in the RCRA groundwater quality assessment report (Johnson and Chou 2001). Borehole 299-W23-19 was completed to further characterize the nature and extent of vadose zone contaminants supplied by a tank SX-115 leak. The most significant data provided by this characterization effort were soil measurement of radionuclides and chemicals attributed to the tank SX-115 leak. Elevated concentrations of several constituents were primarily measured in soils between 22 and 48 m (73 and 156 ft) bgs. This depth interval includes subunits H1 and H2 and subunit PPlz. The primary radionuclide present in this zone is technetium-99. Cesium-137 is present in very small concentrations at the top of this contaminated soil zone. The primary chemical characteristics attributed to tank fluid-soil interaction at different locations within this zone are elevated pH, sodium, chromium, nitrate, and chloride.

The absence of tank fluid constituents in the PPlc subunit of the Plio-Pleistocene unit and the Ringold Formation down to the water table is significant because of the very high technetium-99 content in the first water samples taken from borehole 299-W23-19. Subsequent conversion of this borehole into a monitoring well and continued groundwater sampling has revealed sustained high technetium-99 content. Also, the technetium-99/nitrate ratios at this well are indicative of a tank waste source because they are significantly greater than ratios in surrounding wells (Figure C.25) indicating a different source that is enriched in technetium-99. Also, the well ratio values (0.11 pCi/ $\mu$ g or 110 pCi/mg) are essentially the same as the ratio values in water extract data from soil samples in the high technetium-99/nitrate zone of borehole 299-W23-19 (Table 3.5). Assuming that both vadose zone and groundwater contamination from this borehole come from the tank SX-115 leak, a complicated migration path is indicated which must include both lateral and vertical movement.

Moisture content and matric potential measurements are consistent with recent high recharge through the soil column at this location imposed by one or more leaking water lines. Moisture contents are generally above average in the soil column and matric suction measurements indicate drainage is occurring throughout the soil column. These data and the presence of contaminants in other wells downgradient of tank SX-115 (Appendix C, Section C.7.0) present a logical pattern of accelerated migration of tank SX-115 fluid contaminants to and subsequent limited distribution within the unconfined aquifer.

### B.3.1 GEOLOGY

Borehole 299-W23-19 was drilled using air-rotary techniques. Samples were collected via the split spoon technique in as near-continuous manner as possible. The split-spoon samplers were driven into the formation ahead of the casing. After the samples were extracted from the hole, a standard bit was lowered in the hole and materials removed to the depth at which the sampling stopped. The casing was driven to that same depth and the process repeated. Samples were attempted in the Ringold Formation but the cemented gravels proved too much for the technique. Samples were collected from near the historic high groundwater elevation and again at the water table.

### B.3.1.1 Backfill

Backfill material extends from the surface to 18.7 m (61.5 ft) bgs. The material consists of non-cohesive sand with variable silt and minor pebbles. There was little variation in the geophysical logs of borehole 299-W23-19 confirming its relatively uniform nature.

### B.3.1.2 Hanford formation

All three Hanford formation subunits (H1a, H1, and H2) were present and sampled.

- **Subunit H1a** – Subunit H1a occurs from 18.7 to 23.8 m (61.5 to 78 ft) bgs in borehole 299-W23-19. The subunit consists of several upward fining, coarse sand to silty fine sand rhythmites. Sedimentary structures within these beds range from planar-laminated sand at the base to wavy ripple cross-laminated sand and silt at the top. Grain sizes within individual beds are gradational but the upper and lower boundaries of individual beds are sharp, where coarse sand associated with the overlying bed lies in direct contact with fine material from the underlying bed. Higher moisture is usually associated with the finer grained upper portions of these graded beds.
- **Subunit H1** – Subunit H1 occurs from 23.8 to 28.7 m (78 to 94 ft) bgs in borehole 299-W23-19. The subunit is predominantly a pebbly, medium- to coarse-grained sand. At least two layers of fine sand to muddy sand are present in the sequence.
- **Subunit H2** – Subunit H2 occurs from 28.7 to approximately 37.2 m (94 to 122 ft) bgs in borehole 299-W23-19. The subunit is predominantly fine grained, consisting of stratified fine sand to silty fine sand. Several coarser sand interbeds are present toward the top of the sequence. Graded rhythmites development is not as obvious in subunit H2 as in subunit H1a. Instead, there appear to be many irregular subtle gradations, mostly between platy (laminated), silty-fine to very-fine sand and occasionally medium to coarse sand. The calcium carbonate content of this unit is relatively low. Based on an increase in total gamma activity on geophysical logs the base of subunit H2 has been identified at 37.2 m (94 ft) bgs in an interval where there was no core recovery.

### B.3.1.3 Plio-Pleistocene Unit

The two Plio-Pleistocene unit subunits are the upper subunit PPlz, characterized by a relatively high silt content and the lower subunit PPlc, characterized by secondary, pedogenic, calcium-carbonate cement.

- **Subunit PPlz** – Subunit PPlz is interpreted to extend from 37.2 to 47.5 m (122 to 156 ft) bgs at borehole 299-W23-19. The subunit consists of mostly fine to very fine sand that is intercalated with silty fine sand to silt/clay. Most beds display well-preserved stratification, except within paleosols where the bedding has been disturbed by blocky soil-ped development, mottling, and/or bioturbation associated with pedogenesis. Dark carbonaceous aggregates (i.e., decomposed organic matter) and secondary iron-oxide and manganese-oxide staining are also common.

- **Subunit PPlc** – Subunit PPlc is interpreted to extend from 47.5 to 48.8 m (156 to 160 ft) bgs at borehole 299-W23-19. At this site subunit PPlc consists of weathered, dark-olive gray, loose, basaltic, pebbly sand interspersed with more indurated layers of mud and calcium carbonate. The geologic interpretation of this unit at this location differs from elsewhere in the vicinity of the SX tank farm. In this borehole the unit is highly basaltic and coarse in nature; elsewhere the unit is typically a massive carbonate facies. Additionally, the calcium carbonate does not occur as a single, well-developed caliche layer but appears to occur as stringers within the coarse-grained basaltic alluvium.

#### B.3.1.4 Ringold Formation

The remainder of the vadose zone at borehole 299-W23-19 below 48.8 m (160 ft) bgs is composed of Ringold Formation, member of Wooded Island, unit E as described in *Vadose Zone Geology of Boreholes 299-W22-50 and 299-W23-19-S-SX Waste Management Area Hanford Site, South-Central Washington* (Lindsey et al. 2000). The recovered materials consist predominately of fluvial, weakly cemented sandy gravel to strongly cemented, matrix-supported conglomerate. The gravel/conglomeratic facies is both clast supported and matrix supported. The matrix ranges from sandy mud, to muddy fine sand, to well-sorted quartz-rich fine or medium sand, to very coarse sand. The gravel clasts are subrounded to rounded and range up to 70 mm (3 in.) in diameter. The clasts are composed predominately of quartzite, basalt, and granite. In places, the basalt and granitic clasts are highly weathered, and iron oxide staining is common.

#### B.3.2 GEOPHYSICAL AND PHYSICAL PROPERTY MEASUREMENTS

Downhole geophysical measurements included a high-purity germanium spectral gamma log, a neutron-neutron log, a neutron-gamma log, and a temperature log. The total gamma log (derived from the spectral gamma logs) and the neutron-neutron log are shown in Figure B.11. In borehole 299-W23-19 where negligible manmade gamma contamination is present, the gamma data track relative potassium-40 concentrations and higher potassium-40 concentrations indicate silt-rich layers. In this case the PPlz subunit contains maximum potassium-40 concentrations. The spike at 30 m (100 ft) bgs is considered to be an artifact of the measuring event, not a real indicator of high potassium-40 concentration. The neutron-neutron log shows qualitative relative moisture content and is consistent with laboratory-measured moisture contents shown in the adjacent column (moisture) and provided in Table B.7. The neutron-gamma log (not shown; see Lindsey et al. 2000) provides an indication of relative amounts of silica, calcium and hydrogen in the formation. A maximum temperature of 82 °F (28 °C) was measured at 20 m (65 ft) bgs, about the same depth as the tank bottom indicating that residual heat loading from the tank waste continues to have a local effect.

Soil suction measurements were completed for several soil samples. Soil suction values are plotted as a function of depth in Figure B.12. All values plot to the left of the drainage curve indicating that drainage is occurring in the soil column at borehole 299-W23-19. Conversely, in two RCRA groundwater monitoring wells east of WMA S-SX, where no indication of manmade discharge to the soil column is known to occur, drainage is not indicated for soil samples below the Plio-Pleistocene unit.

