

**FIELD INVESTIGATION  
REPORT FOR WASTE  
MANAGEMENT AREA B-BX-BY  
VOLUME 1, MAIN TEXT AND APPENDICES A - C**

**December 13, 2002**

**Prepared for  
CH2M HILL Hanford Group, Inc.  
Richland, Washington**

**Prepared by  
Jacobs Engineering Group, Inc.  
Richland, Washington**

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AREA B-BX-BY  
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Author  
Anthony J. Knepp

Prepared for  
CH2M HILL Hanford Group, Inc.  
Richland, Washington

Prepared by  
Jacobs Engineering Group, Inc.  
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## EXECUTIVE SUMMARY

This *Field Investigation Report for Waste Management Area B-BX-BY* presents the most recent (December 2002) comprehensive assessment of existing and new information to clarify the current understanding of the nature and extent of past releases in the B, BX, and BY tank farms that comprise waste management area (WMA) B-BX-BY. This report evaluates the potential for 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 leaks from B, BX, and BY farm single-shell tanks. Computer simulation results of future groundwater impacts from such past releases, as well as a risk assessment, are presented. 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 tasks; the Groundwater Protection Program; and national laboratories and universities funded from DOE Headquarters as part of the Environmental Management Sciences Program. This report follows the *Field Investigation Report for Waste Management Area S-SX*.<sup>1</sup>

This *Field Investigation Report for Waste Management Area B-BX-BY* was produced using the RCRA Corrective Action Process, as documented in *Phase I RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas*.<sup>2</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>3</sup> (HFFACO) 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., Groundwater Protection Program [formerly the Groundwater/Vadose Zone Integration Project] and Single-Shell Tank Retrieval).

Major conclusions are as follows:

- The future impacts from wastes currently in the vadose zone that resulted from past releases from the B, BX, and BY tank farms are not expected to exceed drinking water standards at or beyond the WMA boundary as long as high volume liquid discharges to the vadose zone are eliminated. Note, however, that a peak concentration of approximately 12,000 pCi/L for technetium-99 was measured in groundwater well 299-E33-41 directly east of BX tank farm in 1997. This contamination is most likely due to releases from the BX tank farm.

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<sup>1</sup> Knepp, A. J., *Field Investigation Report for Waste Management Area S-SX*, RPP-7884, CH2M HILL Hanford Group, Inc., Richland, Washington.

<sup>2</sup> DOE-RL, 2000, *Phase I 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>3</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.

- Vadose zone and groundwater contamination levels were lower than generally anticipated prior to the initiation of the field investigation<sup>4</sup>.
- Estimations of technetium-99 distribution during Hanford Site reprocessing, storage, and disposal and the residue left in the vadose zone have been improved and past assumptions corrected. However, the amount of technetium-99 that was initially discharged to the vadose zone and that might have already reached groundwater is still uncertain.
- Complex hydraulic processes play a major role in contaminant movement in WMA B-BX-BY. Strong evidence of extensive vadose zone lateral migration in the WMA exists. Lateral migration may have extended into WMA B-BX-BY from adjacent past practice discharge sites. Ponding of runoff from natural precipitation in the WMA may have added significant amounts of spatially confined infiltration. Changes in groundwater flow direction have caused plumes from other sources to be found under the WMA.
- Borehole soil characterization performed by the Tank Farm Vadose Zone Project and other laboratory measurements by the Groundwater Protection Program's Science and Technology Project have identified precipitated uranium phases, and strontium-90 phases and sorption sites. These data indicate limited future mobility unless abnormally high amounts of infiltration occur. Neither uranium nor strontium-90 is expected to significantly impact groundwater in the current moisture and geochemical environment. However, the precipitated uranium phases may function as a long-term source to percolating waters if artificial recharge is not controlled.
- Interim measures (e.g., capping boreholes, cutting off inactive water lines, and building surface run-on barriers and diversions) have been implemented in the WMA. These are expected to mitigate future contamination risks.

Recommendations in this report address interim measures, accelerated corrective measures, future tank operations, collection of additional WMA B-BX-BY data and information, and lessons learned. Key recommendations are the following:

- Installation of interim surface barriers is not recommended. Because of the location of key mobile contaminants near the water table, an interim surface barrier would not result in measurable reductions of mobile contaminants reaching the unconfined aquifer.
- Soil and ancillary equipment removal should be evaluated as part of the corrective measures study process. Surface contamination at depths of less than 4.6 m (15 ft) below ground surface (bgs) is widespread. Soil removal could not be conducted without considering removal of the ancillary piping systems that connect the tanks throughout the tank farms. Removal of these pipes would have to be conducted in unison with soil removal activities.

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<sup>4</sup> Jones, T. E., B. C. Simpson, M. I. Wood, and R. A. Corbin, 2001, *Preliminary Inventory Estimates for Single-Shell Tank Leaks in B, BX, and BY Tank Farms*, RPP-7389, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

- The numerical model of the vadose zone underneath BX tank farm (including its supporting data) should be used in future modeling, particularly for simulating potential leaks from tank waste retrieval and releases following tank closure.
- The study of uranium mobility to refine solid phase solubility and transport conditions should be continued and reported in the next field investigation report (i.e., the field investigation report for WMAs T and TX-TY).

This field investigation report includes the following sections that are summarized below:

- Section 1.0. Introduction
- Section 2.0. Investigative Basis and Approach
- Section 3.0. Investigative Results
- Section 4.0. Summary and Conclusions of the Impact (Risk) Evaluations
- Section 5.0. Interim Measures
- Section 6.0. Conclusions
- Section 7.0. Recommendations.

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

Twelve 23-m (75-ft) diameter underground tanks with a capacity of 2,006,050 L (530,000 gal) in the B tank farm and 12 similar tanks in the BX tank farm have stored hazardous, high-level radioactive mixed wastes for several decades. Twelve tanks in the BY tank farm serve the same purpose and have the same diameter, but have a larger capacity (i.e., 2,869,030 L [758,000 gal]). In addition, there are four 6-m (20-ft) diameter tanks with a capacity of 208,175 L (55,000 gal) in the B tank farm. These tanks, along with the associated infrastructure for WMA B-BX-BY, are located in the 200 East Area of the Hanford Site (Figure ES.1). This WMA was placed in RCRA groundwater monitoring assessment because of elevated specific conductance of groundwater from downgradient monitoring wells.<sup>5</sup> Based on the groundwater impacts at WMA B-BX-BY and similar determinations for other single-shell tank 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 waste releases.

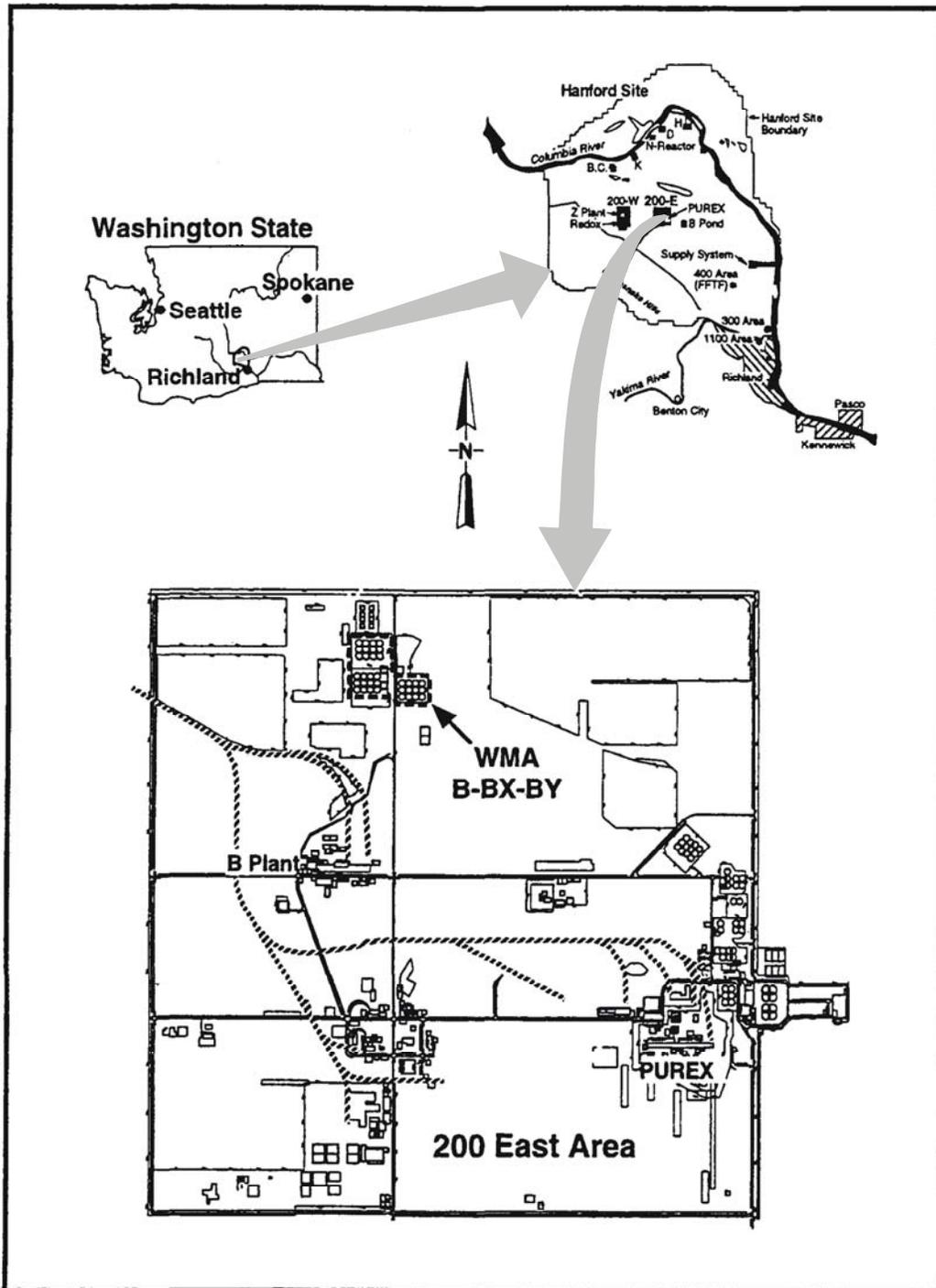
The framework for the investigative approach for the RCRA Corrective Action Program was developed through negotiations with the Washington State Department of Ecology and DOE and was documented in *Hanford Federal Facility Agreement and Consent Order*<sup>3</sup> Change Package M-45-98-03. The RCRA facility investigation/corrective measures study work plan<sup>2</sup> encompasses the aspects of work common to all WMAs and establishes the regulatory and programmatic framework for the overall RCRA Corrective Action Program.

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>2</sup>. Key to the implementation plan approach is first understanding what efforts would be most appropriate for a field

<sup>5</sup> Caggiano, J., 1996, *Groundwater Water Quality Assessment Monitoring Plan for Single-Shell Tank Waste Management Area B-BX-BY*, WHC-SD-EN-AP-002, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

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.

**Figure ES.1. Waste Management Area B-BX-BY Location Map**



The effort for WMA B-BX-BY 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>6</sup> and in *Subsurface Conditions Description for B-BX-BY Waste Management Area*.<sup>7</sup> This information was used in a set of data quality objectives processes to determine data gaps. Data gaps were filled by field programs documented in *Site-Specific SST Phase 1 RFI/CMS Work Plan Addendum for WMA B-BX-BY*.<sup>8</sup> DOE and the Washington State Department of Ecology approved this work plan addendum. Other work, particularly that of the 200 Area Remediation Project, the DOE national laboratories, and universities funded by DOE Headquarters, is in addition to and complements the work presented in the work plan addendum.

### Section 3.0, Investigative Results

New data were collected as part of the total WMA B-BX-BY characterization effort. This discussion is divided into three main sections:

- Field activities, which involve the collection of soil samples and geophysical measurements
- Laboratory analyses of those soil samples, including evaluations by the Groundwater Protection Program's Science and Technology Project
- Data evaluations of these laboratory measurements and analyses.

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

- Installation of a new vertical borehole (299-E33-45) east of tank BX-102 through a known uranium plume
- Installation of a new vertical borehole (299-E33-46) northeast of tank B-110 through a suspected strontium-90 plume
- Collection of samples from boreholes installed by the 200 Area Remediation Project in trench 216-B-38 (west of BX tank farm) and from 216-7B-7A cribs (north of B tank farm)
- Collection of supplemental vadose zone characterization data from the installation of a RCRA groundwater monitoring well (299-E33-338) at the southeast corner of B farm
- Vadose zone flow and transport field experiments at the 299-E24-111 Experimental Test Well (Sisson and Lu) Site, about a mile southeast of the WMA.

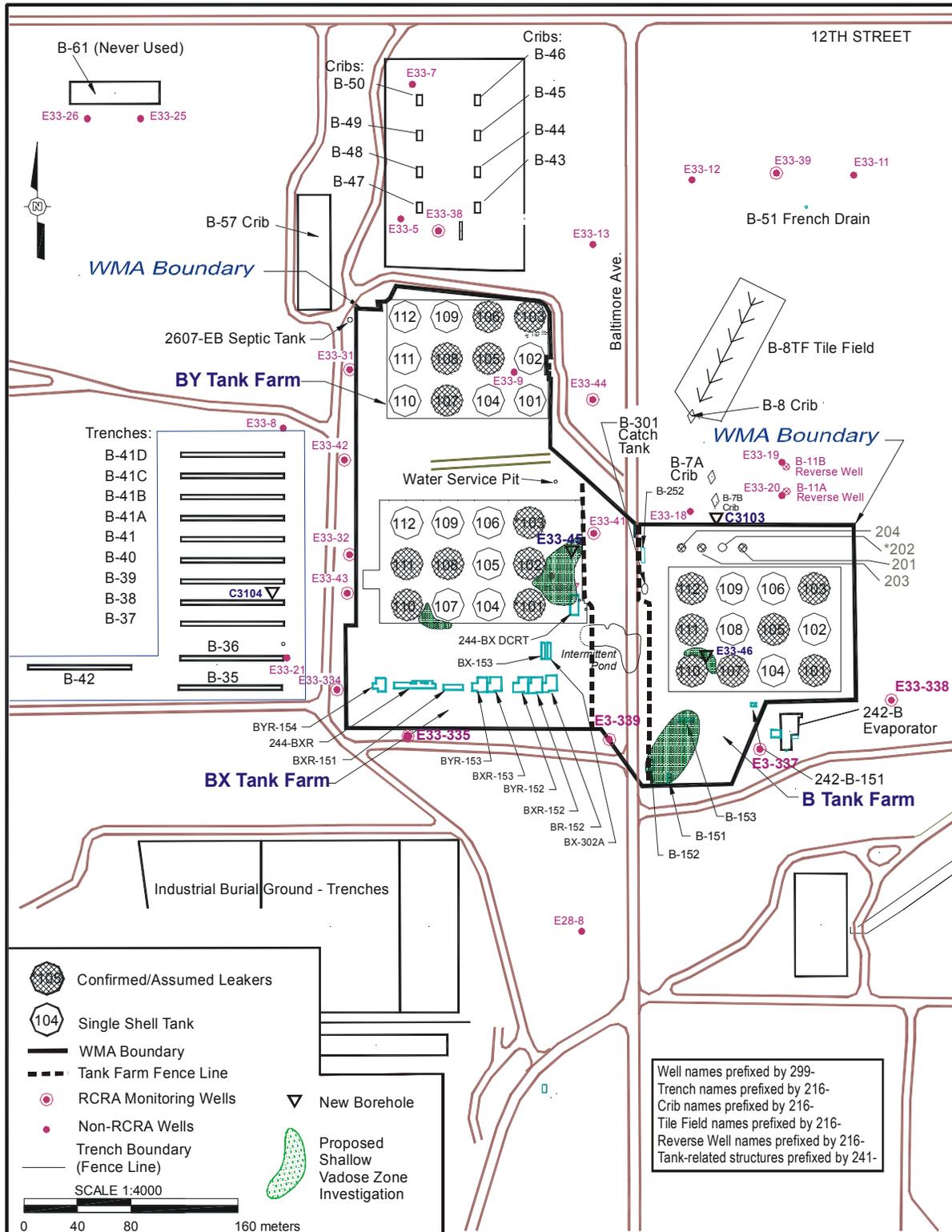
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<sup>6</sup> Jones, T. E., R. Khaleel, D. A. Myers, J. W. Shade, and M. I. Wood, 1998, *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination*, HNF-2603, Rev. 0, Lockheed Martin Hanford Corporation, Richland, Washington.

<sup>7</sup> Wood M. I, T. E. Jones, R. Schalla, B. N. Bjornstad, and S. M. Narbutovskih, 2000, *Subsurface Conditions Description for B-BX-BY Waste Management Area*, HNF-5507, Rev. 0, Fluor Hanford, Inc., 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 B-BX-BY*, RPP-6072, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

**Figure ES.2. Waste Management Area B-BX-BY, Location Map of Characterization Activities, Surrounding Facilities, and Wells**



Note: All wells are preceded by 299-.

Note: The intermittent pond between the B and BX tank farms has been addressed by interim measures.

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.

Typical RCRA Corrective Action Program laboratory analyses included the measurement of important properties (such as moisture content, specific conductivity, and elemental and isotopic concentrations). To examine mobility, 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 investigated included technetium-99 and uranium-238 for borehole 299-E33-45 near tank BX-102 and strontium-90 for borehole 299-E33-46 near tank B-110.

The major conclusions based on the field characterization activities included the following:

- At the position of borehole 299-E33-45 (about 30 m [100 ft] east of tank BX-102), technetium-99 was found from 36 to 52 m (120 to 170 ft) bgs with porewater extract values up to 546,000 pCi/L. Uranium peaked higher in the formation at approximately 40 m (130 ft), with a total range extending from 21 to 52 m (70 to 170 ft) bgs. The peak soil concentration for uranium was 1.65 mg/g. Mobile contaminants (e.g., nitrates and cations) have a similar spatial profile to technetium-99, with retarded contaminants (e.g., most metals) having a distribution similar to uranium.
- At borehole 299-E33-46 (near tank B-110), strontium-90 was found down to 26 m (85 ft) bgs with strontium-90 values up to 11,250 pCi/g of sediment. Other tank wastes contaminants (e.g., nitrate) were found down to 69 m (200 ft) bgs. The strontium-90 was immobile under the current ionic regime in the porewater.
- The Fluor Hanford 200 Area Remediation Program investigated two types of past practice discharge sites near WMA B-BX-BY including 216-B-38 which is a specific retention, low-volume discharge trench and 216-B-7A which is a high-volume discharge crib. The CH2M HILL Hanford Group Inc. Tank Farm Vadose Zone Project obtained supplementary findings by analyzing additional samples (particularly those deeper in the profile). These sites showed relatively minimal contamination levels in the deep vadose zone.
- The Hanford Groundwater Protection Program has extensively monitored the groundwater in and around WMA B-BX-BY<sup>9</sup>. High levels of contamination are known to exist in the area. For example, technetium-99 values of 12,000 pCi/L were measured in fiscal year 2001 under the BY cribs, just north of the BY tank farm. The groundwater sampled in this effort is in the southern part of the region where contamination is much lower. The levels found in the boreholes near tanks BX-102 and B-110 were fairly similar to each other but less than the values reported in the northern areas of the WMA

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<sup>9</sup> Hartman, M. J., L.F. Morasch, and W. D. Webber (editors), 2002, *Hanford Site Groundwater Monitoring for Fiscal Year 2001*, PNNL-13788, Pacific Northwest National Laboratory, Richland, Washington.

(i.e., tritium: up to 2,410 pCi/L and 2,810 pCi/L, nitrate: up to 57.5 mg/L, technetium-99: 1,900 pCi/L, and uranium: 2.7 µg/L).

- Groundwater well 299-E33-41 lies directly east of BX tank farm. Measured peak concentrations in the well are most likely due to releases from this tank farm. The bases of this conclusion are: 1) that the nitrate to technetium-99 ratios for the groundwater at this location are the same order of magnitude (10 to 100 µg/pCi) as in the soil profile and 2) the observation of near coincident uranium and technetium-99 peaks in 1997. A peak concentration of the order of 12,000 pCi/L for technetium-99 was measured in this well in August 1997. Sharp spikes that are followed by immediate drops in concentration levels characterize the observed history of contamination in the monitoring area. Such a behavior in the observed profiles, coupled with high technetium-99 concentrations, and the fact that the simulated peak technetium-99 concentrations for the water line leak cases were of the order of  $1 \times 10^4$  to  $1 \times 10^5$  pCi/L, suggest that local high-volume liquid discharges of water may have played a key role in contaminant migration in the BX tank farm. A plausible source is repeated ponding of runoff from natural precipitation created by tank farm construction.
- The historical groundwater flow analysis performed as part of this study showed that the major drivers for groundwater flow were wastewater discharges to Gable Pond and B Pond. Because of the changing surface water discharges, groundwater flow in this region has gone from easterly (natural conditions) to northerly (B Pond influence) to southerly (Gable Pond influence), back to northerly (new B Pond discharges), to southerly, and finally returning to more natural conditions (i.e., easterly) as discharges to B Pond and Gable Pond ceased.

The Science and Technology Project has begun studies on uranium mobility. Because the T, TX, and TY tank farms have waste streams similar to those in the B, BX, and BY tank farms, the study of uranium mobility will continue. This work will be documented in the field investigation report for WMAs T and TX-TY.

**Data Evaluation.** Previous estimates of soil inventories resulting from the major tank loss events 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 improved estimates of the composition of the waste at the time of the losses. Also, kriging analysis estimates of uranium inventory and distribution were completed using spectral gamma and soil concentration data. Uranium became a key contaminant for inventory analysis because extensive measurements in the vadose zone were available and estimates of other key constituents (e.g., technetium-99) could be scaled to the inventory. Because of the extensive measurements (both laboratory and geophysical) of uranium-238 soil concentrations and because of the known ratios of other contaminants to uranium-238 in tank waste, uranium-238 became a key contaminant for inventory analyses. Kriging was performed in support of work on inventory estimates.

Key inventory estimates for WMA B-BX-BY include the following:

- In the tanks BX-101 and BX-102 contamination area, technetium-99 discharge is attributed to two past operational release events including a metal waste loss in 1951 from a tank BX-102 overflow and a cesium recovery waste loss between 1968 and 1972

from the pump pit on top of tank BX-101. The metal waste loss is well documented for waste loss volume and waste composition providing reasonable confidence that an estimated 3.15 Ci were released into the vadose zone.

- A reasonable estimate of waste composition for the tank BX-101 pump pit loss can be made but insufficient information is available to quantify the waste loss volume, thereby preventing an estimate of inventory released. It is plausible that tens of curies of technetium-99 could have been released. During the time that the tank BX-101 pump pit could have been leaking (i.e., 1968 to 1972), a nearby poorly sealed borehole (i.e., 21-02-04) to groundwater was present after early 1970. Rapid discharge to the aquifer would have been possible down this poorly sealed borehole. Appropriate groundwater monitoring data were not collected during this time to confirm or deny this hypothesis. For modeling purposes, an estimated 1.1 Ci of technetium-99 are assumed to remain in the vadose zone from this pump pit leak along with the 3.15 Ci from the metal waste loss.
- Regardless of the total inventory disposed initially, soils analyses from borehole 299-E33-45 suggest that the current vadose zone technetium-99 inventory is small in the WMA. An estimated current inventory of about 0.3 Ci of technetium-99 was derived by extrapolating technetium-99 inventory with depth in the borehole over an area similar to the uranium footprint defined by drywell spectral gamma data.
- Technetium-99 discharges into the vadose zone near tank B-110 cannot readily be quantified since neither the waste composition nor the waste loss volume are well understood. Initially, Jones et al. (2001)<sup>4</sup> proposed that a waste from the cesium recovery process was released and potentially large quantities of technetium-99 could have been present. However, soils characterization data from borehole 299-E33-46 near tank B-110 show that hypothesis to be inaccurate. Technetium-99 releases into the vadose zone near tank B-110 from a transfer line leak appear to be inconsequential based on soil characterization data. Technetium-99 does not occur above detection limits in the upper parts of the vadose zone where other tank waste constituents (e.g., strontium-90, fluoride, carbonate, and nitrate) are present. Technetium-99 is present at very low levels in a few soil samples in the Plio-Pleistocene unit. This unit appears to be an effective conduit for lateral migration and the presence of technetium-99 is postulated to have a source other than cesium recovery waste.
- Historical records and recent inventory source term estimates (Simpson et al. 2001)<sup>10</sup> indicate that most of the discharged technetium-99 inventory (about 162 Ci) was through the BY cribs (i.e., the cribs north of BY tank farm) in 1954 and 1955. Part of this inventory was measured (as beta readings) in the unconfined aquifer shortly after discharge. Between 1955 and the present, essentially the entire inventory was flushed into the unconfined aquifer as indicated by an extensive soil sampling and analysis program under the BY cribs in the early 1990s<sup>11</sup>.

<sup>10</sup> Simpson B.C., R.A. Corbin, and S.F. Agnew, 2001, *Hanford Soil Inventory Model*, BHI-01496, Bechtel Hanford, Inc., Richland, Washington

<sup>11</sup> DOE-RL, 1993, *Phase I Remedial Investigation Report for 200-BP-1 Operable Unit*, DOE/RL-92-70, U.S. Department of Energy, Richland, Washington

- In the BX trenches, approximately 8 Ci of technetium-99 were discharged, the bulk of which was received in trench 216-B-42. Trench 216-B-42 is the only trench in this group to receive uranium recovery waste, which is a primary waste stream generated by the uranium recovery program in the early 1950s. All other BX trenches received first cycle waste, a secondary and more dilute waste stream generated by the uranium recovery program. Soils characterization was done at one of these trenches (216-B-38) and minor technetium-99 concentrations were measured. The depth distribution and concentrations of technetium-99 beneath trench 216-B-42 are unknown. However, discharges to the BX trenches were limited to calculated volumes that were expected to be retained in the vadose zone. For groundwater modeling purposes, the technetium-99 inventory for the BX trenches was assumed to remain in the vadose zone.
- In the cribs and trenches north of B tank farm, liquid discharge volumes and waste types are well documented. While large volumes were discharged, the waste types were highly diluted compared to the uranium recovery wastes discharged to the BY cribs. Simpson et al. (2001)<sup>10</sup> estimated a total of 0.8 Ci of technetium-99 was disposed in three of the largest volume discharge facilities in this area. In a recent soils characterization activity from borehole C3103 from one of those facilities, crib 216-B-7A, technetium-99 concentrations were below detection limits. It is concluded that, of whatever limited technetium-99 inventory was discharged to the soil column in cribs and trenches north of B tank farm, inconsequential quantities remain in the vadose zone.

Because no site-specific recharge measurements are available, estimates of natural recharge are based primarily on analogous Hanford Site measurements (e.g., lysimetry studies). In the absence of site-specific data, natural recharge estimates at the tank farms 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<sup>1</sup>. For the first time, a set of lysimeters has been installed in a tank farm (as part of the decommissioning of borehole 299-E33-46 near tank B-110) that will allow long-term measurements of water flux deep in the vadose zone.

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

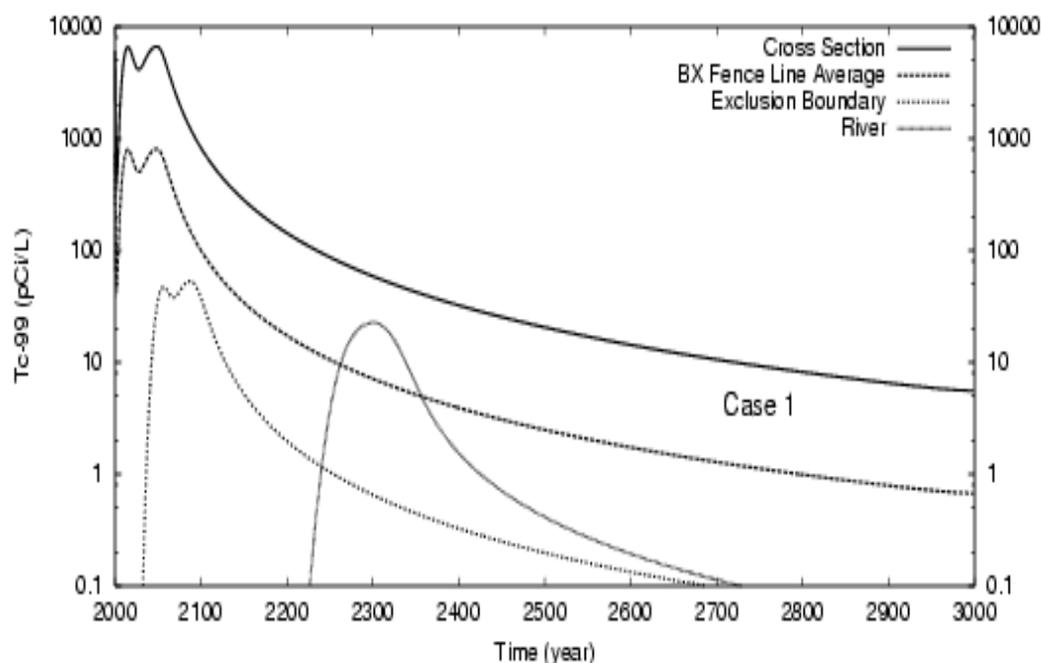
To estimate the future impact of past operational releases, a suite of numerical simulations was performed. For some of the more important simulations, the results were converted into human health risk values. The estimated inventory for technetium-99 (4.37 Ci) used in the modeling is higher than the total curies attributed to the BX-102 borehole data and the footprint provided by the spectral gamma contamination plume east of the BX tank farm. Nonetheless, for numerical modeling and risk assessment, the inventory was assumed to be present within the vadose zone and the measured soil profile contaminant concentrations were scaled up to match the estimated inventories.

*Modeling Data Package for B-BX-BY Field Investigation Report (FIR)*<sup>12</sup> provided the conceptual models and parameters used in the two-dimensional numerical simulations for the 14 cases (i.e., 11 tank cases and 3 trench cases) studied. The simulations started in the year 2000, using an initial contaminant distribution in the vadose zone based on an evaluation of the inventory data. 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 assumed 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 BX tank farm fence line (which is inside of the WMA boundary). In addition to the cross-section and the fence line boundaries, two additional boundaries (i.e., 200 Areas exclusion boundary and the Columbia River) were considered.

Figure ES.3 displays the technetium-99 groundwater concentrations as a function of time for various locations of interest. Arrival times for peak concentrations for 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, the peak concentration for uranium is projected to reach groundwater only near the end of the 1,000-year simulation period.

The interim surface barriers had little impact for the mobile contaminants. Travel times and peak concentrations changed very little when the interim barriers were considered. This is to be expected because the source of the contamination is very deep in the vadose zone and near groundwater.

**Figure ES.3. Groundwater Concentrations of Technetium-99 at Various Boundaries for the Base Case (Recharge = 100 mm/yr)**



<sup>12</sup> Khaleel, R., T. E. Jones, A. J. Knepp, F. M. Mann, D. A. Myers, and M. I. Wood, 2001, *Modeling Data Package for B-BX-BY Field Investigation Report (FIR)*, RPP-9223, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

Simulation results indicate that two key drivers affecting future 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. 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 also influence the predicted peak concentrations and their arrival times.

Other key findings from the numerical simulations include the following:

- Wastes that currently reside in the vadose zone beneath the WMA and may have resulted from past leaks from the B, BX, or BY tank farms are not expected to exceed drinking water standards in the groundwater at or outside the WMA B-BX-BY boundary.
- A peak concentration in groundwater on the order of 12,000 pCi/L for technetium-99 was measured in well 299-E33-41 (directly east of tank BX-102) in August 1997 (Section 6.2.4). Numerical simulation results suggest that such a high concentration level cannot be explained with natural recharge alone. The fact that peak technetium-99 concentrations for the simulated water line leak numerical cases were the same order of magnitude (i.e.,  $1 \times 10^4$  to  $1 \times 10^5$  pCi/L) as those measured in well 299-E33-41 suggest that artificial recharge played a key role in contaminant migration in the BX tank farm (i.e., BX tank farm ponding).
- Numerical results show that artificial recharge could potentially play a significant role in the mobilization of relatively immobile uranium-238. The peak uranium-238 concentrations for the water line leak case scenarios were not only the largest and had the earliest arrival time but were considerably larger than the base case peak concentration. It should be noted however that no leaking water lines were found when all water lines in the WMA were tested in the summer of 2002. The water line cases are presented to help illustrate past leak scenarios.
- Any future impacts from these wastes are expected to be small compared to the impacts to groundwater already caused by discharges to past-practice sites that surround the WMA.

Risk and dose were evaluated for four of these 14 cases using the *Hanford Site Risk Assessment Methodology*<sup>13</sup> and Method B (unrestricted) and Method C (industrial) exposure scenarios as required by the Washington Administrative Code<sup>14</sup>. The major findings include the following:

- Incremental lifetime cancer risk (ILCR) ranged from  $5.39 \times 10^{-5}$  to  $4.83 \times 10^{-5}$  at the eastern fence line of the BX tank farm for the industrial worker scenario.
- The hazard index ranged from  $1.98 \times 10^{-1}$  to  $1.77 \times 10^{-1}$  at the BX tank farm east fence line boundary for the industrial worker scenario.

<sup>13</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>14</sup> *Washington Administrative Code* 173-340, as amended.

- Technetium-99 is the key contaminant of concern for the ILCR, while chromium and nitrate are the key contaminants of concern for the hazard index.
- Regulatory performance objectives are  $1.0 \times 10^{-5}$  for ILCR and 1.0 for hazard index; thus the predicted ILCR risks exceed performance objectives and the hazard index predictions are below performance objectives.

### **Section 5.0, Interim Measures**

The field investigations for WMA B-BX-BY and also for WMA S-SX<sup>1</sup> suggest that artificial water sources have resulted in accelerated contaminant migration. Therefore, interim measures were identified and have been completed to minimize infiltration from these sources. These interim measures include the following:

- Emplaced upgradient surface water run-on control measures.
- Performed leak tests of the water lines to B, BX, and BY tank farms. No leaks in the tank farm area were detected.
- Verified that the sanitary water line to B farm had been cut and capped.
- Capped existing dry wells to prevent water intrusion.

The Office of River Protection has implemented interim measures related to upgradient surface water run-on control measures including cutting and capping water lines at other single-shell tank farms. The key findings and recommendations are that:

- These activities have been completed for all single-shell tank farms.
- An installation of an interim surface barrier should be demonstrated in a single-shell tank farm.

### **Section 6.0, Conclusions**

Six major conclusions have resulted from this work including:

- The future impacts from wastes currently in the vadose zone that resulted from past releases from the B, BX, and BY tank farms are not expected to exceed drinking water standards at or beyond the WMA boundary as long as high volume liquid discharges to the vadose zone are eliminated. Note, however, that a peak concentration of about 12,000 pCi/L for technetium-99 was measured in groundwater well 299-E33-41 directly east of BX tank farm in 1997. This contamination is most likely due to releases from the BX tank farm.
- Vadose zone and groundwater contamination levels were lower than generally anticipated prior to the initiation of the field investigation.<sup>4</sup>
- Estimations of technetium-99 distribution during Hanford Site reprocessing, storage, and disposal and the residue left in the vadose zone have been improved and past assumptions corrected. However, the amount of technetium-99 that was initially discharged to the vadose zone and that might have already reached groundwater is still uncertain but could amount to tens of curies from the BX-101 pump pit leak.

- Complex hydraulic processes play a major role in contaminant movement in WMA B-BX-BY. Strong evidence of extensive vadose zone lateral migration in WMA B-BX-BY exists. Lateral migration may have extended into WMA B-BX-BY from adjacent past practice discharge sites. Ponding of runoff from natural precipitation in the WMA may have added significant amounts of spatially confined infiltration. Changes in groundwater flow direction have caused plumes from other sources to be found under the WMA.
- Borehole soil characterization performed by the Tank Farm Vadose Zone Project and other laboratory measurements by the Groundwater Protection Program's Science and Technology Project have identified precipitated uranium phases, and strontium-90 phases and sorption sites. These data indicate limited future mobility unless abnormally high amounts of infiltration occur. Neither uranium nor strontium-90 is expected to significantly impact groundwater in the current moisture and geochemical environment. However, the precipitated uranium phases may function as a long-term source to percolating waters if artificial recharge is not controlled.
- Interim measures (e.g., capping boreholes, cutting off inactive water lines, building surface run-on barriers, and diversions) have been implemented in the WMA. These are expected to mitigate future contaminant risks.

### **Section 7.0, Recommendations**

This section provides recommendations for further investigations and decisions based on findings from the WMA B-BX-BY vadose zone and groundwater characterization activities. The key recommendations are:

- Installation of interim surface barriers is not recommended. Because of the location of key mobile contaminants near the water table, an interim barrier would not result in measurable reductions of mobile contaminants from existing contamination reaching the unconfined aquifer. If significant new leaks occur, the need for an interim surface barrier should be reevaluated.
- Soil and ancillary equipment removal should be evaluated as part of the corrective measures study process. Surface contamination at depths of less than 4.6 m (15 ft) bgs is widespread. Soil removal could not be conducted without considering removal of the ancillary piping systems that connect the tanks throughout the tank farms. Removal of these pipes would have to be conducted in unison with soil removal activities.
- The numerical model of the vadose zone beneath the BX tank farm (including its supporting data) should be used in future modeling, particularly for simulating potential leaks from tank waste retrieval and releases following tank closure.
- The study of uranium mobility to refine solid phase solubility and transport conditions should be continued and reported in the next field investigation report (i.e., the field investigation report for WMAs T and TX-TY). Such new work may require more complicated geochemical treatment in numerical simulations.

## READERS GUIDE

The following information is provided to assist the reader in understanding the technical data and format of this document.

### Definitions of Terms

A number of terms are conventionally abbreviated in this document; for example, waste management area is expressed as WMA. Abbreviated terms are spelled out on their first use, and as a convenience for the reader, a list of acronyms and abbreviations with their definitions can be found following the Tables of Contents of the main document and in each appendix.

### Reference Citations

Throughout the text of this document, reference citations are presented where information from the referenced document was used. These reference citations are contained within parentheses and provide a brief identification of the referenced document. This brief identification corresponds to the complete reference citation located in the reference list at the end of the main document and at the end of each appendix.

### Chemical Elements and Radioactive Isotopes

Many chemical elements and radioactive isotopes are referenced in this document. Examples of the chemical elements are cesium, strontium, and uranium; isotopes are expressed after the element name (for example, cesium-137). To save space in tables and illustrations, elements and isotopes may appear in abbreviated form (for example, Cs-137).

### Scientific Notation

Scientific notation is used in this document to express very large or very small numbers. For example, the number one million could be written in scientific notation as 1.0E+06 (or  $1.0 \times 10^6$ ) or in traditional form as 1,000,000. Translating from scientific notation to the traditional number requires moving the decimal point either right or left from the number being multiplied by 10 to some power depending on the sign of the power (i.e., negative power move left or positive power move right).

### Units of Measure

The primary units used in this document are metric. However, the approximate American customary system of units is shown in parentheses directly following the use of many of the metric units. For example, a distance presented as 10 meters (m) is followed by 33 feet (ft). This example would be presented in the text as: 10 m (33 ft). Information derived from historical or referenced sources is presented in the units cited in the reference. Field and laboratory data are presented in the units as measured in the field or reported by the laboratory.

### Electronic Viewing Option

An electronic version of this document is available. The reader is encouraged to utilize the electronic version to view this document, particularly the graphics. Throughout the document, graphics in particular make use of color to convey information. When the document is printed in black and white, the color differences may be lost.

## Well Numbering and Identification

Several well numbering methods exist on the Hanford Site, leading to confusion in identifying those structures on various maps and cross-referencing them in this document. Three numbering methods are used here:

- Tank Farm System – in this method, drywells are numbered to identify the tank farm, associated tank, and the clock position of the well relative to the tank. The tank farm numbers are B = 20, BX = 21, and BY = 22; each tank is assigned a two-digit number corresponding to its official number (101 = 01, 102 = 02, etc.); and the two-digit clock position numbers are based on north as 12 o'clock (for example, south would be 06).

*Example: well 20-10-12 is north of tank B-110*

Within the BX tank farm, the series of drywells constructed in 1970 to assess the postulated loss from tank BX-102 are designated sequentially in the order drilled as “27” series wells.

*Example: drywell 21-27-10 is in the northwest part of the BX tank farm*

Many farms have drywells drilled along the peripheries; these wells are noted by the tank farm number, followed by “00”, and then the clock position related to the entire farm.

*Example: drywell 21-00-11 is at the 11:00 position on the periphery of the BX tank farm*

Use of the tank farm numbering system is common as it permits the reader to readily visualize the spatial position of a given well relative to the tank it monitors.

- Hanford Site Well Numbering – in this method, based on the Hanford Site 200 Area Well Number protocol, each well is assigned a number based on the Hanford area in which the well exists (for example, 299 = 200 Area well), followed by a number designating the survey sheet on which it can be found (for B-BX-BY, this is sheet E33), and finally a number based on the sequential order in which the well was drilled. Groundwater monitoring wells are numbered from 1 to 50, or generally greater than 300. Drywells are numbered from 51 to 299.

*Example: the tank BX-102 borehole is designated 299-E33-45*

- Washington Department of Ecology Start Card Number – in this method, every well drilled on the Hanford Site has a tracking number assigned by Ecology. Wells drilled solely for the purpose of collecting soils samples, and decommissioned after those samples have been collected, often have only this number. The number is alphanumeric, such as C3390. All characterization boreholes, not extending to groundwater, drilled by the Groundwater Protection Program have only this number assigned.

*Example: the crib B-7A borehole is designated C3103.*

Every effort has been made to minimize confusion by including the name ‘well’ or ‘borehole’ with the unit identifying number.

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## LIST OF TERMS

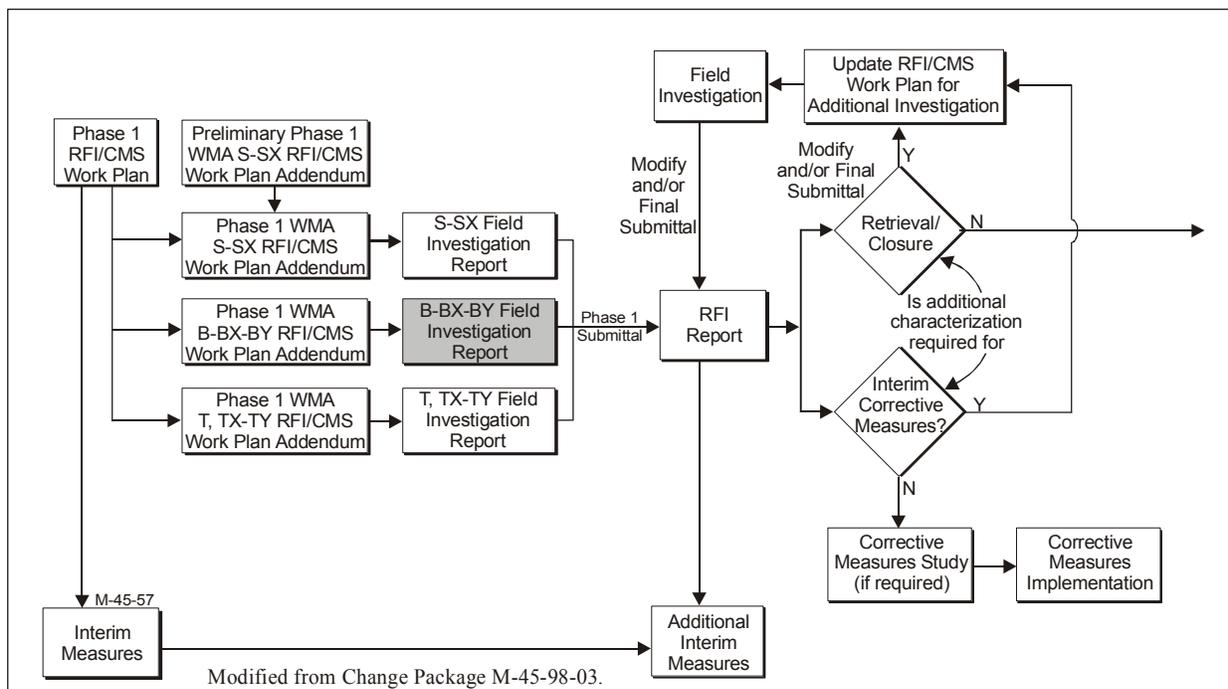
bgs	below ground surface
BTC	breakthrough curve
CAW	current acid waste
CERCLA	<i>Comprehensive Environmental Response, Compensation, and Liability Act</i>
CH2M HILL	CH2M HILL Hanford Group, Inc.
CMS	corrective measures study
CoC	contaminant of concern
CoPC	constituent of potential concern
DOE	U.S. Department of Energy
DOE-RL	U.S. Department of Energy, Richland Operations Office
DQO	data quality objectives
DWS	drinking water standard
Ecology	Washington State Department of Ecology
EDTA	ethylene-diamine-tetraacetic acid
EPA	U.S. Environmental Protection Agency
FIR	field investigation report
HEDTA	hydroxethyl-ethylenediamine-triacetic acid
HFFACO	<i>Hanford Federal Facility Agreement and Consent Order</i>
HI	hazard index
HSRAM	<i>Hanford Site Risk Assessment Methodology</i>
ICM	interim corrective measure
ILAW	immobilized low activity waste
ILCR	incremental lifetime cancer risk
Kd	distribution coefficient
MTCA	“Model Toxics Control Act”
NA	not applicable
NTA	nitrilotriacetic acid
ORP	Office of River Protection
PSN	PUREX supernatant
PSS	PUREX sludge supernatant
PUREX	Plutonium-Uranium Extraction Plant
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
REDOX	reduction-oxidation
RFI	RCRA facility investigation
RPP	River Protection Project
RSN	REDOX supernatant
S&T	Science and Technology
SPT	splitspoon
SST	single-shell tank
TWRS EIS	Tank Waste Remediation System Environmental Impact Statement
WAC	<i>Washington Administrative Code</i>
WMA	waste management area
ZAW	zirconium acid waste

## 1.0 INTRODUCTION

This *Field Investigation Report for Waste Management Area B-BX-BY* 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-T02. *Phase 1 RCRA Facility Investigation/Corrective Measures Study Work Plan for Single-Shell Tank Waste Management Areas (DOE-RL 2000)* contains functional and format requirements for the field investigation reports.

This document fulfills the SST RCRA Corrective Action Program process criteria by completion of the second site-specific field investigation at waste management area (WMA) B-BX-BY and preparation of a 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. The *Field Investigation Report for Waste Management Area S-SX* was issued in January 2002 (Knepp 2002).

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



Placement of the WMA B-BX-BY 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 B-BX-BY. 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 I 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 properties, 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 designated boundaries over a period of 1,000 years.

The purposes of this WMA B-BX-BY FIR are to:

- Summarize data and evaluations from the site-specific field investigation activities at WMA B-BX-BY 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 initiate 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 and closure of SSTs.

The project objectives fulfilled in this document are defined in the work plan addendum for this effort: *Site-Specific SST Phase I RFI/CMS Work Plan Addendum for WMA B-BX-BY* (Rogers and Knepp 2000). The objectives identified in the work plan addendum 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 (Section 3.0)

- Collect data to support an improved understanding of the nature and extent of contamination and the fate and transport of contaminants to perform a risk assessment (Section 4.0)
- Provide WMA-specific information on source, nature, and extent of contamination for planned activities identified in the work plans (Section 3.0)
- Provide WMA-specific characterization programs data to address data gaps identified through a data quality objectives (DQO) process (Section 4.0).

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 evaluations of impact to ecological receptors are not included.

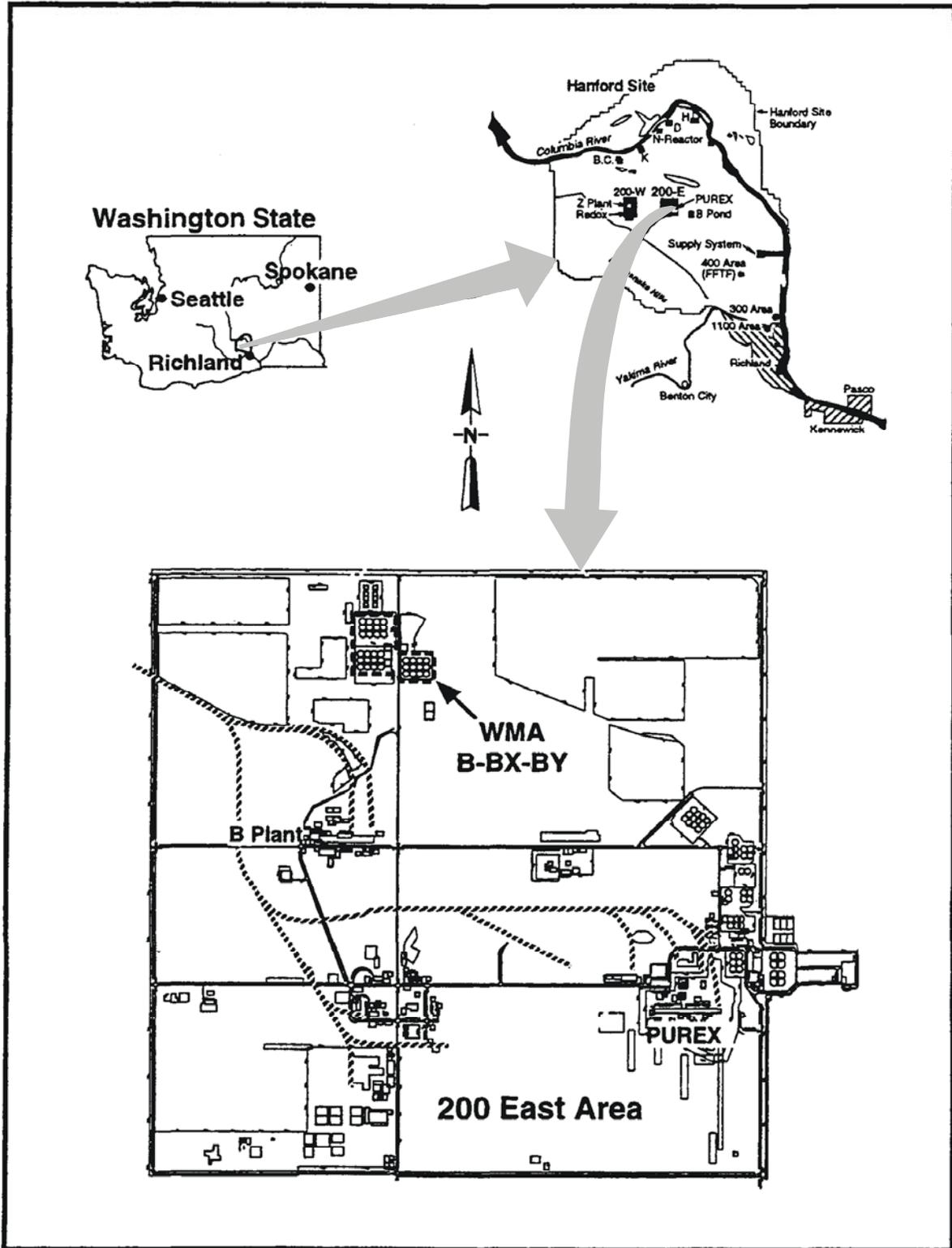
## 1.2 OVERVIEW

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 south central 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 HFFACO (Ecology et al. 1989) provides that 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 (Ecology et al. 1989). 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. (CH2M HILL) 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 the purview of the CH2M HILL 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 Groundwater Protection Program (formerly the Hanford Groundwater/Vadose Zone Integration Project).

The B, BX, and BY tank farms comprise WMA B-BX-BY. These tank farms are located in the northern portion of the 200 East Area near B Plant (Figure 1.2).

Figure 1.2. Location Map of Single-Shell Tank Waste Management Area B-BX-BY and Surrounding Facilities in the 200 East Area



Source: Wood et al. 2000

The B tank farm comprises the following:

- 12 SSTs each with 2,006,050-L (530,000-gal) capacity
- 4 SSTs each with 208,175-L (55,000-gal) capacity
- Waste transfer lines
- Leak detection systems
- Tank ancillary equipment.

The BX tank farm comprises the following:

- 12 SSTs each with 2,006,050-L (530,000-gal) capacity
- Waste transfer lines
- Leak detection systems
- Tank ancillary equipment.

The BY tank farm comprises the following:

- 12 SSTs each with 2,869,030-L (758,000-gal) capacity
- Waste transfer lines
- Leak detection systems
- Tank ancillary equipment.

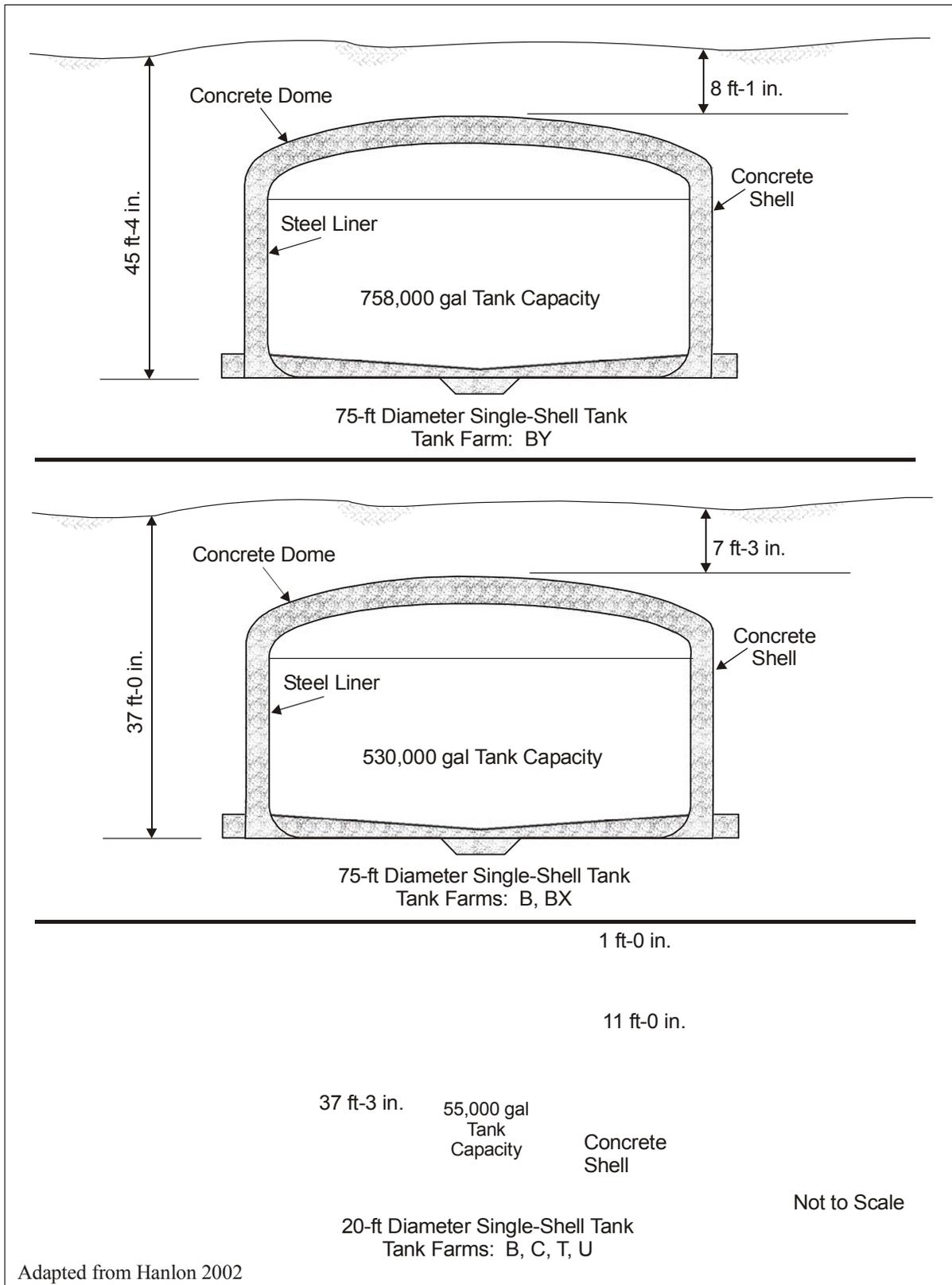
The SSTs in these tank farms are 23 m (75 ft) in diameter, except for four SSTs in B tank farm that are 6 m (20 ft) in diameter. The B and BX tank farm SSTs are approximately 9 m (30 ft) tall from base to dome. The SSTs in BY tank farm and the small SSTs in B tank farm are approximately 11 m (37 ft) tall from base to dome (Hanlon 2002). The sediment cover from the apex of the dome to ground surface is 2.5 m (8.1 ft) at the BY tank farm, and 2.2 m (7.3 ft) at the B and BX tank farms (Hanlon 2002). The top of the smaller SSTs in B tank farm are approximately 0.3 m (1 ft) above ground surface (Hanlon 2002). All of the tanks have a dish-shaped bottom (Figure 1.3). The 23 m (75 ft) diameter SSTs were constructed with cascade overflow lines in a three-tank series that allowed gravity flow of liquid waste between the tanks. The end of the cascade series in the BX tank farm is hooked to the first cascade tank in the BY tank farm (Brevick 1995). The cascade overflow height for B and BX tank farm SSTs is 4.8 m (15.7 ft) from the tank bottom, while the cascade overflow height for BY tank farm SSTs is 6.9 m (22.7 ft) from the tank bottom (Brevick 1995). Ten of the 16 SSTs in B tank farm, 5 of the 12 SSTs in BX tank farm, and 5 of the 12 SSTs in BY tank farm are classified as assumed leakers (Hanlon 2002).

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

### **1.2.1 General Background**

WMA B-BX-BY was placed in assessment groundwater monitoring in June 1996 because of elevated specific conductance in downgradient monitoring wells (Caggiano 1996). The drinking water exceedances in the RCRA-compliant monitoring wells are currently limited to two wells (299-E33-41 and 299-E33-44) located along the east side of the BX tank farm. Technetium-99, nitrate, uranium, cyanide, and chromium are the only constituents to have exceeded drinking water standards (Narbutovskih 1998).

**Figure 1.3. General Configuration of Tanks in Waste Management Area B-BX-BY**



Based on the information obtained from the results of the groundwater assessment for WMA B-BX-BY (Narbutovskih 1998), the site-specific work plan (Rogers and Knepp 2000) was prepared. The work plan describes the following field investigation activities:

- Installation and sampling of two vertical boreholes to groundwater located east-northeast of tank BX-102 and north of tank B-110
- Shallow vadose zone soil investigation in the vicinity of tanks B-110, BX-102, BX-107, and BX-110 and the diversion boxes (241-B-151, 241-B-152, and 241-B-153) in B tank farm planned in May 2003
- Vadose zone sediment sampling of proposed RCRA groundwater monitoring wells south and southwest of BX tank farm.

Two of these characterization activities provided the data collected from the field investigations to support the identification of the nature and extent of contamination in WMA B-BX-BY.

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 Protection Program
- Integrated Technology and Research Demonstration Project
- 200 Area Remediation Project
- Hanford Site Groundwater Monitoring Program.

These programs and projects all provide valuable data and information that are expected to enhance the FIR evaluations. On July 1, 2002, the Hanford Groundwater/Vadose Zone Integration Project was transferred from Bechtel Hanford, Inc. to Fluor Hanford, Inc. The name was changed to Groundwater Protection Program.

### **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 B-BX-BY, as prescribed in the change package, is as follows:

- Characterization of WMA B-BX-BY in fiscal year 2000 based on the work plan addendum (Rogers and Knepp 2000) to fulfill HFFACO Milestone M-45-53
- Preparation of this document, the *Field Investigation Report for Waste Management Area B-BX-BY*, in fiscal year 2002 to fulfill HFFACO Milestone M-45-55-T02

- Preparation of an RFI report in fiscal year 2003 and fiscal year 2004 that rolls up the results and recommendations from the FIRs for 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). Eight sections and nine appendices are included in this WMA B-BX-BY FIR. The document is structured to describe the vadose zone and associated groundwater field and laboratory investigation results at WMA B-BX-BY from 1997 to present. The following are the sections and appendices that compose this report:

- **Section 1.0** – Introduction to the WMA B-BX-BY 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.
- **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 B-BX-BY are presented. A comparison of these results to regulatory standards is provided.
- **Section 5.0** – Interim measures performed at WMA B-BX-BY.
- **Section 6.0** – Conclusions based on information provided in Sections 3.0 and 4.0.
- **Section 7.0** – Recommendations based on the conclusions.
- **Section 8.0** – List of the references used to develop the WMA B-BX-BY 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) Program evaluation of data related to chemical and physical attributes of the effects of the waste stream related to WMA B-BX-BY.
- **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 at WMA B-BX-BY.
- **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 B-BX-BY FIR.

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## 2.0 INVESTIGATIVE BASIS AND APPROACH

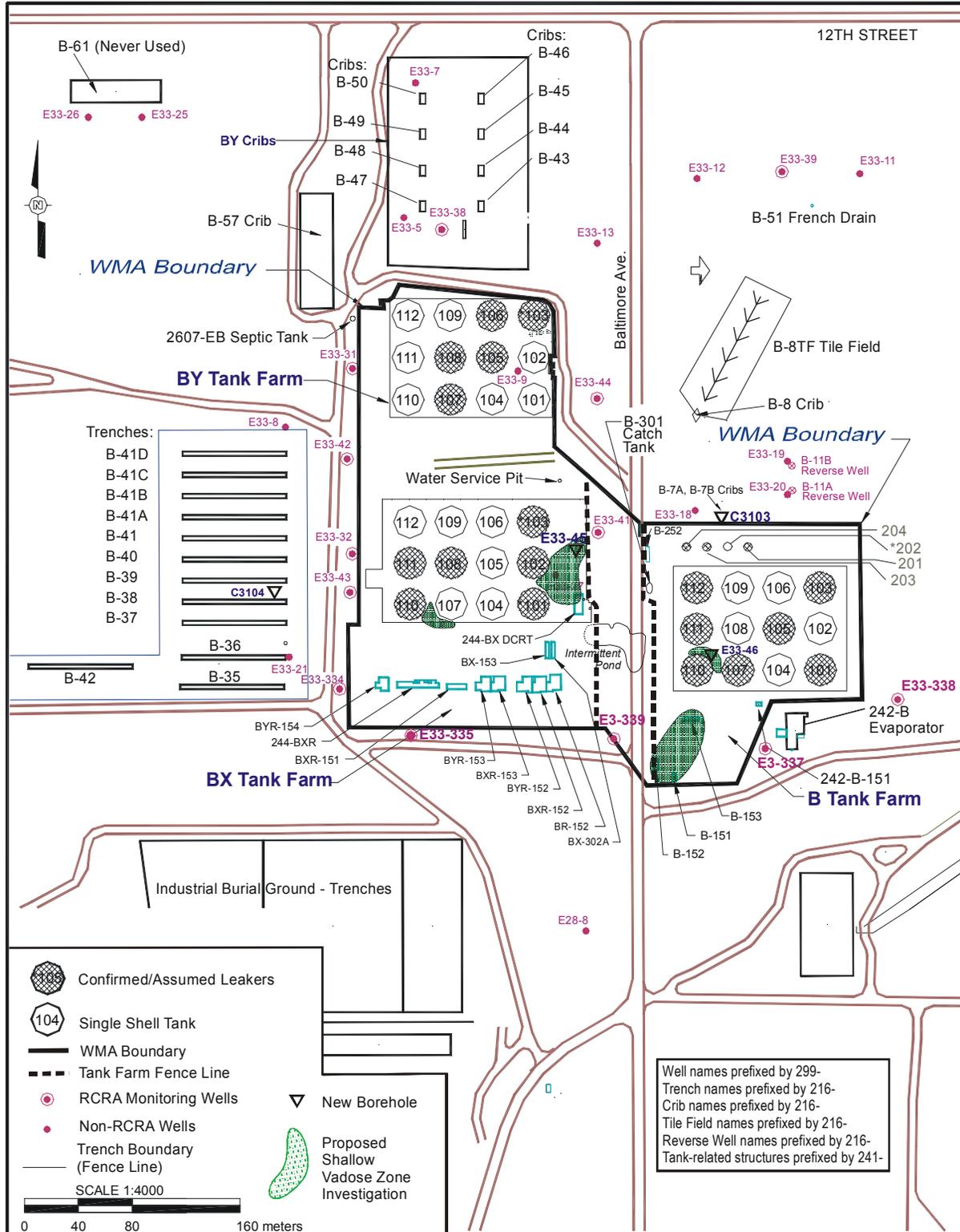
This section describes the investigative basis and approach used for this WMA B-BX-BY FIR. The regulatory framework used in the WMA B-BX-BY field investigation was developed through negotiations with Ecology and DOE in HFFACO Change Package M-45-98-03. The technical framework that identifies data needs 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) 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 Phase 1 RFI/CMS work plan (DOE-RL 2000) and work plan addendum (Rogers and Knepp 2000) provide the documentation for implementation of the field investigation activities. Appendix A of this document provides detailed information on the investigative approach. The site-specific work plan addendum for WMA B-BX-BY (Rogers and Knepp 2000) provides selected field investigations and the basis for verifying the extensive knowledge base that exists for WMA B-BX-BY consisting of geology, hydrology, geophysics, groundwater chemistry, waste chemistry, and releases from the tank systems (e.g., transfer pipelines). An additional science and technology workscope that supports the field investigation was defined in the Groundwater Protection Program Science and Technology roadmap. The RPP field investigation program leverages these results. These selected field investigation results (Section 3.0), provide a basis for integrating extensive databases that lead to a reasonable understanding of the important constituentss of concern (CoCs). Flow and transport modeling results then lead to human health risk assessments (Section 4.0) to assist in determining whether implementation of interim measures are required (Section 5.0).

To ensure appropriate data are collected to meet the data needs for the FIRs as identified in the site-specific work plan, an implementation plan was 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 is the potential risk to a human receptor.

The data needed to complete the WMA B-BX-BY evaluation are complicated and the fulfillment of those data needs becomes less certain when WMA-specific factors are considered. Those factors include the following:

- The long time span over which the SSTs operated (i.e., 1944 through 1980)
- Transient geochemical conditions that have existed from the time of waste releases to present
- Associated cribs and waste sites adjacent to the WMA boundary (Figure 2.1) that have contributed to groundwater contamination for the same CoCs
- Lack of access due to existing infrastructure near tanks and the high cost of site-specific data collection.

**Figure 2.1. Waste Management Area B-BX-BY Location Map of Characterization Activities, Surrounding Facilities, and Wells**



Note: All wells are preceded by 299-.

Note: The intermittent pond between the B and BX tank farms has been addressed by interim measures.

## 2.1 PREVIOUS DATA AND INFORMATION

The site-specific work plan addendum (Rogers and Knepp 2000) includes the following actions:

- Collect and assimilate historic 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 contaminant distribution 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 and address the data needs through a DQO process.

### 2.1.1 Existing WMA B-BX-BY Data

Because of the significant amount of existing B, BX, and BY tank farms data, only a brief summary of that data is given in this report. The Tank Farm Vadose Zone Project created *Subsurface Conditions Description for B-BX-BY Waste Management Area* (Wood et al. 2000) to be the primary reference for such previous knowledge. Existing data relevant to the tank system waste loss events and associated vadose zone and unconfined aquifer contamination in WMA B-BX-BY were summarized and used to develop conceptual models of these tank system waste loss events and subsequent contaminant migration in the subsurface. These conceptual models were then used to develop the investigative approaches applied in this WMA.

Geologic descriptions of this WMA have been published (Price and Fecht 1976). These descriptions were updated by Lindsey et al. (1992) and these updated geologic descriptions were applied to this investigation. Determination of the unsaturated flow characteristics in the region of this WMA was based on reports by Khaleel et al. (2001), Section 3.1.3 of this field investigation report, and immobilized low-activity waste (ILAW) results (Mann et al. 2001). Both historical and more recent geophysical logging techniques provided considerable insight into the nature and extent of contaminants in the vadose zone near the high-level waste tanks (Myers 1999a, b; Sydnor and Knepp 2000; DOE-GJPO 1997a, 1998, 2000a through d). Chemicals and radionuclides have been tracked in unconfined aquifer samples collected from monitoring wells in and around this WMA for about the past 15 years (Hartman et al. 2002). Historical chemical processing and waste transfer records have been compiled into a predictive model to describe tank waste compositions as a function of time (Agnew 1997) and this approach was used to develop preliminary tank fluid compositions and inventories for this WMA that were lost from the tank system to the vadose zone (Jones et al. 2001). An operational history of the B, BX, and BY tank farms also was prepared (Williams 1999). Since 1990, many thousands of Hanford Site special nuclear materials production documents have been declassified. Information from these documents provided considerable insight into tank system waste loss and intentional discharge events in and around this WMA.

WMA B-BX-BY is surrounded by a number of cribs and specific retention trenches (Figure 2.1). Most of the cribs and all of the specific retention trenches received wastes directly from single-shell tanks (Waite 1991). Because of the high volumes of fluids discharged to the cribs, crib discharges undoubtedly contaminated the unconfined aquifer. Thus, assigning the source for

groundwater contamination in and around the WMA is problematic. Impacts of crib and trench discharges near this WMA are being investigated in a parallel effort by the Groundwater Protection Program (DOE-RL 2002).

A brief discussion of information from a number of areas is included here to provide the basis of the conceptual models that were used to develop characterization plans.

**2.1.1.1 Hydrogeologic Data.** The vadose zone and unconfined aquifer underlying WMA B-BX-BY are made up of the two primary formations that are present throughout much of the Hanford Site:

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

The thickness of the Hanford formation/Plio-Pleistocene unit ranges from 6 m (20 ft) to 15 m (50 ft). The thickness of the Hanford formation ranges from 43 to 73 m (140 to 240 ft) from north to south. Directly beneath WMA B-BX-BY, these strata tend to be of fairly uniform thickness and gradually thin to the north. A more detailed description is provided in Section 3.1.

At WMA B-BX-BY, the unconfined aquifer, found within the basal gravels interpreted as fluvial pre-Missoula sediments, extends upward at places into the Hanford formation H3 unit, and is between 1.9 and 4.3 m (6.2 and 14 ft) thick (Wood et al. 2000; Hartman et al. 1999). In 1998, water level measurements indicated that the water table in the unconfined aquifer was at approximately 123 m (403 ft) above mean sea level and dropping. Both water level and general direction of groundwater flow in this region have been altered multiple times throughout Hanford operations history by high volume wastewater discharges to various ponds. Most recently (i.e., 1980s), a groundwater mound in this area was maintained by liquid discharge to B pond east of WMA B-BX-BY, elevating the water table and imposing a southeast to northwest trend in groundwater flow under WMA B-BX-BY.

**2.1.1.2 Geophysical Logging Data.** Two types of geophysical logging data have been collected for WMA B-BX-BY from a set of drywells placed around and between tanks in the B, BX, and BY tank farms. Since the 1950s, gross gamma logging has been used as a secondary tank leak monitoring system (Isaacson and Gasper 1981). In practice, strategically placed shallow boreholes extending 80 to 150 ft bgs, called drywells were routinely monitored for changes in total gamma activity. Electronic versions of the gross gamma logging data were kept from 1974 until the end of the program (i.e., 1994). As part of WMA B-BX-BY vadose zone characterization effort, historic gross gamma logging data were assessed for the three farms in this WMA (Myers 1999a, b; Sydnor and Knepp 2000). Because this logging program provided a record of gross gamma intensities over time in numerous locations, it was possible to develop some perspective on the locations of contaminant occurrence, movement in the vadose zone over time, and the fraction of total gamma-emitting contaminants involved in migration. Analysis of historical gross gamma logging records (Myers 1999b) identified several boreholes in the BY tank farm where changes in the gamma flux were taking place. The mobile gamma-emitting radionuclide tracked in the gamma logging data was identified as cobalt-60, a known mobile

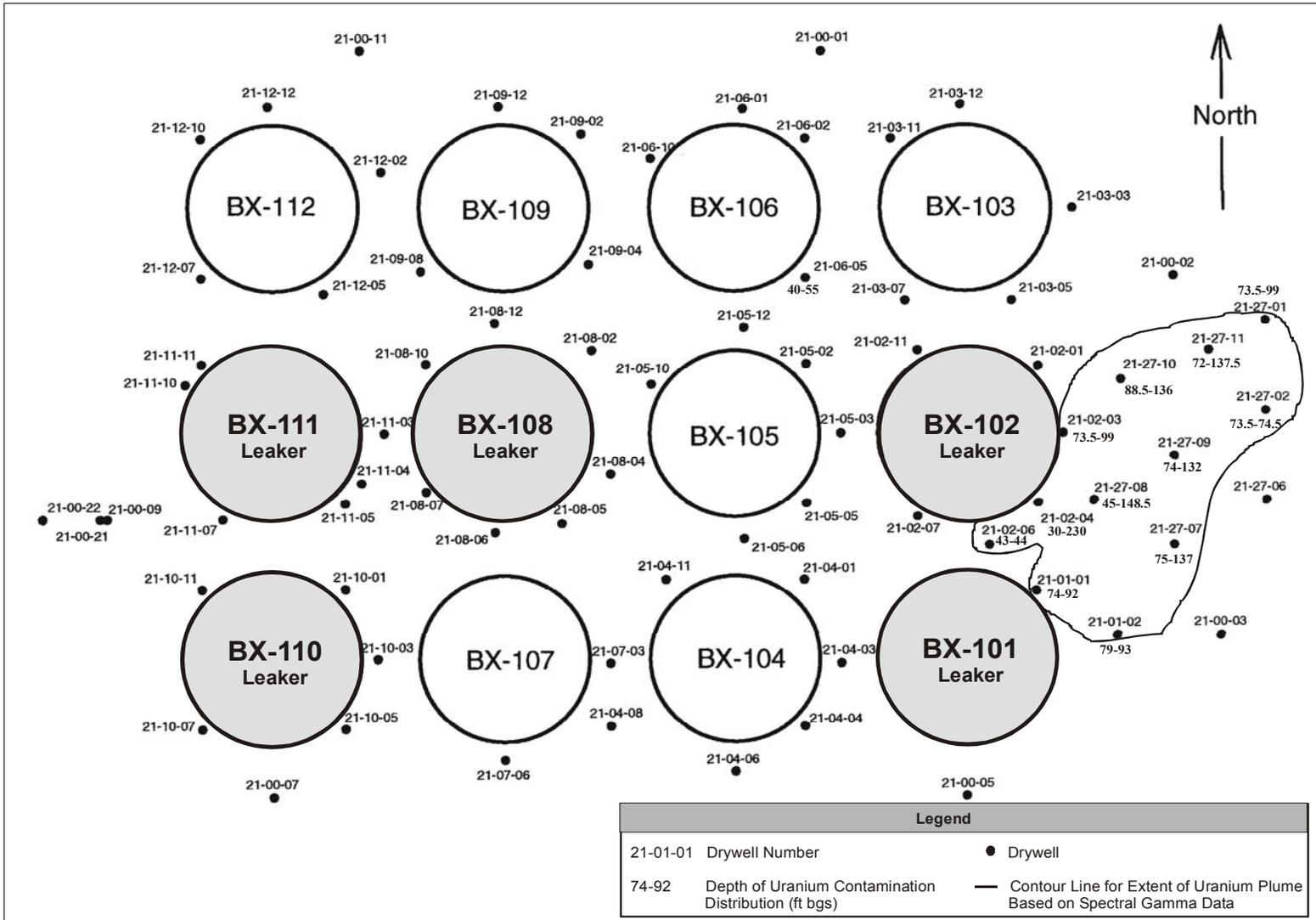
radionuclide that occurs in a number of tank waste types. This contamination was moving downward at approximately 1 to 2 ft/year.

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 by using the unique radiation emitted to identify and quantify gamma-emitting radionuclides. The spectral gamma logging data provided a three-dimensional quantification of specific gamma-emitting radionuclide concentrations. Spectral gamma logging data for the three tank farms of interest are available (DOE-GJPO 1997a, 1998, 2000a through d). These data provided a significant contribution to the initial conceptualizations of vadose zone contamination in the B, BX, and BY tank farms (Wood et al. 2000).

In the BX tank farm, the spectral gamma logging data suggest at least two waste loss events near tanks BX-101 and BX-102 (Figure 2.1). A uranium plume is identified in drywells east of tanks BX-101 and BX-102 extending from approximately 70 ft to 150 ft bgs (Figure 2.2). A second plume appears to emanate from tank BX-101 at approximately 15 ft bgs. The gamma emitting radionuclides in the second plume include cesium-137, antimony-125, cobalt-60, europium-152, and europium-154. The spectral gamma logging data suggest that there was likely a surface spill of fluids containing cesium-137 east of tank BX-102. By far the highest contamination occurs in well 21-02-04. This well has high levels of cesium-137 that extend from the surface down to groundwater. As discussed in Section 3.0, this well was drilled in 1970 through highly contaminated soil and left unsealed for approximately six years. The gamma logging data near tank B-110 provide qualitative evidence for the presence of strontium-90 in the subsurface between tanks B-110, B-111, B-107, and B-108 from 60 to 100 ft bgs.

**2.1.1.3 Previous Soil Contamination Investigations.** In 1951, a tank overflow event occurred at tank BX-102 leading to a significant uranium plume in the subsurface east of that tank (GE 1951a). It was reported that 92,600 gal of metal waste had been lost through a spare inlet port when tank BX-102 had been overfilled. Details of the 1951 waste loss event at tank BX-102 were included in the classified site monthly production report. This information was not declassified until the early 1990s. In 1970, tank BX-102 was suspected of being a leaker because of increasing gamma activity in a nearby drywell (Womack and Larkin 1971). Nineteen new drywells were installed in the area east of tanks BX-101 and BX-102, including well 21-02-04 to groundwater. Based on this work, tank BX-102 was declared a leaker in 1970 and the tank was pumped to a minimum level. In 1971, continuing increases in gamma activity in nearby drywells led to the addition of 50 tons of diatomaceous earth to tank BX-102. In mid-1972, further investigations in this area found a leaking pump pit on the dome of tank BX-101. Tank BX-101 was taken out of active service at the end of 1972. The spectral gamma logging data from drywells in the region east of tanks BX-101 and BX-102 show a uranium plume from about 70 ft down to 150 ft bgs. The spectral gamma logging data also showed a second plume containing a variety of radionuclides that overlies the uranium plume. The second plume is believed to have originated from (what is assumed to be) a long-term pump-pit leak on the dome of tank BX-101. Thus, the region east of tanks BX-101 and BX-102 became the focus of one of the exploratory boreholes (299-E33-45).

Figure 2.2. Uranium Vadose Zone Plume Map for the BX Tank Farm



A second area of interest was the region between tanks B-107, B-108, B-110, and B-111. The preliminary leak inventory estimate for tank B-110 implied extensive vadose zone contamination in this region. However, the spectral gamma logging indicated only a strontium-90 plume in this area. Since the waste processing records indicate that much of the wastes passing through tank B-110 originated from the B Plant isotope recovery process, compositions of waste that may have been lost were highly uncertain. Thus, placing an exploratory well northeast of tank B-110 became a priority to assess what appeared to be a reasonably large contamination plume containing what inventory data indicates was a mobile strontium-90 plume.

**2.1.1.4 RCRA Groundwater Monitoring Data.** Recent groundwater contaminant data in RCRA monitoring wells surrounding the tank farms provide indications of tank waste having reached the unconfined aquifer (Narbutovskih 1998; Narbutovskih 2000). What is not clear is whether the tank waste origins were losses from the tanks or the intentional discharges of tank waste to nearby cribs. Significant data include elevated concentrations of constituents in groundwater also known to be present in the vadose zone because of tank leaks (and intentional discharges to cribs and trenches). Wells monitoring WMA B-BX-BY have shown transient elevated levels (spikes) of technetium-99, nitrate, uranium, cyanide, and chromium along the eastern edge of the BX tank farm and along the northern and western edges of the WMA since 1997 (Appendix C).

Based on the information outlined above, the two main areas of interest in the vadose zone underlying WMA B-BX-BY are the area east of tanks BX-101 and BX-102, and the region east of tank B-110.

## 2.1.2 Conceptual Models

Conceptual models provided in Wood et al. (2000) and Jones et al. (1998) integrated 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 the two main areas of contamination because current information suggests that enough differences in contaminant occurrence and migration exist in the areas to warrant distinct explanations. The conceptual models were developed to aid the evaluation of potential impacts and to plan additional characterization efforts. No other conceptual models were used to plan characterization activities.

In Wood et al. (2000), the description of contamination in the area around tanks BX-101 and BX-102 was focused on the 1951 metal waste loss event from tank BX-102. Outstanding features of this contamination event included the following:

- High uranium concentrations (0.5 lbs/gal) in the supernatant plus fission products
- Apparent rapid (<4 weeks) and high volume discharge (92,600 gal)
- Slightly contaminated groundwater directly below these tanks
- Extensive horizontal and vertical extent of uranium contamination in the vadose zone.

From these observations, a gross two-step process for how the overflow event 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 lateral direction. In the

second step, the hydraulic impetus of the overflow event ceased and water movement reverted to control by natural infiltration that induced slow downward percolation for mobile constituents.

The spectral gamma logging data indicate the uranium plume east of tank BX-102 to be at least 150 ft bgs (i.e., the bottom of the drywell). Drywells in this area also show what appears to be remnants of the poorly defined waste losses from the pump-pit on the dome of tank BX-101. Soil sample data from the characterization borehole were intended to refine the conceptual model and improve quantification of the source term, the first two data needs identified in Table 2.2 and further discussed in Section 2.2. These observations led to the selection of the drill site for the BX-102 well.

Outstanding features of contamination in the area around tank B-110 include the following:

- Origin of the tank waste appeared to be near the cascade line between tanks B-110 and B-111. Drywell 20-10-12 has a mixture of cesium-137 and strontium-90 from approximately 20 ft bgs down to 100 ft bgs. Other drywells in this area showed only strontium-90.
- The preliminary inventory estimate (Jones et al. 2001) was inconsistent with the spectral gamma logging data.
- No tank waste type consistent with the spectral gamma logging was apparent, and leak volume estimates for tank B-110 were not apparent.

From these observations, it was concluded that an exploratory well through the apparent strontium-90 plume was required. Soil sample data from the characterization borehole were intended to refine the conceptual model and improve quantification of the source term (Table 2.2. and Section 2.2).

### 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 *A Summary and Evaluation of Hanford Site Tank Farm Subsurface Contamination* (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 ranked of the 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 B, BX, and BY tank farms.

**Table 2.1. Data and Analysis Needs**

<b>Item</b>	<b>Rank</b>
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 the state of knowledge were confirmed in a DQO process (Figure 2.3).

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)(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. 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 B-BX-BY are illustrated in Figure 2.3. The DQO process also involved evaluating the site-specific data collected during the field investigation to address principal study questions to evaluate against performance standards. This analysis is presented in Section 4.4.5.

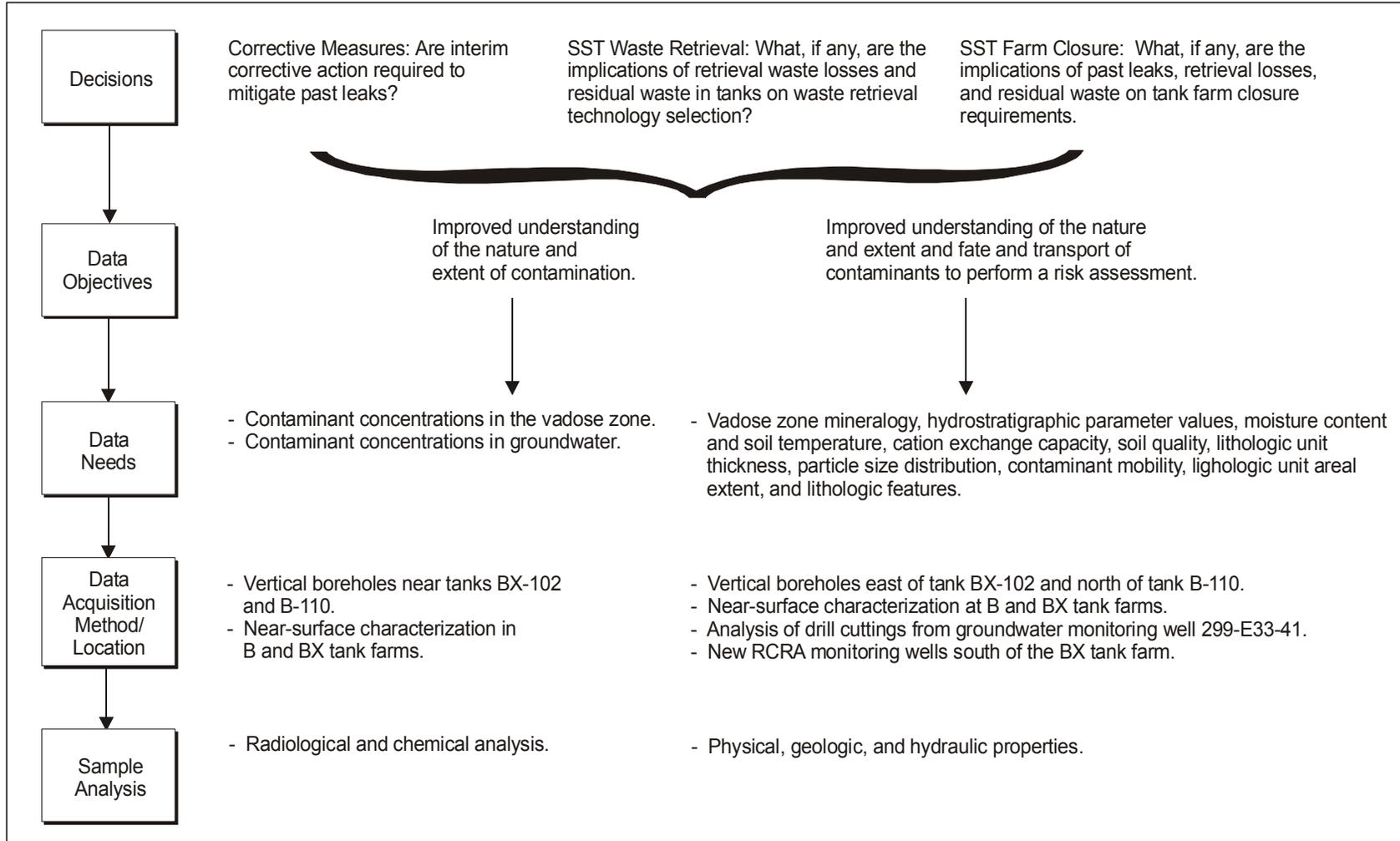
## 2.2 SUMMARY OF WORK PLAN ADDENDUM

The following sections discuss the overview of the site-specific work plan addendum, characterization locations, characterization techniques, and deviations from the work plan addendum.

### 2.2.1 Overview

The field characterization efforts (Rogers and Knepp 2000) conducted in fiscal year 2001 included the collection of vadose zone data from installation of boreholes east of tank BX-102 and north of tank B-110. Shallow vadose zone soil investigations along the eastern edge of the BX tank farm were deferred until fiscal year 2003. The requirements for these activities are provided by Rogers and Knepp (2000). The following summarize the field activity decisions reached by Ecology and DOE based on the DQO process.

**Figure 2.3. Data Quality Objectives and Data Needs**



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

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 pages)**

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<sup>a</sup></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)

<sup>(a)</sup>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 of water run on, temperature, and the time and rate of precipitation.

CoCs = contaminants of concern

WMA = waste management area

**2.2.1.1 Installation of New Vertical Exploratory Boreholes Northeast of Tank BX-102 and Northeast of Tank B-110.** The DQO process resulted in the identification of several potential locations for the proposed new boreholes. Locations north-northeast of tank BX-102 and northeast of tank B-110 were selected based on spectral gamma data, groundwater quality data, historical process knowledge, and physical restrictions within the individual farms. These locations are near past leak events either from the tank or a transfer line. The new boreholes were installed using the cable-tool percussion technique with casing size reductions where necessary to reduce the likelihood of cross-contamination resulting from penetration through the highly contaminated zones. Collection of sediment samples were attempted at preselected horizons from about 3 m (10 ft) bgs to just below the water table on 3-m (10-ft) intervals. The water table was encountered at a depth of 78 m (256 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. Borehole 299-E33-46 (northeast of tank B-110) was completed as a vadose zone monitoring well. Borehole 299-E33-45 (northeast of tank BX-102) was decommissioned in accordance with WAC 173-160.

## 2.2.2 Characterization Locations

The location of the characterization efforts is shown in Figure 2.1. The figure shows the location for new borehole 299-E33-46 north of tank B-110, borehole 299-E33-45 northeast of tank BX-102, and the region of near-surface characterization efforts in the BX tank farm near tanks BX-101 and BX-102 planned for May 2003.

## 2.2.3 Characterization Techniques

Three distinct techniques were employed in field characterization of WMA B-BX-BY:

- Borehole geophysical logging
- Percussion drilling and sampling
- Laboratory measurements.