**Figure B.11. Borehole 299-W23-19 Lithology, Stratigraphy, and Moisture Content (wt%) Distribution as a Function of Depth**

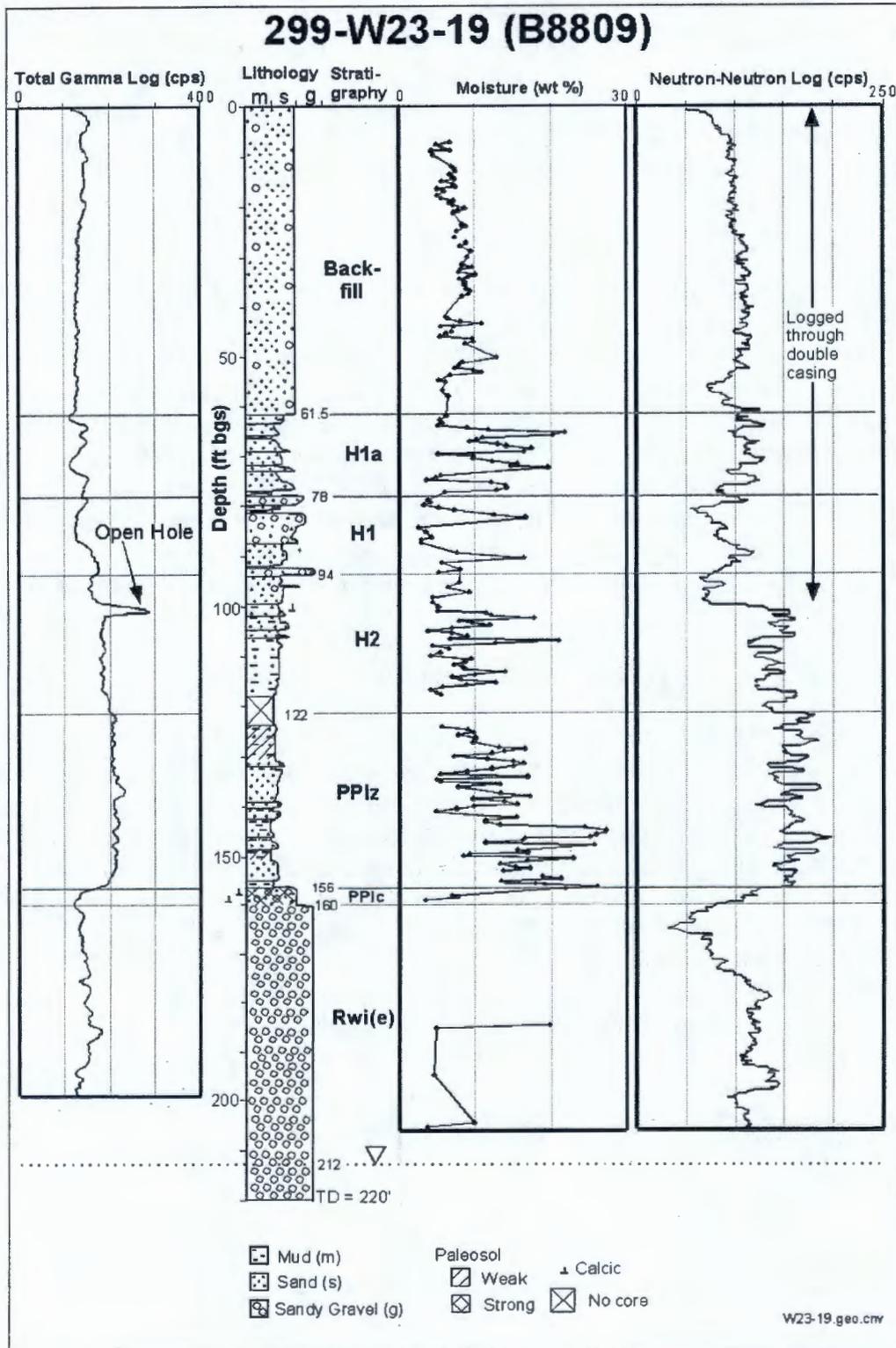


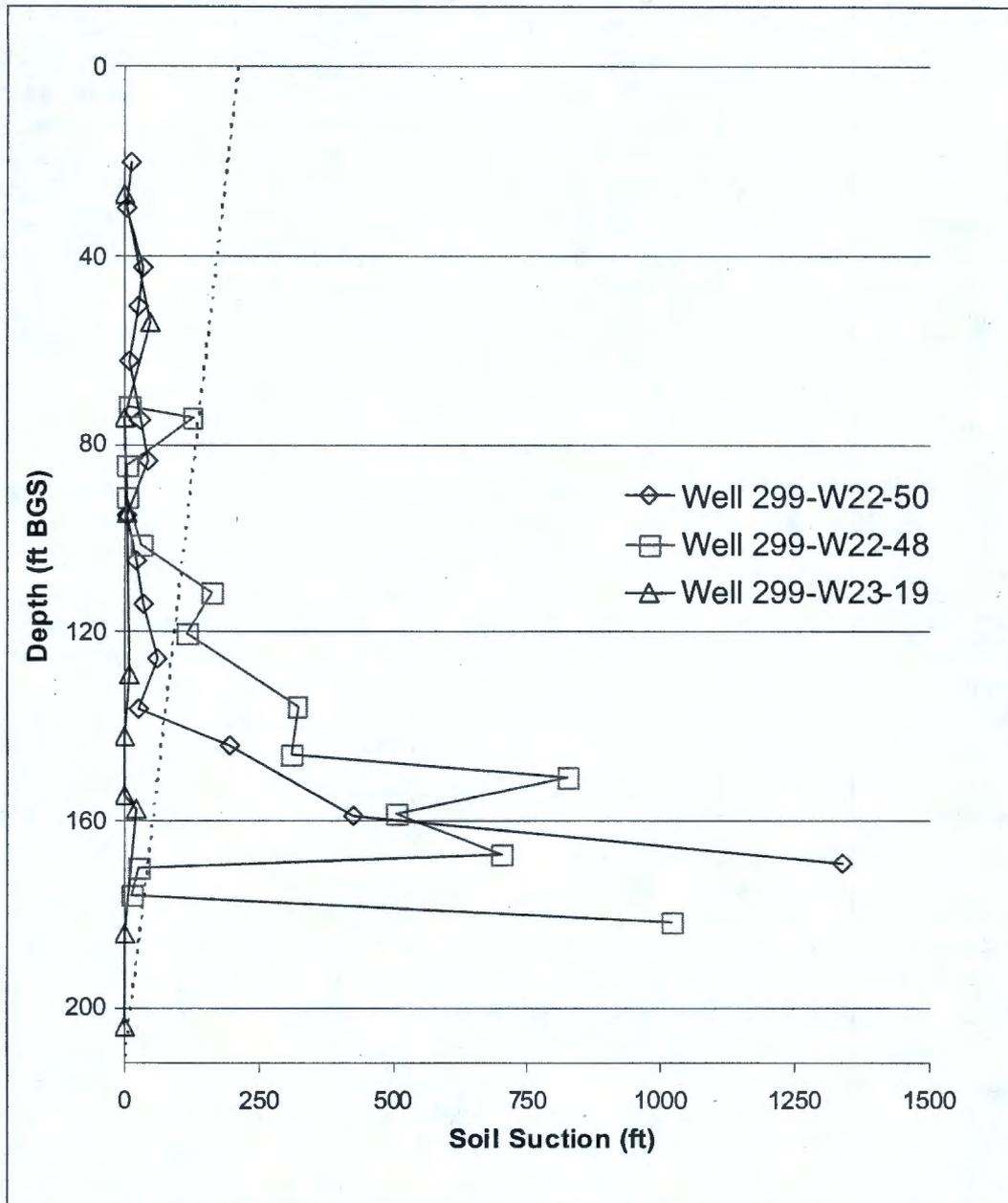
Table B.7. Moisture Content of Sediments from Borehole 299-W23-19 (2 Sheets)

Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)
01F	6.55	6.80	10C	36.35	9.42	18E	69.45	9.81	26E	102.95	7.04	31C	131.15	8.98	38F	152.60	13.47
01E	7.05	4.96	10B	36.85	9.15	18D	69.95	12.32	26D	103.45	3.79	31B	131.65	5.43	38E	153.10	14.07
01D	7.55	5.79	10A	37.35	8.38	18C	70.45	15.66	26C	103.95	6.99	31A	132.15	16.92	38D	153.60	15.96
01C	7.86	6.89	11F	40.85	6.20	18B	70.95	14.86	26B	104.45	8.99	32G	132.75	4.97	38C	154.10	17.95
01B	8.34	4.41	11E	41.35	6.51	18A	71.45	19.61	26A	104.95	6.81	32F	133.25	5.47	38B	154.60	19.15
01A	9.54	4.56	11D	41.85	8.18	19J	72.25	5.59	27J	105.55	21.03	32E	133.75	13.28	38A	155.10	26.11
03K	11.35	6.96	11C	42.35	11.00	19I	72.75	4.82	27I	106.05	12.76	32D	134.25	7.82	38	155.55	21.95
03J	11.85	7.49	11B	42.85	7.28	19H	73.25	3.61	27H	106.55	4.45	32C	134.75	8.60	39D	155.35	6.97
03I	12.35	7.59	11A	43.35	5.53	19G	73.75	12.15	27G	107.05	6.66	32B	135.25	13.33	39C	155.85	7.80
03H	12.85	6.81	13G	43.85	7.02	19F	74.25	14.11	27F	107.55	5.43	32A	135.80	17.27	39B	156.35	3.49
03G	13.35	7.18	13F	44.35	6.23	19E	74.75	14.20	27E	108.05	4.18	33I	136.65	9.81	39A	156.85	19.81
03F	13.85	7.45	13E	44.85	5.44	19D	75.25	12.92	27D	108.55	9.55	33H	137.15	13.86	40B	157.75	4.88
03E	14.35	5.73	13D	45.35	9.72	19C	75.75	6.05	27C	109.00	8.69	33G	137.65	15.57	40A	158.25	4.65
03D	14.85	7.25	13C	45.85	9.95	19B	76.25	3.84	27B	109.55	7.29	33F	138.15	9.90	40	158.65	10.12
03C	15.35	7.53	13B	46.35	8.80	19A	76.75	4.18	28G	110.25	8.42	33E	138.65	7.60	17SK	159.75	8.39
03B	15.85	5.13	13A	46.85	12.89	20H	78.25	3.32	28F	110.75	8.71	33D	139.15	4.95	18SKA	161	6.89
03A	16.35	5.99	14J	50.15	8.48	20G	78.75	5.26	28E	111.25	14.04	33C	139.65	7.99	18SKB	161.00	5.24
04H	17.15	5.07	14I	50.65	8.00	20F	79.25	7.32	28D	111.75	10.03	33B	140.15	15.49	18SKC	166.50	2.95
04G	17.65	5.63	14H	51.15	7.41	20E	79.75	12.58	28C	112.25	7.10	33A	140.65	11.49	19SKA	166.50	1.35
04F	18.15	7.24	14G	51.65	9.89	20D	80.25	16.67	28B	112.75	8.30	35K	141.05	11.47	19SKB	176.00	1.24
04E	18.65	6.86	14F	52.15	11.01	21E	82.00	2.58	28A	113.20	12.75	35J	141.35	13.24	41A	184.45	3.95
04D	19.15	7.26	14E	52.65	6.80	21D	83.00	3.55	29I	113.85	8.91	35I	141.85	24.48	19SKC	185	0.88
04C	19.65	8.72	14D	53.15	5.28	21C	84.00	4.31	29H	114.35	5.78	35H	142.35	27.23	20SKA	185	1.28
04B	20.15	7.94	15B	54.12	6.23	21B	85.00	2.94	29G	114.85	4.22	35G	142.85	27.15	20SKB	189.5	1.14