Each technique was applied to provide specific samples or information meeting the project needs that were identified in Rogers and Knepp (2000) or later identified as important for understanding the physical or chemical processes in the vadose zone. Other improvements aided the programs in a variety of areas.

**2.2.3.1 Borehole Geophysical Logging.** Spectral gamma logging data were available for all boreholes within WMA B-BX-BY (DOE-GJPO 1997a, 1998, 2000a through d). Neutron-moisture logs were run in selected boreholes to identify zones of above normal water content. These zones were selected for sampling during the field effort, as they had the highest probability of containing mobile contaminants.

**2.2.3.2 Drilling and Sampling.** A standard cable-tool percussion drilling machine was employed to advance the boreholes in the vicinity of tanks BX-102 and B-110. Special care was taken to assure that the potential for sample cross contamination was minimized. Splitspoon samples were taken by driving the sampler ahead of the casing. All grab samples were collected using a drive barrel that was also driven ahead of the casing. Casing was telescoped to a smaller diameter immediately following drilling through a high contamination area or zone of high moisture content. The boreholes were sealed to prevent drag-down using bentonite clay at each horizon where casing was downsized.

**2.2.3.3 Laboratory Measurements.** The philosophy and methods in performing laboratory measurements on soil samples from the WMA B-BX-BY field investigation were the same as were applied to samples for the WMA S-SX field investigation (Knepp 2002). These are documented in Appendix A of the work plan addendum for WMA B-BX-BY (Rogers and Knepp 2000).

During the investigations at WMA S-SX, changes in sediment type and contaminant concentrations were noted over a distance of a few centimeters within a given sleeve. It was concluded that a more methodical scoping approach would be necessary to provide the technical justification for selecting samples for detailed characterization as defined in the data quality objectives process. Subsequently, a tiered method was developed that considered depth, geology (e.g., lithology, grain-size composition, carbonate content), individual sleeve contaminant concentration (e.g., radionuclides and chemicals), moisture content, and overall sample quality. Inexpensive analyses and certain key parameters (i.e., moisture content and gamma energy analyses) were performed on sediments from each sleeve.

The objective of the tier 1 characterization was to quantify the extent of penetration of mobile contaminants into the vadose zone sediments. Only the sediment from the A Sleeve (deepest) was analyzed for most constituents except moisture and gamma energy. Measurable or significant drag-down of contaminants was not noticed, perhaps because the borehole was installed 100 ft away from the tank walls and the main contaminants (i.e., uranium-238 and technetium-99) are associated primarily with the porewater and not exclusively concentrated on the sediment. Because drag-down is dominated by highly contaminated sediment particles, the contaminants in this borehole had less chance of concentrating onto particles.

Immediately following the geologic examination, the sleeve contents were subsampled for moisture content, gamma-emission radioanalysis (i.e., natural potassium-40, uranium-238, and natural thorium-232 data), one-to-one water extracts (which provided soil pH, electrical conductivity, cation, and anion data), total carbon and inorganic carbon content, and 8 M nitric acid extracts (which provided a measure of the total leachable sediment content of contaminants). The remaining sediment from each sleeve was then sealed and placed in cold storage. Later, additional aliquots of selected sleeves or grab samples were removed to measure particle size distribution and mineralogy and to squeeze porewater.

The complete set of measurements were:

- Moisture Content (Tier 1)
- 1:1 Sediment-to-Water Extract (Tier 1)
  - pH and Conductivity
  - Anions
  - Cations and Trace Metals
  - Alkalinity and Carbon
  - Cyanide Analysis
- Porewater, Perched and Groundwater Composition (Tier 1)
- Radioanalytical Analysis (Tier 1)
  - Gamma Energy Analysis
- Carbon Content of Sediment
- 8 M Nitric Acid Extract
- Elemental Analysis
- Particle Size Distribution
- Particle Density
- Mineralogy
- Water Potential (Suction) Measurements
- Uranium Desorption Experiments.

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

Deviations from the work plan addendum for WMA B-BX-BY (Rogers and Knepp 2000) were documented. The deviations from the planned work were moderate differences between how the work was originally planned and how the work was actually accomplished for two tasks: cone penetrometer work and completion of the B-110 borehole. There were no deviations for the other tasks. The following sections summarize the deviations encountered for the shallow soil investigation and B-110 borehole.

**2.2.4.1 Shallow Soil Investigation.** This work is scheduled to begin in May 2003 for the transects as described in the work plan addendum (Rogers and Knepp 2000).

**2.2.4.2 B-110 Borehole 299-E33-46.** This borehole did not meet the criterion for completion as a RCRA monitoring well; however, it was completed as a Vadose Zone Monitoring System well. Details of that completion can be found in Section C.5.3 of Appendix C.

### **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 contributed during the planning and often provided specialized analyses. These projects include the Hanford Groundwater Program, 200 Area Remedial Action Project, the Groundwater Protection Program (formally known as Groundwater/Vadose Zone Integration Project), and projects supported by DOE Headquarters.

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

The CH2M HILL 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 CH2M HILL 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, and Authorization Basis organizations, and from 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 CH2M HILL 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 and tank closure 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 assisted the waste retrieval program in establishing the appropriate waste retrieval technologies and in setting criteria for leak detection, monitoring, and mitigation strategies.

### **2.3.3 Hanford Groundwater Project**

The Hanford Groundwater Project is responsible for monitoring 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 vadose zone sediments from at least one new monitoring well being drilled by the Hanford Groundwater Project is sampled in a near-continuous manner at each WMA. Adjacent to WMA B-BX-BY, the Tank Farm Vadose Zone Project has participated in the sampling of one such well.

**2.3.3.2 RCRA Groundwater Monitoring Wells.** Three groundwater monitoring wells, 299-E33-336, 299-E33-337, and 299-E33-338, were drilled and completed in 2001 to provide a more complete RCRA compliance monitoring network for WMA B-BX-BY. During drilling, well 299-E33-338 was sampled in a near continuous manner using splitspoon methods to further characterize the nature of sediments not impacted by WMA contamination. The most significant data provided by this characterization effort were soil chemistry and physical attributes. The wells remain in place as part of the compliance groundwater monitoring network.

### 2.3.4 Hanford 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 under the Environmental Restoration Program. Data from the Environmental Restoration Program acquired from trench B-38 and crib B-7A were used in the WMA B-BX-BY investigation.

### 2.3.5 Groundwater Protection Program (Formerly Hanford Groundwater/Vadose Zone Integration Project)

The work reported in this document was performed with full cooperation and input from the Groundwater Protection Program. The name of this organization was changed to the Groundwater Protection Program upon its transfer to Fluor Hanford, Inc. from Bechtel Hanford, Inc. where it was known as the Hanford Groundwater/Vadose Zone Integration Project. Progress reports were made through the DOE Headquarters-mandated Integration Project Expert Panel convened by the Groundwater Protection Program as well as through other public meetings hosted by the Groundwater Protection Program. Input from this body of experts was used to help guide the direction taken by the Groundwater Protection Program. In addition, the Groundwater Protection Program 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 Integration Project.

**2.3.5.1 Science and Technology Project.** The S&T Project of the Groundwater Protection Program is an important aspect of the team effort that produced this document. The following outline some of the S&T Project 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 Groundwater Protection Program funded enhanced analyses of the samples from the characterization and RCRA-supported boreholes. Appendix D summarizes much of this effort.
- **Advanced Modeling.** Although the modeling done by the Tank Farm Vadose Zone Project was relatively complex, some effects (e.g., thermal and transient chemical effects and strong heterogeneity) are not included. The S&T Project investigated the impacts of such effects. Appendix D summarizes much of this 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 Project.** 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 effects of 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 Project has been and will continue to be an important focus of the Tank Farm Vadose Zone Project.

**2.3.5.3 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 research activities to study vadose zone issues. Many of these research studies are utilizing the soil samples taken during this characterization effort to perform advanced analyses. A summary of some of these activities is provided in Appendix D.

### 3.0 INVESTIGATIVE RESULTS

Activities undertaken to assess the long-term impacts of waste losses from B, BX, and BY tank farm operations on the vadose zone, and potentially to groundwater, have involved a combination of fieldwork, laboratory analyses, and analysis of historical data. (i.e., “data mining”) from historical records. CH2M HILL field activities included: 1) the drilling of two vertical boreholes within the tank farm boundaries and 2) the associated soil sampling and analyses. One borehole was drilled approximately 25 m (75 ft) east of tank BX-102 to investigate the depth of processed uranium and to determine levels of technetium-99, as well as other fission products. The second borehole was drilled near tank B-110 (northeast side) to identify the source of gamma activity in the soil and to identify other chemical and radioactive species that were present in the soil column. Two additional boreholes were drilled in nearby waste disposal sites (i.e., B-38 Specific Retention Trench and crib B-7A) under guidance from the 200 Area Remediation Project. Field activities of the two DOE contractors (i.e., Bechtel Hanford, Inc. and CH2M HILL Hanford Group, Inc.) were coordinated. Field and laboratory data were shared between the two groups. Finally, three RCRA groundwater monitoring wells were drilled during this investigation. Near-continuous core samples from one of these wells provided uncontaminated sediments for characterization.

The levels of contamination found in soil samples from the two tank farm boreholes 299-E33-45 and 299-E33-46 and the trench B-38 borehole (C3104) were unexpected. Although the core sample indicated anticipated levels of processed uranium at the BX-102 borehole, other fission product contaminants were significantly less than expected based on historical tank leak reports (GE 1951a; Womack and Larkin 1971), spectral gamma logging data (DOE-GJPO, 1997a, 1998, 2000c), and the leak inventory estimates (Jones et al. 2001). Strontium-90 was the major fission product found in soils analysis data from the B-110 borehole (299-E33-46), in marked contrast to the array of fission products that were expected based on the preliminary tank leak inventory estimate (Jones et al. 2001). Soil analysis data from trench B-38 borehole (C3105) samples revealed far less technetium-99 than was anticipated based on the inventory estimates (Simpson et al. 2001) for wastes discharged to this trench. Thus, results from analyses of samples collected during drilling activities in and around this WMA led to significant reductions in the preliminary tank leak inventory estimates for tanks in B and BX tank farms and in estimates of technetium-99 discharges to nearby specific retention trenches.

The major investigation findings developed from the fieldwork are summarized as follows:

- Radiological and chemical analyses of water and acid extract samples of soils were taken from the tank BX-102 (299-E33-45) and the tank B-110 (299-E33-46) boreholes. In borehole 299-E33-45, the elevated concentrations of several constituents in the tank farm borehole soils were attributed to tank fluid leakage (primarily from tanks BX-102 and BX-101). The set of tank constituents included technetium-99, uranium isotopes, nitrate and sodium. Elevated concentration levels were observed primarily between 23 and 52 m (75 and 170 ft) bgs in the H2 subunit of the Hanford formation. In water extract samples from this zone, technetium-99 concentrations ranged from 5,200 to 536,000 pCi/L, nitrate ranged from 60 to 6,155 mg/L, and sodium ranged from 120 to 11,900 mg/L. Gamma energy analyses of bulk soils showed uranium concentrations between 60 and 1650 µg/g. In a secondary elevated concentration zone in the Plio-Pleistocene unit between 67 and

76 m (220 and 250 ft) bgs, technetium-99 concentrations ranged from 29,800 to 79,100 pCi/L and nitrate ranged from 100 to 1,370 mg/L. Gamma energy analyses of bulk soils showed uranium concentrations between 14 and 31 µg/g between 180 and 180 ft bgs.

- In borehole 299-E33-46, the elevated concentrations of several constituents in the tank farm borehole soils were attributed to tank fluid leakage (primarily from tank B-110). The set of tank constituents included strontium-90, carbonate, fluoride, nitrate, and sodium. Elevated concentration levels were observed at different depth intervals for various constituents. In the upper part of the soil column between 15 and 40 m (50 and 130 ft) bgs, carbonate (3,000 to 8,400 mg/L), fluoride (100 to 215 mg/L), and sodium (1,000 to 83,500 mg/L) were most concentrated. Elevated concentrations of strontium-90 (15 and 60 pCi/L) were observed between 14 and 28 m (46 and 83 ft) bgs. Conversely, nitrate was more concentrated (130 and 1460 mg/L) at 26 and 61 m (84 and 200 ft) bgs. An unusual feature of this porewater chemistry was that carbonate and fluoride are major constituents attributed to the tank waste source. Finally, a few samples at depths in the Plio-Pleistocene unit between 68 and 69 m (222 and 226 ft) bgs contained concentrations of technetium-99 between 39,800 and 89,800 pCi/L. Because technetium-99 is well separated from all other tank waste constituents in the soil column, its source is not attributed to the tank B-110 event. The source is likely from nearby crib discharges.
- A groundwater sample was collected from each borehole. In the sample taken from borehole 299-E33-45, the groundwater was slightly alkaline (pH ~7.5) and contained the contaminants technetium-99 (2460 pCi/L), tritium (2410 pCi/L), and nitrate (55 mg/L). In the sample taken from borehole 299-E33-46, the groundwater was slightly alkaline (pH ~7.5) and contained the contaminants tritium (2810 pCi/L) and nitrate (164 mg/L). In neither case is there a clear indication that the contaminants were discharged into the unconfined aquifer at the borehole location (e.g., vadose zone contamination just above the water table is not consistent with groundwater contaminant concentrations).
- Characterization of soils from the trench B-38 borehole C3104 (DOE-RL 2002) revealed minimal concentrations of technetium-99 and nitrate. Soils analyses from the crib B-7A borehole C3103 (DOE-RL 2002) showed concentrations of cesium-137 (7 to 153,000 pCi/g) and uranium (22 to 330 µg/g) near the bottom of the crib between 7 and 12 m (22 and 48 ft) bgs. Also, zones of elevated pH and sodium were present indicating wastewater-soil interactions. Elevated pH values (greater than 8.5) were measured between 11 and 30 m (35 and 100 ft) with maximum values (9.0 to 9.5) occurring between 11 and 27 m (35 and 90 ft) bgs. Highest sodium concentrations (1,900 and 6,200 mg/L) were between 9 and 40 m (30 and 130 ft) bgs. The soils data indicated that whatever mobile contaminants were initially in the wastewater had been flushed from the soil column and additional contamination would provide no significant potential to contaminate the unconfined aquifer in the future.
- Characterizations of soil samples uncontaminated by tank waste and crib/trench discharges (well 299-E33-338) showed a standard chemical profile with pH values moderately alkaline (~7.5) and ion concentrations moderate. Primary anions were carbonate, sulfate, and chloride with average concentrations of 1370, 290, and 35 mg/L,

respectively. Primary cations included sodium, potassium, calcium, and magnesium, with average concentrations of 190, 60, 140, and 34 mg/L, respectively. These values were likely somewhat artificially elevated because of the water extraction of naturally occurring soluble salts.

In response to the inconsistencies between initial assumptions about tank leak and trench discharge inventories, a major re-evaluation of tank leak records, chemical process operations, and waste transfer records was conducted. In addition, laboratory experiments were conducted to track technetium-99 through the initial plutonium recovery steps of the bismuth phosphate process. An integration of field data, laboratory experimental results, and historical records reevaluation led to the following observations:

- Water content, as well as matric water potential data on core samples were obtained from three boreholes in WMA B-BX-BY. The data indicate the recharge is occurring at all three locations but the drainage near tanks BX-102 and B-110 boreholes is greater than the RCRA well (299-E33-338) at the perimeter of the B tank farm.
- Field data indicate extensive lateral migration of contaminants in WMA B-BX-BY, particularly east of tanks BX-101 and BX-102. Spectral gamma logging data in this area (DOE-GJPO 1998, 2000c) show uranium contamination extending from near the tank walls to more than 30 m (100 ft) east of the tanks demonstrating lateral migration over that distance. Near tanks BX-102 and BX-101, the contact between the coarse-grained and fine-grained sediments of the upper Hanford formation occurs at a depth of about 23 m (75 ft). The fine-grained sediments of the upper Hanford formation appear to have played a major role in the initial migration and transport of uranium. Similar stratigraphic controls also may be operating deeper in the vadose zone. Substantial concentrations of tank waste contaminants were measured in borehole 299-E33-45 (near tank BX-102) soils between two fine-grained layers at 37 and 52 m (120 and 170 ft) bgs. The potential for extensive lateral spreading is also supported by the moisture plume data collected at the injection test site (Sisson and Lu 1984; Ward and Gee 2002) directly southwest of the Plutonium-Uranium Extraction Plant (PUREX) in the 200 East Area. The moisture plume data within the Hanford formation at this controlled field experiment clearly show evidence of extensive lateral spreading and limited vertical migration.
- Inventory estimates for the 1951 tank overfill event at tank BX-102, as reported in Jones et al. (2001), are acceptable and were used in risk modeling activities.
- Current information does not support listing tanks BX-101 and BX-102 as leakers. Contamination around tanks BX-101 and BX-102 can be explained by the 1951 tank overfill event and what was likely a long-term pump pit leak on the dome of tank BX-101. Spectral and gross gamma logging data suggest the tank leak event reported by Womack and Larkin (1971) actually originated from the defective pump pit on top of tank BX-101. The waste composition estimate (Jones et al. 2001) for the pump pit leak at tank BX-101 is acceptable. However, no leak volume (or inventory) estimate could be developed because quantitative data of the discharge event are not available.

- Inventory estimates for the assumed tank B-110 leak (Jones et al. 2001) are not supported by the field data. Although it was possible to identify a likely waste type that was involved in a waste loss event, no volume (or inventory) estimate could be developed. Spectral gamma data suggest a pipe leak source rather than a tank failure (Section 3.2.2.5).
- Technetium-99 inventory estimates for all BX specific retention trenches that received first cycle wastes, as reported by Simpson et al. (2001), were over-estimated by at least an order of magnitude. Revised technetium-99 inventory estimates for first cycle waste discharges were developed using the results from the bismuth phosphate process chemistry simulation experiments (Sections 3.2.3.1 and Appendix C, Section C.3.2.3).
- A distinct contamination zone was present in the Plio-Pleistocene unit in both characterization boreholes within WMA B-BX-BY. The origins of these contaminants in the Plio-Pleistocene unit are unclear, but some contamination from sources outside the tank-associated leaks was indicated. The unusual combination of constituents and relative proportions were unique relative to those at other depths in the boreholes. Further, because distinct contamination was present in both boreholes, the influence of the Plio-Pleistocene unit as a widespread stratigraphic control within the vadose zone, at least over the WMA B-BX-BY area, was plausible. If so, contaminant releases to the unconfined aquifer likely have been and continue to be affected by this unit.

Detailed information is provided in the remainder of Section 3 that supports the noted observations. A summary of hydrogeologic conditions (i.e., local geology, hydrology, undisturbed geochemical conditions, and groundwater flow and contaminant history) in WMA B-BX-BY that are generally applicable to all contamination areas is provided in Section 3.1. Subsequent discussions are organized by major areas of contamination including the area east of tanks BX-101 and BX-102 (Section 3.2.1), the area near tank B-110 (Section 3.2.2) and nearby cribs and trenches (Section 3.2.3). Each subsection assimilates information from the various characterization activities and develops a conceptual model of the impacts of tank wastes entering the vadose zone and groundwater. Estimates of inventories for modeling purposes also are provided. Finally, an overall conceptual model is provided that considers the contaminant contributions to the vadose zone and unconfined aquifer from the combined sources and contaminant history in the unconfined aquifer (Section 3.3).

### **3.1 HYDROGEOLOGIC CONDITIONS**

Geologic, geochemical, and hydrologic characteristics of the Hanford Site and local areas within the Hanford Site (e.g., WMA B-BX-BY) have been extensively studied. The results of those studies, both regional and site-specific, are summarized in Sections 3.1.1, 3.1.2, and 3.1.3. More detailed discussion of the borehole-specific geologic and geochemical characteristics of the WMA B-BX-BY vadose zone are provided in Appendix B. Geologic cross-sections used in numerical modeling and impact assessment (Section 4.0) are included in Appendix E. Undisturbed geochemical conditions in the vadose zone and flow and contaminant history of the local unconfined aquifer are also summarized (Sections 3.1.3 and 3.1.4). More detailed discussion of the unconfined aquifer historical conditions is provided in Appendix C, Section C.6.0.

### 3.1.1 Geology

The geology of the vadose zone underlying WMA B-BX-BY forms the framework through which the contaminants move and provides the basis with which to interpret and extrapolate the physical and geochemical properties that control the migration and distribution of contaminants. Of particular interest are the interrelationships between the coarser- and finer-grained facies, and the degree of contrast in their physical and geochemical properties.

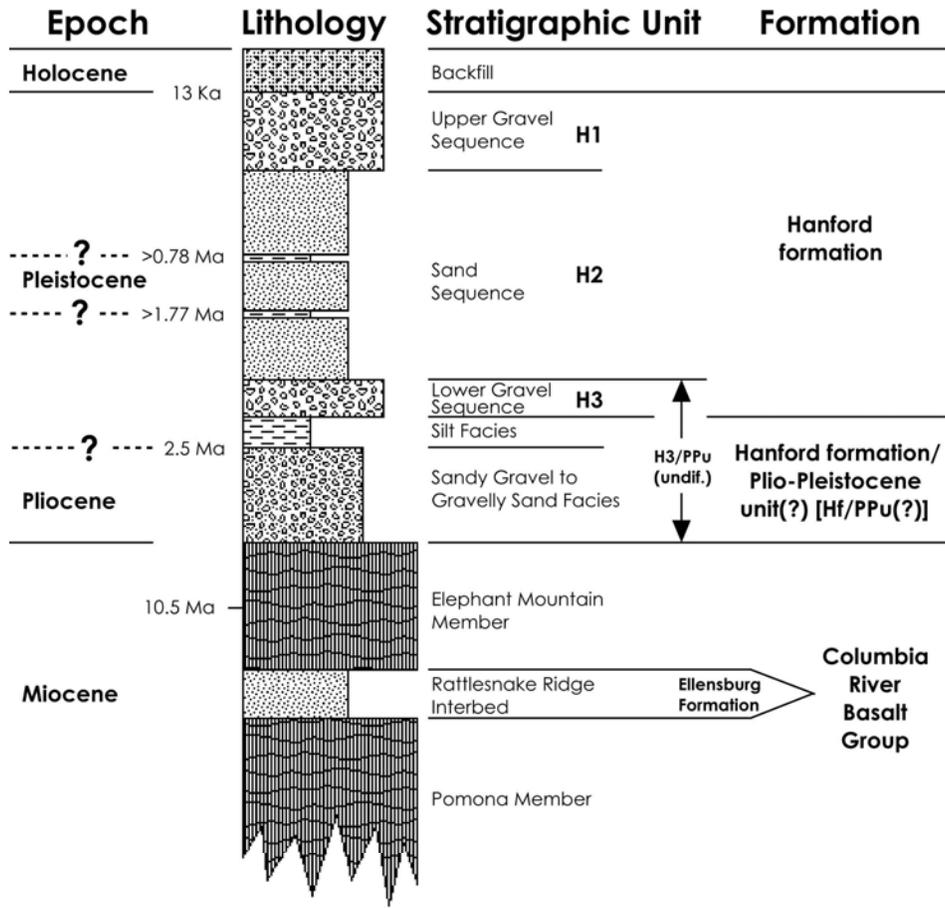
**3.1.1.1 Geologic Setting of WMA B-BX-BY.** The three tank farms in the WMA were constructed over a period of many years. The 241-B tank farm was constructed in 1943 and 1944, the 241-BX tank farm was constructed in 1947 and 1948, and the 241-BY tank farm was constructed in 1949 and 1950. The farms were designed to store high-level radioactive waste generated by chemical processing of irradiated uranium fuel at the chemical separation plants (Appendix C, Section C.2.0). The tank farms were excavated into the Pleistocene-age Hanford formation and Holocene eolian deposits that mantle a portion of the northern flank of the Cold Creek flood bar (Wood et al. 2000). The geology beneath the WMA has been described in numerous reports (Price and Fecht 1976; Caggiano and Goodwin 1991; Caggiano 1996; Narbutovskih 1998; DOE-GJPO 2000a; Wood et al. 2000; and Lindsey et al. 2001). The major stratigraphic units beneath the WMA include (in descending order); the Hanford formation, a unit described as Hanford formation/Plio-Pleistocene unit [Hf/PPu], and the Columbia River Basalt Group (Figure 3.1). The uppermost portions of the Hanford formation were removed during construction of the tank farms; these stockpiled sediments were later used as backfill, and placed around and over the underground storage tanks (Appendix C includes a description of the 241-BX tank farm construction).

The stratigraphic nomenclature used in this report is summarized in Table 3.1. Stratigraphic terminology used in this report is consistent with that presented in Wood et al. (2000) and Lindsey et al. (2001) for the Hanford formation.

Geologic horizons that appear to control the disposition of both wastewaters and contaminants are thin paleosols or fine-grained sand horizons that are encountered within the Hanford formation sediments. The paleosols are soil horizons that developed during periods between major glacial flood events. Paleosols may contain root casts and other organic material; the sediments exhibit features typical of present day soils. Fine-grained (fine sand, silt, and clay) sediments are typical of slack water or overbank depositional environments. Because of the repetitive nature of the Pleistocene flood events, these fine-grained deposits are not always continuous over great distances. Even when readily recognized paleosols are absent, cyclic upward fining sequences are present within the sediments. These fine-grained horizons have been recognized at depths ranging from 26 m (84 ft) in the 241-B tank farm to 72.5 m (238 ft) in the 241-BX tank farm. Extensive horizons, that are present in both B and BX farms, have been recognized at about 58 m (170 ft) and 67 m (220 ft). These fine-grained sediments, both paleosols and less obvious fining upward sequences, provide horizons along which infiltrating water and associated contaminants are laterally dispersed. Detailed geologic descriptions of boreholes 299-E33-45 and 299-E33-46, which were drilled and sampled to support this investigation, are found in Appendix B of this report. These data have been compiled into a physical model as shown in Figures 3.2 and 3.3.

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

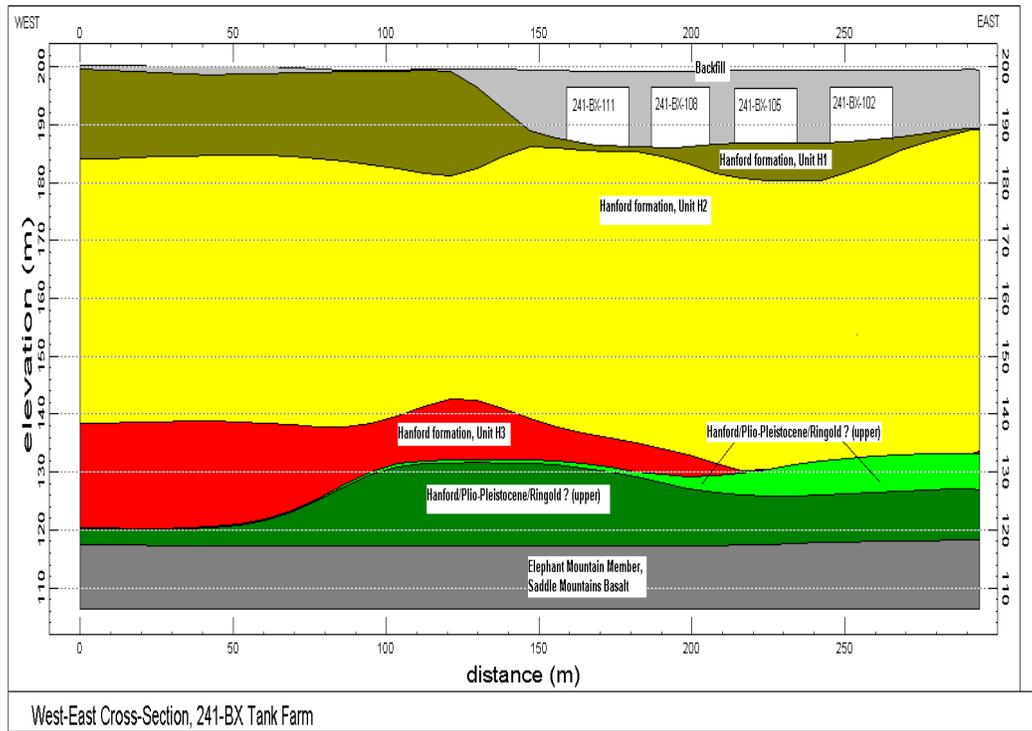
**Modified After Wood et al. 2000**



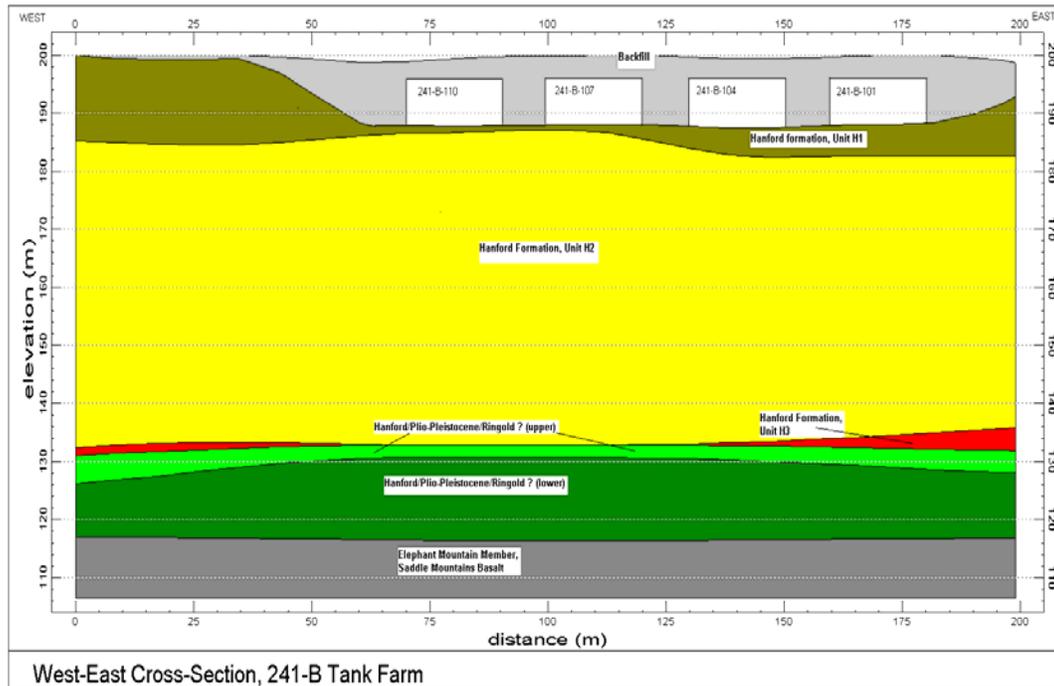
**Table 3.1. Stratigraphic Terminology Used in this Report for the Vadose Zone Beneath Waste Management Area B-BX-BY from Wood et al. 2000**

Stratigraphic Symbol	Formation	Facies / Subunit	Description	Genesis
Backfill	NA	Backfill	<b>Moderately sorted cobbles, pebbles, and coarse to medium sand with some silt</b> derived from Hanford formation excavated around tanks (Price and Fecht 1976)	Anthropogenic
H1	Hanford formation	Unit H1	<b>An upper gravelly sequence consisting of high-energy, gravel-dominated facies interbedded with lenticular and discontinuous layers of sand-dominated facies.</b> Equivalent to the upper gravel sequence discussed by Last et al. (1989) and Lindsey et al. (1992), to the H1 sequence discussed by Lindsey et al. (1994) and the Qfg documented by Reidel and Fecht (1994). Excavated out of most of tank farms in the WMA.	Cataclysmic Flood Deposits
H2		Unit H2	<b>Sand sequence</b> consisting predominantly of sand-dominated facies, with multiple graded beds of horizontal to tabular cross-bedded sand or gravelly sand. Graded beds sometimes capped with thin layers of silty sand or silt. Equivalent to the sandy sequence discussed in Last et al. (1989) and Lindsey et al. (1992), to the H2 sequence discussed by Lindsey et al. (1994) and to Qfs documented by Reidel and Fecht (1994).	
H3		Unit H3	<b>Lower gravel sequence consisting predominantly of gravel-dominated facies with occasional interbedded lenticular and discontinuous sand-dominated facies.</b> Equivalent to the lower gravel sequence discussed by Last et al. (1989) and Lindsey et al. (1992), to the H3 sequence discussed by Lindsey et al. (1994) and the Qfg documented by Reidel and Fecht (1994).	
PPlz	Plio-Pleistocene Unit	Silt Facies	<b>Silty sequence consisting of interstratified well sorted calcareous silt and fine sand.</b> Perhaps equivalent to the “early Palouse soil” (Wood et al 2000) originally described by Tallman et al. (1979). Unit recently included into the Plio-Pleistocene unit (Lindsey et al. 1994; Slate 1996, 2000).	Fluvial overbank and/or eolian deposits (with some weakly developed paleosols)
PPlg		Sandy Gravel to Gravelly Sand Facies	<b>Sandy gravel to gravelly sand sequence consisting predominantly of unconsolidated basaltic sands and gravels.</b> Actual origin of this unit is still uncertain. Without intervening silt facies (PPlz subunit) this unit cannot be differentiated from Hanford formation H3 unit (Wood et al. 2000). Lindsey et al. (2001) believes this unit may be part of the Ringold Formation	Plio-Pleistocene age mainstream alluvium (Wood et al. 2000) or possibly Ringold Formation (Lindsey et al. 2001)

**Figure 3.2. West to East Profile for Cross-Section through Tanks BX-111 through BX-102 (distance ~180 to 300 m) and Trench B-38 (distance ~20 to 70 m)**



**Figure 3.3. West to East Profile for Cross-Section through Tanks B-110 through B-101 (distance ~70 to 180 m)**



The presence of the fine-grained Plio-Pleistocene unit beneath WMA B-BX-BY provides a more extensive horizon along which contaminants can be dispersed. Locally, this unit results in the accumulation of infiltrating water, and can result in the formation of saturated or nearly saturated conditions.

### 3.1.2 Geochemistry of Undisturbed Vadose Zone Soils and Porewater

Geochemical conditions in WMA B-BX-BY are determined by in situ undisturbed vadose zone characteristics, the chemistry of leaked fluids, and the interactions between fluids and the soil-soil water system. Because tank fluids of differing composition were distributed over parts of the vadose zone at various times, geochemical conditions affecting contaminant and other constituent behavior vary both temporally and spatially. This section focuses on the geochemistry of porewater in an area of the vadose zone that has not been contacted by tank, crib or trench waste fluids. Vadose zone geochemical reactions that have influenced contaminant migration in the specific areas of contamination within WMA B-BX-BY are discussed in Section 3.2. The three contaminants of greatest interest identified by these studies are technetium-99, uranium, and nitrate in the tank BX-101 and BX-102 area and strontium-90 in the tank B-110 area.

One RCRA groundwater monitoring well (299-E33-338) was drilled at the southeast corner of the B tank farm just outside WMA B-BX-BY where vadose zone soils have not been subjected to tank leaks or crib and trench discharges.

Soil water chemistry derived from 1:1 extracts is reasonably consistent throughout the soil column and demonstrates no distinct trends (Appendix B, Section B.3). The pH values in borehole 299-E33-338 fall into a normal range (7.0 to 7.8). Primary anions are carbonate (400 to 4,400 mg/L), sulfate (190 to 380 mg/L), and chloride (8 to 60 mg/L). Smaller concentrations of nitrate (3 to 50 mg/L) and fluoride (2 to 24 mg/L) are also present. Primary cations are sodium (70 to 390 mg/L), calcium (60 to 275 mg/L), magnesium (8 to 70 mg/L), and potassium (20 to 110 mg/L). Cation and anion values are likely somewhat elevated because of the dissolution of soluble salts during water extraction. Small quantities of uranium (~ 0.5 µg/g) were measured in all samples and are assumed to be naturally occurring.

### 3.1.3 Hydrology

Natural recharge from meteoric water (from winter precipitation and snowmelt), artificial recharge from operations related sources, and vadose zone hydrology are important drivers for contaminant movement to groundwater. Recharge, vadose zone, and groundwater conditions for WMA B-BX-BY are briefly discussed in the following sections.

**3.1.3.1 Recharge.** 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 the impermeable, sloping surface of the tank domes. This umbrella effect is created by the 23 m (75 ft) inside diameter buried tank domes. Water that is 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 leaks from 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 range 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 (crib B-57) suggest that recharge through gravels can range from 15% to 70% of precipitation, with the lower amount occurring under vegetated conditions (Gee et al. 1993, 1996; Fayer and Walters 1995; Fayer 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). 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 possible that the tank farms experience a recharge rate that ranges between that observed for bare sand and the rate for 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 are not applicable to disturbed sites such as the tank farms.

Soil matric potential is often used as an indicator for deep drainage (recharge) conditions. Attempts were made to determine the soil water status and use the analysis to confirm the occurrence of recharge within WMA B-BX-BY. Water content as well as matric potential data on core samples were obtained from three boreholes in WMA B-BX-BY. The data indicate that recharge is occurring at all three locations but that drainage near the tank BX-102 borehole (299-E33-45) and the B-110 borehole (299-E33-46) is greater than at the RCRA borehole (299-E33-338) at the perimeter of the B tank farm. In situ vadose zone monitoring at the B-110 borehole since August 2001 (Gee et al. 2002) confirms drainage at this location. Water content data at the B-110 borehole show very little variation over time, indicating that conditions at this borehole reflect unit gradient (equilibrium) conditions. Compared to the RCRA borehole, the enhanced observed drainage near the BX-102 and B-110 boreholes is attributed to the coarse, bare gravel surfaces that cover the tank farms. Matric potential data at the RCRA borehole are consistent with the hypothesis that non-vegetated areas, with coarse-textured surfaces, drain more than areas with similar soil, but with vegetation present. It appears that the wetting front from meteoric sources has not reached the water table at this site. Similar conclusions were also reached for matric potential data for sediment samples at the two RCRA borehole sites outside of the SX tank farm in WMA S-SX (Knepp 2002). The matric potential and the water content data for the three boreholes in WMA B-BX-BY are discussed further in Appendix C.5.0.

While the matric potential data do not provide quantitative estimates of recharge at WMA B-BX-BY, they do suggest enhanced drainage for the gravel-covered, non-vegetated surfaces at the tank farms. For the purposes of the numerical modeling for the FIR, a base case recharge estimate of 100 mm/yr (3.9 in./yr) was 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) was used. This is based on experimental data from a prototype Hanford barrier that has been designed and built in the 200 East Area (crib B-57) to limit recharge to less than 0.5 mm/yr (0.02 in./yr) (DOE-GJPO 2000a). 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 3.2 summarizes the timeline estimates for barrier emplacement and the corresponding recharge estimates.

**Table 3.2. Timeline Estimates for Emplacement of Interim and Closure Barriers at WMA B-BX-BY 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 with design life of 500 years (years 2040 to 2540)	0.1
Degraded closure barrier after 500 years (years 2540 to 3000)	3.5

**3.1.3.2 Vadose Zone Hydrology.** Because water movement is the primary mechanism for radionuclide and chemical transport, an objective of the WMA B-BX-BY 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, pre-existing 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 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 man-made (e.g., unsealed monitoring wells). Although 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 the 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 release events 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, which is a condition that can potentially exist during release events. However, unlike S-SX tank farm conditions where the ionic strength of the plume is extremely high, such conditions are not expected to dominate fluid and contaminant migration during release events at the BX tank farm.

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 conduits 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 1997). Therefore, the presence of clastic dikes in unsaturated media appears unlikely to contribute much to the transport to groundwater of the bulk quantity of leaked wastes and, based on the results of WMA S-SX FIR simulations (Knepp 2002), are not expected to contribute significantly to long-term risk in terms of higher peak concentrations for long-lived mobile radionuclides. Clastic dikes are not considered in WMA B-BX-BY FIR simulations (Appendix E).

A field study in the 200 East Area south of PUREX 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-grained 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 that the vadose zone water content profiles are at quasi-equilibrium with the natural recharge rate. Recent field experiments at the Sisson and Lu site with water and hypersaline fluids demonstrated the importance of fine scale heterogeneities on lateral spreading (Gee and Ward 2001). A variety of advanced characterization and monitoring technologies were used at this particular site to examine vadose zone field scale flow and transport processes. Results of the recent controlled field experiments at the Sisson and Lu site are currently being analyzed using flow and transport modeling. Details are provided in Appendix D.

Stochastic theory suggests that 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 spreads laterally in the fine media rather than

vertically through the coarse media. Such a phenomenon is referred to as moisture dependent anisotropy and can potentially be a dominant mechanism for the observed lateral flow at the Sisson and Lu site. This has important implications for vadose zone contaminant transport from release events. For example, spectral gamma logging data on the distribution of selected radionuclides within the vadose zone at the BX tank farm suggest extensive lateral spreading (DOE-GJPO 1998). Near tanks BX-102 and BX-101, the contact between the coarse-grained and the fine-grained sediments of the upper Hanford formation occurs at a depth of about 23 m (75 ft), and the fine-grained sediments appear to play a major role in transport. Much of the uranium-238 (the most mobile of the measured radionuclides) contamination is in the eastern portion of the tank farm and away from tanks BX-101 and BX-102, and appears to have migrated laterally more than 30.5 m (100 ft) within the fine-grained sediments. Such evidence of extensive lateral spreading is also supported by measurements of vadose zone contamination at the SX tank farm (DOE-GJPO 1996) and the tank T-106 leak (Routson et al. 1979) suggesting significant lateral movement. As described in Appendix E, moisture dependent anisotropy effects are included in modeling.

Site-specific data on soil moisture characteristics (i.e., moisture content versus matric potential and unsaturated hydraulic conductivity versus moisture content relationships) are not yet available for vadose zone sediments in the WMA. 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, 2001; Khaleel and Relyea 1997, 2001; Khaleel 1999). 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 WMA B-BX-BY. 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 WMA B-BX-BY. Details are provided in the WMA B-BX-BY FIR modeling data package (Khaleel et al. 2001). The data used in modeling are summarized in Appendix E. Appendix E also provides effective or upscale values of flow and transport parameters for the vadose zone at WMA B-BX-BY. Upscaling methods are described in Khaleel et al. (2002a, b).

**3.1.3.3 Groundwater Hydrology and Contaminant History.** Groundwater characteristics pertinent to contaminant occurrence and migration in the unconfined aquifer underlying WMA B-BX-BY and surrounding area have undergone considerable changes over time. In particular, major changes in flow direction, and types and levels of contamination have occurred over time (Figure 3.4). A synopsis of the primary changes is provided in this section. A more detailed discussion of groundwater flow and contaminant history is provided in Appendix C, Section C.6.0. An integration of the overall conceptualization of tank, crib, and trench releases and subsequent migration is provided in Section 3.3.

Groundwater flow direction history has been interpreted from two primary sources, water level measurements in a few wells from which relatively regular measurements have been taken since the mid 1950s and historical records of intentional liquid discharges to facilities in the area. From these data, it appears that intentional discharges to B Pond, east of WMA B-BX-BY, and

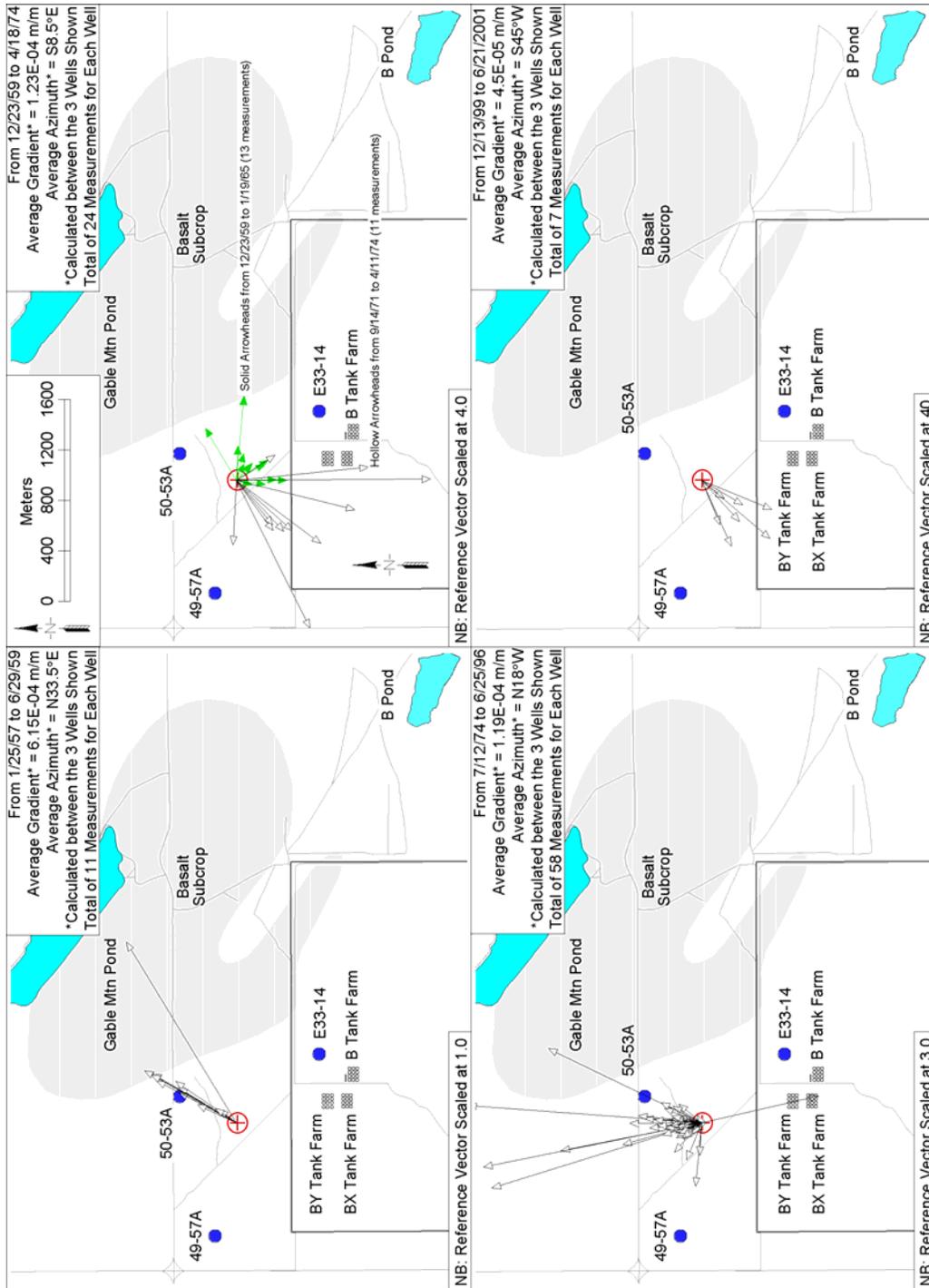
Gable Pond, north of WMA B-BX-BY, were of sufficient magnitude to alter the general flow direction of the unconfined aquifer. Prior to Hanford operations, the general flow direction through this region is thought to have been from west to east. As Hanford operations proceeded, four different flow direction trends have occurred (Figure 3.4). The first major change in flow direction was a shift northward in the mid 1950s due to the development of a groundwater mound underlying B Pond. The second change occurred from the late 1950s to the early 1970s during which the general flow direction was southerly, presumably because of the groundwater mound that had formed underneath Gable Mountain Pond. Then the data show a gradual shifting of flow direction to the west beginning in 1971. The third major period appears to be from the mid 1970s to the mid 1990s. Fourth and currently, the flow direction appears to be reversing again from a northerly to a southerly direction.

Based on analysis of hydrographs and recent flow meter measurements (Hartman et al. 2002), the direction of groundwater flow tends to be southwest from the BY cribs across the BY tank farm; it then swings south to southeast through the BX and B tank farms. Hydraulic gradient estimates are of the order of 0.0001 m/m (Figure 3.4), whereas the saturated hydraulic conductivities are about 1600 m/day (Hartman et al. 2002). Estimates for porosity are of the order of 0.30 (Hartman et al. 2002); such an estimate falls within those usually reported for semi-consolidated to unconsolidated alluvial aquifers of 0.05 to 0.30, and brackets the large-scale value used in the Hanford Site-wide groundwater model (Appendix E).

The estimated Darcy flow rates in WMA B-BX-BY can be as much as 1 m/day (Hartman et al. 2002). In situ flow measurements conducted in fiscal year 2000 indicate that although this rapid flow rate may be correct for some portion of the WMA, it does not apply for the entire WMA. In fact, the flow meter measurements in the northern portion of the WMA are much lower. Flow rates used in the FIR modeling (Appendix E) are based on site-wide groundwater model data and are generally lower than the Hartman et al. (2002) estimates. As mentioned earlier, the natural flow pattern in WMA B-BX-BY is altered by the formation of groundwater mounds created by the discharge of large volumes of wastewater at disposal facilities, Gable Mountain Pond, and B Pond. With the cessation of discharges, groundwater mounds are declining, and groundwater flow is gradually returning to pre-Hanford conditions. The water table is gradually declining at the rate of approximately 15 cm/yr (6.0 in./yr) and the unconfined aquifer thickness is only several meters thick in many places across the WMA (Hartman et al. 2002).

Groundwater contamination aspects in and around the WMA are discussed in Section 3.3 as well as in Appendix C, Section C.6.0. The first appearance of contaminants in the unconfined aquifer was noted in the mid 1950s in groundwater monitoring wells installed around the BY cribs. Nitrate, cobalt-60, and gross beta-emitting contaminants were noted and are attributed to the BY cribs source. Given what is known or deduced about the waste stream composition, technetium-99 was a major contributor to the gross beta measurement. The technetium-99 inventory discharged from this source is considered to be substantially larger than any other subsequent waste discharge in the area (Section 3.3) as the flow directions changed over time. Mobile constituents moved with groundwater.

Figure 3.4. Summary of Trend Surface Groundwater Flow Direction Results



Note: Velocity is proportional to the gradient that is indicated by the lengths of the arrows. A relative scale referenced to the first panel was used. Scaling factors are shown in the lower left hand corner. For example, a factor of 3 means that the arrow length or gradient in this panel is 1/3 of same the length shown in the first panel with a scaling factor of 1, and so on.

After the mid 1950s, relatively little tracking of contaminants in groundwater was done until the early 1990s. Discharges to the unconfined aquifer from other sources likely have occurred in this area and commingled with the BY crib discharges. Currently, elevated concentrations of technetium-99, uranium, cyanide, chromium, tritium, and nitrate are present in local groundwater (Appendix C, Figure C.30). Concentration contours for technetium-99, cyanide, uranium, and chromium generally show a northwest to southeast trend, which may indicate the presence and influence of a paleochannel. Nitrate and tritium are distributed over a much greater area.

Most of these constituents could have been derived from any one or more of several sources and the ability to link contaminants in a particular groundwater monitoring well to a particular source is limited. It does appear that the recent occurrence of cyanide, technetium-99, and nitrate peaks near the BY cribs indicate an ongoing southerly migration of BY crib wastes initially discharged to the unconfined aquifer in the mid 1950s. Also, the uranium and technetium-99 occurrences in groundwater monitoring wells near the BX and BY tank farms appear to be at least partly derived from tank waste sources within WMA B-BX-BY. Finally, chromium contamination may be linked to discharges from the 216-B-8 crib.

### **3.2 NATURE AND EXTENT OF SUBSURFACE CONTAMINATION IN TARGETED AREAS**

An understanding of the nature and extent of subsurface contamination in WMA B-BX-BY is needed to complete transport modeling and risk assessment calculations (Section 4.0 and Appendix E). Developing this understanding has been challenging because of the long time these tanks were in active service (1944 to 1980), complexity of the waste streams residing in these tanks (Section 3.4), extensive waste losses from tanks and infrastructure (Williams 1999), and intentional discharges of wastes to cribs and trenches near WMA B-BX-BY (Waite 1991). Before the field investigation phase of this study, a preliminary conceptual model of the subsurface contamination was developed that was based on historical tank farm operations records (Williams 1999), geology and hydrology (Wood et al. 2000), gross gamma and spectral gamma logging data, and preliminary tank leak inventory estimates (Jones et al. 2001). A field investigation program was developed based on this conceptual model and wells were drilled near tanks BX-102 and B-110. Results from the field activities coupled with additional laboratory studies and additional evaluation of historical processing records have led to a better understanding of the nature and extent of subsurface contamination in WMA B-BX-BY. Finally, consideration has been given to wastes discharged to the vadose zone from nearby cribs and trenches because of apparent interactions of contaminants from these sources with tank farm waste.

This section summarizes the estimates of current vadose zone contaminant concentrations and their distribution in the subsurface for several separate areas of contamination within and around WMA B-BX-BY. Section 3.2.1 addresses contamination in the vadose zone east of tanks BX-101 and BX-102. Section 3.2.2 discusses contamination in the vadose zone between tanks B-110, B-111, B-107, and B-108. Section 3.2.3 discusses contamination in the vadose zone underlying the cribs and trenches around WMA B-BX-BY.

### 3.2.1 Nature and Extent of Contamination East of Tanks BX-101 and BX-102

Tank waste contamination in the vadose zone east of tanks BX-101 and BX-102 is the result of a complex series of events. Several lines of investigation have been completed to better understand these events including soils analyses from the characterization borehole (299-E33-45), a reevaluation of the historical operations and process flow chemistry records, and integration of these data with gamma logging data and kriging estimates of uranium inventory. The information derived from these studies is summarized in the following sections. Also, the information has been used to derive a set of conceptual models to explain the current state of contamination and to estimate mobile contaminant inventories for risk modeling analyses described in Section 4.0.

Integration of this information leads to the following key observations:

- Two events discharged tank waste into the vadose zone, one as a result of a tank overflow in tank BX-102 in 1951 and the other as a pump pit leak on top of tank BX-101 in the late 1960s to early 1970s.
- The 1951 tank BX-102 volume and composition are well documented as a 91,600 gal loss of metal waste. Uranium is a signature contaminant for this waste type. The later pump pit leak characteristics are less well understood. The waste type from this later leak is likely from the cesium recovery process waste derived from B Plant operations, but a volume estimate cannot be determined because quantitative data of the discharge rate and duration are not available. Antimony-125, europium-154, and cobalt-60 found in the vadose zone are signature contaminants for this waste type.
- Strong lateral movement to the east of the BX tank farm characterized early distribution of contaminants as indicated by elevated concentrations of tank waste constituents between 37 and 52 m (120 and 170 ft) bgs in soils analyzed from borehole 299-E33-45. Also, spectral gamma data of the signature contaminants in a suite of drywells east of tanks BX-101 and BX-102 cover a large area and show concentration peaks at approximately the same depth interval.
- A second zone of concentrated technetium-99, nitrate, and tritium occurs in and slightly above the Plio-Pleistocene unit between 61 and 70 m (200 and 230 ft). A perched water layer exists within this zone. The difference in contaminants between this and the shallower layer combined with the occurrence of perched water suggests alternate sources of contamination and additional lateral migration in the vadose zone.
- Subsequent migration of these contaminants is poorly understood. A 1997 observation of coupled uranium and technetium-99 peaks at a groundwater monitoring well (299-E33-41) just east of the contaminated vadose zone area provide one indication of waste migration into the unconfined aquifer (Hartman et al. 1999). Additional, but unrecorded, discharges to the unconfined aquifer are likely as the estimates of current inventories in the vadose zone from soils data yield inventory estimates well below those estimated from historical evidence.

From these observations, the contaminants uranium, technetium-99, and nitrate were selected as those most likely to contaminate groundwater in the future. Selection of inventory values for risk modeling was complicated by source term uncertainty and inconsistency between field measurements and historical information. Estimates were made by relying on the most credible information: the contaminant concentrations measured in soils taken from borehole 299-E33-45, drywell spectral gamma measurements of uranium, and the metal waste inventories of uranium, technetium-99, and nitrate based on historical records. Using this approach, current vadose zone inventory values of 3.15 Ci, 4.37 Ci, and 13,100 kg were estimated for uranium, technetium-99, and nitrate, respectively (Appendix E, Section E.2.4.2). The database strongly indicates that these values are conservatively high relative to field data extrapolations. Given the generally proportional relationship between source inventory and future environmental impacts, it is concluded that bounding high estimates of future environmental impacts can be calculated, thereby fulfilling the field investigation plan objectives identified in Chapter 1, Section 1.1. Therefore, the cost of additional characterization efforts cannot be justified.

**3.2.1.1 Borehole 299-E33-45 Construction and Sampling.** Borehole 299-E33-45 was constructed in the 241-BX tank farm using a cable-tool (percussion) drill rig. An on-site geologist conducted geologic logging using drill cuttings collected from drive barrel samples and observation of splitspoon (SPT) sleeve and shoe contents. Geologic logging was performed on near-continuous samples within the limits of drive barrel and SPT sampling techniques.

A total of 35 SPT samples were collected and submitted for laboratory analyses (Table 3.3). Depth control for the samples was established by measuring the depth of the borehole with a steel line measure. Measurements were recorded to the nearest one hundredth of a foot.

**3.2.1.2 Summary of Field Data from Borehole 299-E33-45.** Radiological and chemical analyses were performed on water and acid extracts of soil samples taken from borehole 299-E33-45, about 25 m (75 ft) east of tanks BX-101 and BX-102. Constituents at elevated concentrations that are attributed to a tank waste source include technetium-99, uranium, tritium, nitrate, sulfate, and possibly phosphate and iron (Figure 3.5). Two distinct depth intervals containing elevated contaminants are apparent. First, the depth interval between 37 and 52 m (120 and 170 ft) bgs in the H2 subunit of the Hanford formation contains the majority of the waste constituents. In water extract samples from this zone, technetium-99 concentrations ranged from 5,200 to 536,000 pCi/L; nitrate ranged from 60 to 6,155 mg/L and sodium ranged from 120 to 11,900 mg/L. Concentration peaks occur at about 49 m (160 ft) bgs for nitrate, sulfate, chloride, calcium, magnesium, sodium, potassium, natural strontium, and technetium-99.

Other concentration peaks in this interval include uranium and phosphate at about 37 m (120 ft) bgs and fluoride at about 43 m (140 ft) bgs. Gamma energy analyses of bulk soils showed uranium concentrations between 60 and 1650 µg/g. Sporadic high tritium concentrations occur throughout this zone. Two silt-rich lenses that may have influenced initial lateral migration of multiple tank waste fluids through the vadose zone and subsequent vertical migration through the soil column bracket this depth interval. The silt-rich layer at 52 m (170 ft) bgs is particularly well defined.

**Table 3.3. Sample Recovery from 299-E33-45**

<b>Sample Number</b>	<b>Depth in feet bgs</b>	<b>Sediment Type</b>	<b>Percent Recovery</b>
1	9.34-11.39	Sandy gravel	75
2	19.09-21.59	Sandy to pebbly gravel	98
3	30.0-32.6	Sandy gravel	100
4	40.29-42.59	Sand w/pebbles	100
5	49.89-52.39	Sand	100
6	60.94-63.74	Sand	100
7	69.34-71.99	Sand w/ occ. pbls	100
8	72.14-74.14	Sand	100
9	73.9-76.4	Sand w/ silt	100
10	76.44-78.94	Sand	100
11	77.59-81.79	Sand	100
12	87.9-91.1	Sand	100
13	98.34-100.54	Sand turning silty	100
14	109.39-111.59	Sand	100
15	117.29-119.49	Sand	100
16	119.14-121.34	Silty sand	100
17	129.1-131.4	Sand	100
18	139.8-141.7	Sand	100
19	149.5-152.1	Sand	100
20	159.1-161.3	Sand	100
21	166.9-169.1	Silt/sand stringers	100
22	169.3-171.5	Coarse sand w/ silt contact	100
23	171.6-173.8	Sand w/ trace pbls	100
24	180.2-182.1	Sand, some gravely sand	90
25	189.0-191.3	Sand	90
26	199.7-201.9	Sand, slightly gravelly	100
27	209.67-211.9	Sand, slightly gravelly	100
28	217.8-220	Sand/silt contact	100
29	219.97-222.2	Silt	100
30	222.2-224.1	Silt	90
31	229.7-231.9	Silt	100
32	240.1-242.3	Sandy gravel	90
33	243.5-245.7	Sandy gravel	100
34	250.1-252.3	Sandy, silty gravel	75
35	251.9-254.1	Sandy, silty gravel	100



Quantitative correlation between the observed contaminants and their sources in this zone is ambiguous. With the exception of uranium whose source is almost entirely the metal waste leak, either the tank BX-102 metal waste overflow event or the tank BX-101 cesium recovery waste pump pit leak could have contributed the other constituents. Also, comparisons of constituent ratios do not yield a good fit with estimated tank leak compositions. These observations lead to multiple conceptualizations of events that have created the current state of contamination (Section 3.5).

A second high concentration zone (Figure 3.5) containing elevated technetium-99, tritium, and nitrate occurs in the Plio-Pleistocene unit between 61 and 70 m (200 and 230 ft) bgs. Technetium-99 concentrations ranged from 29,800 to 79,100 pCi/L and nitrate ranged from 100 to 1,370 mg/L. Within this zone is a perched water interval between 69 and 70 m (226 and 228 ft) bgs. Perched water analyses show slightly elevated tritium and nitrate levels and decreased technetium-99 concentrations relative to water extract concentrations from porewater in soils above and below the perched water zone. This variation with depth suggests lateral influx of water from a non-tank source that was enriched in tritium and nitrate and depleted (or absent) in technetium-99 relative to contamination already present in soil at and around the current perched water depth interval.

### **3.2.1.3 Tank BX-101 and BX-102 (299-E33-45) Vadose Zone Contaminant Geochemistry.**

Two primary tank waste fluids (a metal waste loss in 1951 and a cesium recovery waste discharged between 1968 and 1972) are postulated to have interacted with the vadose zone thereby enriching the soil column in a variety of constituents at borehole 299-E33-45. Both waste streams were characterized by an elevated pH (~10 to 11) and contained significant quantities of technetium and nitrate. Other primary constituents present in both waste streams included the anions carbonate, nitrite, and sulfate and the cation sodium. Metal waste also contained elevated uranium, phosphate, and iron. Cesium recovery waste contained high concentrations of antimony-125. These constituents provide the most direct evidence of tank waste interaction with the soil column and clues to the geochemical perturbation that developed subsequently. At the same time, the fact that both waste streams have numerous chemical similarities creates ambiguity as to the genesis of contaminant distribution patterns in the soil column.

In addition to these events, other wastewater releases in the area are inferred from contaminant residue in the soils. First, several drywells near borehole 299-E33-45 show typical indications of surface spills as maximum cesium-137 concentrations shown by spectral gamma analysis occur near ground surface and decrease with depth. In drywells 21-27-10 and 21-27-09, cesium-137 extends to the bottom of the borehole at about 150 ft bgs. No record of a specific spill event has been identified to provide an indication of spill timing or chemistry. Second, a perched water zone was observed between 69 and 70 m (226 and 228 ft) bgs that is enriched in tritium and nitrate and depleted in technetium-99 relative to porewater in soils immediately above and below this zone. This contaminant distribution pattern suggests a zone of preexisting contamination into which a fluid of differing composition migrated.

Beginning with the introduction of metal waste into the soil column, an interaction between different pH fluids began. Initially, the metal waste high pH (i.e., about 10) would have been dominant. Over time, the overwhelming buffering capacity of the soil water system should

reduce the overall pH back to in situ values of approximately 7.5 to 8. In borehole 299-E33-45, an elevated pH zone (i.e., values between 8.5 and 9.5) between 23 and 46 m (75 and 150 ft) bgs remains. This indicates incomplete buffering has occurred. However, it is not clear that this remnant high pH zone is primarily an indicator of the metal waste leak discharged in 1951 or the incursion of a high pH cesium recovery waste leak that occurred about 20 years later. It is possible that pH values have cycled up and down since 1951 as successive infiltrations of high pH fluids passed through the soil column.

One effect of the initial pH drop appears to have been the precipitation of uranium-bearing phases, uranium sorption, or both (Appendix D, Sections D.3.2, D.3.3, D.3.4) that provided a substantial retardation of uranium migration. In borehole 299-E33-45, the enriched uranium zone is generally coincident with the partially buffered pH zone. The hypothesis that a substantial fraction of the uranium inventory that was initially deposited into the soil column is still present is supported by the comparison of kriging estimates of current inventory using spectral gamma data (i.e., about 1 metric ton) with estimates from processing and tank operations records (i.e., about 8 metric tons according to Jones et al. [2001]).

A second effect of metal waste infiltration was the introduction of a large sodium inventory into the soil column that should have had the effect of displacing divalent cations sorbed on various soil minerals. If vertical flow is dominant, a crude ion exchange effect should occur with divalent cations being enriched below sodium in the soil column. An enriched zone of calcium, magnesium, and natural strontium does exist about 49 m (160 ft) bgs suggesting that this phenomenon has occurred. However, the sodium peak also occurs at approximately the same location so the mechanism explaining these data is unclear. As with the changes in pH, the cesium recovery waste intrusion provides an additional source of enriched sodium to the soil column. Consequently, the true source of the observed sodium enrichment cannot be determined. It is also not clear if vertical or horizontal migration of sodium-bearing liquid is having the largest effect on divalent cation displacement.

Little data exist suggesting that nitrate or technetium-99 is chemically reactive in the soil-soil water system. Thus, it is generally postulated that the zones of highest enrichment mark the leading edge of plume migration generated strictly by physical processes. In borehole 299-E33-45, maximum technetium-99 and nitrate levels coincide about 49 m (160 ft) bgs, which is just above the silt-rich zone at about 52 m (170 ft) bgs. Smaller technetium-99 and nitrate peaks are also shown in the Plio-Pleistocene between 67 and 70 m (220 and 230 ft) bgs. The similarity of the nitrate and technetium-99 distribution patterns indicates that both constituents are nonreactive as expected and travel with water. However, given the multiple events releasing these constituents to the soil column, the dominant source of the two enriched zones is unclear.

The final chemical process that probably occurred in the soil column affecting tank waste constituents was a temporary mobilizing condition for multivalent cations that existed in the tank waste fluid as it was discharged. In particular, the widespread presence of antimony-125, cobalt-60, and europium-154 indicate that these constituents must have been chemically mobile long enough to migrate 30 m (100 ft) from the point of discharge. Available laboratory and thermodynamic data (Appendix C, Section C.7) indicate that antimony-125 is naturally mobile. Therefore, the observed distribution of antimony-125 is reasonably explained. However, cobalt-60 and europium isotopes should be reactive and less mobile in the undisturbed vadose

zone geochemical environment. Several organic chelating agents were used in the isotope recovery process to improve the efficiency of cesium-137 and strontium-90 separation using ion exchange columns. Chelating other cationic species with organics to prevent their preferential sorption favored cesium-137 and strontium-90 sorption. The chelating species could have remained stable as waste was transferred from B Plant to tank BX-101 and subsequently leaked into the vadose zone. Because these contaminants are still present high in the vadose zone, the chelating species must have destabilized causing these constituents to sorb on nearby soils.

**3.2.1.4 Historical Tank Leak Investigations.** Tank BX-102 is currently listed as a known or suspected leaker in the monthly waste tank summary report (Hanlon 2002) with an estimated leak volume of 70,000 gallons. The Hanlon (2002) leak information about tank BX-102 is derived from a 1971 report (Womack and Larkin) documenting the results of an extensive field investigation. The 70,000-gallon leak volume reported by Womack and Larkin (1971) was based on analysis of neutron logging (soil moisture) data from nineteen new drywells installed to investigate the plume from the suspected tank leak event that was thought to have taken place in the 1969 to 1970 time frame. However, the validity of the moisture logging data is highly questionable. Womack and Larkin (1971) report the saturated moisture plume to be coincidental with the high gamma activity region. Recent moisture-logging activities in the SX tank farm have demonstrated that high gamma activity may invalidate the moisture measurements (Myers 2000). Thus, neither the 70,000-gallon leak volume estimate nor the Womack and Larkin (1971) estimate that 51,000 Ci of cesium-137 were lost can be defended. The gamma logging analysis (Myers 1999a; DOE-GJPO 1998) show that little cesium-137 was in the high gamma activity region reported by Womack and Larkin (1971). It appears the gross gamma activity reported by Womack and Larkin was likely a combination of ruthenium-106, cobalt-60, and antimony-125.

The waste type associated with a 1951 tank BX-102 overfill event was incorrectly characterized as a bismuth phosphate first-cycle waste spill (Womack and Larkin 1971). However, detailed information about the 1951 tank overfill event, not declassified until 1992, clearly identifies the waste plume as involving a bismuth phosphate metal waste. It was reported in the classified *Hanford Works Monthly Report for February 1951* (GE 1951a) that 22.5 tons of uranium were lost in the 91,600 gallons of metal waste that overflowed from tank BX-102 in 1951. However, uranium solubility data published in the *Uranium Recovery Technical Manual* (GE 1951b) would indicate the total amount of uranium lost to be much closer to 7 to 8 tons.

In 1970, tank BX-102 was declared a leaker, pumped to a minimum heel, and 50 tons of diatomaceous earth were added to the tank, thus ending the leak investigation (Womack and Larkin 1971). During the 1970 BX-102 field investigation, one well (21-02-04) close to tank BX-102 was drilled to groundwater. Laboratory analyses of soils from this borehole indicated that cesium-137 contamination was to a depth of ~120 ft bgs. The drilling log reports indicate contaminated soil with up to 10,000 cpm in the region around 200 ft bgs (DOE-GPJO 1997b). However, gross gamma logging shortly after the well was completed indicated gamma contamination had spread to groundwater (Womack and Larkin 1971). Drilling logs indicate that additional well maintenance activities were completed over the next several years. Finally, in 1976, this well casing was sealed through a grouting process. The likely scenario is that since well 21-02-04 was drilled through a highly contaminated zone and the casing was left unsealed, the borehole provided a pathway for tank wastes to reach the groundwater.

Complicating the situation even further was a leak from a pump pit on the top of tank BX-101. It is not known when tank BX-101 pump pit leak began nor is the leak volume known. However, tank BX-101 began being used as a B Plant receiver tank in 1968 and received about 22.5 million gallons of tank waste between the beginning of 1968 and the end of 1972, when the tank was taken out of service. A detailed discussion of fuel processes, waste types, and waste transfers associated with tank BX-101 during this time is provided in Appendix C, Section C.3.1.4. It was concluded that the variety of waste streams transferred through tank BX-101 were generated by the cesium recovery process and from PUREX low-level waste streams. The tank BX-101 pump pit leak was confirmed in mid-1972 by hand auguring a borehole down to the base of the pump pit. Highly contaminated soil samples were collected from the base of the pump pit (Jensen 1972). These findings led to the deactivation of tank BX-101 at the end of 1972.

It is not unreasonable to speculate that the source of the tank waste contamination assumed to have come from tank BX-102 by Womack and Larkin (1971) may have come from the leaking pump pit on top of tank BX-101. It is reasonably certain that liquids from the tank BX-101 pump pit leak would have drained down the open borehole 21-02-04 into the groundwater. Although the leak volume estimate from tank BX-101 is unknown, the spectral gamma logging data show a plume that appears to emanate from a region near the pump pit.

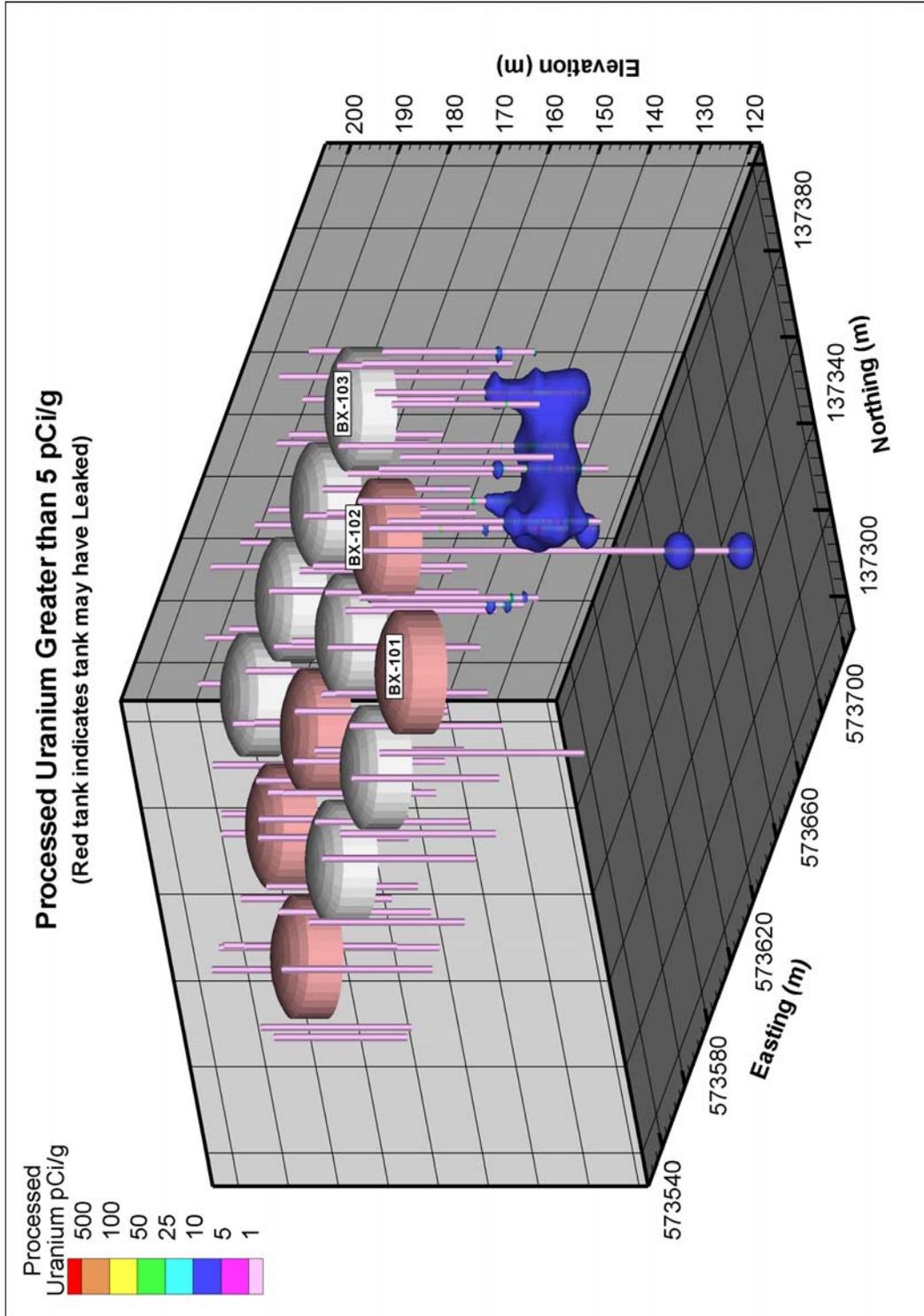
**3.2.1.5 Kriging Analysis.** The historical gross gamma data (Myers 1999a) and spectral gamma logging data (DOE-GJPO 1998, 2000c) from wells east of tanks BX-101 and BX-102 strongly support the idea of two major waste loss events from tanks BX-101 and BX-102. That is, the 1951 tank BX-102 metal waste leak and the suspected 1968 to 1972 BX-101 pump pit leak. In addition, there is strong evidence for an undocumented surface spill of cesium-137 contaminated waste east of tank BX-102. In part, the rationale for the selection of the location of the BX-102 borehole (299-E33-45) was to collect soil samples from the apparent overlapping plumes.

The baseline spectral gamma logging data provided the most current and extensive assessment of vadose zone contamination in the tank farms of interest (DOE-GJPO 1997a; DOE-GJPO 1998; DOE-GJPO 2000a through d). Given the large database, opportunities for estimating radionuclide inventories in the contamination area using kriging methodology were explored. This task involved two major efforts, one was to establish the zones where there was sufficient data density to support the mathematical analysis and the second component was the application of the geostatistical technique to the data sets of interest. All individual radionuclide data sets were evaluated and only the uranium data set was large enough to apply the kriging methodology. Uranium activities and associated volumes are summarized in Table 3.4 by activity level. An example of the projected three-dimensional image of the contaminated soil is shown in Figure 3.6. A total uranium inventory of about 0.415 Ci was calculated. Additional details of the analysis are found in Appendix C, Section C.3.3.

**Table 3.4. Kriged Estimates of Contaminated Soil Activities and Volumes for Various Activity Levels of Uranium**

Cutoff Threshold (pCi/g)	1	5	10	25	50	100	500
Volume (m <sup>3</sup> )	8390.8	5764.0	4459.4	2703.1	1326.3	479.1	3.4
Activities (pCi)	4.15E+11	4.03E+11	3.86E+11	3.34E+11	2.45E+11	1.40E+11	3.54E+09

**Figure 3.6. Three-Dimensional Krigged Image of Processed Uranium Soil Contamination Greater than 5 pCi/g**



Krigged uranium-238 plumes indicating contamination below 120 feet in drywell 21-02-04 are based on somewhat less reliable uranium-238 spectral gamma logging data. These data are less reliable because of interferences from the high levels of cesium-137 in the soil

**3.2.1.6 1951 BX-102 Metal Waste Leak Inventory and 1968 through 1972 Tank BX-101 Waste Composition Estimates.** Tank waste composition estimate for the 1951 tank BX-102 overfill was previously published (Jones et al. 2001) and the estimate remains unchanged as a result of this field investigation. The waste composition estimates are presented in Table 3.5.

The tank waste composition estimate for tank BX-101 published in Jones et al. (2001) is a best estimate of waste composition that may have been lost from tanks BX-101 from 1968 through 1972; these estimates are presented in Table 3.6.

The composition of waste streams from B Plant to the tanks varied with the waste type being processed. The waste composition listed in Table 3.5 is a composite of B Plant waste stream estimates generated from three major waste types that were processed in B Plant: aged PUREX supernatants (PSN), PUREX-sludge supernatant (PSS), and diluted aged Reduction-Oxidation Plant (REDOX) supernatant (RSN). PSN carried the highest fission-product load and RSN had the highest hydroxide and aluminum concentrations. The pH of the PSN and PSS was between 10 and 13 while the RSN contained molar concentrations of hydroxide. The technetium-99 concentrations were highest in PSN ( $\sim 6 \times 10^{-4}$  Ci/L) and much lower in PSS and RSN ( $1$  to  $8 \times 10^{-5}$  Ci/L). The leak composition estimate listed in Table 3.5 used a technetium-99 concentration of  $7.28 \times 10^{-5}$  Ci/L. The most concentrated PSN waste stream had a technetium-99 concentration of  $7.5 \times 10^{-4}$  Ci/L, or an order of magnitude higher than the value listed in Table 3.5. The PSN and PSS were processed through B Plant from 1968 through mid-1970. The RSN was processed through B Plant after mid-1970.

Losses between 1968 through mid-1970 would have involved primarily a PSN waste type. Thus, the concentration estimate in Table 3.5 underestimates the technetium-99 concentrations for any PSN waste leaks by possibly a factor of 5. On the other hand, the technetium-99 losses after mid-1970 are likely overestimated. Without a better understanding of the timing of waste losses from tank BX-101, all composition estimates are uncertain.

The total inventory estimate for the tank BX-101 leak discussed in Jones et al. (2001) assumes a nominal volume of 15,100 L (4000 gal). It is likely that 15,100 L (4000 gal) is a gross underestimate if the loss occurred over a four-year period. Therefore, the inventory estimate in Jones et al. (2001) is not considered to be reliable. It is concluded from this investigation that there is no firm basis for a leak inventory estimate for losses from tank BX-101 from 1968 through 1972. An approach for resolving this inventory uncertainty for purposes of risk assessment, particularly with regard to technetium-99, is provided in Section 3.2.1.7.5.

**Table 3.5. Inventory Estimate for Metal Waste Leak from Tank BX-102 (2 pages)****Leak Volume = 91,600 gal or 347,000 L and Leak Date - 1951**

Analyte	Median (kg)	Conc (mol/L)	Analyte	Median (Ci)	Ci/L
Na	2.33 E+04	2.92 E+00	Nb-93m	3.92 E-01	1.13 E-06
Al	0.00 E+00	0.00 E+00	Tc-99	3.27 E+00	9.42 E-06
Fe	1.48 E+02	7.62 E-03	Ru-106	6.43 E-08	1.85 E-13
Cr	2.90 E+01	1.60 E-03	Cd-113m	1.23 E+00	3.56 E-06
Bi	0.00 E+00	0.00 E+00	Sb-125	1.29 E-01	3.71 E-07
La	0.00 E+00	0.00 E+00	Sn-126	1.50 E-01	4.32 E-07
Hg	0.00 E+00	0.00 E+00	I-129	6.17 E-03	1.78 E-08
Zr	0.00 E+00	0.00 E+00	Cs-134	3.88 E-04	1.12 E-09
Pb	0.00 E+00	0.00 E+00	Cs-137	3.53 E+03	1.02 E-02
Ni	3.30 E+01	1.62 E-03	Ba-137m	3.35 E+03	9.66 E-03
Sr	0.00 E+00	0.00 E+00	Sm-151	3.65 E+02	1.05 E-03
Mn	0.00 E+00	0.00 E+00	Eu-152	2.61 E-02	7.53 E-08
Ca	1.85 E+02	1.33 E-02	Eu-154	2.40 E+00	6.93 E-06
K	3.70 E+01	2.73 E-03	Eu-155	1.75 E+00	5.04 E-06
NO3	1.14 E+04	5.30 E-01	Ra-226	2.01 E-05	5.80 E-11
NO2	7.36 E+02	4.61 E-02	Ra-228	7.19 E-11	2.07 E-16
CO3	1.34 E+04	6.43 E-01	Ac-227	5.28 E-05	1.52 E-10
PO4	1.19 E+04	3.60 E-01	Pa-231	1.40 E-04	4.02 E-10
SO4	7.67 E+03	2.30 E-01	Th-229	1.37 E-08	3.95 E-14
Si	3.94 E+01	4.05 E-03	Th-232	1.24 E-10	3.57 E-16
F	0.00 E+00	0.00 E+00	U-232	7.42 E-05	2.14 E-10
Cl	1.54 E+02	1.25 E-02	U-233	3.38 E-06	9.75 E-12
DBP	0.00 E+00	0.00 E+00	U-234	3.07 E+00	8.85 E-06
Butanol	0.00 E+00	0.00 E+00	U-235	1.36 E-01	3.91 E-07
TBP	0.00 E+00	0.00 E+00	U-236	3.16 E-02	9.10 E-08
NPH	0.00 E+00	0.00 E+00	U-238	3.15 E+00	9.07 E-06
U-Total (kg)	9.43 E+03	1.14 E-01	Np-237	1.97 E-02	5.67 E-08

**Table 3.5. Inventory Estimate for Metal Waste Leak from Tank BX-102 (2 pages)****Leak Volume = 91,600 gal or 347,000 L and Leak Date - 1951**

Analyte	Median (kg)	Ci/L	Analyte	Median (Ci)	Ci/L
H-3	8.76 E+00	2.52 E-05	Pu-238	1.78 E-02	5.14 E-08
C-14	3.02 E-01	8.69 E-07	Pu-239	2.23 E+00	6.42 E-06
Ni-59	1.31 E-01	3.78 E-07	Pu-240	2.17 E-01	6.26E-07
Ni-63	1.20 E+01	3.45 E-05	Pu-241	7.85 E-01	2.26 E-06
Co-60	1.24 E-01	3.58 E-07	Pu-242	3.59 E-06	1.03 E-11
Se-79	9.89 E-02	2.85 E-07	Am-241	1.07 E+00	3.07 E-06
Sr-90	2.96 E+03	8.53 E-03	Am-243	7.70 E-06	2.22 E-11
Y-90	2.96 E+03	8.53 E-03	Cm-242	5.07 E-04	1.46 E-09
Zr-93	4.70 E-01	1.35 E-06	Cm-243	1.04 E-05	3.01 E-11
			Cm-244	2.06 E-04	5.95 E-10

**3.2.1.7 Conceptual Model for the Contamination Area Adjacent and East of Tanks BX-101 and BX-102.** Contributions to vadose zone contamination in this region are attributed to two primary sources, a metal waste loss from tank BX-102 in 1951 through a failed spare inlet port and an isotope recovery waste loss from tank BX-101 pump pit (northeast side) between 1968 and 1972. Contamination from each of these sources is discussed separately. Also, it is likely that other poorly defined fluid discharge events have occurred in this area subsequent to the two events that have influenced contaminant migration in this area. Given the complexity of events, the following discussion is divided into three parts, the first two discussing each tank loss event and the last one discussing events following the tank waste losses.

**3.2.1.7.1 Tank BX-102 Overfill Event.** The occurrence and subsequent migration of the tank BX-102 overfill loss is considered to be a multi-event process. Historical information (Section 3.2.1.4) clearly identify that about 346,700 L (91,600 gal) of metal waste was discharged from a failed spare inlet port in 1951. Both vertical and pronounced lateral migration occurred in the vadose zone at the time of loss as indicated by tank waste constituents remaining in the soil column, particularly uranium. Spectral gamma measurement of uranium in a group of drywells east of tank BX-102 (Section 2.2.1.1.) show a narrow oval plume whose axis is about 200 ft long and oriented in a northeast-southwest direction. At the time of discharge, some of the uranium inventory initially present in metal waste (Appendix C, Section C.3) was dissolved in the supernatant and remained dissolved for some time as indicated by the distance between uranium-contaminated soil and the source. After some time, uranium reacted with the vadose zone soils and porewater and precipitated. Appendix D, Sections D.3.3.2, D.3.3 and D.3.4 includes a discussion of uranium precipitates identification in borehole 299-E33-45. A substantial portion of uranium remained in place following precipitation.

**Table 3.6. Composition Estimate for Waste in Tank BX-101  
During Leak Events (2 pages)**

Assumed Leak Event Dates 1968 through 1972

Analyte	mol/L	Analyte	Ci/L
Na	3.90 E+00	Nb-93m	4.98 E-06
Al	3.19 E-01	Tc-99	7.28 E-05
Fe	3.03E-03	Ru-106	4.95 E-09
Cr	1.63 E-02	Cd-113m	3.01 E-05
Bi	3.55 E-05	Sb-125	6.22 E-05
La	4.25 E-10	Sn-126	2.16 E-06
Hg	3.68 E-07	I-129	1.41 E-07
Zr	4.65 E-06	Cs-134	8.73 E-08
Pb	4.92 E-05	Cs-137	1.16 E-02
Ni	1.82 E-03	Ba-137m	1.10 E-02
Sr	0.00 E+00	Sm-151	4.99 E-03
Mn	1.13 E-03	Eu-152	1.46 E-06
Ca	9.10 E-03	Eu-154	2.29 E-04
K	1.67 E-02	Eu-155	8.55 E-05
NO3	1.02 E+00	Ra-226	6.26 E-11
NO2	3.57 E-01	Ra-228	3.16E-10
CO3	2.59 E-01	Ac-227	3.64 E-10
PO4	1.12 E-02	Pa-231	1.31 E-09
SO4	6.96 E-02	Th-229	1.43 E-11
Si	3.44 E-02	Th-232	1.31 E-10
F	1.56 E-03	U-232	1.91 E-08
Cl	6.90 E-02	U-233	7.38 E-08
DBP	6.79 E-03	U-234	1.06 E-07
Butanol	5.23 E-03	U-235	4.35 E-09
TBP	0.00 E+00	U-236	3.56 E-09
NPH	0.00 E+00	U-238	9.81 E-08
U-Total	1.23 E-03	Np-237	2.45 E-07

**Table 3.6. Composition Estimate for Waste in Tank BX-101  
During Leak Events (2 pages)**

Assumed Leak Event Dates 1968 through 1972

Analyte	Ci/L	Analyte	Ci/L
H-3	6.17 E-05	Pu-238	6.49 E-07
C-14	1.04 E-05	Pu-239	1.56 E-05
Ni-59	6.38 E-07	Pu-240	2.99 E-06
Ni-63	6.32 E-05	Pu-241	4.54 E-05
Co-60	1.32 E-05	Pu-242	2.76 E-10
Se-79	1.40 E-06	Am-241	3.03 E-05
Sr-90	4.46 E-02	Am-243	1.90 E-09
Y-90	4.48 E-02	Cm-242	6.92 E-08
Zr-93	6.58 E-06	Cm-243	7.07 E-09
		Cm-244	1.01 E-07

B Plant process records indicate the cesium recovery wastes were pH 10. Total complexant concentration was likely to have been 115% of sum of iron, aluminum, and manganese.

The pronounced lateral migration indicated by the uranium distribution required the existence of effective stratigraphic controls that induce lateral flow. Some controls were artificially imposed during tank farm construction as the excavation base was compacted and inadvertently sprayed with concrete (Appendix C, Section C.2). Naturally occurring horizontal fine silt lenses are abundant in this area (Section 3.1.1) and much of the tank waste contamination in borehole 299-E33-45 is found between two fine sand layers at 37 and 52 m (120 and 170 ft) bgs (Appendix B, Section B.3).