Table B.7. Moisture Content of Sediments from Borehole 299-W23-19 (2 Sheets)

Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)	Sample ID	Depth (ft bgs)	Moisture (%)
04A	20.65	7.25	15A	54.50	5.84	21A	86.00	2.89	29F	115.35	4.97	35F	143.35	26.00	42	194.55	5.87
05E	22.85	8.48	16B	56.95	6.59	22E	87.10	7.72	29E	115.85	5.51	35E	143.85	25.08	43B	204.50	6.16
05D	23.55	8.87	16A	57.45	6.32	22D	88.10	16.49	29D	116.35	5.60	35D	144.35	16.57	43A	205.15	2.70
05C	24.65	7.77	17J	61.75	5.33	22C	89.10	5.65	29C	116.85	9.08	35C	144.85	16.25			
05B	25.75	7.42	17I	62.25	5.70	22B	91.10	8.12	29A+B	117.85	9.87	35B	145.35	11.50			
05A	26.85	8.87	17H	62.75	5.18	22A	91.10	5.27	30G	123.85	7.86	35A	145.85	25.75			
08C	27.55	8.15	17G	63.25	8.99	24C	93.00	8.01	30F	124.35	10.12	36F	146.45	15.67			
08B	28.65	9.51	17F	63.75	11.77	24B	94.00	6.42	30E	124.85	10.07	36E	146.95	16.91			
08A	29.75	9.13	17E	64.25	21.84	24A	95.00	9.25	30D	125.35	9.78	36D	147.45	9.36			
09I	30.95	8.46	17D	64.75	20.18	25E	96.06	4.46	30C	125.85	13.18	36C	147.95	8.52			
09H	31.45	9.69	17C	65.25	11.13	25D	97.06	4.47	30B	126.35	16.57	36B	148.45	22.95			
09G	31.95	8.23	17B	65.75	10.30	25C	98.06	5.21	30A	126.85	13.86	36A	148.95	16.89			
09F	32.45	8.00	17A	66.25	9.34	25B	99.06	5.12	31J	127.80	12.27	37E	149.15	13.30			
09E	32.95	10.16	18K	66.45	13.04	25A	100.06	11.54	31I	128.15	7.26	37D	149.65	12.95			
09D	33.45	9.18	18J	66.95	14.17	26J	100.45	12.18	31H	128.65	11.59	37C	150.15	15.33			
09C	33.95	8.11	18I	67.45	17.48	26I	100.95	17.79	31G	129.15	15.12	37B	150.65	17.24			
09B	34.45	8.73	18H	67.95	16.46	26H	101.45	7.98	31F	129.65	16.32	37A	151.15	13.73			
09A	34.95	8.72	18G	68.45	5.16	26G	101.95	9.72	31E	130.15	15.09	38H	151.75	18.93			
10D	35.85	8.96	18F	68.95	9.88	26F	102.45	11.96	31D	130.65	12.30	38G	152.10	21.31			

Figure B.12. Soil Suction Profiles for Borehole 299-W23-19



Note: Dashed line is the equilibrium soil suction line. Drainage occurs only for values to left of the equilibrium line.

### B.3.3 SOIL WATER CHEMISTRY MEASUREMENTS

In addition to soil physical property measurements (Section B.3.2), an extensive water chemistry analysis has been completed for borehole 299-W23-19 samples collected between 10 and 62 m (32 and 205 ft) bgs. The primary means of measuring porewater composition was to add deionized water to soil samples to generate enough water for performing analyses.

By back-calculating for the dilution introduced by the added water, 'true' concentrations were derived. For a few samples porewater was directly separated from the same soil sample or one nearby and analyzed directly. By comparing the dilution-corrected water extract data with the porewater data in these few samples, an indication of the closeness of the water extract chemistry to original water chemistry was determined. In general, comparisons were not exact but concentration values were generally within a factor of two or better, agreement improved with increasing constituent concentration, and both sets of data showed similar concentrations versus soil depth correlations. Thus, the water extract method is an effective tool for evaluating tank fluid interactions with vadose zone soil.

Water extract pH and electrical conductivity measurements with depth are listed in Table B.8 and graphed in Figure B.13. Elevated pH values (greater than 8) are measured between 23 and approximately 32 m (75 and 105 ft) bgs with maximum values (8.5 to 9.7) occurring primarily in subunit H1 between 23 and 26 m (75 and 86 ft) bgs. Because pH values are expected to decrease as increasing interaction with soil and soil water occurs, the location of maximum pH values suggests the approximate initial depth of tank fluid interaction with the vadose zone at this location. Increases in electrical conductivity values compared to undisturbed soil water values are also an indicator of tank fluid occurrence in soil. Substantive increases are measured between 22 and 48 m (73 and 156 ft) bgs with maximum values (approximately 20,000 to 40,000  $\mu\text{S}/\text{cm}$ ) between 37 and 46 m (123 and 150 ft) bgs in the silt-rich subunit PPlz. Maximum electrical conductivity values are an indicator of location for mobile tank fluid constituents and maximum vertical penetration of tank fluids.

Water extract anion concentrations as a function of depth are listed in Table B.9 and graphed in Figure B.14. The primary indicator of tank fluid occurrence is elevated nitrate concentrations which are measured in borehole 299-W23-19 between 22 and 48 m (73 and 156 ft) bgs with maximum values between 38 and 46 m (125 and 150 ft) bgs. Elevated levels of chloride (between 22 and 62 m [73 and 205 ft] bgs) and sulfate (between 22 and 62 m [73 and 190 ft] bgs) are also observed. Chloride maximum concentrations (between 38 and 46 m [125 and 150 ft] bgs) track closely with the nitrate at the Plio-Pleistocene unit and above. However, an additional peak occurs in the Ringold Formation between 51 and 58 m (166 and 190 ft) bgs. The sulfate peak occurs between 22 and 38 m (73 and 125 ft) bgs, a maximum concentration depth interval that does not coincide with chloride and nitrate. A secondary sulfate peak range occurs in the Ringold Formation between 51 and 58 m (166 and 190 ft) bgs, coincident with the secondary chloride peak.

Elevated concentrations of these anions do not provide a straightforward indication of tank fluid occurrence. Elevated concentrations of chloride and sulfate extend well into the Ringold Formation (to groundwater in the case of chloride), unlike nitrate. This observation suggests other sources of chloride and sulfate (e.g., U pond water) which as late as 1986 elevated the water table up to 55 m (182 ft) bgs. In the Hanford formation and the Plio-Pleistocene unit, chloride and sulfate concentrations may come from the tank fluid or may result from some interaction between tank fluid nitrate and indigenous chloride and sulfate that preferentially dissolves these anions.

Table B.8. Borehole 299-W23-19 Water Extract pH and Electrical Conductivity Values (2 Sheets)

Sample ID	Depth (ft bgs)	Dilution Factor	1:1 pH	1:1 EC ( $\mu\text{S/cm}$ )	Pore EC ( $\mu\text{S/cm}$ )	Sample ID	Depth (ft bgs)	Dilution Factor	1:1 pH	1:1 EC ( $\mu\text{S/cm}$ )	Pore EC ( $\mu\text{S/cm}$ )
09E	32.95	9.85	7.94	166	1635	31A	132.15	6.36	6.95	5198	33066
15A	54.50	17.13	7.25	233	3992	32D	134.25	11.80	6.96	1658	19561
16A	57.45	15.82	7.27	226	3576	32A	135.80	5.79	6.8	4973	28781
17J	61.75	18.84	7.57	153	2883	33G	137.65	6.43	6.82	4860	31270
17G	63.25	11.13	7.52	186	2071	33B	140.15	6.45	6.81	4840	31238
17F	63.75	8.53	7.41	217	1851	35K	141.05	8.72	6.9	4593	40058
17F-dup	63.75	8.56	7.1	211	1807	35IH-aft	141.85	6.30	6.88	4265	26852
17DE-aft	64.75	10.70	7.48	206	2204	35F-aft	143.35	7.18	6.93	3264	23439
17C	65.25	9.03	7.32	160	1445	35C	144.85	6.15	6.95	2830	17409
18I	67.45	5.74	7.44	243	1394	35A	145.85	3.89	6.86	4315	16781
18E	69.45	10.19	7.62	226	2302	36D	147.45	10.20	6.98	1593	16254
18CB	70.45	6.56	7.91	431	2826	36B	148.45	4.35	7.02	2655	11562
18CB-dup	70.95	6.56	7.46	413	2709	37D	149.65	7.72	6.96	3792	29278
19H	73.25	27.70	8.61	603	16701	38G	152.10	4.32	7.21	979	4232
19G	73.75	7.49	8.33	1207	9038	38E	153.10	7.11	7.37	624	4439
19F	74.25	7.09	7.71	1248	8847	38E-dup	153.10	7.11	7.43	604	4297
19D	75.25	9.61	9.35	1039	9980	38A-aft	155.10	10.92	7.04	280	3057
20F	79.25	9.47	9.12	1094	10364	39D	155.35	9.49	7.39	768	7288
20F-dup	79.25	9.38	9.15	1025	9617	39C	155.85	12.83	6.83	352	4516

**Table B.8. Borehole 299-W23-19 Water Extract pH and Electrical Conductivity Values (2 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	1:1 pH	1:1 EC ( $\mu\text{S/cm}$ )	Pore EC ( $\mu\text{S/cm}$ )	Sample ID	Depth (ft bgs)	Dilution Factor	1:1 pH	1:1 EC ( $\mu\text{S/cm}$ )	Pore EC ( $\mu\text{S/cm}$ )
20E	79.75	7.79	9.28	1014	7902	39C-dup	155.85	12.82	6.97	342	4385
20D	80.25	6.00	8.5	1198	7184	40B	157.75	20.49	7.68	201	4119
21A	86.00	13.58	9.72	762	10350	40	158.65	10.96	7.65	297	3256
22D	88.10	6.07	7.79	1328	8056	17SK	159.75	11.92	7.7	281	3350
24A	95.00	10.82	7.91	1023	11065	18SKA	161	14.68	7.64	251	3684
25B	99.06	14.17	9.08	693	9822	18SKB	161.00	19.78	7.05	252	4984
25B-dup	99.06	15.85	8.74	595	9430	18SKC	166.50	34.13	7.26	148	5051
25A	100.06	11.40	7.83	1071	12212	19SKA	166.50	74.25	7.24	124	9207
26E	102.95	13.75	8.93	639	8786	19SKB	176.00	80.64	7.26	116	9354
26A	104.95	12.21	9.31	592	7226	41A	184.45	25.37	7.9	85	2157
27G	107.05	15.02	7.84	944	14182	19SKC	185	114.65	8.38	85	9745
29DC	116.35	13.67	7.33	1124	15363	20SKA	185	78.06	7.62	93	7260
30GF	123.85	11.13	7.02	1922	21390	20SKB	189.5	82.45	7.43	101	8327
30D	125.35	6.78	6.96	3902	26448	42	194.55	17.10	7.7	142	2428
30B	126.35	6.03	6.61	5730	34580	43B	204.50	16.25	7.52	273	4435
31G	129.15	6.62	6.71	6907	45724	43A	205.15	41.39	7.86	112	4636

EC = electrical conductivity.

Figure B.13. Calculated and Actual Porewater pH and Electrical Conductivity Values for Borehole 299-W23-19 Sediments

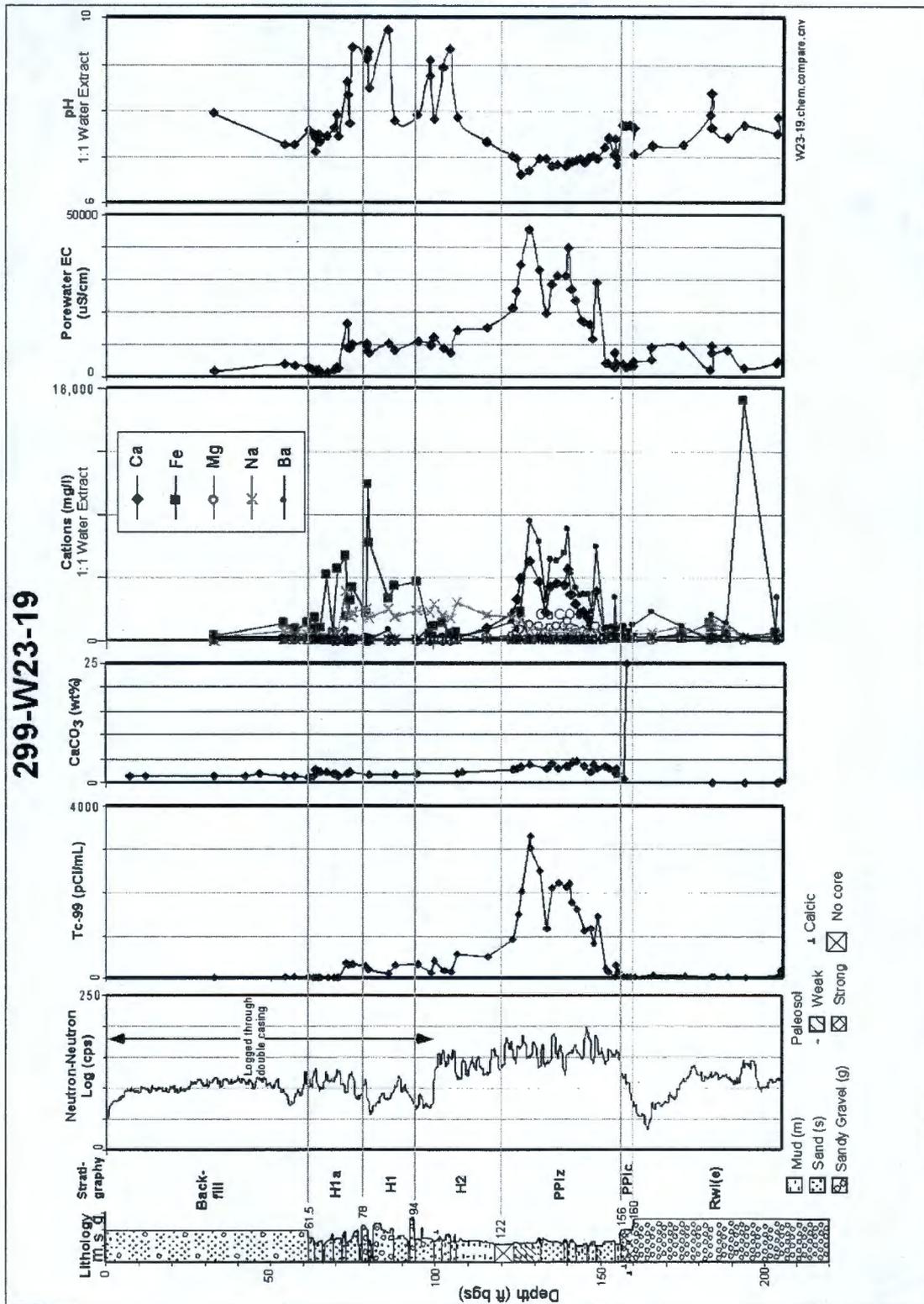


Table B.9. Anion Content of Water Extracts of Borehole 299-W23-19 Sediments (3 Sheets)

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	1:1 Extracts (mg/L)							Dilution Corrected Porewater (mg/L)						
				Nitrate	Fluoride	Nitrite	Chloride	Sulfate	Phosphate	Alk*	Nitrate	Nitrite	Chloride	Sulfate	Phosphate	Fluoride	Alk*
09E	32.95	9.85	1.00	1.00	0.64	<0.04	0.16	2.34	0.14	124	10	<0.39	1.6	23	1.4	6.3	1219
15A	54.50	17.13	1.00	0.76	0.77	<0.04	0.71	11.66	<0.1	96	13	<0.69	12.2	200	1.7	13.2	1647
16A	57.45	15.82	1.00	3.10	0.78	<0.04	0.91	18.33	0.10	305	49	<0.63	14.4	290	1.6	12.3	4830
17J	61.75	18.84	1.00	1.35	0.45	<0.04	0.37	7.14	<0.1	58	25	<0.75	7.0	135	1.9	8.5	1101
17G	63.25	11.13	1.00	5.25	0.60	<0.04	0.39	11.86	0.12	83	58	<0.45	4.3	132	1.3	6.7	921
17F	63.75	8.53	1.00	8.83	0.72	<0.04	0.60	15.77	0.19	78	75	<0.34	5.1	135	1.6	6.1	664
17FDUP	63.75	8.56	1.01	8.3	0.73	<0.08	0.5	13.67	0.18		71	<0.69	4.3	117	1.5	6.3	
17C	65.25	9.03	1.00	12.43	0.55	<0.04	0.62	17.31	0.24	65	112	<0.36	5.6	156	2.2	5.0	586
18I	67.45	5.74	1.00	19.93	0.57	<0.04	0.91	25.14	0.44	78	114	<0.23	5.2	144	2.5	3.3	447
18E	69.45	10.19	1.00	10.26	0.54	<0.04	0.66	12.66	0.30	91	105	<0.41	6.7	129	3.1	5.5	928
18C	70.45	6.56	1.00	28.02	1.02	<0.04	1.20	22.91	1.24	160	184	<0.26	7.9	150	8.1	6.7	1047
18B	70.95	6.56	1.00	27.69	1.02	<0.08	1.28	23.02	1.76		182	<0.52	8.4	151	11.5	6.7	
19H	73.25	27.70	1.00	136.83	2.43	<0.1	2.05	15.71	0.62		3790	<2.8	56.8	435	17.2	67.3	
19G	73.75	7.49	0.86	400.86	2.54	<0.1	6.73	42.45	0.74		3002	<0.7	50.4	318	5.5	19.0	
19F	74.25	7.09	1.00	431.09	2.64	<0.04	6.69	44.49	<1	131	3056	<0.28	47.4	315	<7.1	18.7	931
19D	75.25	9.61	1.18	321.44	1.52	<0.1	4.6	28.31	0.89		3088	<1.0	44.2	272	8.5	14.6	
20F	79.25	9.47	0.76	292.01	3.35	<0.1	3.87	31.17	1.19		2766	<0.9	36.7	295	11.3	31.7	
20FDUP	79.25	9.38	1.04	250.53	4.36	<0.1	3.43	25.87	1.3		2351	<0.9	32.2	243	12.2	40.9	
20E	79.75	7.79	1.00	275.95	3.78	<0.1	3.43	27.1	1.37		2150	<0.8	26.7	211	10.7	29.5	
20D	80.25	6.00	1.00	358.65	2.01	<0.04	4.63	35.21	3.16	175	2151	<0.24	27.8	211	18.9	12.1	1051
21A	86.00	13.58	0.61	73.51	3.83	<0.1	1.21	12.68	0.67		998	<1.4	16.4	172	9.1	52.0	
22D	88.10	6.07	1.00	446	2.62	<0.04	6.46	44.80	1.61	182	2716	<0.24	39.5	274	10.7	15.9	1105
24A	95.00	10.82	1.00	340.37	0.72	<0.04	4.11	37.24	1.45	215	3682	<0.43	44.5	403	15.7	7.8	2320
25B	99.06	14.17	0.81	183.64	1.71	<0.1	3.42	33.28	0.83		2603	<1.4	48.5	472	11.8	24.2	