Subsequent migration of tank BX-102 tank waste contaminants has been complex because of the innate different chemical characteristics of the constituents and the interaction of these constituents with liquids from subsequent discharge events. Of the three contaminants considered the most capable of contaminating groundwater in the future (uranium, nitrate and technetium-99), uranium is apparently the least mobile and therefore, its migration history is perhaps the most easily understood. Soils characterization data (Appendix D, Sections D.3.2, D.3.3, and D.3.4) indicate that uranium is now largely present in a precipitated form. Migration has apparently occurred by solubility-controlled dissolution. The uranium spike in groundwater monitoring well 299-E33-41 in 1997 (Appendix C, Section C.6) and modeling results (Section 4) suggest that discharge to the unconfined aquifer has occurred but required a man-made high volume liquid discharge through the uranium-contaminated soil.

Subsequent nitrate and technetium-99 migration is much more difficult to understand. The uranium distribution in the vadose zone only provides an indication of the initial dispersion of nitrate and technetium-99. Comparison of soil inventory estimates with chemical processing records (Appendix E) shows a marked depletion of nitrate and technetium-99 relative to uranium

initially present in the metal waste stream (Appendix C, Section C.3.0) implying more widespread distribution of these contaminants within the vadose zone and into the unconfined aquifer. One plausible example of migration to the unconfined aquifer is the 1997 technetium-99 spike at groundwater monitoring well 299-E33-41 that is likely derived from a tank waste source. In addition, other sources have likely contributed these contaminants to the local vadose zone (e.g., the pump pit leak associated with tank BX-101 described in Section 3.2.1.6.2). These events add more complexity to the interpretation of nitrate and technetium-99 migration history. Additional post discharge events are discussed in Section 3.2.1.6.3.

**3.2.1.7.2 Tank BX-101 Pump Pit Loss.** A reevaluation of chemical processing records (Section 3.2.1.3) and spectral gamma data (Section 2.1.1.1) indicates that tank waste discharge into the vadose zone occurred from a pump pit at tank BX-101 between 1968 and 1972. Because large quantities of liquid passed through tank BX-101 during this time, the persistence and magnitude of the loss was not recognized. Consequently, a definitive estimate of total volume cannot be generated. Spectral gamma data of antimony-125, europium-154, and cobalt-60 are found high in the vadose zone near tank BX-101 and coincident with uranium from the BX-102 leak in many of the drywells as far as 30 m (100 ft) east of the tank BX-101. These contaminants (excluding uranium) are likely constituents in the various waste streams that passed through tank BX-101 between 1968 and 1972 (Appendix C, Section C.3.0) and are attributed to the tank BX-101 source. Their distribution in the vadose zone again indicates the strong lateral component of initial tank waste migration.

In addition, rapid vertical migration is postulated as the leak continued because a nearby borehole between tanks BX-101 and BX-102 (21-02-04) was constructed in 1970 that extended to the unconfined aquifer and was poorly sealed. It is plausible that a locally saturated zone was created on the tank farm floor between tank BX-101 and borehole 21-02-04 because of continuous leakage from the pump pit and construction design of the BY tank farm. If so, BX-101 tank waste could have discharged to the unconfined aquifer through the borehole and drained into the Plio-Pleistocene unit (about 220 ft bgs) and migrated laterally. Unfortunately, clear indicators of this migration pathway are not available. One possible indicator is the technetium-99 and nitrate concentrations found in the Plio-Pleistocene unit in borehole 299-E33-45.

After the initial distribution of pump pit waste fluid, subsequent migration of mobile contaminants in the vadose zone is indicated, but poorly understood. As with the metal waste loss from the overflow event at tank BX-102, the borehole soils analyses of mobile constituents and groundwater contaminant history provide the only potential source of information. Nitrate and technetium-99 are the observed mobile constituents that exceed background values in borehole 299-E33-45 soils and were present in both metal and cesium recovery waste. The evolution of nitrate and technetium-99 migration in the 299-E33-45 borehole soils, and by extrapolation, in the entire tanks BX-101 and BX-102 contaminated vadose zone, is uncertain.

**3.2.1.7.3 Post-Tank Waste Loss Fluid Discharge Events.** As previously discussed, the quantities and distributions of radioactive and chemical constituents that were added to the 299-E33-45 borehole soils from tank waste sources cannot be simply explained by the two tank events followed by contaminant migration due to natural infiltration. In particular, the mismatch of nitrate, technetium-99, and uranium concentrations and various ratios of these contaminant

concentrations with process based inventory estimates indicate a complex migration history during and after the leak events. Also, groundwater contamination was observed in borehole 299-E33-41 around 1997 as near coincident uranium and technetium-99 spikes that appear to be derived from these events. Thus, it seems likely that additional fluid discharge events have played a role in the migration of tank waste in this area.

One of the earliest post-leak discharge events may have been the tank BX-101 pump pit leak with respect to the tank BX-101 metal waste event. If, as postulated, the BX-101 fluids followed a similar migration path as the earlier event, mobile constituents could have been pushed ahead of the incoming fluids. A substantial lateral component to the metal waste contaminants migration pattern is viable.

There are several indications that additional fluid discharge events have occurred since the tank BX-101 pump pit loss occurred between 1968 and 1972. These indications include:

- Cesium-137 contamination from the surface down to about 30 to 46 m (100 to 150 ft) bgs in several drywells east of tank BX-102 (e.g., drywells 21-27-07, 21-27-09, 21-27-10, and 21-27-11) suggests separate past surface spills that may also have discharged locally significant quantities of liquid into the soil column.
- A perched water zone was encountered in the 299-E33-45 borehole in the Plio-Pleistocene unit about 69 m (227 ft) bgs whose nitrate to technetium-99 ratio ( $> 500 \mu\text{g/pCi}$ ) is distinct from water extract data from soils sampled above in the Hanford formation ( $< 25 \mu\text{g/pCi}$ ) and in adjacent Plio-Pleistocene soils ( $< 50 \mu\text{g/pCi}$ ). This very different ratio and the location of the saturated zone in the Plio-Pleistocene suggest lateral migration of fluids from a source outside WMA B-BX-BY. The Plio-Pleistocene can easily be a stratigraphic control for lateral migration. The reduced technetium-99 concentrations and the high tritium content compared to adjacent porewaters suggest the influx of unlike waters mixing with pre-existing porewater in the perched water zone, the result being a distinct chemical profile.
- Tank farm construction features in the southeastern end of the BX tank farm have been conducive to the enhanced capture of natural precipitation (rainfall and snowmelt) and subsequent infiltration through the contaminated vadose zone (Section 5.1.3). An east-west berm covering an overland pipe at the southern end of the tank farm was emplaced in the early 1980s and has acted as a dam that facilitated ponding at the south end of the farm. Observations have found that, after heavy rainfall and snowmelt events, ponding occasionally occurred followed by surface runoff into the tank farm. It is likely that hundreds of thousands of gallons of water has drained through the contamination zone as a result of repeated ponding and runoff events occurring in this area. Section 5.1.3 discusses actions taken in fiscal year 2002 to mitigate this condition.

The characterization information that permits the identification of these types of events does not quantitatively explain current tank waste contaminant concentrations and distributions in the 299-E33-45 borehole soils. They are also generic enough that within each category more than one event may have occurred. Thus, a unique set of post event fluid discharge events cannot be identified to explain the current contaminant conditions. At the same time, it is unlikely that the current conditions could have evolved without one or more of these events.

**3.2.1.7.4 Summary of Tank BX-101 and BX-102 Conceptual Models.** A preferred conceptual model that comprehensively explains the primary contamination characteristics in this area can only be partially derived. The numerous discharge events, uncertainty about loss volumes, limited vadose soil analyses, and an incomplete groundwater monitoring record in the vicinity of these tanks prevent a clear determination of contaminant migration history. The collected information does indicate that the tank waste contaminant release and migration history is comprised of a series of events. These include the occurrence of the 1951 metal waste overflow event at tank BX-102, and the occurrence of a cesium recovery waste loss from the pump pit at tank BX-101 in the late 1960s to early 1970s. The spectral gamma data suggest that fluids from both release events were initially discharged in about the same region within the vadose zone. Subsequently, one or more liquid discharge events occurred that were sufficiently large to accelerate further migration of existing contaminants to other areas of the vadose zone and into the unconfined aquifer. It is also likely that contaminants from other sources have been introduced into this area because of strong tendencies for lateral migration induced by local stratigraphy combined with large liquid discharges in surrounding cribs and trenches. The occurrence of these events is supported by the historical record and types and concentrations of contaminants measured in the vadose zone and the unconfined aquifer.

Several inconsistencies are apparent when measured tank waste constituents in the vadose zone are compared with estimated values from process knowledge including the following:

- In the 299-E33-45 borehole soils, technetium-99 and nitrate inventories are depleted relative to uranium inventories with respect to estimated leak inventories for the metal waste release from tank BX-102 in 1951. If additional nitrate and technetium-99 were added to the vadose zone by the tank BX-101 pump pit leak in the late 1960s (possibly tens of curies of technetium-99), the depletion delta increases. Calculated uranium inventories also appear to be lower than those predicted from historical information. However, the difference is smaller than those observed for nitrate and technetium-99.
- In the 299-E33-45 borehole soils, nitrate to technetium-99 ratios are larger than predicted from historical inventory estimates of either the metal waste event from tank BX-102 or the postulated cesium recovery waste leak from the tank BX-101 pump pit.
- Nitrate to technetium-99 ratios change with depth in the soil column. They are maximized in the perched water zone, intermediate in the Plio-Pleistocene unit, and lowest in the Hanford formation.

Specific physical and chemical characteristics of the primary contaminant discharge and migration events are not sufficiently quantified to explain these inconsistencies. Two options to explain each of the major inconsistencies are described below with respect to nitrate and technetium-99, two of the primary constituents. Either or both options may partly explain current contaminant distribution.

One option to explain the overall current apparent depletion of tank waste inventory and inconsistent constituent ratios in the vadose zone is that estimates of specific constituent concentrations in the leaking fluids based on chemical processing knowledge are incorrectly high. This hypothesis is considered unlikely for the metal waste event whose composition and volume are well documented. However, the amount of uranium and perhaps technetium-99 that

may have been separated from supernatant prior to leakage is not entirely certain. Confidence in the BX-101 pump pit leak information is lower because neither waste composition nor volume can be clearly defined. Numerous waste streams passed through tank BX-101 during the likely leak period with different nitrate and technetium concentrations. However, the nitrate and technetium-99 concentration estimates for the various waste streams that passed through tank BX-101 are not particularly small (Appendix C, Section C.3). Therefore, mixing of fluids from both tank waste sources in the vadose zone should not reduce the nitrate and technetium-99 concentrations. One hypothesis for reducing technetium-99 concentration estimates in the pump pit fluid is radiolytic reduction to the IV oxidation state and precipitation in tank sludge prior to leakage. If this was a real chemical reaction and the pump pit contaminants were the majority of currently observed contamination in borehole 299-E33-45, a partial explanation for the current reduced technetium-99 concentrations and inventory in the vadose zone is provided.

The second option is that subsequent liquid discharge events occurred whose nitrate and technetium-99 concentrations were substantially lower than tank waste fluids and mixed with contaminated vadose zone soils, thereby reducing the local concentrations. In situ surface discharges and lateral migration from more distant sources along stratigraphic layers deeper in the vadose zone are both plausible. In the process, excess nitrate and technetium-99 could have been redistributed within the soil column and/or discharged to the unconfined aquifer. The coincident uranium and technetium-99 peaks observed in monitoring well 299-E33-41 in 1997 are a plausible example of tank waste breakthrough to the unconfined aquifer caused by a high volume man-made fluid release passing through the contaminated vadose zone. Contamination in the Plio-Pleistocene unit and the perched water zone within the Plio-Pleistocene unit appears to have been at least partially derived from a source different from tanks BX-101 and BX-102. The Plio-Pleistocene unit acting as a stratigraphic control to induce lateral migration may be locally extensive (e.g., a contaminant signature in borehole 299-E33-46 near tank B-110 [Section 3.2.2] occurs in the Plio-Pleistocene unit that appears to be unrelated to the tank B-110 event).

Despite the uncertainties in the conceptual model provided by an apparently contradictory source and contaminant distribution information, the evaluation of the future risk and recommendations for remediation have not been jeopardized. The databases strongly indicate that the actual source term remaining in the vadose zone is less than that predicted from historical processing information. By assuming the higher source term inventory for risk assessment (Section 4), a bounding high estimate of the future impact has been determined upon which remediation recommendations have been based. Therefore, attempts to resolve conceptual model uncertainties through further characterization are not needed.

**3.2.1.7.5 Integration of Inventory Information for Risk-Producing Constituents of Concern.** In the tanks BX-101 and BX-102 area, selection of the appropriate initial inventories of the primary constituents is complicated by different pieces of conflicting inventory estimating information, all of which are uncertain in one way or another. The primary sources of contaminants were the metal waste overflow event from tank BX-102 in 1951 and the cesium recovery waste leaked from the tank BX-101 pump pit between 1968 and 1972. The metal waste event effectively provided uranium inventory. Historical information quantifying volume and initial waste composition is relatively well documented. Actual uranium inventory discharged by this event into the vadose zone is uncertain because a large fraction of uranium initially in the

waste stream precipitated out of solution as it was transferred from tank to tank. Jones et al. (2001) estimate about one-third of the initial uranium inventory (about 8 MTU or 6.53 Ci) remained in solution as it discharged into the vadose zone.

Prior to the initiation of transport modeling analyses (Section 4.0), uranium-238 inventory was estimated by extrapolating the soil column concentrations measured in borehole 299-E33-45 over a hypothetical soil cylinder whose diameter was consistent with the areal footprint defined by uranium spectral gamma measurements in an array of drywells east of tanks BX-101 and BX-102. Uranium inventory estimates using this method were lower than, but reasonably consistent with, the estimated inventory. Conversely, kriging estimates completed with the uranium-238 spectral gamma database in the contamination zone (Section 3.2.1.5) were about 0.415 Ci compared to the historical estimate of 3.15 Ci, a substantially smaller value. Given these various estimates, a uranium-238 inventory of 3.15 Ci was selected as a reasonable and somewhat conservative initial inventory for contaminant migration modeling runs (Section 4.2).

Historical information indicates that technetium-99 and nitrate were discharged into the soil column from both waste loss events. All of the technetium-99 and nitrate in the initial metal waste inventory (3.27 Ci and 11,500 kg, respectively) was assumed to remain in solution. Contributions from tank BX-101 were considerably more difficult to estimate. While the composition of the cesium recovery waste has a reasonable basis when historical waste stream estimates are compared to the partial analysis of tank BX-102 supernatant (Womack and Larkin 1971), the leak volume cannot be determined. Discharge could have occurred between 1968 and 1972 at an undetermined rate and the drilling of drywell 21-02-04 near the tank BX-101 pump pit in 1970 to groundwater further complicated the migration pattern of leaked waste. Initially, a nominal 15,100 L (4,000 gal) loss (Jones et al. 2001) was assumed yielding technetium-99 and nitrate inventories of 1.1 Ci and 957 kg, respectively. Given the high volume of waste transferred through tank BX-101 in that four-year period, volumes could have been substantially higher, yielding considerably larger discharged technetium-99 and nitrate inventories. However, soils characterization data from borehole 299-E33-45 do not indicate a large residual in the vadose zone.

As with the uranium inventory estimates completed for modeling, a similar calculation was completed for technetium-99 and nitrate inventories by extrapolating the contaminant concentration data approximately over the uranium footprint. Unlike uranium, technetium-99 and nitrate inventory estimates were substantially depleted relative to the combined respective inventories from the metal and cesium recovery waste leaks by factors of 16.6 and 3.3, respectively. The discrepancy between historically derived inventory estimates and field analysis based estimates cannot be resolved with the available information. However the field data are quantified, the historical data are more uncertain and opportunities for subsequent soil column washing of mobile constituents are plausible. A compromise decision was made to assume the initial estimates (Jones et al. 2001) of 4.37 Ci and 13,100 kg for technetium-99 and nitrate, respectively, as a reasonably conservative estimate of current vadose inventory in this region. These values may underestimate the inventories initially discharged into the vadose zone but are well above those indicated by current field data.

### 3.2.2 Nature and Extent of Contamination Near Tank B-110

Tank waste contamination in the vadose zone between tanks B-110, B-111, B-107, and B-108 is the result of one leak event from a transfer line attached to tank B-110. Several lines of investigation have been completed to better understand this event including soils analyses from the characterization borehole (299-E33-46), a reevaluation of the historical operations and process flow chemistry records, and integration of these data with gamma logging data. The information derived from these studies is summarized in the following sections. Also, the information has been used to derive a conceptual model to explain the current state of contamination.

Integration of this information leads to the following key observations and conclusions:

- Waste leaked from a transfer line attached to tank B-110 in the late 1960s to early 1970s.
- Neither the volume nor the waste type is well understood. Soils analysis data from borehole 299-E33-46 indicate a waste stream rich in strontium-90, fluoride, and carbonate. Historical records suggest a plausible waste stream derived from strontium recovery waste from dissolved PUREX fuel as opposed to an initial conclusion (Jones et al. 2001) that the waste was a cesium recovery waste similar to that released by the tank BX-101 pump pit leak.
- Initial migration occurred both vertically and laterally. Soils analysis data suggest that strontium-90 was initially rather mobile, perhaps because of complexation with organic constituents. Currently, neither strontium-90 nor any other constituent appears to be mobile (Appendix D, Section D.2.0).
- A small zone of technetium-99 occurs in the Plio-Pleistocene unit that appears to be unrelated to the tank B-110 transfer line leak.
- The groundwater sampled from borehole 299-E33-46 was moderately alkaline (pH ~7.5) and contained contaminants including tritium (2,810 pCi/L) and nitrate (164 mg/L). There is no clear indication from the vadose zone contamination measured at this borehole location that the contaminants were discharged directly into the unconfined aquifer.

From these observations, it was concluded that currently there are no tank waste constituents from this event that can significantly contaminate the unconfined aquifer in the future. Therefore, no future contaminant migration modeling from this contamination area was considered.

**3.2.2.1 Borehole 299-E33-46 Construction and Sampling.** Borehole 299-E33-46 was constructed in the 241-B tank farm using a cable-tool (percussion) drilling machine. Geologic logging was done by an on-site geologist using drill cuttings collected from drive barrel samples and observation of SPT sleeve and shoe contents. Geologic logging was performed on near-continuous samples within the limits of drive barrel and SPT sampling techniques. A total of 33 SPT samples (Table 3.7) were collected and submitted for laboratory analyses. Depth control for the samples was established by measuring the depth of the borehole with a steel line measure. Measurements were recorded to the nearest one hundredth of a foot.

**Table 3.7. Sample Recovery from Borehole 299-E33-46**

Sample No.	Depth ft bgs	Sediment Type	Percent Recovery
1	9.50-11.73	Sandy gravel	60
2	19.3-21.6	Sandy to pebbly gravel	85
3	27.7-30.0	Sand and cobbles	75
4	40.0-42.3	Sand	100
5	42.03-44.6	Sand	100
6	44.07-47.0	Sand	100
7	48.9-51.2	Coarse Sand	100
8	51.3-53.6	Sand	100
9	59.0-61.3	Sand	100
10	68.7-71.0	Sand	100
11	78.2-80.5	Sand	100
12	81.3-83.6	Sand	100
13	88.6-90.9	Sand	100
14	97.9-100.2	Sand	100
15	109.7-112.0	Sand	100
16	118.2-120.5	Sand	95
17	130.1-132.4	Sand, salt and pepper	100
18	138.3-140.6	Sand	100
19	148.4-150.7	Sand	100
20	158.4-160.7	Sand	100
21	162.8-165.1	Sand	100
22	165.1-167.4	Sand	100
23	169.4-171.7	Sand	100
24	178.1-180.4	Sand	100
25	189.1-191.4	Coarse sand	100
26	199.2-201.5	Sand	100
27	208.4-210.7	Sand	100
28	217.7-220.0	Sand/silt-clay contact	100
29	220.4-222.7	Silt/clay	100
30	229.2-231.7	Gravel/sand	75
31	239.4-241.7	Gravel/sand	87.5
32	245.2-247.5	Gravel	44
33	252.4-254.7	Gravel/sand	69

**3.2.2.2 Summary of Field Data from Borehole 299-E33-46.** In borehole 299-E33-46, elevated concentrations of several constituents in the tank farm borehole soils are present that are attributed to tank fluids (primarily from tank B-110). The set of tank constituents includes strontium-90, carbonate, fluoride, nitrate, and sodium. High concentration levels occurred at different depth intervals for various constituents (Figures 3.7 and 3.8). In the upper part of the soil column between 15 and 40 m (50 and 130 ft) bgs, carbonate (3,000 to 8,400 mg/L), fluoride (100 to 215 mg/L), and sodium (1,000 to 83,500 mg/L) were most concentrated. Elevated concentrations of strontium-90 (15 and 60 pCi/L) occurred between 14 and 28 m (46 and 83 ft) bgs. Conversely, nitrate was more concentrated (130 and 1460 mg/L) between 26 and 61 m (84 and 200 ft) bgs. An unusual feature of this porewater chemistry is that carbonate and fluoride are major constituents attributed to the tank waste source. A few samples from depths in the Plio-Pleistocene unit between 68 and 69 m (222 and 226 ft) bgs contained concentrations of technetium-99 between 39,800 and 89,800 pCi/L. The technetium-99 source is not attributed to the tank B-110 event (see Section 3.2.2.5 for additional discussion).

**3.2.2.3 Tank B-110 (299-E33-46) Vadose Zone Soil Contaminant Geochemistry.** Three aspects of the water extract chemistry from 299-E33-46 borehole soils indicate geochemical perturbations caused by the introduction of tank waste into the vadose zone at this location. First, an elevated pH zone between 16 and 37 m (52 and 120 ft) bgs indicates the common effect of high pH wastewater reacting with lower porewater pH leading to an intermediate pH value. Over time, complete buffering probably results and porewater pH reverts to ambient values. In borehole 299-E33-46, this chemical reaction path is not complete.

Second, strontium-90 distribution indicates a larger range of vertical migration than expected under undisturbed conditions. This suggests a period of enhanced mobility that probably occurred at the time of leakage and continued for some time thereafter. Process knowledge suggests that an organic chelating agent was present in the waste fluid that could have formed an anionic mobile species. This condition appears to have been short-lived. The current water extract and soils analysis has not detected an unusual organic constituent. Comparison of water versus acid extraction of strontium-90 indicates that much of the strontium-90 is strongly sorbed to the soil. This suggests that the strontium-90-organic species aqueous complex has broken down and strontium-90 has reverted to normal sorption behavior routinely observed with undisturbed Hanford soils (e.g.,  $K_d$  values of 6 to 10 mL/g).

Third, sodium, calcium, and magnesium distribution in the soil column shows a classic ion exchange reaction has occurred at the borehole 299-E33-46 location because of the influx of relatively high sodium concentrations in the tank waste fluid. As sodium migrates vertically through the soil column, it displaces the primary divalent cations sorbed on soil phases. Consequently, sodium concentrations increase and divalent cation concentrations decrease in the zone of displacement. The divalent cations migrate ahead of the sodium and are enriched in that area. These characteristics are clearly displayed in the B-110 borehole (299-E33-46) soils where, between 15 and 40 m (50 and 130 ft) bgs, sodium concentrations are maximized and calcium and magnesium concentrations are reduced below ambient values. Between 40 m (130 ft) bgs and 77 m (254 ft) bgs, which is the bottom of the borehole, calcium and magnesium concentrations are clearly enriched relative to the upper zone.

Figure 3.7. Key Constituent Concentration Profiles from Borehole 299-E33-46

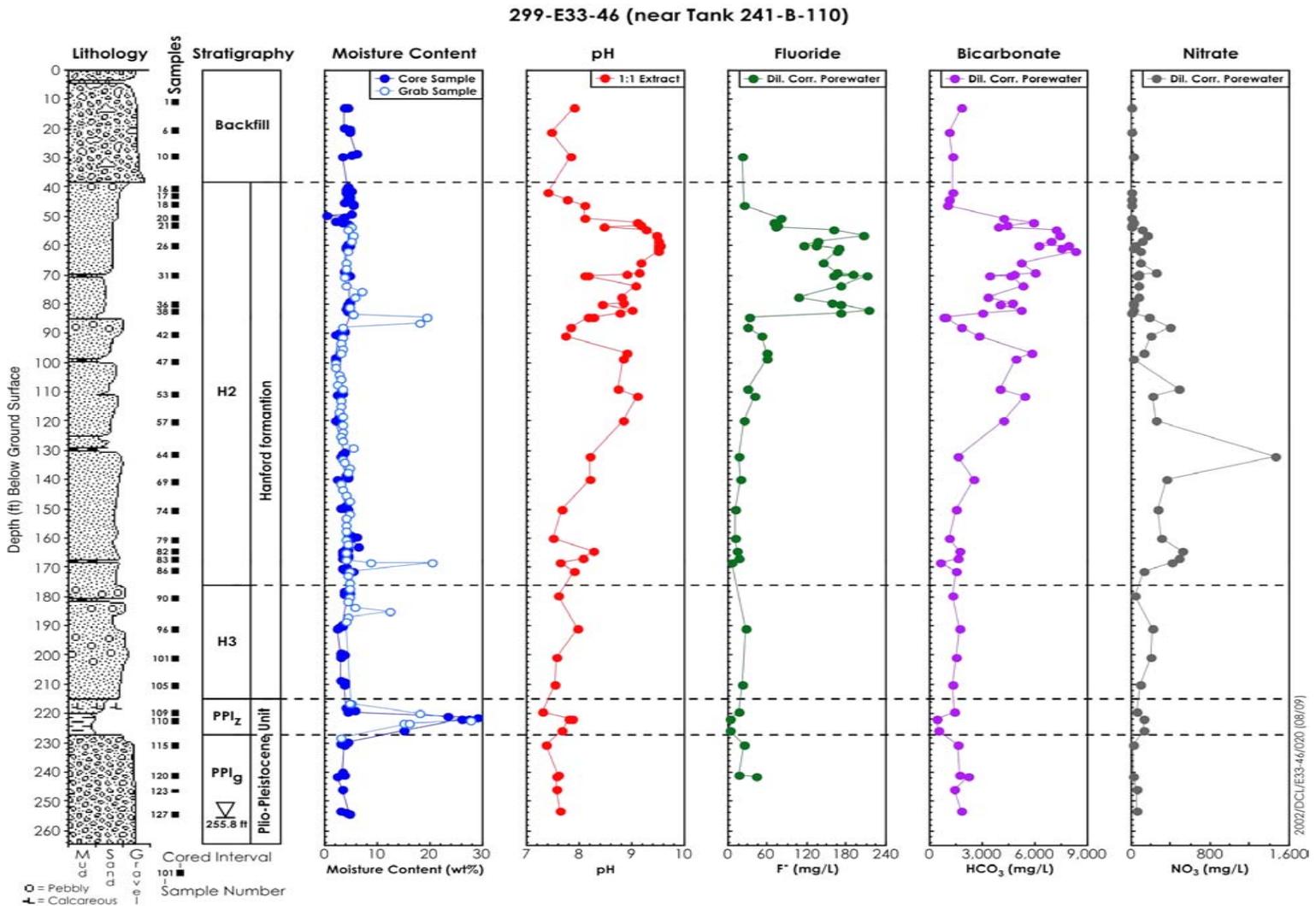
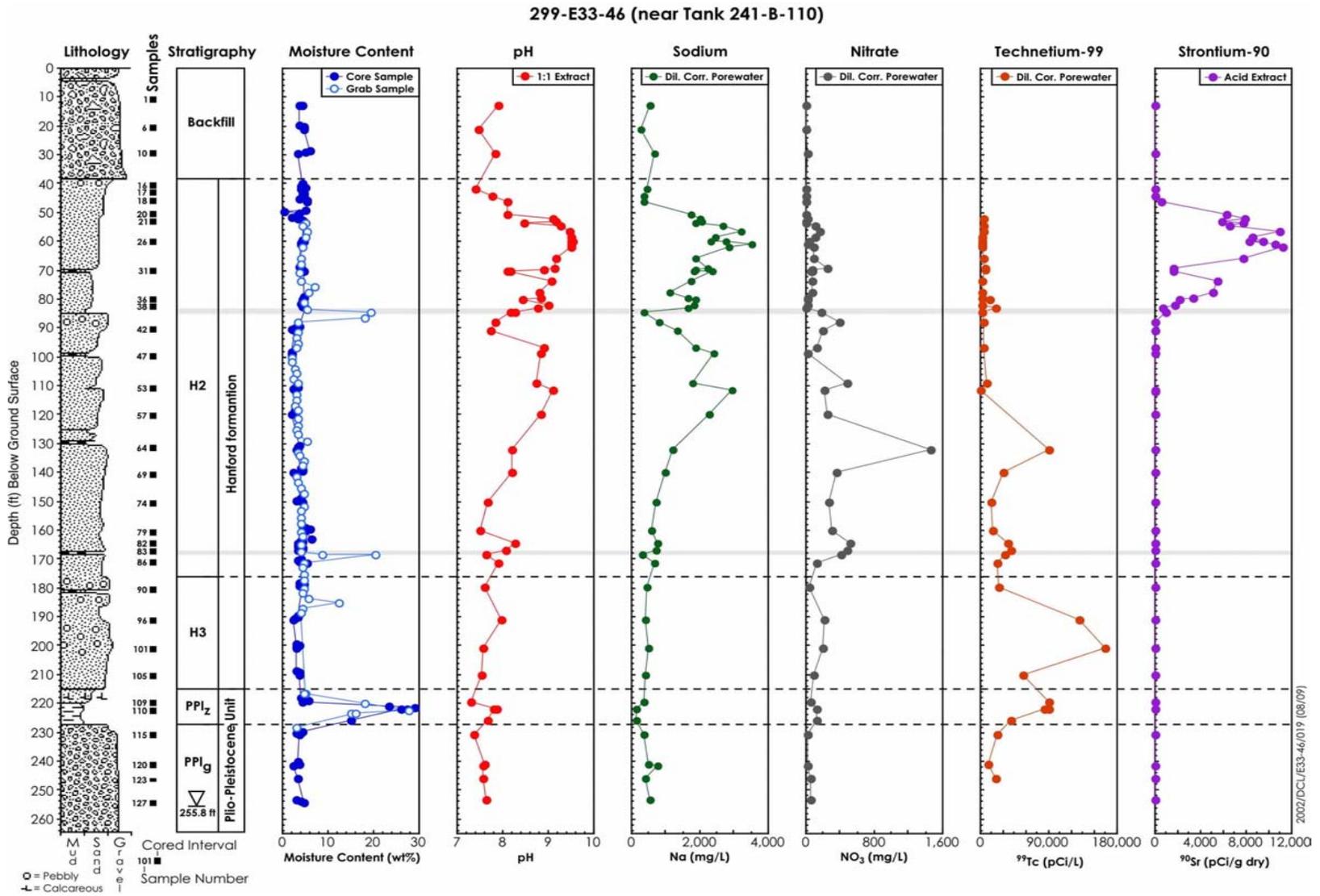


Figure 3.8. Key Constituent Concentration Profiles from Borehole 299-E33-46



**3.2.2.4 B-110 Tank Loss Composite Estimate.** A substantially revised estimate of the tank B-110 loss composition is presented in this section compared to that previously completed (Jones et al. 2001). The combination of the field data described in the previous section and inconsistencies between historical process information and the spectral gamma data has led to the revised estimate. The important aspects from various lines of evidence are summarized below and a composition estimate is provided.

Tank B-110 was in active service between 1945 and 1972, during which a wide variety of wastes were stored in the tank. Of particular interest are the wastes that were present in the tank in the late 1960s when a leak event occurred from a transfer line attached to tank B-110, releasing contaminants to the vadose zone between tanks B-110, B-111, B-107, and B-108. From 1963 through 1967, tank B-110 received approximately 675,000 gal of PUREX high-level wastes, identified as fission product waste type. The PUREX wastes were added in reasonably small batches (~100,000 gal) with frequent transfers to boiling waste tanks in the A tank farm. A review of the isotope recovery process and waste transfer records suggest these PUREX waste streams transferred to tank B-110 likely came from the Phase I/II Isotope Recovery Program conducted in PUREX, Hot-Semiworks, and B Plant. The Phase I/II Program involved, at different times, recovery of strontium-90, cesium-137, technetium-99, and other isotopes. In 1968, the waste storage mission of tank B-110 shifted to supporting the Phase III B Plant isotope recovery operations. In 1968 and 1969, tank B-110 received 645,000 gal of B Plant wastes. Waste transfer records suggest the waste levels were maintained well above the nominal tank capacity of 530,000 gal.

In the initial inventory estimates for tank B-110 (Jones et al. 2001), a 25,000-gal leak volume was assumed and the event was assumed to have taken place in 1971 and 1972. It was assumed the leaked supernatant would have carried substantial amounts of tank waste components, thus, inventory estimates were quite large. For example, the tank B-110 leak inventory estimate included 8,220 kg of sodium, 7,810 kg of nitrate, 134 kg of chromium, 13.8 Ci of technetium-99, and 16,000 Ci of cesium-137. At the same time, it was clear that the cesium-137 inventory estimates from the assumed B-110 event seemed to be inconsistent with recently measured spectral gamma logging data (DOE-GJPO 2000d).

The spectral gamma logging data for the B tank farm identified what appeared to be a strontium-90 rather than a cesium-137 plume in the region between tanks B-110, B-111, B-107, and B-108. This hypothesis was based on bremsstrahlung radiation. The main interest in drilling the B-110 borehole was to resolve the question about a possible strontium-90 plume in the region and to identify the chemical constituents that may be associated with the suspected strontium-90 plume. Analyses of soil samples from the B-110 borehole (299-E33-46) confirmed that strontium-90 was responsible for the bremsstrahlung radiation detected in a number of B tank farm boreholes. Bremsstrahlung radiation is a secondary gamma ray produced from the interaction of the high-energy beta rays produced from the strontium-90 decay chain with matter, which in this case is assumed to be the steel well casing. In addition to the soil analyses confirming strontium-90, the B-110 borehole was logged with the spectral gamma tool. The soil analysis data and spectral gamma logging curve allowed quantification of strontium-90 in other nearby drywells where bremsstrahlung radiation was detected. However, efforts to date have been unsuccessful in developing a useful calibration curve for quantifying strontium-90 from spectral gamma logging data because of differing well casing thicknesses.

In 1968, B Plant began to process PUREX current acid waste (CAW). The B Plant processing of the zirconium acid waste (ZAW), the CAW stream generated from zirconium-clad fuels, could have led to a waste composition that included (and was generally limited to) mobile strontium-90, fluoride, and carbonate. According to the flowsheet data (Larson 1967), ZAW contained 0.3 M fluoride. Thus, the fluoride could have originated from the zirconium decladding operation and remained in the dissolved fuel when it was sent to B Plant for isotope separations. As waste was further processed in B Plant and cesium-137 and strontium-90 were recovered, high fluoride concentrations could have remained in the generated waste streams. A strontium-90-rich waste stream could have resulted from a processing step that occurred after the removal of cesium-137. Strontium-90 was precipitated using a lead sulfate carrier process (Larson 1967). The strontium/lead sulfate cake was then converted to a carbonate salt using a metathesis process. The carbonate cake was then dissolved in nitric acid. After a pH adjustment and the addition of complexants, the strontium-90 was extracted into an organic phase in a solvent extraction column system (Larson 1967). The aqueous phase was then neutralized at least partially with sodium carbonate and sent to the tanks. However, the solvent extraction process was difficult to control and a substantial strontium-90 concentration could have ended up in the waste stream sent to B tank farm. A list of possible constituent concentrations is included in Table 3.8.

**Table 3.8. Strontium-90 Recovery Waste Streams from Zirconium-Clad Fuel** <sup>(a)</sup>

Chemical / Radionuclide (M)	Concentration	Chemical / Radionuclide	Concentration
Na	3.3	Phosphate (M)	<0.003
Al	0.0305	Total Carbonate (M)	0.8 <sup>(c)</sup>
Fe	<0.1	Fluoride (M)	0.10
Cr	0.00545	HEDTA (M)	0.52
H	<sup>(b)</sup>	Hydroxyacetic acid (M)	0.25
Hydroxide	<sup>(b)</sup>	Cs-137 (Ci/gal)	Assumed ~2
Nitrate	3.1 – 4.0	Sr-90 (Ci/gal)	0.43
Nitrite	NR	Tc-99	0.00042 M
Sulfate	<1.8	pH <sup>(b)</sup>	~10 (assumed)

<sup>(a)</sup> Data in this includes the 1AW data from Table 11 of Larson 1967

<sup>(b)</sup> Assumed waste stream neutralized to pH ~10 with sodium carbonate.

<sup>(c)</sup> Assumed sodium carbonate used to neutralize HEDTA, AcOH, and initial acid.

Reference: Larson 1967, "B Plant Phase III Flowsheets", ISO-986

The list of constituents in Table 3.8 provides a possible source for strontium-90 and fluoride in a tank B-110 event, and also suggests that technetium-99 should have been present, as well. However, the borehole 299-E33-46 soil waste leach analytical data found essentially no technetium-99 with the other mobile constituent (nitrate) that is postulated to have been present in the tank B-110 waste. Possible explanations are that the historical information is not correct, that technetium-99 was separated from this waste during the various processing steps, or that technetium-99 has been flushed from the soil column and that the nitrate contaminants found in the soils and presumed to be associated with the B-110 waste are derived from another source.

Regardless, the field data strongly indicate that technetium-99 is currently not present in the B-110 tank waste.

**3.2.2.5 Conceptual Model for the Tank B-110 Contamination Area.** Contributions to vadose zone contamination in this region are attributed to one primary source, a strontium recovery waste leak (Section 3.2.2.3) in the late 1960s to early 1970s initially present in tank B-110 (Section 3.2.2.2). Borehole 299-E33-46 soils data (Appendix B, Section B.3), spectral gamma data (Section 2.1.1.2), and additional historical processing information (Section 3.2.2.2) indicate this was a rather dilute waste stream containing strontium-90 and very little else. This is contrary to the initial hypothesis (Jones et al. 2001) that a highly contaminated cesium recovery waste was discharged from tank B-110. The spectral gamma data in drywell 20-10-12, located near the tank B-110 cascade line, place strontium-90 contamination beginning at 8 m (25 ft) bgs, coincident with the cascade line depth. The estimated leak volume is uncertain.

The best indicator of initial waste distribution into the vadose zone appears to be strontium-90 distribution. Strontium-90 was apparently mobile in the leaking fluid because of organic complexation generated by PUREX fuel processing steps at B Plant (Section 3.2.2.2). Subsequently, sorption and precipitation reactions occurred to fix the majority of strontium-90 in the soil column (Appendix D, Section D.2.0 contains details of current strontium-90 disposition in borehole 299-E33-46 soils). Spectral gamma data (Section 2.2.1.1) indicate that lateral migration was moderate. Spectral gamma data show strontium-90 present between tanks B-110, B-111, B-107, and B-108.

Subsequent vertical migration after the initial leak event appears to be rather uncomplicated and driven by natural infiltration and desorption (Appendix D, Section D.2.3). It is best indicated by the nitrate distribution in the vadose zone. Maximum elevated nitrate concentrations (Appendix B, Section B.3) occur in the Hanford formation between 50 and 51 m (165 and 169 ft) bgs.

The other radionuclide measured in this borehole, technetium-99, occurs in the Plio-Pleistocene unit. It is unlikely that technetium-99 comes from the tank B-110 waste source because its concentration distribution profile is incongruent with the nitrate profile (e.g., technetium-99 is found primarily in the Plio-Pleistocene and nitrate is found in both the Hanford formation and the Plio-Pleistocene with maximum values in the Hanford formation). The actual source of the technetium-99 in the Plio-Pleistocene is unclear, but emplacement by lateral migration is likely.

Future migration of contaminants from this waste stream are unlikely to impact groundwater. Vadose zone contaminants attributed to the tank B-110 pump pit leak are either relatively immobile or mobile but relatively dilute in the vadose zone, as described in Appendix D, Section D.2.3.

### **3.2.3 Nature and Extent of Contamination in Cribs and Trenches Adjacent to Waste Management Area B-BX-BY**

Significant inventories of contaminants have been disposed in numerous cribs and trenches adjacent to WMA B-BX-BY (Figure 2.2 of Section 2) and are likely to have commingled with any tank waste constituents that have reached the unconfined aquifer. Waste discharge volumes

and waste composition types discharged to these cribs and trenches are shown in Tables 3.9 through 3.11, along with selected contaminant inventory data. Complete contaminant inventory estimates, developed by Simpson et al. (2001), are available in Appendix C. This information, combined with soils analyses data from three characterization efforts, provides a reasonable understanding of the current state of contamination in the vadose zone underlying cribs and trenches.

The first characterization effort in this area involved an extensive drilling, sampling, and analysis program completed in the BY cribs north of the BY tank farm (DOE-RL 1993). As shown by the data in Table 3.10, the largest discharge of environmentally mobile contaminants to the vadose zone occurred through these cribs compared to any other operations in and around WMA B-BX-BY. The BY cribs received uranium recovery waste primarily and the technetium-99 inventory estimate of 164 Ci (the constituent of greatest concern from a risk perspective) represents > 90% of estimated technetium-99 from other sources. The soils analyses indicate that mobile constituents such as technetium-99 were effectively flushed from the vadose zone into the unconfined aquifer.

Two other characterization efforts have been conducted concurrently with the WMA B-BX-BY field investigation as part of the site-wide *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) waste site remediation program (200 Area Remediation Project). One borehole was drilled in the 216-B-7A crib north of B tank farm and one in the BX trench 216-B-38 west of the BX tank farm (Figure 2.2 of Section 2). The drilling and sampling of these wells, including analyses, were performed under the direction of the 200 Area Remediation Project, although some soil samples were transferred to Pacific Northwest National Laboratory for analyses supporting CH2M HILL and the Environmental Management Science Program (EMSP).

Integration of this information leads to the following observations:

- Although large inventories of chemicals and radionuclides were discharged to the BY cribs, the extensive field characterization conducted in the early 1990s failed to find much remaining vadose zone contamination.
- Soil sample water extract data from crib B-7A (borehole C3103) indicate that there is minimal contamination remaining in the vadose zone. Whatever mobile contaminants were initially in the effluents discharged to this crib have flushed to the unconfined aquifer and appear to provide no potential to further contaminate the unconfined aquifer in the future.
- Soil analysis data from the trench B-38 borehole (C3104) strongly indicate the mobile constituents discharged to the specific retention trench still reside in the vadose zone between 11 and 46 m (35 and 150 ft) bgs.
- Estimates of contaminant inventories for the BX trenches were based primarily on the data from Simpson et al. (2001) with modifications to the published technetium-99 inventories. Technetium-99 inventories for first cycle waste discharges were reduced by an order of magnitude to be more consistent with revised process chemistry knowledge (Section 3.2.3.1).