Table B.9. Anion Content of Water Extracts of Borehole 299-W23-19 Sediments (3 Sheets)

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	1:1 Extracts (mg/L)							Dilution Corrected Porewater (mg/L)						
				Nitrate	Fluoride	Nitrite	Chloride	Sulfate	Phosphate	Alk*	Nitrate	Nitrite	Chloride	Sulfate	Phosphate	Fluoride	Alk*
25BDUP	99.06	15.85	0.97	141.66	1.83	<0.1	2.46	25.36	0.81		2245	<1.6	39.0	402	12.8	29.0	
25A	100.06	11.40	0.79	423.71	0.58	<0.1	6.94	61.74	<0.5		4831	<1.1	79.1	704	5.7	6.6	
26E	102.95	13.75	1.00	156.9	0.95	<0.1	3.16	34.49	1.28		2157	<1.4	43.4	474	17.6	13.1	
26A	104.95	12.21	1.00	75.31	1.06	<0.1	2.49	28.44	0.84		919	<1.2	30.4	347	10.3	12.9	
27G	107.05	15.02	1.00	342.38	<2	<0.04	4.71	39.20	1.07	611	5144	<0.60	70.8	589	16.1	<30	9174
29D	116.35	13.67	1.00	467.69	0.35	<0.04	5.79	45.67	ND	49	6392	<0.55	79.1	624	ND	4.8	676
30G	123.85	11.13	1.00	864.67	<0.4	0.72	9.55	83.98	1.72	84	9623	8.01	106.3	935	19.1	<4.5	936
30D	125.35	6.78	0.79	2179.7	0.82	<0.1	17.81	89.94	<5		14774	<0.7	120.7	610	<33.9	5.6	
30B	126.35	6.03	1.00	3168.8	<0.2	42.80	25.28	39.80	0.91	83	19123	258.29	152.6	240	<5.5	<1.2	502
30BDUP	126.35	6.03	1.00	3439.5	<0.2	31.17	26.88	43.8	3.49		20757	188.11	162.2	264	<21.1	<1.2	
31G	129.15	6.62	1.00	3932.5	<0.2	27.78	32.52	23.92	<1	66	26033	183.90	215.3	158	<6.6	<1.3	436
31A	132.15	6.36	1.00	3195.7	<0.5	<1	30.57	10.95	<5		20329	<6	194.5	70	<31.8	<3.2	
32D	134.25	11.80	0.84	811.76	1.16	<1	9.94	6.86	<5		9577	<12	117.3	81	<59.0	13.7	
32A	135.80	5.79	1.00	2775.7	<0.2	12.86	26.98	14.88	<1	38	16064	74.43	156.1	86	<5.8	<1.2	221
33G	137.65	6.43	1.00	2733.6	<0.2	9.34	26.41	10.33	<1	72	17588	60.09	169.9	66	<6.4	<1.3	462
33B	140.15	6.45	1.00	2738.1	<0.2	13.15	25.44	11.05	<1	34	17672	84.87	164.2	71	<6.5	<1.3	219
35K	141.05	8.72	1.00	2593.9	<0.2	8.51	23.87	8.49	<1	43	22623	74.22	208.2	74	<8.7	<1.7	376
35C	144.85	6.15	1.00	1552.5	<0.2	2.01	15.77	10.75	<1	134	9550	12.36	97.0	66	<6.2	<1.2	826
35A	145.85	3.89	1.00	2454.2	<0.2	4.16	26.28	12.40	8.12	41	9544	16.18	102.2	48	<31.6	<0.8	160
36D	147.45	10.20	1.00	761.89	0.75	<1	9.86	7.66	<5		7774	<10	100.6	78	<51.0	7.7	
36B	148.45	4.35	1.00	1385.4	<0.2	0.78	17.42	19.82	<1	39	6033	3.40	75.9	86	<4.4	<0.9	171
37D	149.65	7.72	1.00	2140	<0.2	2.32	21.31	11.87	<1	59	16524	17.91	164.5	92	<7.7	<1.5	452
38G	152.10	4.32	1.00	408.97	1.28	<1	11.33	17.88	<5		1768	<4	49.0	77	<21.6	5.5	
38E	153.10	7.11	1.00	241.57	<2	<0.04	7.39	17.71	0.22	60	1718	<0.28	52.6	126	<1.6	<14	425

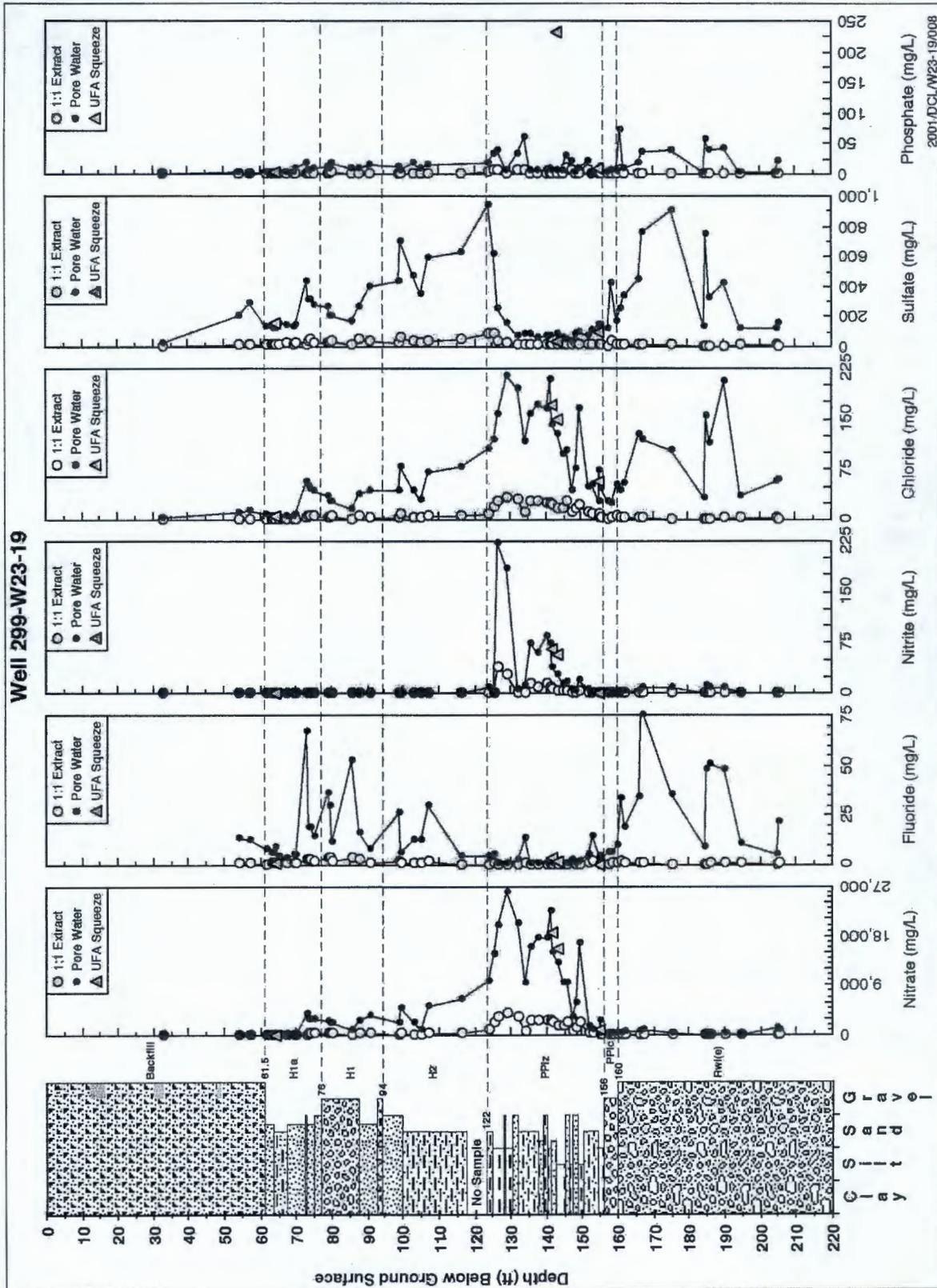
Table B.9. Anion Content of Water Extracts of Borehole 299-W23-19 Sediments (3 Sheets)