**Table 3.9. B Crib Discharges**

	<b>216-B-7A and 7B</b>	<b>216-B-8</b>
<b>Volume Discharged (L)</b>	4.29E+07	2.72E+07
<b>Waste type</b>	(a)	(b)
<b>Date of Discharge</b>	1946 – 1953	1948 – 1953
<b>Analyte</b>	<b>kg</b>	<b>kg</b>
Na	1.06E+06	6.69E+05
NO3	1.86E+06	1.18E+06
U-Total	2.75E+03	1.73E+03
	<b>Ci</b>	<b>Ci</b>
Tc-99	5.08E-01	3.21E-01
Cs-137	8.50E+03	5.37E+03

From Simpson et al. 2001

(a) 224-B facility wastes and 2<sup>nd</sup> Cycle wastes, tank 5-6 wastes from B Plant

(b) Second cycle supernatant and 5-6 cell wastes from B Plant

**Table 3.10. BY Crib Discharges**

	<b>216-B-43</b>	<b>216-B-44</b>	<b>216-B-45</b>	<b>216-B-46</b>	<b>216-B-47</b>	<b>216-B-48</b>	<b>216-B-49</b>
<b>Volume Discharged (L)</b>	2.12E+06	5.60E+06	4.92E+06	6.70E+06	3.71E+06	4.09E+06	6.70E+06
<b>Waste type</b>	(a)						
<b>Date of Discharge</b>	1954	1954–1955	1955	1955	1955	1955	1955
<b>Analyte</b>	<b>kg</b>						
Na	1.98E+05	5.27E+05	4.62E+05	6.32E+05	3.50E+05	3.88E+05	6.29E+05
NO3	4.42E+05	1.18E+06	1.03E+06	1.41E+06	7.79E+05	8.65E+05	1.41E+06
U-Total	1.15E+02	3.08E+02	2.67E+02	3.64E+02	2.03E+02	2.22E+02	3.67E+02
	<b>Ci</b>						
Tc-99	1.01E+01	2.69E+01	2.35E+01	3.23E+01	1.78E+01	1.97E+01	3.22E+01
Cs-137	4.68E+02	1.23E+03	1.09E+03	1.51E+03	8.18E+02	9.22E+02	1.48E+03

From Simpson et al. 2001

(a) Scavenged uranium recovery waste from U Plant

**Table 3.11. BX Trench Discharges**

	216-B-35	216-B-36	216-B-37	216-B-38	216-B-39	216-B-40	216-B-41	216-B-42
<b>Volume Discharged (L)</b>	1.06E+06	1.94E+06	4.32E+06	1.43E+06	1.54E+06	1.64E+06	1.44E+06	1.50E+06
<b>Waste type</b>	(a)	(a)	(b)	(a)	(a)	(a)	(a)	(c)
<b>Date of Discharge</b>	1954	1954	1954	1954	1953-1954	1954	1954	1955
<b>Analyte</b>	<b>kg</b>							
Na	9.18E+04	1.14E+05	4.79E+05	8.42E+04	8.65E+04	9.65E+04	8.49E+04	1.42E+05
NO3	1.44E+05	1.79E+05	7.43E+05	1.32E+05	1.35E+05	1.51E+05	1.32E+05	3.18E+05
U-Total	5.21E+01	6.44E+01	4.08E+03	4.80E+01	4.96E+01	5.44E+01	4.79E+01	8.15E+01
	<b>Ci</b>							
Tc-99	2.02E+00	2.51E+00	2.55E+01	1.84E+00	1.90E+00	2.11E+00	1.86E+00	7.21E+00
Cs-137	3.94E+02	4.89E+02	6.64E+04	3.62E+02	3.71E+02	4.15E+02	3.65E+02	3.34E+02

From Simpson et al. 2001

(a) First-cycle supernatant from B Plant

(b) Evaporator bottoms from B Evaporator

(c) Scavenged uranium recovery wastes

**3.2.3.1 Field Data.** Discharges to the B-7A crib primarily involved low-activity process effluents (Waite 1991). Soil analysis data from the B-7A borehole are presented in Appendix B, Section B.5.0. Soils analyses from the crib B-7A borehole (C3103) showed concentrations of cesium-137 (7 to 90,800 pCi/g) and uranium (22 to 330 µg/g) near the bottom of the crib between 7 and 12 m (22 and 48 ft) bgs. Zones of elevated pH and sodium are present indicating wastewater-soil interactions. Elevated pH values (greater than 8.5) were measured between 11 and 30 m (35 and 100 ft) with maximum pH values (9.0 to 9.5) occurring between 11 and 27 m (35 and 90 ft) bgs. Highest sodium concentrations (1,900 and 6,200 mg/L) exist between 9 and 40 m (30 and 130 ft) bgs.

The moderate amounts of uranium and cesium-137 occur from the bottom of the B-7A crib at about 7 m (22 ft) bgs to about 15 m (50 ft) bgs suggesting that precipitation/sorption reactions were rapidly removed from wastewater as it entered the vadose zone. Another indication of wastewater/soil interaction is a zone of elevated pH between 11 and 30 m (35 and 100 ft) bgs, consistent with interaction between high pH wastewater and moderately alkaline porewater. Elevated concentrations of carbonate, fluoride, and sodium are also present in this depth interval. These observations are consistent with the estimated inventories provided by Simpson et al. (2001).

Soil sample water extract data for the borehole in BX trench 216-B-38 show even less indication of tank waste interaction, even though the trench received 1.43 million liters of first cycle waste in 1954 (Waite 1991). Characterization of soils from the trench B-38 borehole (C3104) revealed minimal technetium-99 but with modest amounts of nitrate (Appendix B, Tables B.29 and B.31). The extremely low levels of technetium-99 found and wide differences between the ratios of nitrate to technetium in the field data as compared to the ratios developed from process

knowledge (Agnew 1997; Anderson 1990) lead to the conclusion there are likely errors in assumptions used to develop the process knowledge. The estimated technetium inventories provided by Simpson et al. (2001) for BX trench B-38 (Table 3.11) are inconsistent with the technetium-99 soil analysis data. As discussed in Appendix C, Section C.3.2.3, laboratory experiments were designed to evaluate the separations chemistry associated with the initial plutonium recovery step of the bismuth phosphate process. Results from these experiments show that some assumptions about the fate of technetium-99 in the bismuth phosphate process were incorrect. The incorrect assumptions led to an over-estimate of the amount of technetium-99 expected to have reached the first cycle waste stream by at least an order of magnitude.

Trench 216-B-42 received uranium recovery waste while the other seven BX trenches received first cycle waste. It has been concluded that the initial allocation of technetium-99 from the metal waste stream of 10% to first cycle waste is far too high, that 99+% of the technetium-99 is in the metal waste fraction, and that a fraction of < 1% is likely in first cycle waste. Thus, the total technetium-99 inventory estimate is biased high. The total technetium-99 contribution from the BX trenches was estimated from the data reported by Simpson et al. (2001) according to the following:

- The estimated technetium-99 inventory from trench 216-B-42, the one unit that received uranium recovery waste, was used as reported by Simpson et al. (2001).
- The technetium-99 inventories reported by Simpson et al. (2001) for all BX trenches that received first cycle waste (about 38 Ci) were summed and divided by 10 to obtain a technetium-99 value to be incorporated in the risk modeling activities.

### 3.2.3.2 Conceptual Models of Crib and Trench Leaks in the Vicinity of Waste

**Management Area B-BX-BY.** Numerous cribs and trenches near WMA B-BX-BY intentionally received large quantities of wastewater containing significant quantities of environmentally mobile radionuclides and chemicals. These include the BY cribs north of the BY tank farm, the BX trenches east of the BX tank farm, and a collection of cribs, trenches, and reverse wells north of B tank farm. For the most part, the liquid volumes, waste stream types, and chronology are well known. Volumes and waste types are summarized in Tables 3.9 through 3.11 and in Simpson et al. (2001) that provide inventory estimates for these facilities. Vadose zone characterization studies have been completed in the BY cribs (DOE-RL 1993) and characterization reports for boreholes recently drilled in trench B-38 and crib B-7A are in preparation (DOE-RL 2002). Some data from these recent characterization efforts are reported in Appendix B. Groundwater monitoring data have been collected since the 1950s and have indicated crib and trench inventories as primary contributors to local groundwater contamination.

Liquid discharge methods were either unrestricted (crib discharge) or restricted (specific retention trenches). The purpose of restricted discharges was to limit total volume discharge such that the soil column would retain all wastewater. Crib discharges were assumed to release some of the contaminants into the aquifer. Consequently, cribs generally received more liquid volumes than trenches. In the cribs and trenches surrounding WMA B-BX-BY, BY cribs received  $9.3 \times 10^7$  L. Except for BY crib 216-B-50, BY cribs operated in 1954 and 1955. Discharges to most individual cribs and trenches were completed over relatively short times (e.g., from a month to a year) creating a strong driving force for rapid migration through the soil

column. In the complex of discharge facilities north of B tank farm, the facilities receiving the highest volumes were cribs 216-B-7A and 216-B-7B ( $4.3 \times 10^7$  L between 1954 and 1967), crib 216-B-8 ( $2.7 \times 10^7$  L between 1948 and 1952), and the 216-B-11A and 216-B-11B reverse wells ( $3.0 \times 10^7$  L between 1951 and 1954). In contrast to crib disposal, eight BX trenches received a total of  $1.5 \times 10^7$  L and discharges in each trench were completed within a few weeks.

Groundwater monitoring records show that contamination from crib disposal around WMA B-BX-BY reached the aquifer shortly after discharge. For example, cobalt-60 and cyanide contaminants from the BY cribs entered the unconfined aquifer (Appendix C, Section C.7) within weeks of the discharges. This very rapid migration indicates that some portion of the soil column must have become saturated. The percentage of total inventory flushed through the soil column during the initial operation period is not known. Additional local crib discharges occurred later from crib 216-B-50 ( $5.9 \times 10^7$  L) between 1965 and 1974 and from crib 216-B-57 ( $8.4 \times 10^7$  L) between 1968 and 1973. These liquids may also have flushed BY crib contaminants into the unconfined aquifer.

Groundwater monitoring data do not clearly indicate if contamination discharged to the BX trenches has reached groundwater and because smaller volumes of tank wastes were discharged into the soil column over a larger surface footprint than cribs, even mobile contaminants may not have migrated completely through the vadose zone. In fact, soil analysis data from recent characterization efforts at trench 216-B-38 provide strong evidence that mobile constituents discharged to this trench are concentrated between 12 and 46 m (35 and 150 ft) bgs. In this region, the nitrate concentrations range between 520 to 3,180 mg/Kg of soil with the highest value at 46 m (150 ft) bgs. The nitrate concentration drops to 58 mg/kg at 200 ft bgs and down to 1.5 mg/kg at 265 ft bgs. The extent of lateral migration in the area is unknown.

Inventory estimates for this group of liquid waste discharge sites (Simpson et al. 2001) show that the contaminant totals are dominated by disposal into the BY cribs because of volume and the composition of the discharged waste stream. The BY cribs received uranium recovery waste, a waste stream that contained the majority of radioactive constituents (minus plutonium and most of the uranium) produced in the first reacted fuels from Hanford in the mid 1940s and early 1950s. The most mobile contaminants that have been found in local groundwater and attributed to the BY crib source include technetium-99, uranium, nitrate, and cyanide. Of these, technetium-99 is the most significant risk driver. The estimated technetium-99 inventory of 164 Ci discharged into BY cribs may be 90% or more of the technetium-99 inventory released into WMA B-BX-BY and vicinity from all sources combined.

The BX trenches are estimated to have received the next largest contaminant inventory. Simpson et al. (2001) estimated about 46 Ci of technetium-99 were discharged into the BX trenches. This estimate is considered to be high because only one trench, 216-B-42, with an estimated 7.3 Ci of technetium-99, received uranium recovery waste. The rest of the BX trenches received first cycle waste. As discussed in Section 3.2.3.1, it is believed that the chemical processing assumptions that are the basis of the Simpson et al. (2001) work overestimate technetium-99 inventory by at least a factor of ten.

At the liquid discharge sites north of B farm, inventory estimates are available for two of the three major sites, cribs 216-B-7A, 216-B-7B, and 216-B-8. Estimates for cribs 216-B-11A and

216-B-11B are not available. Given the historical record of waste streams sent to these facilities, the inventory estimates for cribs 216-B-7A, 216-B-7B, and 216-B-8, the soils analyses from the 216-B-7A borehole, and the relatively large volume discharged, it is hypothesized that nearly all mobile contaminants have been flushed into the aquifer, but the total inventory is inconsequential relative to the BY crib input.

Currently, only minor contamination is left in the vadose zone underlying the BY cribs (DOE-RL 1993). These observations, coupled with groundwater monitoring data collected over the last fifty years near the BY cribs, indicate that most of the mobile constituents present in the uranium recovery waste stream have been flushed into the unconfined aquifer, beginning shortly after discharge. Subsequently, contaminant migration history has been complex with major changes in the general migration direction having occurred on several occasions as the influences of B Pond versus Gable Mountain Pond discharges controlled the aquifer flow pattern (Appendix C, Section C.6.0). Most recent groundwater data suggest that BY crib contaminants have migrated from the north, are currently underneath the BY cribs, and are migrating in a south to southeast direction under the WMA.

### **3.3 CONCEPTUAL OVERVIEW FOR THE COMBINED WASTE SITES WITHIN AND ADJACENT TO WASTE MANAGEMENT AREA B-BX-BY**

This section provides a broad conceptual overview of the many interacting waste discharges, both unintentional and intentional, that have occurred and subsequently migrated in the vadose zone and unconfined aquifer in and around WMA B-BX-BY using the information summarized in previous sections. The goal of this discussion is to identify the relative significance of current tank waste contamination within WMA B-BX-BY relative to other nearby waste sources and to identify how current vadose zone contamination in the area should be evaluated as a source for future aquifer contamination.

A combination of intentional and unintentional waste discharges has occurred within and adjacent to WMA B-BX-BY beginning in the early 1950s and occurring occasionally at least into the early 1970s. Conceptual models for the various groups of releases are discussed in Section 3.2. Unconfined aquifer behavior has also experienced a complicated history primarily because of the large long-term discharges of dilute wastewater to B Pond and Gable Mountain Pond, which lie east and north of WMA B-BX-BY, respectively (Appendix C, Section C.6.0). By combining the waste release and the aquifer behavior information, a gross chronological conceptual model of composite contaminant release to the vadose zone and subsequent distribution can be generated.

Earliest significant releases of tank waste into the vadose zone were the unintentional 1951 metal waste loss from tank BX-102 and the intentional releases to the cribs and trenches outside WMA B-BX-BY in 1954 and 1955. The subsequent migration characteristics in the vadose zone varied greatly because of the differences in liquid volumes released and perhaps local stratigraphic controls. Transport of crib waste was largely vertical and rapid as mobile contaminants first reached the unconfined aquifer within weeks based on groundwater monitoring data. Transport of metal waste was largely lateral based on the uranium distribution east of tank BX-102. It is unlikely that metal waste contaminants reached the unconfined aquifer shortly after the leak event, although groundwater monitoring data are not available to support this assumption. The

characteristics of contaminant release from the BX trenches are not well understood. Total volumes released through these trenches were restricted to prevent breakthrough into the unconfined aquifer. Trench B-38 soil data (Appendix B, Section B.6.0) contain nitrate concentrations that suggest significant retention of waste in the soil column.

Historical records indicate that the primary mobile contaminants in crib discharges were technetium-99, cobalt-60, cyanide, nitrate, and to a lesser extent, uranium. In the metal waste loss, primary mobile contaminants were technetium-99 and nitrate. Total inventory discharges of mobile contaminants are dominantly from the BY cribs (i.e., an estimate of 164 Ci of technetium-99 from BY cribs versus about 3 Ci from the metal waste loss). The combination of greater inventory and more rapid vertical migration caused the early local aquifer contamination to be dominated by the BY crib waste sites. In the 1950s, water level data (Appendix C, Section C.6.0) indicate that the general flow direction in the unconfined aquifer was to the north and was driven by the groundwater mound that was being generated from liquid discharges to B Pond east of WMA B-BX-BY. How much of the BY crib contaminant inventory was present in the aquifer in the 1950s is not known. Any BY crib contaminant inventory present in the aquifer in the 1950s would have migrated northward through the Gable Mountain gap.

In the 1960s, water level data indicate that the groundwater flow direction shifted to the south as discharges to Gable Mountain Pond became prominent and overwhelmed the effects of B Pond discharges. No significant waste releases are known or postulated until the late 1960s when the tank BX-101 pump pit leak began. Thus, during the 1960s, some of the BY crib contaminant inventory may have reversed direction and migrated southward.

The next and final potentially significant waste release to the vadose zone in this area is postulated to have been leaks from the BX-101 pump pit between 1968 and 1972. The proposed waste stream, cesium recovery waste, contained large concentrations of technetium-99, the primary mobile contaminant of concern. In 1970, a drywell (21-02-04) just southeast of tank BX-102 was drilled to groundwater and poorly sealed. Some groundwater data at the time show that contamination was reaching groundwater. Thus, for two years it is plausible that tank BX-101 waste was entering the unconfined aquifer as well as the vadose zone and perhaps tens of curies of technetium-99 were added to the subsurface. Although no groundwater monitoring data are available to corroborate or disprove this hypothesis, as discussed in Section 3.2.1.4, high levels of gamma activity were found throughout well 21-02-04 shortly after it was drilled.

In the same time period, dilute condensate wastes were intentionally discharged to crib 216-B-57 northwest of the BY crib. Also, a low contaminant-bearing leak occurred near tank B-110 and is postulated to have leaked from a transfer line in the late 1960s. The borehole 299-E33-46 soil water extract data suggest that little if any discharge into the unconfined aquifer occurred because of this leak.

Water level data indicate that another significant shift in groundwater flow direction began about 1971 as B Pond discharges increased. Southerly flow began to swing around to the west and eventually pushed northward. Thus, BY crib contamination and any contaminant contribution from other sources would have migrated northward. Additional contaminant sources entering the unconfined aquifer could have been remnant waste from the BY cribs, waste underlying the BX trenches, and wastes from the BX-102 metal waste leak and the BX-101 pump pit leak.

Northerly migration continued until the mid-1990s at which point liquid discharges to both B Pond and Gable Mountain Pond had ceased, thereby losing influence on aquifer flow direction. Currently, northward migration has ceased and appears to be swinging toward the south and east. A much more extensive groundwater monitoring program has been in place since the mid 1990s and two observations from data collected during this time are pertinent. First, contaminants that appear to be characteristic of the BY crib wastes are being observed in monitoring wells around the BY cribs and appear to be migrating southward, consistent with the changing aquifer flow direction estimates. Second, a short contaminant release event was indicated by data from groundwater monitoring well 299-E33-41 in 1997 whose source appears to be the tanks BX-101 and BX-102 contamination area. The contaminants were uranium and technetium-99 and the event appears to have been triggered by some man-made, high volume, inadvertent liquid discharge event (e.g., ponding event). When considering the total recent groundwater monitoring data set and comparing these two observations, the BY crib contamination is the most pervasive source of unconfined aquifer contamination in the area now and in the near future.

Contaminant sources left in the vadose zone capable of supplying contaminants to the unconfined aquifer are assumed to be in the vadose zone east of tanks BX-101 and BX-102 and under the BX trench 216-B-42, which is the one trench among the BX trenches that received the waste stream most concentrated in mobile constituents, primarily technetium-99. These areas were modeled for future contaminant migration from the vadose zone to the unconfined aquifer and associated risk (Section 4.0).

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#### 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 B-BX-BY. The evaluation also predicted human health risk at four defined boundaries 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, water line leaks, and recharge rate assumptions. The scope and parametric data for these simulations were defined by a modeling data package (Khaleel et al. 2001). This section summarizes results for 11 simulated cases involving two-dimensional cross-sections through BX tank farm and three trench cases for the series of trenches just west of 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 (WAC 173-340).

The major findings are described below.

- Predicted groundwater concentrations for technetium-99, nitrate, and uranium-238 met the drinking water standard (40 CFR 141) at the BX tank farm east fence line boundary for all cases except for the two water line leak scenarios.
- Incremental lifetime cancer risk (ILCR) ranged from  $5.39 \times 10^{-5}$  to  $4.83 \times 10^{-5}$  at the BX tank farm east fence line boundary for the industrial worker scenario all from radioactive CoCs. The hazard index ranged from  $1.77 \times 10^{-1}$  to  $1.98 \times 10^{-1}$  at the BX tank farm east fence line boundary for the industrial worker scenario. Technetium-99 was the key CoC for the ILCR, while chromium and nitrate were the key CoCs for the hazard index. Regulatory exceedances were  $1.0 \times 10^{-5}$  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 B-BX-BY and the regulatory standards (Appendix G). 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, b). 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 various boundaries within the unconfined aquifer. Three contaminant species (technetium-99, uranium-238, and nitrate) were considered in the migration and risk analyses. A 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, nonuniform inventories, and meteoric recharge.

The simulations do not attempt to model a waste release, instead they model the potential risk posed by existing contamination within the vadose zone. All simulations were 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 and water line leaks. All simulations were run assuming isothermal conditions. The vadose zone was modeled as an aqueous-gas porous media system where transport through the gas phase was neglected.

Fluid flow within the vadose zone was described by Richards' equation, whereas the contaminant transport was 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 included 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 were included in the model.

The physical domains for the two-dimensional simulations involving the tanks were a representative east-west cross-section across the row of tanks from tank BX-108 to the BX tank farm fence line (i.e., a cross-section through tanks BX-108, BX-105, and BX-102). Because the inventory was emplaced at areas east of the BX-108 tank, the western-most tank, BX-111, was not included in the domain. To avoid boundary effects when the domain terminated at the BX tank farm east fence line, the eastern edge of the BX cross-section was extended by an additional 15 feet.

Note that in the discussion below and elsewhere, the BX tank farm cross-section is also labeled as BX-HH'. From cross-section BX-HH', a domain west of tank BX-111 was developed to model flow and transport in trench 216-B-38 (also labeled as B-38). The horizontal extent of this cross-section was 109.9 m (306.5 ft); the width was 10 ft.

Detailed descriptions of individual cases are included in Appendix E, Section E.2.1. Table 4.1 provides a summary description of individual cases. On the basis of information presented in Sections 3.2 and 3.3, no modeling was conducted for tank cross-sections in B and BY tank farms. Losses from B tank farm (e.g., tank B-110) and BY tank farm are not considered because the releases were small and the contaminants have short half-lives. Limited attention is given to past practice sites (e.g., cribs and trenches), which are the focus of the 200 Area Remediation Project.

**Table 4.1. Case Descriptions for the Two-Dimensional Tank Cross-Sectional and Trench Simulations**

Case	Description	Interim Barrier	U-238 K <sub>d</sub> (mL/g)	Recharge Rate History (mm/yr)			
				Time <sup>1</sup> (yr)			
				2000 to 2010	2010 to 2040	2040 to 2540	2540 to 3000
<b>Tank Cases (BX-108 - BX-102 Cross-Section)</b>							
1	Base Case (No Action Alternative)	No	0.6	100	100	0.1	3.5
2	Barrier Alternative	Yes	0.6	100	0.5	0.1	3.5
3	Water Line Leak (1gpm for 20 yr)	No	0.6	100 + leak	100 + leak <sup>2</sup>	0.1	3.5
4	Water Line Leak (200,000 gal over 5 days)	No	0.6	100 + leak <sup>3</sup>	100	0.1	3.5
5	Alternate Inventory	No	0.6	100	100	0.1	3.5
6	Alternate Inventory with Interim Barrier	Yes	0.6	100	0.5	0.1	3.5
7	Base Case with 50 mm/yr Recharge	No	0.6	50	50	0.1	3.5
8	Base Case with 30 mm/yr Recharge	No	0.6	30	30	0.1	3.5
9	Base Case with 10 mm/yr Recharge	No	0.6	10	10	0.1	3.5
10	Base Case with U-238 K <sub>d</sub> = 0.1	No	0.1	100	100	0.1	3.5
11	Base Case with U-238 K <sub>d</sub> = 1.0	No	1.0	100	100	0.1	3.5
<b>Trench Cases (B-38 Cross-Section)</b>				<b>Time<sup>4</sup> (yr)</b>			
				<b>1954 to 2010</b>	<b>2010 to 2540</b>	<b>2540 to 3000</b>	
12	Trench B-38 with 55.4 mm/yr Recharge	No	0.6	55.4	0.1	3.5	
13	Trench B-38 with 100 mm/yr Recharge	No	0.6	100	0.1	3.5	
				<b>Time<sup>5</sup> (yr)</b>			
				<b>1954-2040</b>	<b>2040-2540</b>	<b>2540-3000</b>	
14	Trench B-38 with delayed closure barrier	No	0.6	100	0.1	3.5	

<sup>(a)</sup> At 2010, for cases 2 and 6, an interim barrier is placed over the tanks, thereby reducing recharge. At 2040 (in all cases), a closure barrier is in place. At 2540, the closure barrier degrades, thereby increasing recharge.

<sup>(b)</sup> Leak continues through 2020.

<sup>(c)</sup> Leak occurs over 5 days in year 2000.

<sup>(d)</sup> At 2010, a closure barrier is placed over the trench and at 2540, the closure barrier degrades, thereby increasing recharge.

<sup>(e)</sup> At 2040, a closure barrier is placed over the trench and at 2540, the closure barrier degrades, thereby increasing recharge (same as tank base case schedule).

A principal objective of this investigation was to evaluate the effectiveness of interim barriers to control the infiltration (recharge) of meteoric water (from winter precipitation and snowmelt) and minimize accelerated migration of contaminants from previous leak sources. The reference suite of simulations (base case, no interim barriers but a closure barrier by the year 2040) considered the migration of contaminants from field estimates of concentration distributions through the vadose zone and groundwater to the BX tank farm fence line boundary.

Inventory estimates were considered to be a critical factor in calculations, and uncertainties in inventories were considered. The postulated conceptual model used the recently collected data on technetium-99 and other constituents from borehole 299-E33-45 near tank BX-102, and the MACTEC-ERS spectral gamma data (DOE-GJPO 1998). Details on the inventory distribution are discussed in Appendix E. It is assumed that no tank leaks will occur in the future. Also, as part of good housekeeping, water line leaks from existing piping are being addressed and resolved. The water lines in WMA B-BX-BY have been cut and capped. However, as part of sensitivity analysis, simulations were conducted to evaluate long-term effects of water line leaks in the vicinity of tank BX-102. The umbrella-shaped dome structure of the tank and shedding of water were 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 were simulated in the model (Appendix E). Numerical results were obtained for comparison with drinking water standards at the BX tank farm fence line boundary, 200 Areas exclusion boundary, and the Columbia River (Figure 4.7). These boundaries are based on DOE-RL (2000). DOE-RL (2000) also refers to the 200 Areas boundary. However, the 200 Areas and the 200 Area exclusion boundaries are relatively close. The focus of the numerical modeling was primarily the BX tank farm fence line boundary. For the trench cases, numerical results were obtained at the trench fence line boundary, 200 Areas exclusion boundary, and the Columbia River.

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 is recognized and the principle of superposition was used to generate a composite BTC. An analytical/streamline approach was used to route the BTCs through the unconfined aquifer to the remote boundaries (Appendix E). The BTCs were converted into dose estimates using appropriate factors (Appendix E).

As discussed earlier, from the starting conditions, transient simulations of solute transport were conducted for a 1000-year period (i.e., year 2000 to 3000) that involved implementing a closure barrier in 2040, and a degraded closure barrier from 2540 to 3000. Two of the trench simulation cases involved analyzing the effect of an interim barrier from 2010 to 2540. 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 4.1 and also in Appendix E, Table E.1.

In addition to the barrier cases (cases 2 and 6), other simulation cases involved investigating changes in the flow fields in response to the application of water line leaks, variations in recharge and the uranium-238 partitioning coefficient, and inventory placement in the subsurface. For example, the base case (case 1) simulated an initial recharge rate of 100 mm/yr, whereas three separate cases (cases 7, 8, and 9) investigated different recharge rates (50 mm/yr, 30 mm/yr, and 10 mm/yr, respectively). In addition to the base case ( $K_d = 0.6$  g/L), two other

cases (cases 10 and 11) analyzed the effect of different values of the uranium-238 partitioning coefficient ( $K_d = 0.1$  mg/L and 1.0 mg/L). The effect of water line leaks was examined in two of the cases (i.e., cases 3 and 4). The history and details of the water line leaks are mostly unknown and the simulated water line leak scenarios were not designed to be representative of the leak events that actually occurred near tank BX-102. The influence of initial contaminant inventory distributions was investigated by considering, compared to the base case, an alternate inventory distribution (case 5) beneath the BX tanks. In the base case distribution, the inventory was located east of BX-102, and extended to the east fence line at the BX tank farm boundary. In the alternate (case 5) distribution, the inventories were centered between tanks. In both cases, solute concentrations varied with depth, but were uniformly distributed in the horizontal direction. The integrated quantity of contaminant mass ( $C_i$  or kg) was conserved (i.e., held equal to the values used in base case, i.e., case 1), but in case 5, the solute mass was concentrated in the region between tanks BX-105 and BX-102, the tank ‘umbrella-effect’ region.

For the B-38 trench simulations (cases 12, 13 and 14), the start time was 1954 with a discharge to the trench for one year of 378,000 gal with unit inventory (i.e., 1 Ci or 1 kg) concentrations for sorbing (i.e., uranium-238) and non-sorbing (i.e., technetium-99 and nitrate) species. Two of the trench simulations (cases 12 and 13) included a closure barrier at 2010 and a degraded closure barrier from 2510 to 3000. A closure barrier schedule analogous to the one used for the BX tank farm was used for the third trench simulation (case 14), with a closure barrier at 2040, and a degraded closure barrier from 2540 to 3000. Trench B-38 simulations were run with unit inventory distributions. The first trench simulation (case 12) had a recharge rate of 55.4 mm/yr, whereas the latter two simulations (cases 13 and 14) had recharge rates of 100 mm/yr. The domain of the two-dimensional trench simulation was from the west to the east fence line of the B trenches at B-38. The results of the trench simulations were scaled to the disposal inventory of trench B-38 and the total disposal inventory of all eight trenches.

No simulations were conducted to evaluate the influence of preferential pathways such as clastic dikes. These pathways are expected to be present in the BX tank farm. However, work on the effect of potential preferential flow paths for the WMA S-SX FIR (Knepp 2002) resulting from clastic dikes suggests that these did not have a major influence on the long-term simulations and BTCs. Such predictions are consistent with other long-term impact assessments at the Hanford Site (Wood et al. 1995; Mann et al. 2001).

It should be noted that all simulations were run using an isothermal model. This assumption is supported by the current thermal conditions in WMA B-BX-BY.

## 4.2 NUMERICAL SIMULATION RESULTS

The flow 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. Execution times for these simulations varied from 8 to 48 hours. Mass balance errors were small for all of the simulations. For example, the maximum mass balance errors for each solute in all 14 cases were 0.052% for uranium-238, 0.415% for technetium-99, and 0.140% for nitrate.

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 boundaries. Table 4.5 shows the changes in peak

concentrations for the three species compared to the base case. The simulated BTCs for technetium-99 with (case 1) and without barriers (case 2) are shown in Figure 4.1. The base case (100 mm/yr) simulated BTCs for the three species at various boundaries that are shown in Figures 4.2 through 4.4. Figure 4.5 shows the effect of assumed recharge rate on simulated BTCs for technetium-99 at the fence line boundary. Figure 4.6 shows the simulated BTCs for the three trench cases at the fence line boundary.

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

Tc-99 Conc. (pCi/L)	Cross-Section		BX Fence Line Boundary		Exclusion Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.	Time	Conc.
Case 1	2048	6.65E+03	2048	8.05E+02	2087	5.31E+01	2300	2.27E+01
Case 2	2015	6.58E+03	2015	7.97E+02	2056	4.67E+01	2283	1.49E+01
Case 3	2002	1.40E+05	2002	1.69E+04	2042	3.02E+02	2261	4.68E+01
Case 4	2007	1.67E+04	2007	2.02E+03	2049	7.84E+01	2283	2.62E+01
Case 5	2017	5.79E+03	2017	7.02E+02	2091	4.46E+01	2303	1.95E+01
Case 6	2017	5.78E+03	2017	7.00E+02	2058	4.21E+01	2283	1.34E+01
Case 7	2028	3.59E+03 <sup>(a)</sup>	2028	4.35E+02 <sup>(a)</sup>	2069	2.80E+01	2300	1.15E+01
Case 8	2043	2.27E+03 <sup>(a)</sup>	2043	2.75E+02 <sup>(a)</sup>	2084	1.82E+01	2310	8.01E+00
Case 9	2109	8.33E+02 <sup>(a)</sup>	2109	1.01E+02 <sup>(a)</sup>	2149	6.78E+00	2370	3.39E+00
Case 10	2048	6.65E+03	2048	8.05E+02	2087	5.31E+01	2300	2.27E+01
Case 11	2048	6.65E+03	2048	8.05E+02	2087	5.31E+01	2300	2.27E+01
<b>Unit Inventory</b>								
Case 12	2036	1.31E+03	2036	2.02E+01	2077	1.46E+00	2301	6.74E-01
Case 13	2025	4.39E+03	2025	6.75E+01	2065	4.75E+00	2288	1.98E+00
Case 14	2052	8.11E+03	2052	1.25E+02	2090	8.90E+00	2307	3.76E+00
<b>B-38 Trench</b>								
Case 12	2036	2.41E+01	2036	3.71E-01	2077	2.69E-02	2301	1.24E-02
Case 13	2025	8.08E+01	2025	1.24E+00	2065	8.74E-02	2288	3.64E-02
Case 14	2052	1.49E+02	2052	2.30E+00	2090	1.64E-01	2307	6.92E-02
<b>All Trenches</b>								
Case 12	NA	NA	2036	1.69E+02	2077	1.21E+01	2301	5.60E+00
Case 13	NA	NA	2025	5.61E+02	2065	3.95E+01	2288	1.65E+01
Case 14	NA	NA	2052	1.04E+03	2090	7.40E+01	2307	3.12E+01

<sup>(a)</sup>Because of the inventory distribution near the water table, concentration peaks actually occur in the year 2000. Values in table represent changes in peak concentrations due to variations in meteoric recharge.

NA = not applicable

DWS = drinking water standard

**Table 4.3. Simulated Peak Concentrations and Arrival Times for Nitrate  
(DWS 45000 µg/L) at Various Boundaries**

NO <sub>3</sub> Conc. (µg/L)	Cross-Section		BX Fence Line Boundary		Exclusion Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.	Time	Conc.
Case 1	2012	3.69E+04	2012	4.51E+03	2053	2.54E+02	2279	7.14E+01
Case 2	2012	3.69E+04	2012	4.50E+03	2053	2.53E+02	2276	6.63E+01
Case 3	2002	5.06E+05	2002	6.17E+04	2042	8.92E+02	2261	1.39E+02
Case 4	2006	1.05E+05	2006	1.28E+04	2047	3.88E+02	2272	8.42E+01
Case 5	2000	3.46E+04	2000	4.22E+03	2055	2.32E+02	2280	6.76E+01
Case 6	2000	3.46E+04	2000	4.22E+03	2055	2.31E+02	2277	6.32E+01
Case 7	2023	2.01E+04 <sup>(a)</sup>	2023	2.45E+03 <sup>(a)</sup>	2064	1.56E+02	2288	5.44E+01
Case 8	2036	1.26E+04 <sup>(a)</sup>	2036	1.54E+03 <sup>(a)</sup>	2077	1.01E+02	2301	4.23E+01
Case 9	2091	4.65E+03 <sup>(a)</sup>	2091	5.68E+02 <sup>(a)</sup>	2131	3.81E+01	2353	1.91E+01
Case 10	2012	3.69E+04	2012	4.51E+03	2053	2.54E+02	2279	7.14E+01
Case 11	2012	3.69E+04	2012	4.51E+03	2053	2.54E+02	2279	7.14E+01
<b>Unit Inventory</b>								
Case 12	2036	1.31E+00	2036	2.02E-02	2077	1.46E-03	2301	6.74E-04
Case 13	2025	4.39E+00	2025	6.76E-02	2065	4.75E-03	2288	1.98E-03
Case 14	2052	8.11E+00	2052	1.25E-01	2090	8.90E-03	2307	3.76E-03
<b>B-38 Trench</b>								
Case 12	2036	1.73E+05	2036	2.67E+03	2077	1.93E+02	2301	8.90E+01
Case 13	2025	5.79E+05	2025	8.93E+03	2065	6.27E+02	2288	2.61E+02
Case 14	2052	1.07E+06	2052	1.65E+04	2090	1.17E+03	2307	4.96E+02
<b>All Trenches</b>								
Case 12	NA	NA	2036	3.90E+04	2077	2.82E+03	2301	1.30E+03
Case 13	NA	NA	2025	1.30E+05	2065	9.17E+03	2288	3.82E+03
Case 14	NA	NA	2052	2.41E+05	2090	1.72E+04	2307	7.26E+03

<sup>(a)</sup> Because of the inventory distribution near the water table, concentration peaks actually occur in the year 2000.

Values in table represent changes in peak concentrations due to variations in meteoric recharge.

NA = not applicable

DWS = drinking water standard

**Table 4.4. Simulated Peak Aqueous Concentrations <sup>(a)</sup> and Arrival Times for Uranium-238 (DWS <sup>(b)</sup>= 21 pCi/L) at Various Boundaries**

U-238 Conc. (pCi/L)	Cross-Section		BX Fence Line Boundary		Exclusion Boundary		Columbia River	
	Time	Conc.	Time	Conc.	Time	Conc.	Time	Conc.
Case 1	2149	8.50E-01	2147	1.04E-01	2395	3.49E-02	—	—
Case 2	2999	9.96E-02	2999	1.21E-02	2999	3.80E-03	—	—
Case 3	2008	2.31E+04	2008	2.82E+03	2237	1.87E+02	—	—
Case 4	2075	2.99E+00	2075	3.65E-01	2333	1.10E-01	—	—
Case 5	2284	4.22E-01	2283	5.14E-02	2521	1.74E-02	—	—
Case 6	2999	6.06E-02	2999	7.39E-03	2999	2.23E-03	—	—
Case 7	2999	1.08E-01	2999	1.32E-02	2999	4.09E-03	—	—
Case 8	2999	2.48E-02	2999	3.02E-03	2999	7.80E-04	—	—
Case 9	2999	3.72E-04	2999	4.53E-05	2999	5.98E-06	—	—
Case 10	2063	5.44E+02	2063	6.63E+01	2139	7.43E+00	2552	2.91E+00
Case 11	2999	4.43E-02	2999	5.39E-03	2999	2.40E-03	—	—

<sup>(a)</sup> Simulated peak uranium-238 concentrations for the trench cases (i.e., Cases 12, 13 and 14) were insignificant.

<sup>(b)</sup> Based on a limit of 30 µg/L and a conversion factor of  $6.93 \times 10^{-7}$  Ci/g

Entries marked with a dash (—) indicate that peak concentrations were insignificant

DWS = drinking water standard

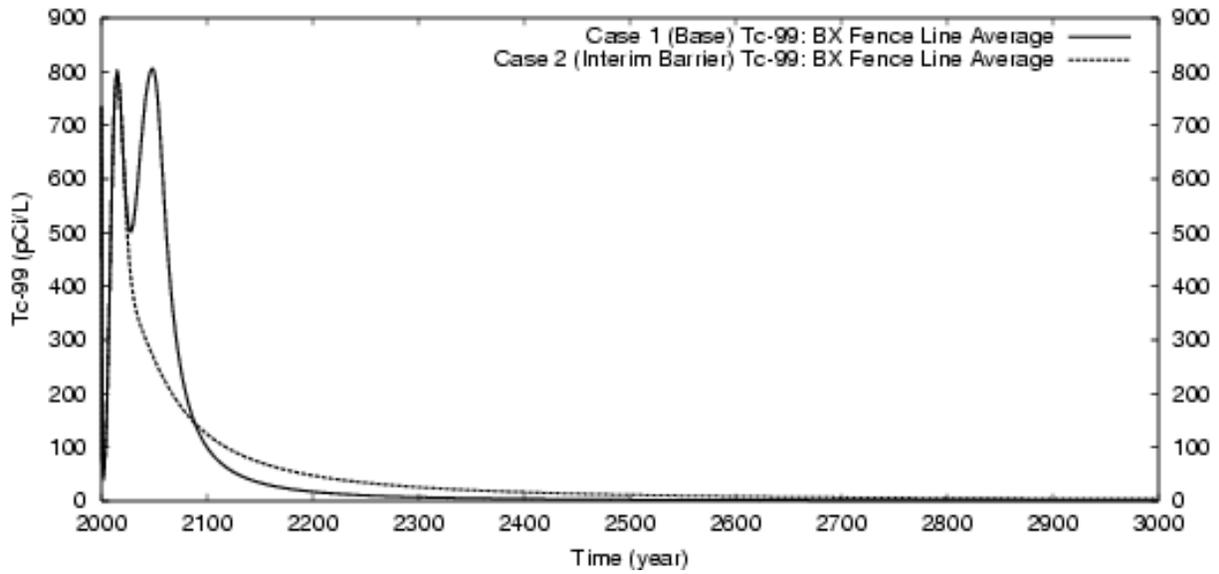
**Table 4.5. Changes in Peak Concentration as a Percentage of the Base Case Peak Concentration**

Case	Percent Change in Peak Concentration from Base Case at the First (Cross-Section) Boundary		
	Technetium-99	Uranium	Nitrate
1	100	100	100
<i>Variations in Inventory</i>			
5	87	50	94
<i>Variations in Recharge</i>			
7	54 <sup>(a)</sup>	13 <sup>(a)</sup>	54 <sup>(a)</sup>
8	34 <sup>(a)</sup>	3 <sup>(a)</sup>	34 <sup>(a)</sup>
9	13 <sup>(a)</sup>	0.04 <sup>(a)</sup>	13 <sup>(a)</sup>
<i>Barrier Effects with Inventory Near Fence Line</i>			
2	99	12	100
<i>Barrier Effects with Alternate Inventory</i>			
6 <sup>(b)</sup>	87	7	94
<i>Water Line Leak Effects</i>			
3	2.1E+3	2.7E+7	1.4E+3
4	250	350	290
<i>Uranium-238 Kd Effects</i>			
10	100	6.4E+5	100
11	100	5	100

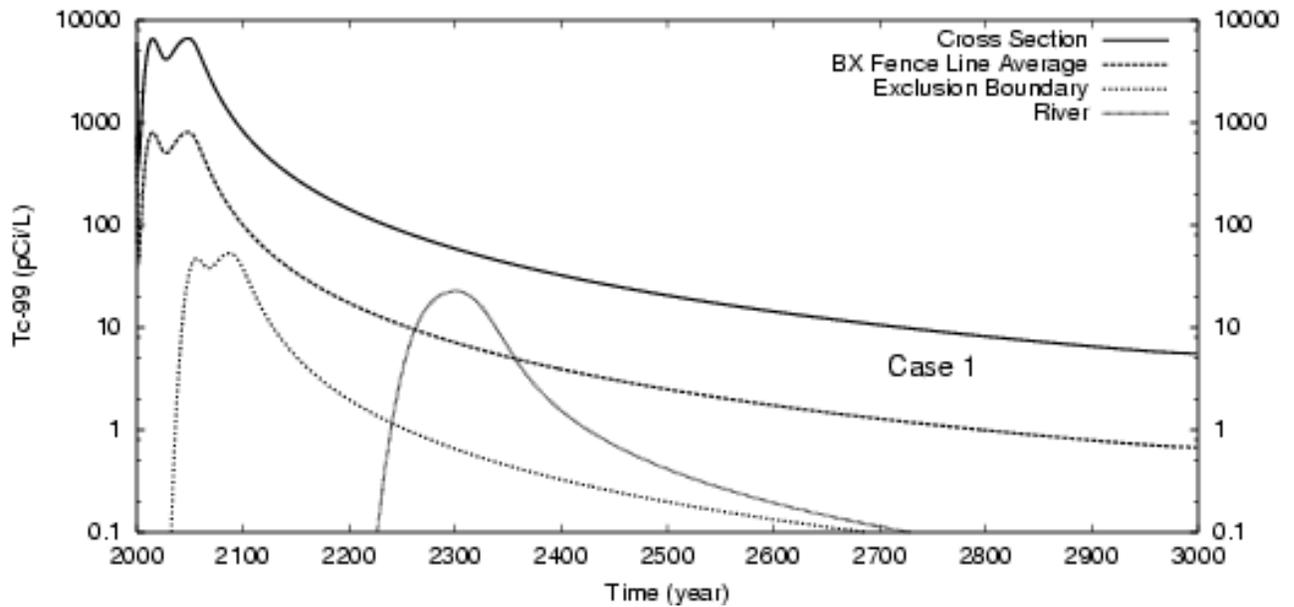
<sup>(a)</sup> Because of the inventory distribution near the water table, concentration peaks actually occur in the year 2000.

<sup>(b)</sup> Except for case 6, percent changes for all cases were with respect to the base case. For case 6, percent changes are with respect to case 5.

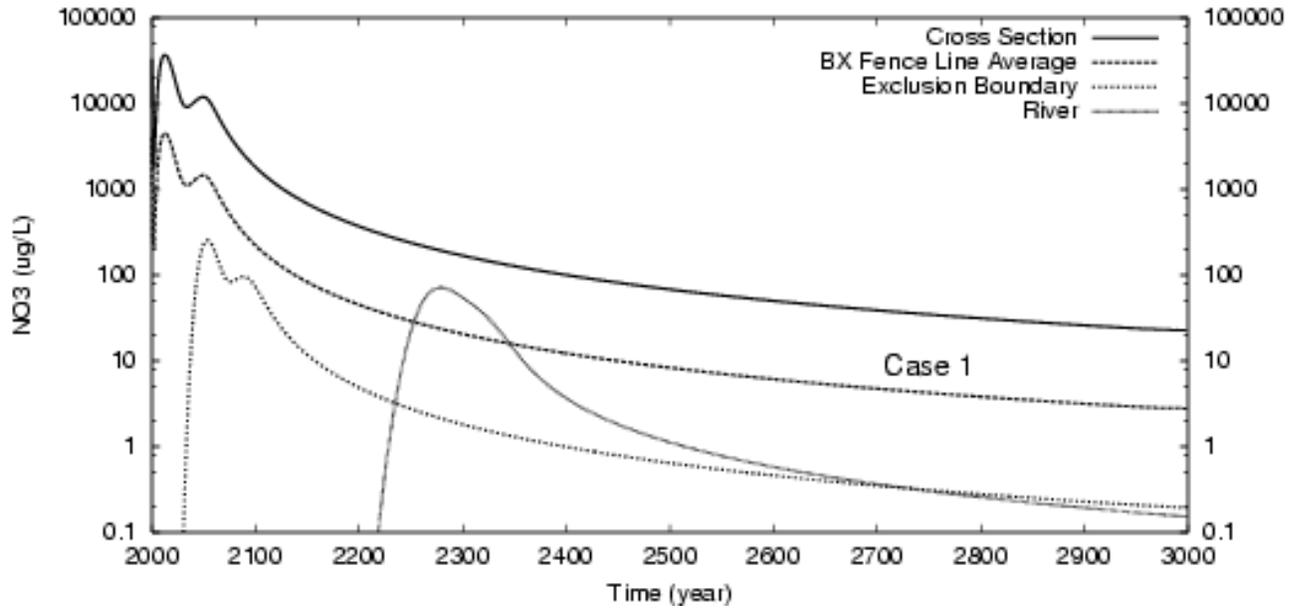
**Figure 4.1. Breakthrough Curves for Technetium-99 at the BX Tank Farm Fence Line Boundary for Cases 1 and 2**



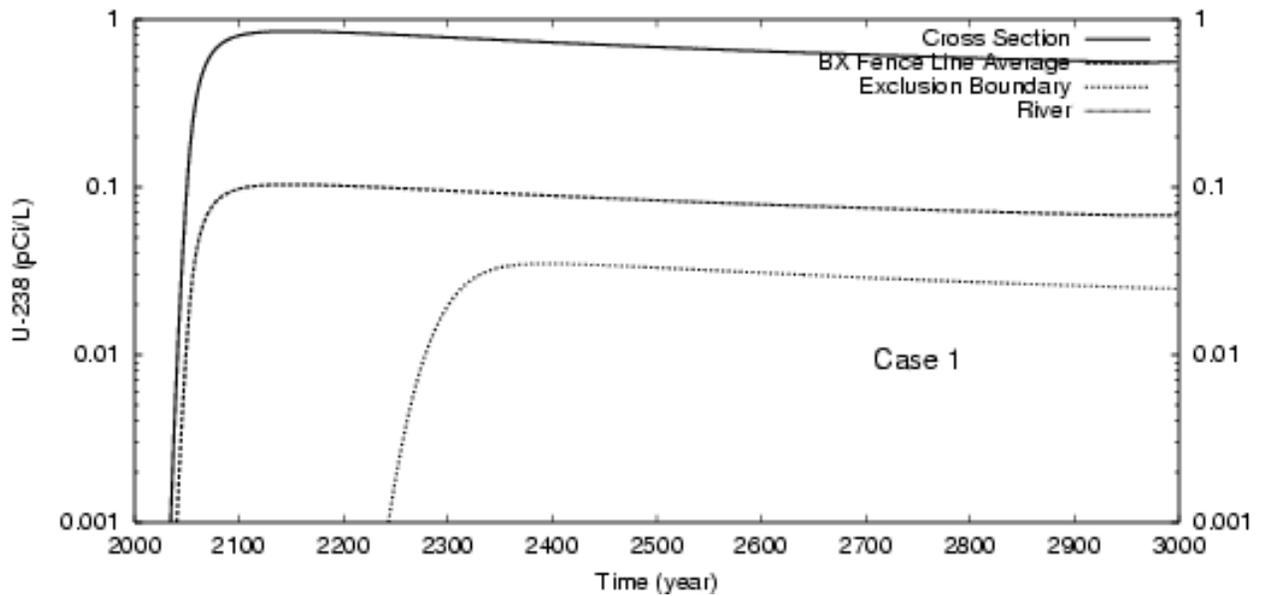
**Figure 4.2. Breakthrough Curves for Technetium-99 at Various Boundaries for the Base Case (Recharge = 100 mm/yr)**



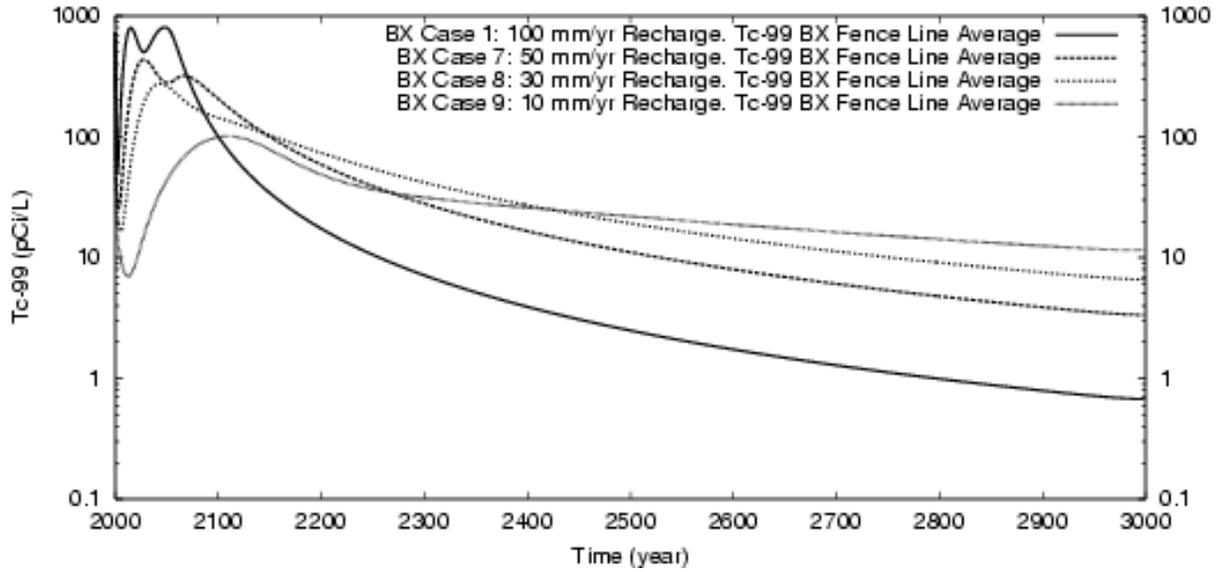
**Figure 4.3. Breakthrough Curves for Nitrate at Various Boundaries for the Base Case (Recharge = 100 mm/yr)**



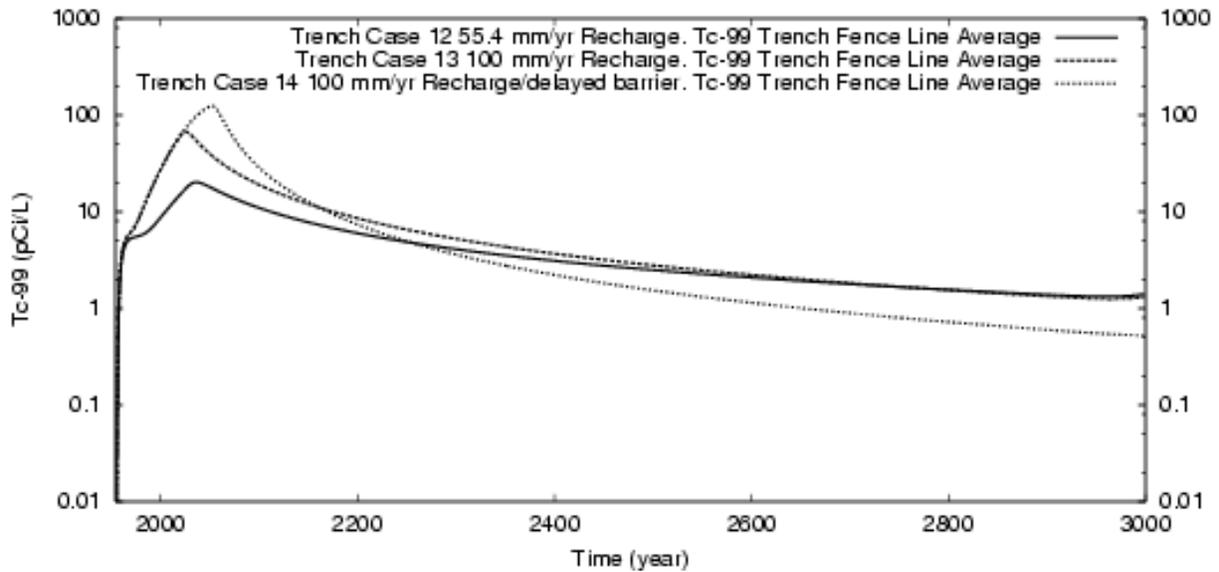
**Figure 4.4. Breakthrough Curves for Uranium-238 at Various Boundaries for the Base Case (Recharge = 100 mm/yr)**



**Figure 4.5. Breakthrough Curves for Technetium-99 at the BX Tank Farm Fence Line Boundary for Various Recharge Rates**



**Figure 4.6. Breakthrough Curves for Technetium-99 at the Trench Fence Line Boundary for Trench B-38 Cases**



As discussed before, a principal objective of this investigation was to evaluate the effectiveness of interim barriers to control the infiltration of meteoric water (from winter precipitation and snowmelt) and minimize accelerated migration of contaminants from previous releases in the BX tank farm. For the two cases that examined the effect of interim barriers (cases 2 and 5), the initial peak arrival times and concentrations for technetium-99 and nitrate were similar to the base case (Figure 4.1). This was due to the initial inventory distribution, which had high concentrations of both technetium-99 and nitrate near the water table. The barrier had little effect on the initial breakthrough because the contaminants (technetium-99 and nitrate) had already migrated to the water table before the lower infiltration rates became effective at that depth. By contrast, the interim barrier did have an impact for uranium-238. Most of the uranium-238 inventory was initially present in the upper part of the vadose zone. Whereas breakthrough curves for uranium-238 for the base case showed an additional peak due to a low concentration region in the middle part of the vadose zone, the reduced recharge caused by the interim barrier effectively eliminated the final peak.

Simulations investigating water line leaks (cases 3 and 4) demonstrated the highest peak concentrations of the 11 BX cases. This is also illustrated by comparing percent increases in peak concentrations for cases 3 and 4 over the base case (Table 4.5). In case 3, the leak at 1 gpm over 20 years had a more significant impact on mobilizing the contaminants than case 4 (200,000 gallons over 5 days). This effect is due to the larger volume of water (525,960 gal) released in case 3. A significant effect is on the mobilization of relatively immobile uranium-238. The peak uranium-238 concentrations in case 3 were not only the highest and earliest of the 11 cases, but they were also at least an order of magnitude higher than case 10, which examined the effect of lowering the value of the partitioning coefficient from 0.6 to 0.1 mL/g. In the summer of 2002, no water lines were found to be leaking when all water lines in the WMA were tested (Section 5.3). The water line cases are presented to help illustrate past leak scenarios.

Overall, simulation results showed that only a small fraction of the uranium-238 inventory migrated from the vadose zone for most of the simulation cases. The main exceptions were the water line leak cases (cases 3 and 4) and the low uranium-238 Kd case (case 10). For various recharge rates (cases 7, 8, and 9), increasingly smaller fractions of the uranium-238 inventory migrated from the vadose zone as the recharge rate was decreased. The most significant reduction occurred in case 9 (10 mm/yr), which had a peak uranium-238 concentration that was two orders of magnitude less than that of case 8 (30 mm/yr). Only an order of magnitude decrease in the uranium-238 peak concentration was noted when recharge was reduced from 100 mm/yr (base case) to 50 mm/yr (case 7), and from 50 mm/yr to 30 mm/yr (case 8).

Peak concentrations and arrival times for technetium-99 and nitrate were sensitive to recharge rates, however, differences were smaller than expected due to the proximity of a high concentration zone near the water table. Simulation results generally showed that the peak concentrations for technetium-99 and nitrate for all of the simulations were of the same order of magnitude, with the exception of the water line leak cases and the lowest (10 mm/yr) recharge case. The most significant impact of reducing recharge was in delaying the arrival of the peak concentrations at the exclusion and Columbia River boundaries. For example, relative to the base case, the arrival of the peak concentrations for technetium-99 and nitrate is delayed an

average of 40 years for technetium-99 and an average of 140 years for nitrate when the recharge rate is reduced to 10 mm/yr (case 9).

It should be noted that there are uncertainties relative to the total inventory in the WMA. Both technetium-99 and nitrate concentrations used in the initial soil concentration profiles were much smaller than the estimated leak inventories relative to the assumed plume size. To resolve these discrepancies, both technetium-99 and nitrate initial concentration distributions were scaled so that the inventory was distributed over the same volume as that of uranium-238. This resulted in the use of the same scaling factor for the average fence line concentrations for all three contaminants from the cross-section values. For the trench cases, simulations predicted that the uranium-238 would not migrate from the vadose zone to the aquifer in the 1000 years of simulation. The simulations also predicted that technetium-99 would appear quickly in the aquifer following the trench discharge in 1954, with peak concentrations occurring around 2020 to 2030. Because unit inventory results were scaled to the estimated technetium-99 discharge to all the B trenches, peak average technetium-99 aquifer concentrations ranged from 170 to 560 pCi/L for the three cases (55.4 mm/yr, 100 mm/yr, and the delayed closure barrier). For the trench cases, the breakthrough curves of nitrate were the same as technetium-99 as they were both scaled as non-sorbing species based on the estimated inventories.

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

- There are uncertainties relative to the total inventory in the WMA. The measured profiles within the vadose zone for technetium-99 were not consistent with the total estimated curie content of 4.37 Ci leaked from in the BX tank farm. This raises the possibility that the bulk of the technetium-99 may have already migrated to the unconfined aquifer. Nonetheless, for the numerical modeling, the technetium-99 measurements within the vadose zone were scaled up to match the total estimated curie content that leaked.
- As expected, contaminant inventories and their locations within the vadose zone influenced the calculated peak concentrations and arrival times of long-lived mobile radionuclides and chemical species at the BX tank farm fence line boundary. Two variations of the inventory distributions were considered. A comparison of the BTCs at the first (cross-section) boundary 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 within the vadose zone.
- Contaminant peak concentrations and arrival times were sensitive to assumed recharge rates. No tank farm specific recharge estimates are, however, presently available. The base case infiltration rate of 100 mm/yr was based on lysimeter data for gravel covered, nonvegetated surfaces that mimic tank farm conditions. Given the current location of the contaminant plumes for the long-lived radionuclides and chemicals within the vadose zone, additional studies to better refine the infiltration rates specific to the BX tank farm are not warranted. However, because of the importance of infiltration rates on contaminant BTCs for a leak event, efforts at reducing the current infiltration rates at the tank farms prior to retrieval or closure should be explored.

- The groundwater well 299-E33-41 lies directly east of BX tank farm. Peak measured concentrations in the well are most likely due to releases from this tank farm. This is supported by a key indicator, in the nitrate to technetium-99 ratios, for the well being of the same order of magnitude (10 to 100  $\mu\text{g/pCi}$ ) as in the soil profile and the near coincident occurrences of technetium-99 and uranium concentration peaks in 1997. A peak concentration of the order of 12,000 pCi/L for technetium-99 was measured in the well in August 1997 (Narbutovskih 1998). Numerical simulation results suggest that such a high concentration level cannot be explained with natural recharge as the primary driver for contaminant migration within the vadose zone. Furthermore, the observed profiles in the monitoring well are characterized by sharp spikes that are followed by immediate drops in concentration levels. Such a behavior in the observed profiles, coupled with high technetium-99 concentrations, and the fact that the simulated peak technetium-99 concentrations for the water line leak cases were of the order of  $1 \times 10^4$  to  $1 \times 10^5$  pCi/L suggests that water line leaks may have played a key role in contaminant migration in the BX tank farm. However, no water lines were found leaking in the summer of 2002 when all water lines in the WMA were tested (Section 5.3). The water line cases are presented to help illustrate past leak scenarios.

### 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 waste releases from WMA B-BX-BY.

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 B-BX-BY address mitigation of groundwater impacts. The exposure pathways for this risk and dose 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 and dose associated with the use of groundwater from a hypothetical water supply well was estimated at various downgradient locations over a 1,000-year time frame. Groundwater contaminant concentration estimates were based on the results of the contaminant transport analysis presented in Appendix E, Sections E.3.0.

Based on DOE-RL (2000), the risk assessment for this WMA B-BX-BY 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 1996). 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 and dose 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 and dose assessment are used to support evaluation of potential interim measures or ICMs (Section 5) and to determine the need for additional WMA-specific characterization data as described in Section 6.

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

- “The Model Toxics Control Act Cleanup Regulation” (WAC 173-340), which implements MTCA requirements
- *Hanford Site Risk Assessment Methodology* (DOE-RL 1995b), which is the risk and dose 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 been applied for site-specific decisions at the Hanford Site in the 300 Area (Ecology 2001).

Under MTCA, risk assessment requirements for nonradioactive contaminants stipulate that carcinogenic risks shall be less than  $1.0 \times 10^{-6}$  ( $1.0 \times 10^{-5}$  for multiple contaminants) for Method B and  $1.0 \times 10^{-5}$  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  $1 \times 10^{-4}$  or the cumulative noncarcinogenic hazard index exceeds 1.0. Carcinogenic risks below  $1 \times 10^{-6}$  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).

Dose assessments are based on HSRAM (DOE-RL 1995b). Four exposure scenarios are defined by HSRM to estimate radiation doses to hypothetical future members of the public: agricultural, residential, industrial, and recreational. The four HSRM exposure scenarios were developed for the Hanford Site to facilitate evaluation of risk related to CERCLA remedial investigations and RCRA facility investigations. Groundwater transport was the primary exposure pathway considered in this analysis.

The primary dose limit specified by DOE Order 435.1 includes the DOE primary dose limit of 100 mrem effective dose equivalent (EDE) in a year applied to a hypothetical future member of the public. This all-pathways dose to the maximally exposed offsite individual is calculated for 1000 years at points on the Hanford Site that a future member of the public could access. The point of access nearest the waste disposal sites in the future is defined by the boundaries indicated in Figure 4.7. The dose constraint is defined as 30 mrem EDE in a year to the maximally exposed offsite individual for 1000 years in DOE Order 435.1 and ensures that no single source, practice, or pathway accounts for an extraordinary portion of the primary dose limit.

#### 4.3.1 Receptor Scenario Rationale

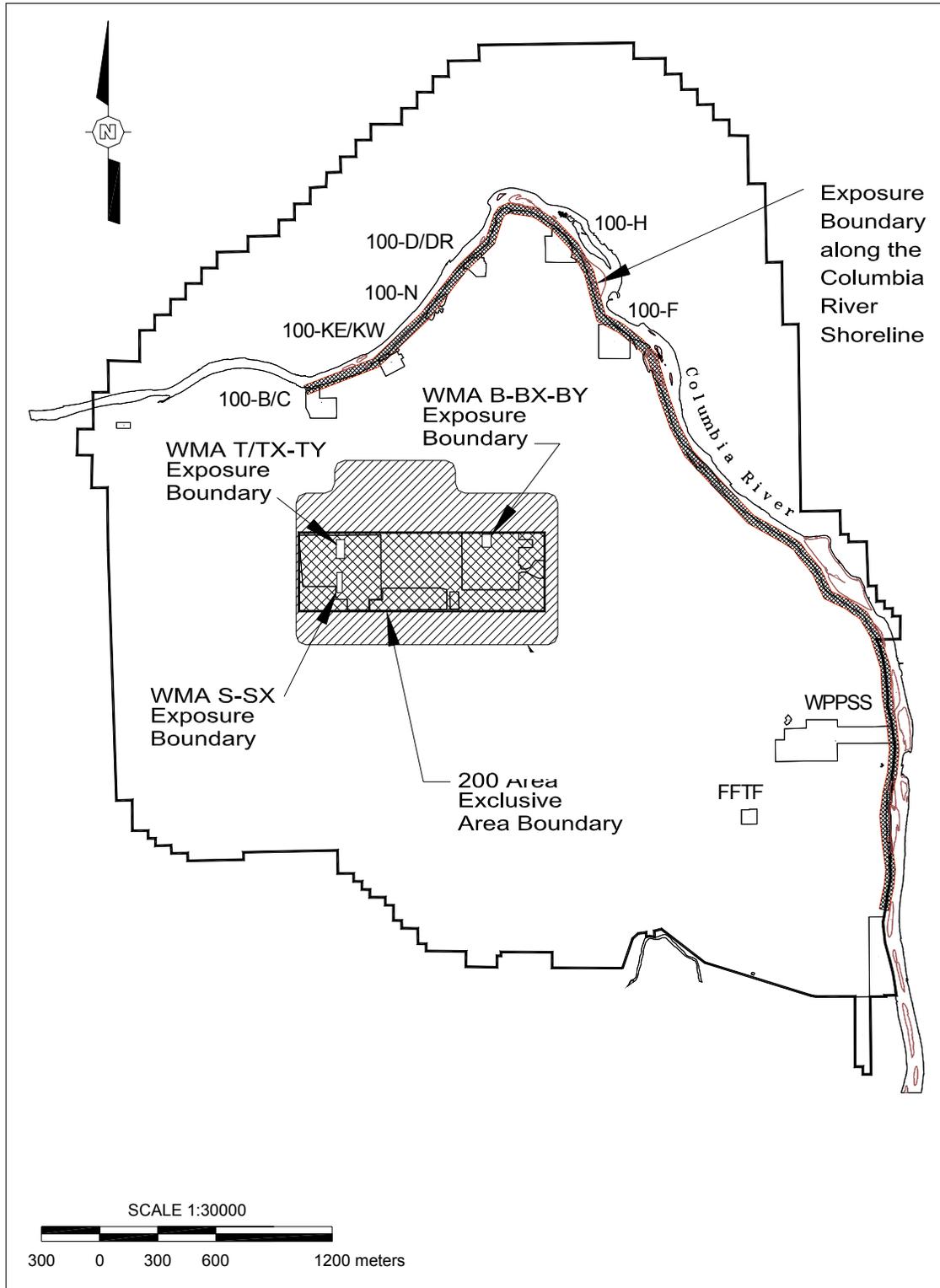
DOE and Ecology have agreed (DOE-RL 2000) to use MTCA Methods B and C in the Corrective Action Program. MTCA Methods B and C risks are calculated based on equations and parameters specified in the MTCA protocol for establishing groundwater cleanup levels (WAC 173-340-720). Risk is calculated for the 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), *Retrieval Performance Evaluation Methodology for the AX Tank Farm* (DOE-RL 1999), and *Field Investigation Report for Waste Management Area S-SX* (Knepp 2002). Risk calculations for the three HSRAM-based scenarios use groundwater pathway unit risk factors adapted without modification directly from the TWRS EIS.

Three hypothetical receptor locations identified by DOE and Ecology (DOE-RL 2000) as the boundaries for which potential risk and dose were calculated are as follows:

- Downgradient at the BX tank farm east fence line boundary
- Downgradient at the 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 BX tank farm east fence line boundary, risk and dose were calculated at one location corresponding to the cross-section through tanks BX-108 to BX-102 considered in the contaminant transport analysis.

Figure 4.7. Hypothetical Receptor Locations for Risk Evaluation



**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 C risk exposure parameters are discussed in Appendix E, Section E.4.1.2. Method C risk is calculated for the same three locations 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.4.1.2. Method C risk is calculated for the same three locations 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.4.1.3. The scenario is intended to represent non-remediation workers who are 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 (DOE and Ecology 1996) and DOE-RL (1999) 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.4.1.3.

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 (1999) and Knepp (2002). Industrial worker risk is calculated for the same three boundaries 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.4.1.4.

Residential farmer risk is evaluated using a unit risk factor approach as discussed for the industrial worker scenario in Appendix E, Section E.4.1.3. Residential farmer risks are calculated for the same three boundaries 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.4.1.5.

Recreational shoreline user risk is evaluated using a unit risk factor approach as described in the industrial worker scenario in Appendix E, Section E.4.1.3. Recreational shoreline user risks are calculated only at the downgradient Columbia River shoreline that is defined in Section 4.3.1. The recreational land user scenario is not included in the WMA B-BX-BY 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 B-BX-BY risk assessment started with the estimated inventory released from the tank farm system to the environment. That estimated inventory is provided in *Preliminary Inventory Estimates for Single-Shell Tank Leaks in B, BX and BY Tank Farms* (Jones et al. 2001). The CoPCs listed in Jones et al. (2001) include the analytes listed in the model cited in *Hanford Tank Chemical and Radionuclide Inventories: Hanford Defined Waste Model* (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 B-BX-BY risk assessment. Because not all of the constituents associated with the released tank waste will migrate to the groundwater, the CoPCs 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 B-BX-BY risk assessment.

- Constituents having distribution coefficients (Kd) 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: 2001 Version* (Mann et al. 2001), 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 S tank farm retrieval performance evaluation (Crass 2001) and for DOE-RL (1999) indicated 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 4.1.

CoPCs eliminated because of the distribution coefficient criterion are: aluminum, iron, bismuth, lanthanum, zirconium, lead, nickel, manganese, plutonium (total), nickel-59,

nickel-63, cobalt-60, strontium-90, yttrium-90, zirconium-93, niobium-93m, cadmium-113m, tin-126, cesium-134, cesium-137, barium-137, samarium-151, europium-152, europium-154, europium-155, radium-226, radium-228, plutonium series, americium series, curium series, and thorium-232.

- Low-activity radionuclides that are present in low concentrations and with short half-lives if they have decayed for at least five half-lives. A decay time of five 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 under normal recharge.

Additional CoPCs eliminated because of the half-life criterion are ruthenium-106, antimony-125, and tritium.

- Constituents that have no documented human health risk or toxicity factors. The basis for these factors is documented in the *Integrated Risk Information System* (EPA 2002a) or the *User's Guide: Radionuclide Carcinogenicity* (EPA 2002b) 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, strontium, sulfate, silica, and sodium.

Although several organic chemicals are listed in the Agnew (1997) model, only ethylene-diamine-tetraacetic acid (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.

**4.3.2.2 Constituents of Potential Concern for Risk Assessment.** The CoPCs used in the WMA B-BX-BY risk assessment after applying the exclusion criteria described in Section 4.3.2.1 were:

- Chemicals: chromium, fluoride, mercury, nitrate, nitrite, uranium (total), and EDTA
- Radionuclides: carbon-14, selenium-79, technetium-99, iodine-129, and uranium series.

### 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 boundaries 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, uranium-238, and nitrate) 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. 2001) 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
Uranium-238	Uranium-232, Uranium-233, Uranium-234, Uranium-235, Uranium-236, Uranium (total), Chromium
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) and Knepp (2002). Unit dose factors are presented in Appendix E, Section E.4.4. 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.4.1.3. Industrial worker dose is calculated at the three boundaries 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 a cross-section at the BX tank farm east fence line boundary are used in Appendix E, Equation E.9 to calculate the risk and dose values with the methodology described in Section 4.3 and Appendix E, Section E.4.0. 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 7 and 8).

**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 B-BX-BY 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 B-BX-BY.
7	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 B-BX-BY.
8	Base case with 30 mm/yr meteoric recharge	

Risk and dose results for the four cases shown in Table 4.7 are presented individually in Sections 4.4.1 to 4.4.4. 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 boundary, the peak residential farmer ILCR is always approximately 34 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. Conclusions of the risk and dose calculations are presented in Section 4.4.6. The relationship between the risk and dose results, compared to the principal study questions for the DQO process, are discussed in Section 4.4.5.

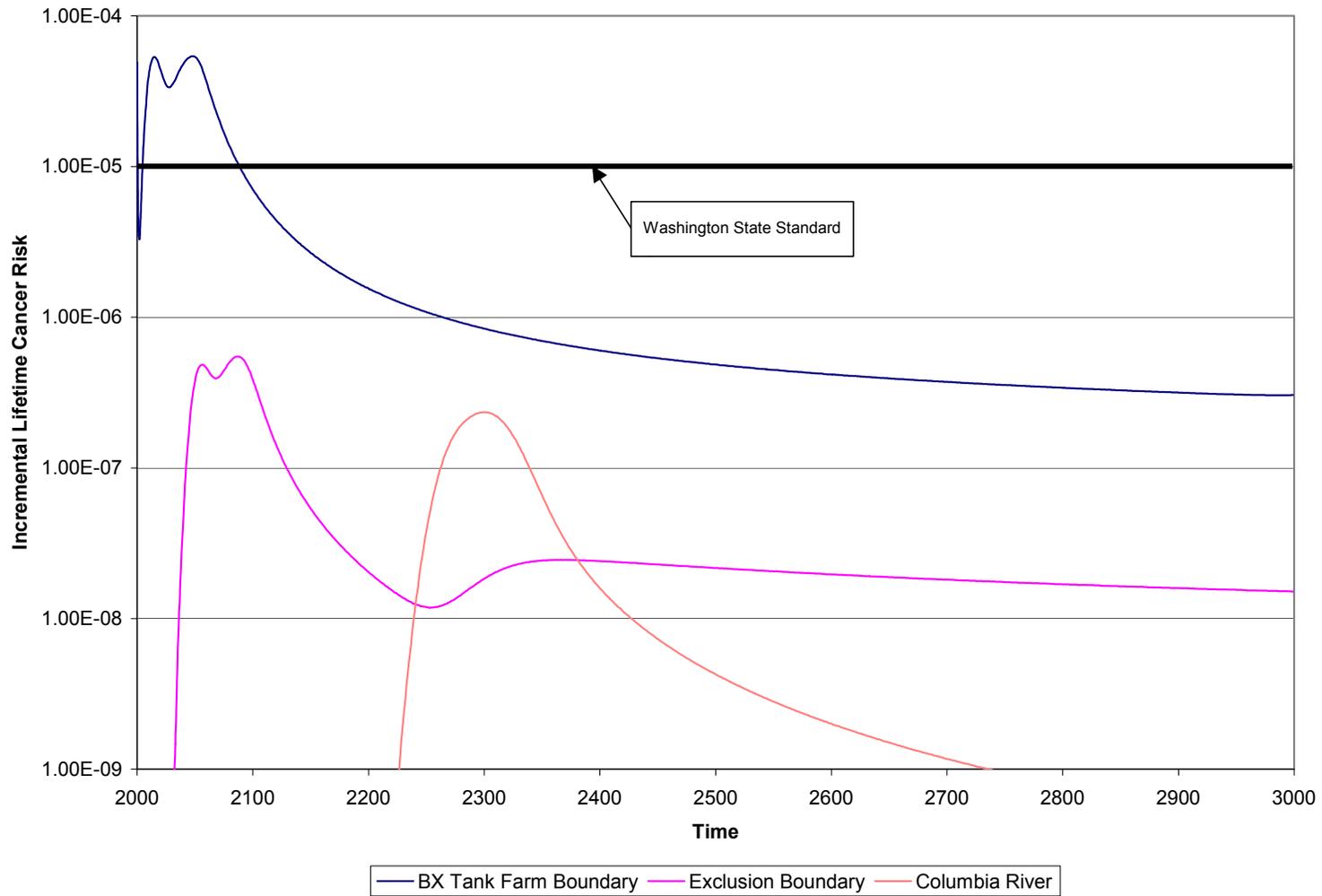
#### 4.4.1 Base Case, No Action Alternative (Case 1)

Results for the base case (case 1) are summarized in Table 4.8. Results for case 1 reveal two general trends that are also evident in the results for the other cases considered (cases 2, 7, and 8). First, peak human health risk values for the cross-section at the BX tank farm east fence line boundary exceed the peak values for the other two downgradient boundaries. Second, peak values at the downgradient calculation boundary (i.e., the Columbia River shoreline) are generally two to three orders of magnitude lower than the peak values at the BX tank farm east fence line boundary.

Peak human health risk values for case 1 are the highest of the four cases considered. Between the BX tank farm east fence line boundary and the Columbia River shoreline boundary, the peak industrial worker ILCR ranges from  $5.39 \times 10^{-5}$  to  $2.34 \times 10^{-7}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index varies from  $1.98 \times 10^{-1}$  to  $4.88 \times 10^{-4}$ . Peak hazard index values are driven by nitrate. The peak dose ranges from 3.18 mrem/yr to  $1.38 \times 10^{-2}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for case 1 are shown in Figure 4.8 for calculation boundaries between the BX tank farm east fence line boundary and the Columbia River shoreline. Temporal variations in hazard index and dose for case 1 are similar to those shown for ILCR. The results for the BX tank farm east fence line boundary and 200 Area exclusion boundary display a bimodal character in the vicinity of the peak. In both cases, the maximum peak occurs in the second of the two high points. The peak at the BX tank farm east fence line boundary occurs in year 2048 and the peaks for the 200 Area exclusion boundary and Columbia River shoreline boundaries arrive after approximately another 40 and 250 years, respectively (i.e., 2098 and 2298).

**Figure 4.8. Case 1 Industrial Worker ILCR Versus Time at Calculation Points Between the BX Tank Farm East Fence Line Boundary and the Columbia River Shoreline**



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

Calculation 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
BX Tank Farm Fence Line	1.83E-03	2.20E+02	5.39E-05	1.98E-01	NA	NA	NA	2.30E+00	NA	1.05E+00	3.18E+00
200 Area Exclusion Boundary	1.86E-05	1.93E+00	5.48E-07	1.74E-03	NA	NA	NA	2.02E-02	NA	9.22E-03	3.23E-02
Columbia River Shoreline	7.94E-06	5.42E-01	2.34E-07	4.88E-04	3.89E-08	6.71E-05	NA	5.67E-03	NA	2.59E-03	1.38E-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 B-BX-BY.

HI = hazard index

ILCR = incremental lifetime cancer risk

MTCA = Model Toxics Control Act

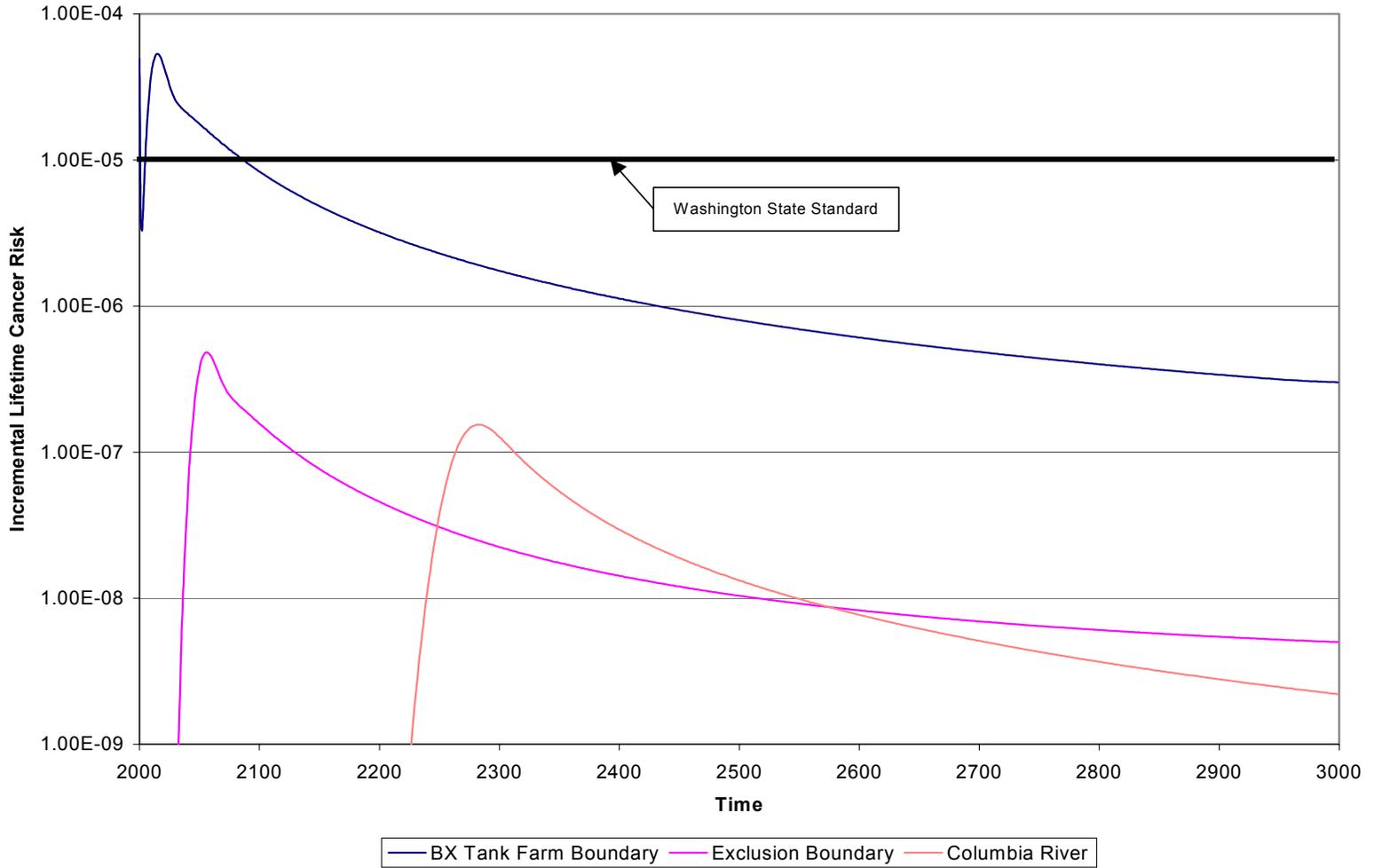
NA = not applicable

#### 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 boundaries as discussed above for case 1. Peak values for case 2 are slightly lower than the corresponding values for case 1. Between the BX tank farm east fence line boundary and the Columbia River shoreline, the peak industrial worker ILCR ranges from  $5.34 \times 10^{-5}$  to  $1.54 \times 10^{-7}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index ranges from  $1.98 \times 10^{-1}$  to  $4.54 \times 10^{-4}$ . Peak hazard index values are driven by nitrate. The peak dose ranges from 3.15 mrem/yr to  $9.07 \times 10^{-3}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for case 2 are shown in Figure 4.9 for calculation points between the BX tank farm east fence line boundary and the Columbia River. Temporal variations in hazard index and dose for case 2 are similar to those shown for ILCR. The peak at the BX tank farm east fence line boundary and 200 Area exclusion boundary occur in the years 2015 and 2056, respectively. In both cases, the peak arrival time is the same year and approximate peak value as the first of the two peaks in the bimodal result found in case 1. The peak at the Columbia River shoreline calculation location arrives approximately 270 years after the peak (i.e., year 2285) at the BX tank farm east fence line boundary.

**Figure 4.9. Case 2 Industrial Worker ILCR Versus Time at Calculation Points Between the BX Tank Farm East Fence Line Boundary and the Columbia River Shoreline**



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

Calculation 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
BX Tank Farm Fence Line	1.81E-03	2.20E+02	5.34E-05	1.98E-01	NA	NA	NA	2.30E+00	NA	1.05E+00	3.15E+00
200 Area Exclusion Boundary	1.63E-05	1.92E+00	4.82E-07	1.73E-03	NA	NA	NA	2.01E-02	NA	9.18E-03	2.84E-02
Columbia River Shoreline	5.21E-06	5.03E-01	1.54E-07	4.54E-04	2.56E-08	6.23E-05	NA	5.27E-03	NA	2.41E-03	9.07E-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 B-BX-BY.

HI = hazard index

ILCR = incremental lifetime cancer risk

MTCA = Model Toxics Control Act

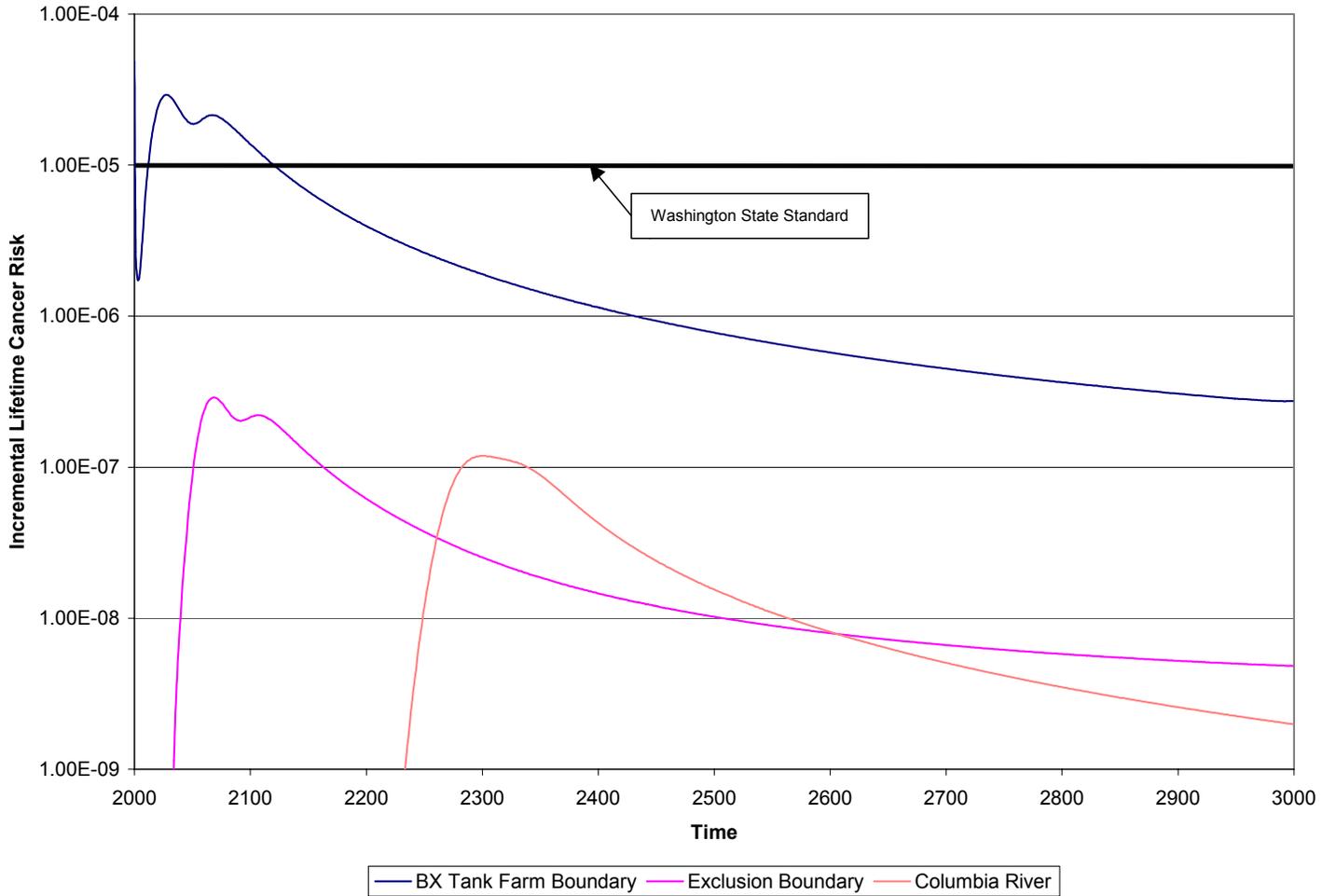
NA = not applicable

#### 4.4.3 Base Case with 50 mm/yr Meteoric Recharge (Case 7)

Results for case 7, base case with 50 mm/yr meteoric recharge, are summarized in Table 4.10. Results for case 7 show the same general trends regarding the boundaries as discussed above for case 1. Peak values for case 7 generally range from slightly lower to a factor of 2 lower than the corresponding values for case 1. Between the BX tank farm east fence line boundary and the Columbia River shoreline, the peak industrial worker ILCR ranges from  $4.85 \times 10^{-5}$  to  $1.19 \times 10^{-7}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index ranges from  $1.77 \times 10^{-1}$  to  $3.72 \times 10^{-4}$ . Peak hazard index values are driven by nitrate. The peak dose ranges from 2.86 mrem/yr to  $7.00 \times 10^{-3}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for case 7 are shown in Figure 4.10 for calculation points between the BX tank farm east fence line boundary and the Columbia River shoreline. Temporal variations in hazard index and dose for case 7 are similar to those shown for ILCR. Overall, the temporal variations for case 7 most closely resemble those for case 1, in that the predictions for the BX tank farm east fence line boundary and 200 Area exclusion boundary display a bimodal character. The peak at the BX tank farm east fence line boundary occurs in the year 2000 and the peaks for the 200 Area exclusion boundary and Columbia River shoreline locations arrive after approximately 70 and 300 years, respectively.