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	1:1 Extracts (mg/L)							Dilution Corrected Porewater (mg/L)						
				Nitrate	Fluoride	Nitrite	Chloride	Sulfate	Phosphate	Alk*	Nitrate	Nitrite	Chloride	Sulfate	Phosphate	Fluoride	Alk*
38E-DUP	153.10	7.11	1.00	216.81	<2	<0.04	6.91	14.34	0.18		1543	<0.28	49.2	102	<1.3	<14	
39D	155.35	9.49	0.82	292.81	0.31	<0.1	7.61	14.22	<0.5		2779	<0.9	72.2	135	<4.7	2.9	
39C	155.85	12.83	1.00	90.08	0.30	<0.04	3.81	11.03	<1	76	1156	<0.51	48.9	142	<12.8	3.85	971
39C-dup	155.85	12.82	1.00	83.59	0.30	<0.04	3.59	11.25	<1		1072	<0.51	46.0	144	<12.8	12.82	
40B	157.75	20.49	1.00	3.56	0.32	<0.04	1.34	5.98	<0.1		73	<0.82	27.5	123	<2.0	6.56	
40	158.65	10.96	1.38	24.93	0.56	<0.1	2.12	38.84	<0.5	74	273	<1.1	23.2	426	<5.5	6.1	815
17SK	159.75	11.92	1.00	32.24	0.84	<0.1	4.25	14.47	<0.5		384	<1.2	50.7	173	<6.0	10.0	
18SKA	161	14.68	1.01	23.02	2.3	<0.1	3.03	17.31	<5		338	<1.5	44.5	254	<73.4	33.8	
18SKB	161.00	19.78	1.04	28.29	<0.1	2.72	0.94	16.99	<0.5		560	54	18.6	336	<9.9	<2.0	
18SKC	166.50	34.13	1.01	17.19	<0.1	3.75	1	12.96	<0.5		587	128	34.1	442	<17.1	<3.4	
19SKA	166.50	74.25	1.00	11.36	1.01	<0.1	1.6	10.29	<0.5		843	<7.4	118.8	764	<37.1	75.0	
19SKB	176.00	80.64	1.00	5.65	0.44	<0.1	1.27	11.28	<0.5		456	<8.1	102.4	910	<40.3	35.5	
41A	184.45	25.37	1.00	6.53	0.37	<0.04	1.28	5.17	<0.1	440	166	<1.01	32.5	131	<2.5	9.4	11170
19SKC	185	114.65	1.01	3.87	0.42	<0.1	1.36	6.5	<0.5		444	<11.5	155.9	745	<57.3	48.2	
20SKA	185	78.06	1.00	0.78	0.65	<0.1	1.45	4.13	<0.5		61	<7.8	113.2	322	<39.0	50.7	
20SKB	189.5	82.45	0.94	3.13	0.58	<0.1	2.51	5.09	<0.5		258	<8.2	206.9	420	<41.2	47.8	
42	194.55	17.10	1.00	1.14	0.65	<0.04	2.00	7.38	<0.1	57	19	<0.68	34.2	126	<1.7	11.1	966
43B	204.50	16.25	1.00	76.79	0.36	<0.04	3.59	7.68	0.13	45	1248	<0.65	58.3	125	<2.1	5.85	736
43A	205.15	41.39	1.00	25.29	0.53	<0.1	1.47	3.68	<0.5		1047	<4.1	60.8	152	<20.7	21.9	

Note: Values in *italics* represent water extracts that were inadvertently run at a ratio of less than 1:1 and analytes reported may be biased high in relationship to the correct 1:1 extract samples. Values in **bold** represent water extracts that were inadvertently run at a ratio greater than 1:1 and analytes reported may be biased low in relationship to the correct 1:1 extract samples.

\*Alk = alkalinity as mg/L of CaCO<sub>3</sub>; alkalinity values in bold red type are anomalous. Auto-Titrator was acting up.  
ND = not determined; blank cells also represent analytes not determined/measured.

Figure B.14. Anions Calculated and Actual Porewaters for Borehole 299-W23-19 Sediments



Water extract cation concentrations as a function of depth are listed in Table B.10 and graphed in Figure B.15. Among the cations, elevated sodium concentrations are the primary tank SX-115 fluid indicator. Maximum values begin abruptly at 22 m (73 ft) bgs, remain elevated above 1000 mg/L until 38 m (126 ft) bgs, and gradually decrease. The lower edge of the sodium zone is blurred (approximately 43 to 46 m [143 to 150 ft] bgs). Calcium, magnesium, potassium, and natural strontium show elevated concentrations between 35 and 46 m (116 and 150 ft) bgs, a depth range slightly lower than the sodium range. The relative positioning of sodium concentration ranges versus that of the other cations supports the hypothesis that sodium preferentially replaces these cations in sorption sites as it migrates vertically and pushes them ahead to the leading edge of the plume.

A small secondary elevated sodium concentration depth interval occurs in the Ringold Formation between 51 and 58 m (166 and 190 ft) bgs, approximately the same location as the secondary elevated sulfate and chloride concentrations. Calcium, potassium, and iron are also slightly elevated, once again suggesting that residual constituents from fluids that created the high water table in the 1980s were left behind in the soil column after drainage.

The last group of constituents analyzed included radionuclides and trace metals. Of these only technetium-99 and chromium are clearly present in concentrations above background and are attributed to have originated in the tank SX-115 fluid. Water extract concentrations are listed in Table B.11, and technetium-99 distribution is shown in Figure B.16. The technetium-99 elevated concentration pattern closely mimics the nitrate concentration distribution where clearly elevated concentrations begin at 22 m (73 ft) bgs and reaches maximum concentrations of approximately 1,100 to 3,000 pCi/L between 38 and 46 m (125 and 150 ft) bgs. Another sharp drop occurs at 49 m (160 ft) bgs, at the contact between subunit PPlc and the Ringold Formation. Chromium concentration values increase above background beginning at 20 m (67 ft) bgs and reach maximum concentrations of 42,000 to 122,000  $\mu\text{g/L}$  between 22 and 38 m (73 and 125 ft) bgs. The occurrence of the maximum chromium range high in the soil column relative to technetium-99 indicates some retarding chemical mechanism has slowed chromium migration relative to technetium-99. Work completed by the S&T activity (Appendix D, Section D.4.1) indicates that iron(II)-rich minerals in the vadose zone soil reduce the oxidation state of a fraction of the chromium in solution from +6 to +3. In the +3 state, chromium is removed from solution by sorption or coprecipitation in iron(II)-rich minerals.

Trace constituents of other radionuclides are present in the soil column including cesium-137, uranium, and tritium. Cesium-137 occurs at concentrations of approximately 0.1 to 0.6 pCi/g between 20 and 23 m (67 and 74 ft) bgs and may be derived from the tank SX-115 leak. If so, the depth interval marks the approximate location of initial tank fluid occurrence at this location. Uranium occurs at background level and tritium, whose concentration levels are low and occur in the Plio-Pleistocene unit, is of uncertain origin.

### **B.3.4 CONTAMINANT CONCENTRATIONS**

Contaminant concentrations at borehole 299-W23-19 were not analyzed.

**Table B.10. Calculated Porewater Cation Composition from Water Extracts from Vadose Zone Sediments from Borehole 299-W23-19 (4 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Aluminum (µg/L)	Barium (µg/L)	Calcium (mg/L)	Iron (µg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Strontium (µg/L)	Sulfate (mg/L)	Manganese (µg/L)
09E	32.95	9.85	1.00	341	248	66	335	44	12	185	189	380	19	10
15A	54.50	17.13	1.00	327	153	134	1097	105	27	611	277	319	226	73
16A	57.45	15.82	1.00	51	197	143	680	79	30	432	253	186	266	38
17J	61.75	18.84	1.00	548	170	101	1093	60	21	359	237	297	163	41
17G	63.25	11.13	1.00	85	156	71	746	32	14	250	172	142	132	21
17F	63.75	8.53	1.00	211	85	65	1416	25	13	243	154	135	125	32
17F-dup	64.75	8.56	1.01	317	101	63	592	25	12	215	159	375	105	11
17DE-aft	64.75	10.70	0.96	164	161	72	308	27	14	316	198	123	126	12
17DE	64.75	5.05	1.00	<250	65	62	71	19	8	164	94	315	157	2
17C	65.25	9.03	1.00	<250	144	77	824	29	15	231	150	123	178	22
18I	67.45	5.74	1.00	2045	103	62	4160	19	12	163	103	154	146	64
18E	69.45	10.19	1.00	182	81	36	526	26	6	373	168	205	126	16
18CB	70.70	6.56	1.00	1882	72	8	4559	11	1	537	119	206	134	84
18CB-dup	70.70	6.56	1.00	2896	90	10	7919	14	2	518	124	54	147	140
19H	73.25	27.70	1.00	3057	692	25	5361	39	3	3081	372	192	458	131
19G	73.75	7.49	0.86	<250	112	18	1477	23	2	1632	112	130	311	54
19E	74.75	7.09	1.00	442	92	17	2543	21	2	1542	113	36	321	96
19D	75.25	9.61	1.18	1554	154	12	3340	22	1	1825	148	98	273	67
20F	79.25	9.47	0.76	529	332	10	1694	25	1	1977	148	86	301	39
20F-dup	79.25	9.38	1.04	1267	910	12	5357	23	1	1841	156	122	265	126
20E	79.75	7.79	1.00	1166	156	9	9829	19	1	1472	125	74	214	146
20D	80.25	6.00	1.00	1210	78	6	6094	15	1	1365	97	2998	219	115
21A	86.00	13.58	0.61	2555	693	10	2660	24	2	2046	254	106	190	76
22D	88.10	6.07	1.00	490	103	7	3413	18	1	1476	63	3033	261	85

**Table B.10. Calculated Porewater Cation Composition from Water Extracts from Vadose Zone Sediments from Borehole 299-W23-19 (4 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Aluminum (µg/L)	Barium (µg/L)	Calcium (mg/L)	Iron (µg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Strontium (µg/L)	Sulfate (mg/L)	Manganese (µg/L)
24A	95.00	10.82	1.00	2038	141	17	3773	28	3	1921	103	140	378	61
25B	99.06	14.17	0.81	747	935	29	365	35	4	1781	148	210	468	11
25B-dup	99.06	15.85	0.97	888	206	19	396	31	3	1612	173	128	396	8
25A	100.06	11.40	0.79	811	365	103	899	62	16	2351	134	651	697	13
26E	102.95	13.75	1.00	<1000	289	16	1142	26	2	1589	127	129	454	39
26A	104.95	12.21	1.00	890	281	9	448	18	1	1360	111	74	322	18
27G	107.05	15.02	1.00	<1000	210	162	480	57	32	2457	181	509	570	12
29D	116.35	13.67	1.00	374	670	844	107	128	158	1619	191	4116	511	52
30G	123.85	11.13	1.00	<500	1157	1670	23	170	338	1481	122	8332	798	428
30D	125.35	6.78	0.79	<500	705	2653	30	142	518	1111	74	12930	587	296
30B	126.35	6.03	1.00	<500	1575	3906	1773	112	749	1289	67	20317	249	818
30B-dup	126.35	6.03	1.00	<500	1730	4349	48	122	835	1414	71	23461	268	832
31G-1st	129.15	6.62	1.00	<500	7202	5618	<50	129	1150	818	71	35522	93	883
31G	129.15	5.15	1.00	<500	7549	5000	12	142	999	680	51	30836	82	728
31A	132.15	6.36	1.00	<500	6285	3740	63	147	892	655	71	23715	71	335
31A	132.15	6.35	1.00	<500	5493	3522	28	132	819	589	66	22157	55	301
32D	134.25	11.80	0.84	<500	2560	1788	88	128	472	513	127	9996	77	70
32A	135.80	5.79	1.00	<500	5168	3374	1	100	823	534	60	19626	69	250
33G	137.65	6.43	1.00	<500	5044	3578	<50	104	893	523	64	20064	65	306
33B	140.15	6.45	1.00	<500	5486	3498	6	111	876	528	65	21405	75	253
35K	"141.05"	8.72	1.00	<500	7003	4552	35	139	1191	689	88	26880	84	450
35IH-aft	141.85	6.30	1.00	<500	4275	2885	151	89	817	533	64	17040	73	30
35F-aft	143.35	7.18	1.04	<500	3275	2361	151	82	723	478	74	13667	87	28
35C	144.85	6.15	1.00	<500	2805	1743	18	81	521	391	55	9738	73	134

**Table B.10. Calculated Porewater Cation Composition from Water Extracts from Vadose Zone Sediments from Borehole 299-W23-19 (4 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Aluminum (µg/L)	Barium (µg/L)	Calcium (mg/L)	Iron (µg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Strontium (µg/L)	Sulfate (mg/L)	Manganese (µg/L)
35A	145.85	3.89	1.00	<500	2921	1811	16	57	554	412	43	10833	55	9
36D	147.45	10.20	1.00	<500	2959	1388	81	106	476	430	85	8160	76	29
36B	148.45	4.35	1.00	<500	1859	1047	30	56	377	341	47	6238	71	6
37D	149.65	7.72	1.00	<500	5891	3086	<50	150	873	554	74	17468	95	2496
38G	152.10	4.32	1.00	<500	661	282	25	36	122	192	48	1753	80	2
38G	152.10	4.32	1.00	<500	709	300	55	37	129	175	47	1845	76	3
38E	153.10	7.11	1.00	93	783	268	138	49	124	257	70	1472	100	8
38E-dup	153.10	7.11	1.00	162	665	252	25	53	117	237	72	1454	95	27
38A-aft	155.10	10.92	1.00	<500	448	152	680	50	74	242	162	513	151	30
39D	155.35	9.49	0.82	<500	2743	526	97	91	226	352	111	3365	179	66
39C	155.85	12.83	1.00	151	706	250	285	75	122	318	222	1231	139	9
39C-dup	155.85	12.82	1.00	<500	554	237	<50	66	115	309	206	1088	131	12
40B	157.75	20.49	1.00	156	451	218	746	79	104	328	323	1210	126	30
40	158.65	10.96	1.38	<500	932	210	65	66	92	226	189	1268	471	6
17SK	159.75	11.92	1.00	<500	596	170	89	65	67	273	195	1083	188	45
18SKA	161	14.68	1.01	<500	822	180	46	74	66	317	222	1088	267	45
18SKB	161.00	19.78	1.04	<500	1009	235	170	97	90	392	278	1371	368	62
18SKC	166.50	34.13	1.01	<500	1843	157	222	118	42	483	239	1018	480	22
19SKA	166.50	74.25	1.00	<500	1336	343	379	209	62	857	626	2036	821	29
19SKB	176.00	80.64	1.00	<500	887	372	419	223	56	904	814	1870	878	79
41A	184.45	25.37	1.00	297	127	76	1091	55	24	213	274	845	128	37
19SKC	185	114.65	1.01	<500	1605	315	757	235	87	965	951	1873	796	83
20SKA	185	78.06	1.00	<500	1952	294	1226	211	74	776	606	1558	342	310
20SKB	189.5	82.45	0.94	<500	1154	308	618	223	83	877	700	1772	501	379

**Table B.10. Calculated Porewater Cation Composition from Water Extracts from Vadose Zone Sediments from Borehole 299-W23-19 (4 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Aluminum (µg/L)	Barium (µg/L)	Calcium (mg/L)	Iron (µg/L)	Potassium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Silicon (mg/L)	Strontium (µg/L)	Sulfate (mg/L)	Manganese (µg/L)
42	194.55	17.10	1.00	15095	257	109	15152	61	39	250	245	990	144	394
43B	204.50	16.25	1.00	421	487	280	487	72	91	267	156	1268	120	123
43A	205.15	41.39	1.00	<500	2691	173	435	101	30	411	421	1064	214	28

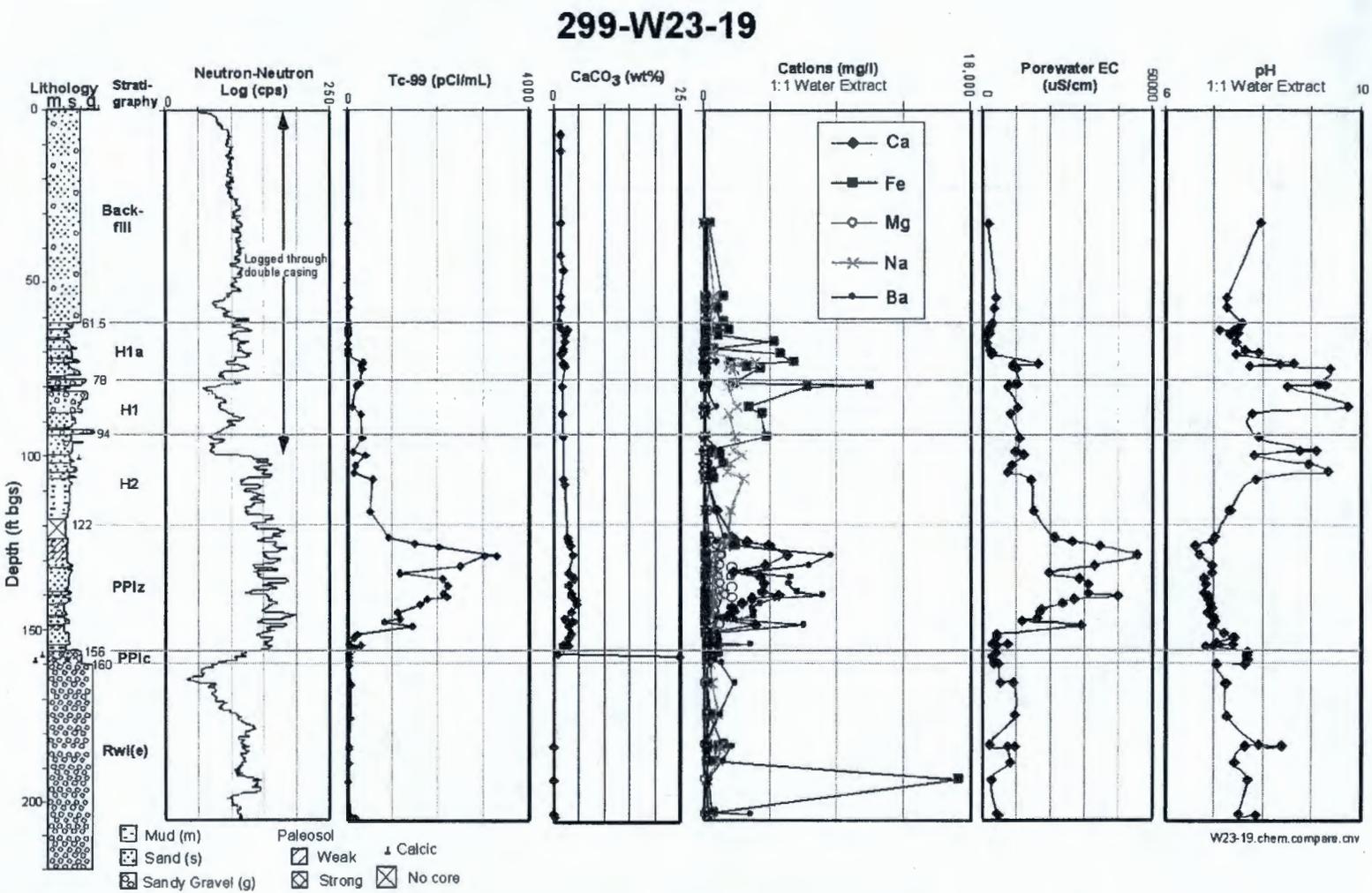
Notes: Extracts with incorrect water to sediment ratios are in bold. Note that some analytes are reported as µg/L and others mg/L.

aft = water extract AFTER Ultracentrifugation to remove actual porewater.

dup = a duplicate water extract on a separate aliquot of sediment.

SK# = sediment from air rotary sock not from core barrel.

Figure B.15. Cations Calculated and Actual Porewaters for Borehole 299-W23-19 Sediments



**Table B.11. Calculated Porewater Trace Metal Composition for Water  
Extracts of Sediments from Borehole 299-W23-19 (3 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Technetium-99 (pCi/mL)	U	Cr	As	Se	Mo	Ag	Cd	Pb
					(µg/L)							
09E	32.95	9.85	1.00	<8	11.7	<25	244	<25	87	<1	<1.0	7.4
15A	54.50	17.13	1.00	<15	19.4	<9	131	<43	149	<4	<4.3	<286
16A	57.45	15.82	1.00	<13	15.7	<8	162	<40	191	<4	<4.0	39.6
17J	61.75	18.84	1.00	<16	20.2	9.6	248	<47	93	<5	<4.7	244.8
17G	63.25	11.13	1.00	<9	14.2	<6	213	<28	62	<3	<2.8	<28
17F	63.75	8.53	1.00	<7	12.9	12.2	185	<21	45	<2	<2.1	<21
17F-dup	64.75	8.56	1.01	<7	13.2	<4	187	<21	44	<2	<2.1	<21
17DE	64.75	5.05	1.00	<2	5.5	8.1	103	6.3	60	<1	<0.2	0.8
17DE-aft	64.75	10.70	0.96	<9	12.4	5.3	327	<27	91	<3	<2.7	<26.75
17C	65.25	9.03	1.00	<8	9.5	<4.5	185	<23	115	<2	<36.1	<23
18I	67.45	5.74	1.00	<5	5.6	96	135	<14	49	<1	<1.4	19.7
18E	69.45	10.19	1.00	<9	9.0	308	190	<25	147	<1	<1.0	6.9
18C	70.45	6.56	1.00	<6	15.6	3224	273	<16	152	0.9	<0.7	6.3
18B	70.95	6.56	1.00	<6	15.6	3343	268	<16	154	1.0	3.9	8.4
19H	73.25	27.70	1.00	357.0	55.1	43262	1175	34	1352	7.5	2.2	15.2
19G	73.75	7.49	0.86	312.4	23.1	37442	681	34	1179	7.1	1.8	12.1
19E	74.75	7.09	1.00	333.9	23.6	48547	617	22	1028	6.1	1.0	8.1
19D	75.25	9.61	1.18	317.7	32.7	30391	2266	26	656	3.9	1.4	7.2
20F	79.25	9.47	0.76	284.4	45.4	35668	2630	26	1412	4.0	2.0	7.1
20F-dup	79.25	9.38	1.04	245.8	41.2	29695	2345	18	1090	3.4	1.6	16.6
20E	79.75	7.79	1.00	198.2	20.7	21235	3463	22	667	4.1	1.4	34.8
20D	80.25	6.00	1.00	192.4	15.6	19834	2433	20	523	1.5	1.5	15.0
21A	86.00	13.58	0.61	94.4	62.3	5422	2229	20	310	1.0	0.8	4.1
22D	88.10	6.07	1.00	288.9	51.6	39232	616	17	731	3.7	0.8	10.0
24A	95.00	10.82	1.00	330.9	26.0	40792	1063	24	3850	4.4	2.7	17.0
25B	99.06	14.17	0.81	120.2	19.7	27723	868	27	164	0.4	0.9	6.2
25B-dup	99.06	15.85	0.97	122.3	20.7	28227	1099	18	144	0.5	0.6	2.3
25A	100.06	11.40	0.79	394.5	13.1	85566	466	45	273	2.3	0.8	9.6
26E	102.95	13.75	1.00	177.2	36.3	35900	1146	18	3495	1.0	4.3	9.1
26A	104.95	12.21	1.00	155.3	33.2	16064	801	18	3288	0.0	3.7	3.9
27G	107.05	15.02	1.00	545.7	14.7	122342	291	38	1875	3.8	3.8	37.6

**Table B.11. Calculated Porewater Trace Metal Composition for Water  
Extracts of Sediments from Borehole 299-W23-19 (3 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Technetium-99 (pCi/mL)	U	Cr	As	Se	Mo	Ag	Cd	Pb
					(µg/L)							
29D	116.35	13.67	1.00	506.2	14.1	93333	70	50	137	3.4	3.4	34.2
30G	123.85	11.13	1.00	919.4	23.8	81170	33	73	332	0.6	1.3	2.5
30D	125.35	6.78	0.79	1504.7	6.6	42511	34	123	129	2.0	0.9	2.2
30B	126.35	6.03	1.00	2034.1	6.5	1788	7.1	139	108	4.0	1.5	28.2
30B-dup	126.35	6.03	1.00	2344.4	7.1	2584	6.5	144	101	4.2	1.5	15.1
31G	129.15	6.62	1.00	3291.0	9.1	18	4.6	102	81	2.0	1.1	4.1
31G	129.15	5.15	1.00	3033.6	3.3	31	20	73	57	1.1	0.7	1.9
31A	132.15	6.36	1.00	2498.7	4.0	0.01	15	45	50	1.4	0.8	1.1
31A	132.15	6.35	1.00	2457.2	4.2	6.4	15	43	49	1.3	0.7	3.4
32D	134.25	11.80	0.84	1169.5	6.7	4.7	33	40	134	0.0	0.5	2.0
32A	135.80	5.79	1.00	2109.7	8.2	<14	2.9	68	67	1.9	0.7	<3
33G	137.65	6.43	1.00	2235.4	8.2	<16	<3	78	71	1.6	1.0	<3
33B	140.15	6.45	1.00	2117.2	10.3	<16	<3	79	104	2.3	0.9	<3
35K	"141.05"	8.72	1.00	2204.1	18.5	<22	5.0	84	164	1.4	1.2	<4
35IH-aft	141.85	6.30	1.00	1772.9	9.4	6.6	5.4	72	91	1.6	<1.6	<16
35F-aft	143.35	7.18	1.04	1613.3	10.5	5.9	6.5	49	100	<2	<1.8	<18
35C	144.85	6.15	1.00	1138.1	7.0	<15	6.5	28	121	<1	<0.6	<3
35A	145.85	3.89	1.00	1115.8	6.7	3.7	4.1	29	48	<1	<1.0	<10
36D	147.45	10.20	1.00	1170.7	7.4	3.6	18	23	141	<1	0.6	3.4
36B	148.45	4.35	1.00	831.2	8.4	6.5	5.8	22	74	<1	<1.1	<11
37D	149.65	7.72	1.00	1438.3	25.3	<19	4.0	50	208	<1	<2.1	<4
38G	152.10	4.32	1.00	237.3	7.6	4.3	19	18	83	<0	0.2	0.8
38G	152.10	4.32	1.00	249.6	7.7	3.8	20	18	88	<0	0.2	0.6
38E	153.10	7.11	1.00	152.8	12.2	5.2	43	24	147	<2	<1.8	<18
38E-dup	153.10	7.11	1.00	142.8	12.0	4.4	44	20	156	<2	<1.8	<18
38A-aft	155.10	10.92	1.00	37.3	20.1	<5	391	<27	157	<3	<2.7	<27
39D	155.35	9.49	0.82	293.2	36.1	9.9	28	21	309	<1	0.8	12
39C	155.85	12.83	1.00	138.6	36.1	<32	510	<32	160	<1	<1.3	<6
39c-dup	155.85	12.82	1.00	133.0	42.5	<32	483	<32	165	<1	<1.3	<6
40B	157.75	20.49	1.00	23.3	99.1	10.4	448	<51	220	<5	<5.1	51.2
40	158.65	10.96	1.38	29.4	217.4	11.2	194	32	445	<1	0.9	2.9

**Table B.11. Calculated Porewater Trace Metal Composition for Water  
Extracts of Sediments from Borehole 299-W23-19 (3 Sheets)**

Sample ID	Depth (ft bgs)	Dilution Factor	Water:Soil Ratio	Technetium-99 (pCi/mL)	U	Cr	As	Se	Mo	Ag	Cd	Pb
					(µg/L)							
17SK	159.75	11.92	1.00	30.7	25.3	64.6	276	30	886	<1	1.3	1.4
18SKA	161	14.68	1.01	23.6	20.0	42.9	332	27	1276	<1	2.1	8.4
18SKB	161.00	19.78	1.04	52.3	28.7	83.4	388	34	1417	<2	2.5	2.4
18SKC	166.50	34.13	1.01	53.8	3.5	41.8	12	24	1157	<3	2.1	6.3
19SKA	166.50	74.25	1.00	68.0	8.9	44.5	40	52	1547	<7	3.9	9.4
19SKB	176.00	80.64	1.00	45.1	11.6	19.0	115	54	1524	<8	4.0	26.1
41A	184.45	25.37	1.00	13.1	9.5	14.1	94	<63	384	<6	<6.3	<63
19SKC	185	114.65	1.01	31.1	12.6	<115	145	83	2368	<11	4.6	8.7
20SKA	185	78.06	1.00	14.6	19.8	0.0	191	47	1212	<8	4.2	33.7
20SKB	189.5	82.45	0.94	25.2	12.2	12.9	205	89	1887	<8	4.0	13.9
42	194.55	17.10	1.00	5.6	34.2	9.2	50	42	279	<4	<4.3	<43
43B	204.50	16.25	1.00	51.1	25.0	<8	23	<41	247	<4	<4.1	47.4
43A	205.15	41.39	1.00	176.2	9.5	23.7	217	25	576	0.2	2.2	6.9