**Figure 4.10. Case 7 Industrial Worker ILCR Versus Time at Calculation Points Between the BX Tank Farm East Fence Line Boundary and the Columbia River Shoreline**



**Table 4.10. Peak Long Term Human Health Impacts for Case 7**

Calculation Point	Residential Farmer		Industrial Worker		Recreational Shoreline User <sup>a</sup>		MTCA Method B <sup>b</sup>		MTCA Method C <sup>b</sup>	
	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI	ILCR	HI
BX Tank Farm Fence Line	1.64E-03	1.97E+02	4.85E-05	1.77E-01	NA	NA	NA	2.06E+00	NA	9.40E-01
200 Area Exclusion Boundary	9.80E-06	1.18E+00	2.89E-07	1.07E-03	NA	NA	NA	1.24E-02	NA	5.66E-03
Columbia River Shoreline	4.02E-06	4.13E-01	1.19E-07	3.72E-04	NA	5.11E-05	NA	4.32E-03	NA	1.97E-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 B-BX-BY.

HI = hazard index

ILCR = incremental lifetime cancer risk

MTCA = Model Toxics Control Act

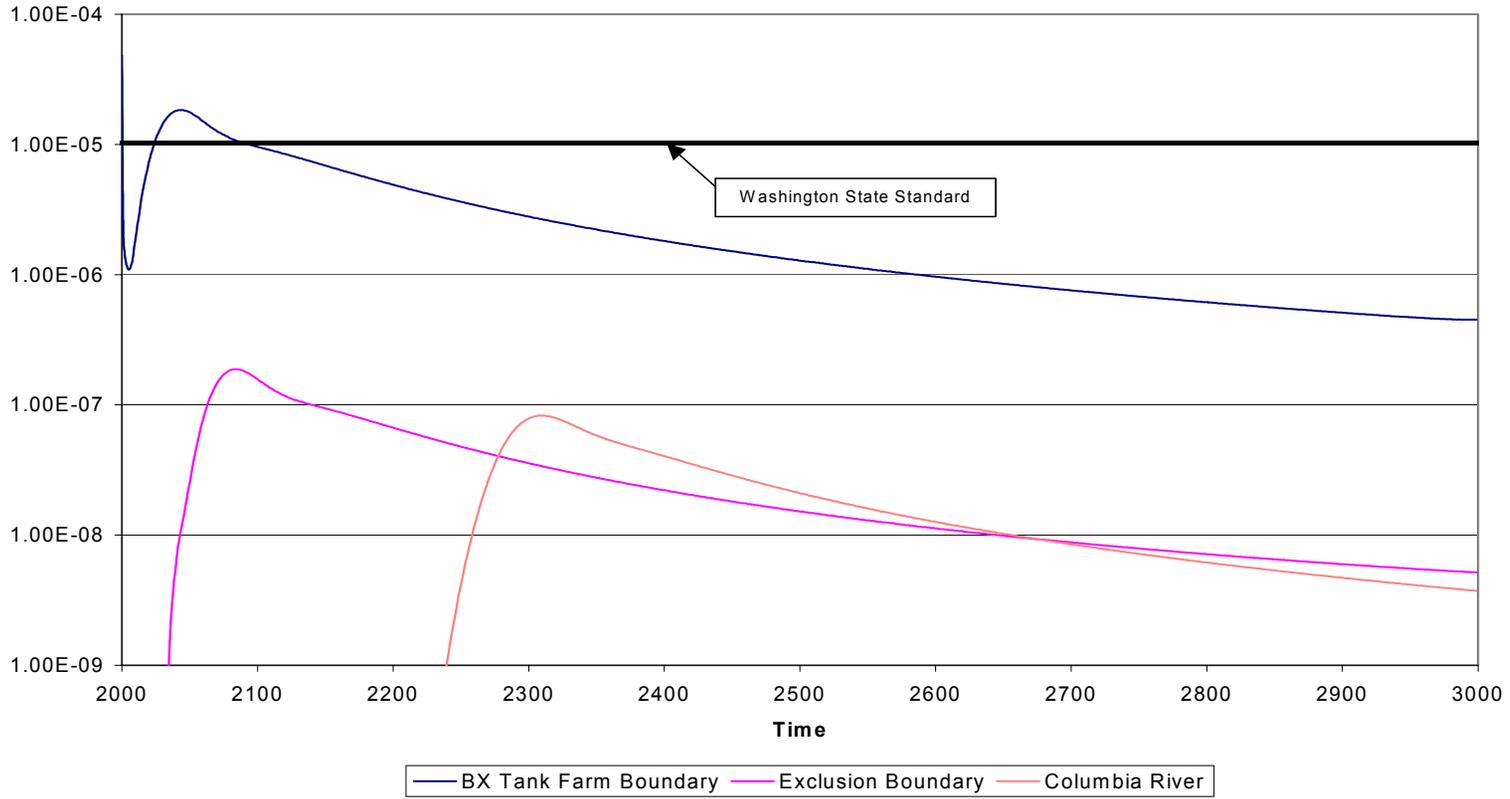
NA = not applicable

#### 4.4.4 Base Case with 30 mm/yr Meteoric Recharge (Case 8)

Results for case 8, base case with 30 mm/yr meteoric recharge, are summarized in Table 4.11. Results for case 8 show the same general trends regarding the boundaries as discussed above for case 1. Peak values for case 8 generally range from slightly lower to a factor of 2 lower than the corresponding values for case 1. Between the BX tank farm east fence line boundary and the Columbia River shoreline, the peak industrial worker ILCR ranges from  $4.83 \times 10^{-5}$  to  $8.27 \times 10^{-8}$ . Peak ILCR values are driven by technetium-99. The peak industrial worker hazard index ranges from  $1.97 \times 10^{-1}$  to  $2.89 \times 10^{-4}$ . Peak hazard index values are driven by nitrate. The peak dose ranges from 2.85 mrem/yr to  $4.88 \times 10^{-3}$  mrem/yr. Peak dose values are driven by technetium-99.

Temporal variations in ILCR for case 8 are shown in Figure 4.11 for calculation points between the BX tank farm east fence line boundary and the Columbia River shoreline. Temporal variations in hazard index and dose for case 8 are similar to those shown for ILCR. The peak at the BX tank farm east fence line boundary occurs in the year 2000, and the peaks at the 200 Area exclusion boundary and Columbia River shoreline calculation locations arrive after approximately 80 and 310 years, respectively.

**Figure 4.11. Case 8 Industrial Worker ILCR Versus Time at Calculation Points Between the BX Tank Farm East Fence Line Boundary and the Columbia River Shoreline**



**Table 4.11. Peak Long Term Human Health Impacts for Case 8**

Calculation 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
BX Tank Farm Fence Line	1.64E-03	2.19E+02	4.83E-05	1.97E-01	NA	NA	NA	2.29E+00	NA	1.05E+00	2.85E+00
200 Area Exclusion Boundary	6.37E-06	7.67E-01	1.88E-07	6.91E-04	NA	NA	NA	8.02E-03	NA	3.67E-03	1.11E-02
Columbia River Shoreline	2.80E-06	3.21E-01	8.27E-08	2.89E-04	1.37E-08	3.98E-05	NA	3.36E-03	NA	1.54E-03	4.88E-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 B-BX-BY.

HI = hazard index

ILCR = incremental lifetime cancer risk

MTCA = Model Toxics Control Act

NA = not applicable

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

Four principal study questions constituting four decision statements are provided in Section 2.0 of Knepp (2000). Those principal study questions, adjusted for WMA B-BX-BY, are evaluated against the results of the potential human health risk from Section 4.4.

**Principal Study Question No. 1** – Do past, current, and future shallow (i.e., 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 BX tank farm east fence line boundary?

**Principal Study Question No. 2** – Do past, current, and future 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., BX tank farm east fence line boundary, 200 Area exclusion boundary, 200 Area buffer zone, and Columbia River shoreline)?

**Principal Study Question No. 3** – Do past, current, and future 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 interim measures ICM retrieval and closure technology evaluations that can be collected concurrent with WMA characterization (i.e., opportunities for project integration)?

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 for technetium-99 at BX tank farm east fence line boundary only. The current groundwater concentration for technetium-99 is 2,461 pCi/L in well 299-E33-45. The soil concentrations were used as input for the numerical simulation of flow and solute transport modeling, and the results of the numerical simulations indicate that the groundwater concentrations would not exceed the maximum contaminant levels, and thereby are protective of groundwater for normal recharge cases.

At the BX tank farm east fence line boundary, soil and groundwater concentrations would exceed the preliminary performance standards for technetium-99 at the cross-section at tank BX-102. Soil and groundwater concentration at the 200 Area exclusion zone boundary and Columbia River would not exceed preliminary performance standards. For principal study question 4, ongoing interim measures have been conducted (Section 5.0) for the waste management area.

#### 4.4.6 Conclusions of Risk and Dose

Table 4.12 presents the peak ILCR, hazard index, and dose for the industrial worker scenario for the four cases analyzed. This comparison indicates the following ranking from the highest risk to lowest risk:

- Case 1 (no action alternative)
- Case 2 (barrier case with no water line breaks)
- Case 7 (base case with 50 mm/yr meteoric recharge)
- Case 8 (base case with 30 mm/yr meteoric recharge).

**Table 4.12. Comparison of Peak Incremental Lifetime Cancer Risk, Hazard Index, and Dose for the Industrial Worker**

Case	BX Tank Farm Fence Line Boundary	200 Area Exclusion Boundary	Columbia River Shoreline
<i>Industrial Worker Peak Incremental Lifetime Cancer Risk</i>			
1	5.39E-05	5.48E-07	2.34E-07
2	5.34E-05	4.82E-07	1.54E-07
7	4.85E-05	2.89E-07	1.19E-07
8	4.83E-05	1.88E-07	8.27E-08
<i>Industrial Worker Peak Hazard Index</i>			
1	1.98E-01	1.74E-03	4.88E-04
2	1.98E-01	1.73E-03	4.54E-04
7	1.77E-01	1.07E-03	3.72E-04
8	1.97E-01	6.91E-04	2.89E-04
<i>Industrial Worker Peak Dose (mrem/yr)</i>			
1	3.18E+00	3.23E-02	1.38E-02
2	3.15E+00	2.84E-02	9.07E-03
7	2.86E+00	1.71E-02	7.00E-03
8	2.85E+00	1.11E-02	4.88E-03

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

- BX tank farm east fence line boundary
- 200 Area exclusion boundary
- Columbia River shoreline.

The CoC driver for risk and dose is technetium-99. For the hazard index, the principal CoC driver is nitrate.

## **5.0 INTERIM MEASURES**

The interim measures and ICMs that have been evaluated and/or implemented as they relate to WMA B-BX-BY 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 under RCRA. Interim measures do not require comprehensive evaluation in a CMS. Interim measures identified to date for WMA B-BX-BY focus on actions to minimize infiltration and contaminant migration to groundwater. 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 B-BX-BY ICMs will be undertaken in a CMS or an accelerated CMS pending results of this FIR. Five categories of interim measures have been implemented at WMA B-BX-BY during the past three years.

### **5.1 INTERIM MEASURES IDENTIFICATION**

An engineering report (Haass 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). Updated rough order of magnitude cost estimates are provided in Anderson (2001).

#### **5.1.1 Abandonment of Active Water Lines**

Combined, the B-BX-BY tank farm areas contain approximately 2,375 m (7,790 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 beginning in the early 1940s through the 1990s. The older water lines have exceeded their design life by 20 to 50 years. Pipe breaks, failed leaded joints, and poorly functioning gate valves are common for older water lines at the Hanford Site. The Hanford Site-wide failure rate appears to be increasing geometrically. The one 6-inch raw water line and associated feeder lines, plus one 10-inch sanitary water line that were identified in FFS (1999) were tested during fiscal year 2002. Of those lines, one was found to be losing water at about 4 L/min (1 gal/min). The source of that leak was a faulty valve associated with the Hanford Barrier test plot. That valve was repaired and returned to service. Other lines were determined to be not needed and were abandoned, effectively removing them as sources of inadvertent recharge.

#### **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. The majority of wells identified in Anderson (2001) are the drywells used to monitor movement of contaminants through the vadose zone. Anderson (2001) identifies a total of five wells in the B, BX, and BY tank farms that are potential Priority 1 candidates for near-term decommissioning. These wells are presently used in the groundwater monitoring program assessing WMA B-BX-BY.

### 5.1.3 Upgradient Surface Water Run-On Control Measures

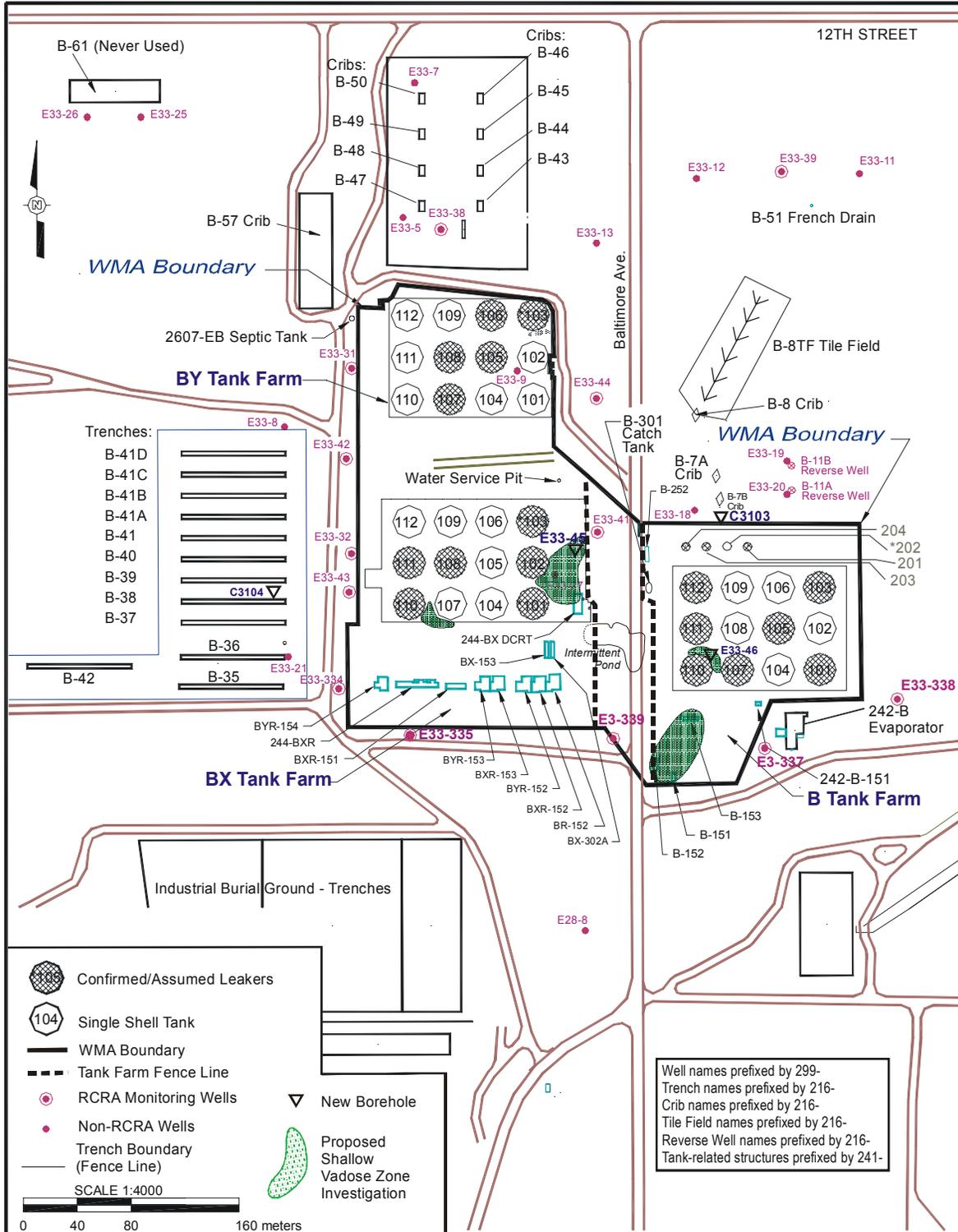
Upgradient surface water run-on control measures consist of some combination of regraded ground surfaces, soil/gravel berms, asphalt pavement, concrete curbs, gutters and valley drains, and culverts all constructed outside the SST farms to prevent surface water from pressurized water line leaks and unusual meteorological events from flowing onto the tank farm areas. Anderson (2001) recommends that run-on control be established to prevent surface water from entering the SST farms from outside sources to reduce infiltration within each SST even if no other interim measures are selected.

During fiscal year 2002, design and construction of run-on control structures were implemented adjacent to WMA B-BX-BY. Berms were placed to redirect surface water away from the tank farm surfaces and curbs and gutters were placed along Baltimore Avenue to redirect anticipated run-off.

Of specific interest to the historical recharge of the WMA was the need to construct a drain and culvert system to move water from south to north across a waste transfer line that crosses Baltimore Avenue from B tank farm to BX tank farm. In the early 1980s, the waste transfer line was constructed at grade to avoid excavating potentially contaminated soils, soil was used to shield the lines, and Baltimore Avenue was raised to go over the lines. The gravel shield and recontouring resulted in a “dam” behind which water has been reported to pond. Design calculations performed for the culvert and drain system indicate a run-off of 8,400 cubic feet with a recurrence probability of 0.033 (1/30 years). Upon completion of the run-on control measures, this water will be diverted to an east-west trending ditch north of 12th Avenue which is the northern perimeter road for 200 East Area. Some future impact to the existing groundwater contaminant plumes may be experienced as this water infiltrates at this new location and reaches the water table. Figure 5.1 shows the area of potential historic ponding as well as the extent of surface water run-on control measures taken at WMA B-BX-BY. This pond has a nominal capacity of 25,000 gal before it overflows to the north. The dashed portion of the line enters the BX farm and extends for an undetermined distance south of the bermed transfer line. This source of infiltrating water is potentially significant in the movement of subsurface contaminants.

Run-on events are most evident when associated with rapid snowmelt and frozen ground. Rapid snowmelt events have taken place at least six times over the history of WMA B-BX-BY. The first of these took place in 1979, followed by one in 1985, two in 1993, and one each in 1995 and 1996. Five of the six events have occurred after construction of the “dam” noted above. The two wettest years of record (i.e., 12.31 and 12.19 inches of precipitation) for the Hanford Site are 1995 and 1996, respectively, and the winter with the greatest total snowfall (i.e., 53+ inches) was 1992-1993. The occurrence of technetium-99 peaks in well 299-E33-41 (Figure 5.2) (Hartman et al. 2002) in a pattern that replicates the 1995-1996 high precipitation events points to the importance of controlling run-on events.

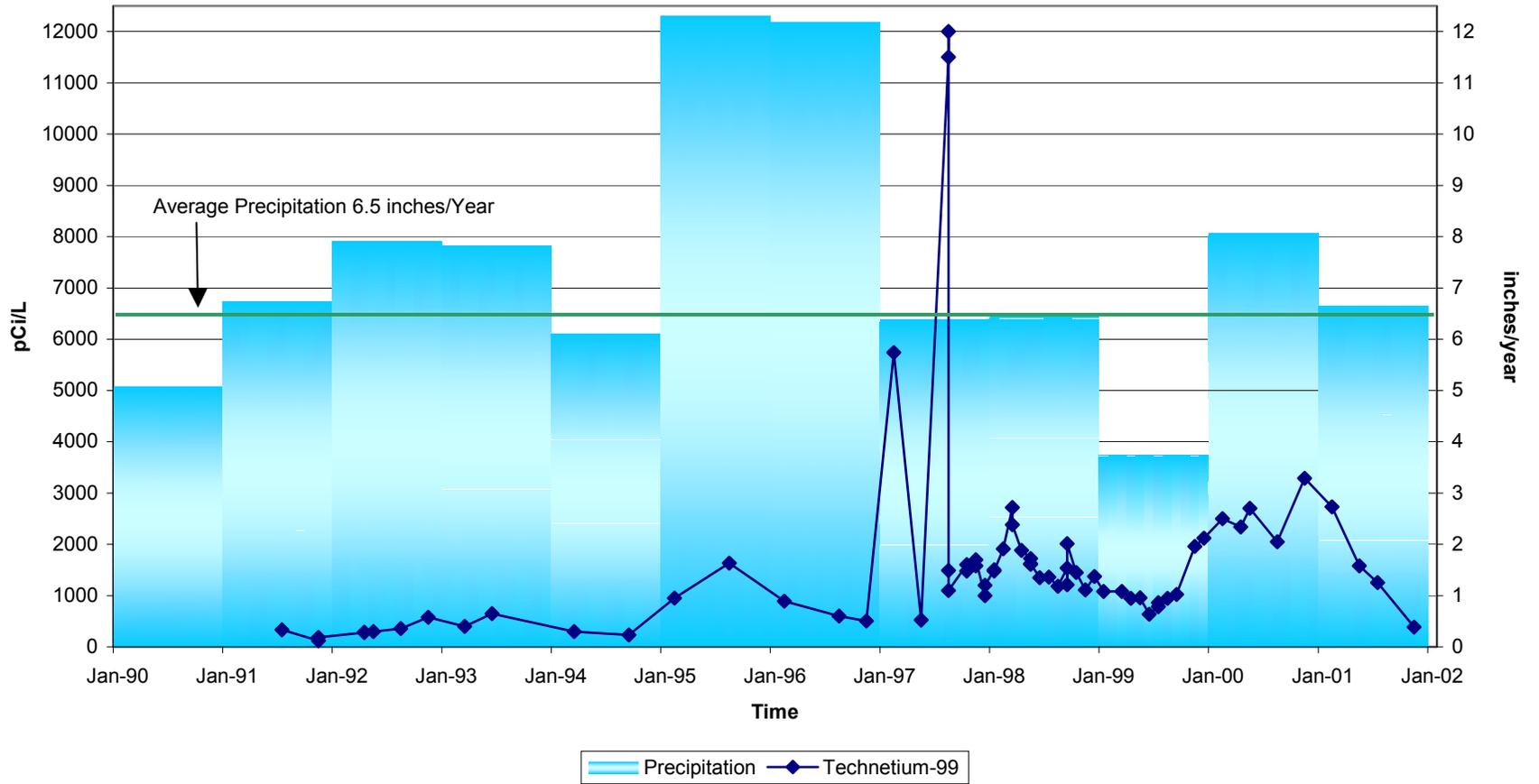
**Figure 5.1. Waste Management Area B-BX-BY Location Map of Characterization Activities, Surrounding Facilities, and Wells**



Note: All wells are preceded by 299-.

Note: The intermittent pond between the B and BX tank farms has been addressed by interim measures.

Figure 5.2. Technetium-99 Concentrations in Well 299-33-41 and Annual Precipitation



#### **5.1.4 Interim Corrective Measures**

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 B-BX-BY have been identified; however, some of these potential ICMs are likely to be implemented sooner than others. The risk assessment (Section 4 and Appendix E) will be used to help determine the advisability of implementing ICMs at WMA B-BX-BY. Because ICMs are a possible future activity, they are discussed separately in Appendix F.

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## 6.0 CONCLUSIONS

This section summarizes the major findings and conclusions for this report. Areas covered include the overview of the process (Section 6.1), a description of the characterization approach (Section 6.2), a summary of the additions to the characterization database (Section 6.3), a discussion of the affirmation and refinement of the conceptual model for WMA B-BX-BY (Section 6.4), a summary of the simulations and associated impacts analysis (Section 6.5), and a summary of the interim measures implemented during this investigation (Section 6.6).

### 6.1 OVERVIEW

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

- Collect and interpret available data pertinent to SST system waste releases and vadose zone contamination
- Determine missing information and develop a plan to collect new data and complete analyses
- Collect new data using sediment collection methods that minimize dose to workers and improve data quality
- 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
- Integrate new and old data with numerical modeling of future contaminant migration and associated risk evaluation
- Implement interim measures and/or additional data collection and analysis.

These work steps are the same as those successfully performed for the *Field Investigation Report for Waste Management Area S-SX* (Knepp 2002). These steps created data and analyses that fulfill the purposes of this WMA B-BX-BY FIR as described in Section 1.1.

The major outcomes that have resulted from this work are:

- The future impacts from wastes currently in the vadose zone that resulted from past releases from the B, BX, and BY tank farms are not expected to exceed drinking water standards at or beyond the WMA boundary as long as high-volume liquid discharges to the vadose zone are eliminated. Note, however, that a peak concentration of about 12,000 pCi/L for technetium-99 was measured in groundwater well 299-E33-41 directly east of BX tank farm. These concentrations are most likely due to releases from the BX tank farm.
- Vadose zone and groundwater contamination levels were lower than generally anticipated prior to the initiation of the field investigation according to Jones et al. (2001).

- Estimations of technetium-99 distribution during Hanford Site reprocessing, storage, and disposal and the residue left in the vadose zone have been improved and past assumptions corrected. However, the amount of technetium-99 that was initially discharged to the vadose zone and that might have already reached groundwater is still uncertain.
- Complex hydrologic processes play a major role in contaminant movement in WMA B-BX-BY. Strong evidence of extensive vadose zone lateral migration in WMA B-BX-BY exists. Lateral migration may have extended into WMA B-BX-BY from adjacent past practice discharge sites. Ponding of runoff from natural precipitation in the WMA may have added significant amounts of spatially confined infiltration. Changes in groundwater flow direction have caused plumes from other sources to be found under the WMA.
- Borehole soil characterization performed by the Tank Farm Vadose Zone Project and other laboratory measurements by the Groundwater Protection Program Science and Technology Project have identified precipitated uranium phases, and strontium-90 phases and sorption sites. These data indicate limited future mobility unless abnormally high amounts of infiltration occur. Neither uranium nor strontium-90 is expected to significantly impact groundwater in the current moisture and geochemical environment. However, the precipitated uranium phases may function as a long-term source to percolating waters if recharge is not controlled.
- Interim measures (e.g., capping boreholes, cutting off inactive water lines, and building surface run-on barriers and diversions) have been implemented in the WMA. These are expected to mitigate future contamination risks.

## 6.2 VADOSE ZONE AND GROUNDWATER CONTAMINATION LEVELS

Based on past efforts (Section 2), it was expected that contamination indicative of metal wastes would be found in borehole 299-E33-45 near tank BX-102. It was also expected that contamination from borehole 299-E33-46 near tank B-110 would contain strontium-90 along with other typical tank waste contaminants. It was believed that relatively little contamination from trench 216-B-38 or crib 216-B-7A would be found at deeper levels in the vadose zone based on knowledge of the operation of these facilities. Finally, groundwater contamination was expected because extensive groundwater monitoring indicates a large plume north of the areas sampled (i.e., north of the BY tank farm). The program generally confirmed these expectations although concentration levels and total inventory estimates were less than anticipated.

### 6.2.1 Borehole BX-102

The location of borehole 299-E33-45, about 30 m (100 ft) east of tank BX-102, was chosen to be among the field of drywells constructed in the early 1970s to trace the plume from the BX-102 tank overflow to intercept the maximum contaminant concentration. At this position, technetium-99 was found from 36 to 52 m (120 to 170 ft) bgs with porewater extract values up to 546,000 pCi/L. Uranium peaked higher in the formation at approximately 40 m (~130 ft), with a total range extending from 21 to 52 m (70 to 170 feet) bgs. The peak soil concentrations for uranium were 1.65 mg/g. Mobile contaminants (e.g., nitrates and cations) have a similar spatial

profile to technetium, with retarded contaminants (i.e., most metals) having a distribution similar to uranium.

### **6.2.2 Borehole B-110**

Borehole 239-E33-46 (near tank B-110) was drilled to investigate what appeared to be bremsstrahlung from strontium-90. High strontium-90 concentrations were found down to 26 m (85 ft) bgs with strontium-90 values up to 11,250 pCi/g of sediment. Although much of the sorbed strontium-90 is present in an ion-exchange state, it is essentially immobile under the current ionic regime present in the porewater. Other tank waste contaminants (e.g., nitrate) were found down to 69 m (200 ft).

### **6.2.3 200 Area Remediation Program Boreholes**

The Fluor Hanford 200 Area Remediation Program investigated two types of past practice discharge sites near WMA B-BX-BY including a specific retention, low-volume discharge trench (216-B-38) and a high-volume discharge crib (216-B-7A). The CH2M HILL Hanford Group Tank Farm Vadose Zone Project obtained supplementary findings by analyzing additional samples (particularly those deeper in the profile).

The samples taken from underneath the B-38 trench showed a clear nitrate zone, although no similar zone is seen for technetium-99. This discrepancy led to experiments reproducing the bismuth phosphate recovery process. The experiments showed that, contrary to widely held assumptions, that almost all (greater than 99%) of the technetium-99 followed the main uranium waste stream, rather than going into the metal waste stream.

### **6.2.4 Groundwater Monitoring Program**

The Hanford Groundwater Protection Program has extensively monitored the groundwater in and around WMA B-BX-BY (Hartman et al. 2002). High levels of contamination are known to exist in the area. For example, technetium-99 values of 12,000 pCi/L were measured in 2001 under the BY cribs, just north of the BY tank farms. The groundwater sampled in this effort is in the southern part of the region where contamination is much lower. The levels found in the boreholes near tanks BX-102 and B-110 were fairly similar to each other but less than the maxima reported in Hartman et al. (2002) (i.e., tritium: 2,410 pCi/L and 2,810 pCi/L; nitrate: 57,500 ug/L and 16,400 ug/L; technetium-99: 2410 pCi/L and 1640 pCi/L; and uranium: 10.8 ug/L and 2.9 ug/L near tanks BX-102 and B-110, respectively).

RCRA groundwater well 299-E33-41 lies directly east of BX tank farm. Peak measured concentrations in the well are most likely due to releases from this tank farm. This conclusion is supported by the nitrate to technetium-99 ratios for the groundwater at this location being of the same order of magnitude (10 to 100  $\mu\text{g/pCi}$ ) as in the soil profile and the observation of near coincident uranium and technetium-99 peaks in 1997. A peak concentration on the order of 12,000 pCi/L for technetium-99 was measured in the well in August 1997. Sharp spikes that are followed by immediate drops in groundwater concentration levels characterize the observed history of contamination in the groundwater monitoring. Such a behavior in the observed profiles, coupled with high technetium-99 groundwater concentrations and the fact that the simulated peak technetium-99 concentrations for the water line leak cases were of the order of

$1 \times 10^4$  to  $1 \times 10^5$  pCi/L, suggest that artificial recharge played a key role in contaminant migration in the BX tank farm (i.e., BX tank farm ponding). Numerical simulations summarized in Section 6.4 further amplify this observation.

The historical groundwater flow analysis performed as part of this study (Section 3.1.3.3 and Appendix C, Section C.6.2) showed that the major drivers for groundwater flow were wastewater discharges to Gable Pond and B Pond. Because of the changing surface water discharges, groundwater flow in this region has gone from easterly (natural conditions) to northerly (B Pond influence) to southerly (Gable Pond influence), back to northerly (new B Pond discharges), to southerly, and finally returning to more natural conditions.

### 6.3 FUTURE IMPACTS

An impact evaluation using a suite of numerical simulations was performed to predict long-term human health risks from potential groundwater contamination from WMA B-BX-BY. Note that the estimated inventory for technetium-99 (4.37 Ci) is much higher than the technetium inventory attributed to borehole 299-E33-45 data. Nevertheless, for numerical modeling and risk assessment, the higher inventory was assumed to be present within the vadose zone and the measured soil profile contaminant concentrations were scaled up to match the estimated inventories. The major findings are as follows:

- Wastes that currently reside in the vadose zone beneath the WMA and may have resulted from past releases from the B, BX, and BY tank farms are not expected to exceed drinking water standards in the groundwater.
- A peak concentration in groundwater on the order of 12,000 pCi/L for technetium-99 was measured in well 299-E33-41 (directly east of tank BX-102) in August 1997 (Section 6.2.4). Numerical simulation results suggest that such a high concentration level cannot be explained with natural recharge alone.
- Any future impacts from the wastes currently in the WMA are expected to be small compared to the impacts to groundwater from discharges to past-practice sites that surround the WMA.
- Because of the current deep location (in the Plio-Pleistocene unit) of technetium-99 contamination in the vadose zone, an interim surface barrier is expected to have little benefit. However, there is some future benefit to an interim surface barrier for reducing future uranium impacts to the groundwater. If significant new leaks occur, the need for an interim surface barrier may need to be reevaluated.
- Simulation results are most sensitive to the amount and distribution of contamination in the vadose zone. Results are also impacted by the natural recharge estimate but the sensitivity of the results to recharge is much less than found in the WMA S-SX investigations (Knepp 2002) because the contamination in WMA B-BX-BY is relatively close to the water table. Inclusion of more detailed geologic features in the model configuration is expected to have minimal effect on the simulation results.

### 6.3.1 Base Case Simulations

Given the amount of contamination inferred to reside in the vadose zone (i.e., technetium-99 value of 4.37 Ci, uranium value of 3.15 Ci, and nitrate value of 13,100 kg), it is not surprising that the simulations predict very little impact on groundwater. The maximum concentrations in the next 1,000 years at the BX tank farm east fence line boundary for the key contaminants were estimated to be 805 pCi/L for technetium-99, 0.10 pCi/L for uranium, and 4.5 mg/L for nitrate. These values are below the relevant regulatory standards of 900 pCi/L for technetium-99, 21 pCi/L (30 µg/L) for uranium, and 45 mg/L for nitrate. Concentrations at points farther downgradient from the tank farm boundary are estimated to be even lower (Section 4.2).

### 6.3.2 Relationship of Tank Releases to Previous Releases

There were massive intentional liquid waste releases to the ground during the 1950s. In some cases, the contaminants reached groundwater in a few months. Groundwater monitoring data indicate that such releases continue to be the main cause of the extensive contamination plume in the WMA B-BX-BY region. The maximum groundwater concentrations are under the BY cribs (north of BY tank farm). The 200 Area Remediation Program is investigating the impacts from these releases.

Contributions from past releases within the WMA are small compared to the contributions from the nearby 200 Area past practice sites (i.e., B and BY cribs and BX trenches). Thus, it is likely that past operational releases will not increase the total groundwater contamination above the values already measured in the area.

### 6.3.3 Importance of Interim Barriers

A major driver for performing the numerical simulations was to determine the benefits of placing interim surface barriers over the contaminated areas. Because of the current deep location of technetium-99, an interim surface barrier is expected to have little benefit (less than 1% decrease in peak groundwater concentrations compared to the base case) (Section 4.2). However, there is some benefit for reducing future uranium impacts to the groundwater thereby delaying the peak arrival times by at least 700 years beyond the arrival times estimated in simulation results.

### 6.3.4 Sensitivity of Results to Other Parameters

Simulation results are most sensitive to the amount and distribution of contamination in the vadose zone and, for uranium, the value selected for the retardation coefficient. The sensitivity of the results to the value for the recharge rate was less than found in the WMA S-SX investigations (Knepp 2002) because the contamination is relatively close to the water table in WMA B-BX-BY.

As expected, contaminant inventories and their locations within the vadose zone influence the calculated peak concentrations and arrival times of long-lived mobile radionuclides and chemical species. Two scenarios of the inventory distribution were considered. A comparison of the breakthrough curves (BTCs) at the BX tank farm east fence line for the tank cross-section suggests that the inventory mass has a much more significant influence on the BTCs than the spatial distribution of the contaminants within the vadose zone.

Contaminant peak concentrations and arrival times were sensitive to assumed recharge rates. No tank farm specific recharge estimates are presently available. The base case infiltration rate of 100 mm/yr was based on lysimeter data for gravel-covered, non-vegetated surfaces that mimic tank farm conditions. Given the current location of the contaminant plumes for the long-lived mobile radionuclides and chemicals within the vadose zone, additional studies to better refine the infiltration rates specific to the BX tank farm are not warranted. However, because of the importance of infiltration rates on contaminant BTCs for a leak event, efforts at reducing the current infiltration rates at the tank farms prior to waste 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 spatial variability of the vadose zone contaminant inventory. BTCs for cases with non-uniform 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.

No simulations were conducted to evaluate the influence of preferential pathways such as clastic dikes. These pathways, nonetheless, are expected to be present in the WMA. However, work on the effect of potential preferential flow paths for the WMA S-SX investigations 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.

#### **6.4 UNCERTAINTY IN THE ESTIMATED TECHNETIUM-99 DISTRIBUTION IN THE VADOSE ZONE WITHIN AND AROUND WASTE MANAGEMENT AREA B-BX-BY**

The discharge of technetium-99 to the vadose zone and subsequent migration through the vadose zone and within the unconfined aquifer has been evaluated in five areas within and around WMA B-BX-BY. These areas are:

- East of tanks BX-101 and BX-102 (borehole 299-E33-45)
- Between tanks B-110, B-111, B-107, and B-108 (borehole 299-E33-46)
- Under the BY cribs north of BY tank farm (DOE-RL 1993)
- Under the BX trenches west of BX tank farm (borehole C3104)
- Under the cribs north of B tank farm (borehole C3103).

The information sources used to complete these evaluations were historical documentation (i.e., waste volumes and waste types, where available) of intentional and unintentional waste discharges to the vadose zone, and soils analysis data from several characterization boreholes. The following primary conclusions were reached.

##### **6.4.1 Tanks BX-101 and BX-102**

- In the tanks BX-101 and BX-102 contamination area, technetium-99 discharge is attributed to two events including a metal waste loss in 1951 from a tank BX-102 overflow and a cesium recovery waste loss between 1968 and 1972 from the pump pit on top of tank BX-101. The metal waste loss is well documented for loss volume and waste

composition providing reasonable confidence that an estimated 3.15 Ci of technetium-99 were released into the vadose zone.

- A reasonable estimate of waste composition for the tank BX-101 pump pit loss can be made, however, insufficient information is available to quantify the loss volume, thereby preventing an estimate of inventory released. It is plausible that tens of curies of technetium-99 could have been released. During the time that the tank BX-101 pump pit could have been leaking (i.e., 1968 through 1972) a nearby poorly sealed borehole (i.e., 21-02-04) to groundwater was present beginning in 1970. A scenario that postulates rapid transport to the aquifer cannot be discarded. However, no appropriate groundwater monitoring data were collected during this time to confirm or reject this hypothesis. For modeling purposes, an estimated 1.1 Ci of technetium-99 was assumed to remain in the vadose zone from the pump pit source along with the 3.15 Ci from the metal waste loss.
- Regardless of the total inventory disposed initially, soils analyses from borehole 299-E33-45 suggest that the current vadose zone technetium-99 inventory is small. An estimated current inventory of about 0.3 Ci of technetium-99 was derived by extrapolating technetium-99 inventory with depth in the borehole over an area similar to the uranium footprint defined by drywell spectral gamma data (Section 2.1).

#### **6.4.2 Tank B-110**

- Technetium-99 discharges into the vadose zone near tank B-110 cannot readily be quantified since neither the waste composition nor the loss volume are well understood. Initially, Jones et al. (2001) proposed that a cesium recovery waste was released and potentially large quantities of technetium-99 could have been present. However, soils characterization from borehole 299-E33-46 near tank B-110 show this hypothesis to be inaccurate. Technetium-99 releases into the vadose zone near tank B-110 from a transfer line leak appear to be inconsequential. Technetium-99 does not occur in the upper parts of the soil column where other tank waste constituents (e.g., strontium-90, fluoride, and nitrate) are present. Technetium-99 is present in a few soil samples in the Plio-Pleistocene unit. This unit appears to be an effective surface for lateral migration and the presence of technetium-99 is postulated to be from another source.

#### **6.4.3 Cribs and Trenches Around Waste Management Area B-BX-BY**

- Historical records and recent inventory source term estimates (Simpson et al. 2001) indicate that most of the discharged technetium-99 inventory (about 162 Ci) was through the BY cribs in 1954 and 1955. Part of this inventory was measured (as beta readings) shortly after discharge. Between 1955 and the present, essentially the entire inventory was flushed into the unconfined aquifer as indicated by an extensive soil sampling and analysis program of the BY cribs in the early 1990s (DOE-RL 1993).
- In the BX trenches, approximately 8 Ci of technetium-99 were discharged, the bulk of which was received in trench 216-B-42. Trench 216-B-42 is the only trench in this group to receive uranium recovery waste, which is a primary waste stream generated by the uranium recovery program in the early 1950s. All other BX trenches received first cycle

waste, a secondary and more dilute waste stream generated by the uranium recovery program. Soils characterization was done at one of these trenches (i.e., 216-B-38) and low technetium-99 concentrations were measured. The depth and concentrations of technetium-99 beneath trench 216-B-42 are unknown. However, discharges to the BX trenches were limited to calculated volumes that were expected to be retained in the vadose zone. For modeling purposes, the technetium-99 inventory for the BX trenches was assumed to remain in the vadose zone.

- In the cribs and trenches north of B tank farm, liquid discharge volumes and waste types are well documented. While large volumes were discharged, the waste types were highly diluted compared to the uranium recovery wastes discharged to the BY cribs. Simpson et al. (2001) estimate a total of 0.8 Ci of technetium-99 was disposed in three of the largest volume discharge facilities in this area. In a recent soils characterization activity from a borehole from one of those facilities, crib 216-B-7A, technetium-99 concentrations were below detection limits. It is concluded that of whatever limited technetium-99 inventory was discharged to the soil column in cribs and trenches north of B tank farm, inconsequential quantities remain in the vadose zone.

## 6.5 EVIDENCE OF EXTENSIVE LATERAL MIGRATION

Field data indicate that lateral migration of fluids in the vadose zone within and around WMA B-BX-BY has been significant on a number of occasions, particularly in the area east of tanks BX-101 and BX-102. Key observations in this area include the following:

- The set of spectral gamma drywell data east of tanks BX-101 and BX-102 define a northeast-trending oval footprint based on the presence of uranium, antimony-125, and europium-154, and to some extent cobalt-60. The uranium distribution is assumed to define the initial distribution of the metal waste loss from the tank BX-102 overfill event in 1951 and the antimony-125, europium-154, and cobalt-60 distributions are assumed to define the initial distribution of isotope recovery waste that leaked from a pump pit on top of tank BX-101 between 1968 and 1972. These isotopes acted as tracers and indicate that the wastes followed similar paths in the vadose zone. The lateral component of the migration path was stronger than the vertical component as the eastern edge of the plumes is more than 30 m (100 ft) away from the points of discharge. This evidence of extensive lateral spreading is supported by the moisture plume data collected at the injection test site directly southwest of PUREX in 200 East Area. The moisture plume data within the Hanford formation at this controlled field experiment show evidence of extensive lateral spreading; vertical migration was of limited extent.
- Borehole 299-E33-45 data on contaminant distributions show a concentration of tank waste species (i.e., technetium-99, nitrate, and sulfate) between two silt-rich layers at 37 and 52 m (120 ft and 170 ft) bgs. These layers may be extensive and probably have hydraulic properties that contrast with the adjacent sandier soils such that preferential lateral flow occurred.
- A perched water zone was encountered in borehole 299-E33-45 in the Plio-Pleistocene unit. The isolated nature of this saturated zone and a water chemistry distinct from water extract data in the 37 to 52 m (120 to 170 ft) bgs zone (i.e., ubiquitous tritium, reduced

technetium-99, and nitrate and sulfate) indicate an alternate or additional source of liquid migrated laterally within the Plio-Pleistocene unit to the borehole location from a source outside WMA B-BX-BY.

- Coincident groundwater peaks of uranium and technetium-99 occurred in groundwater monitoring well 299-E33-41 around 1997 strongly indicating a metal waste source. This well is also more than 100 ft east of the tanks and indicates significant lateral migration in the vadose zone prior to vertical migration to the unconfined aquifer. This hypothesis is strengthened further by the apparent lack of tank waste migration to groundwater in borehole 299-E33-45 at a location between the tank sources and the groundwater monitoring well.

Lateral migration may also be indicated at borehole 299-E33-46 near tank B-110. The contaminant distribution indicates a source that emanated from a transfer line about 8 m (25 ft) bgs that released strontium-90, fluoride, carbonate, and nitrate down to about 24 m (80 ft) bgs. Elevated nitrate, which indicates the maximum depth of leak migration, extends to about 52 m (170 ft) bgs. Then, in the Plio-Pleistocene unit, about 69 m (225 ft) bgs, technetium-99 is present and the other constituents are absent. A lateral migration event is suggested by the divergence of water extract chemistry in the two depth intervals and the apparent effectiveness of the Plio-Pleistocene unit as a surface for lateral migration. The source of technetium-99 has not been determined.

## 6.6 MOBILITY OF URANIUM AND STRONTIUM-90

Strontium-90 and uranium are the two primary radionuclides measured in WMA B-BX-BY soils analyses other than technetium-99 and tritium. Both radionuclides have migrated an appreciable distance from the sources, suggesting enhanced mobility in the vadose zone, at the time of the release events. Uranium has also been measured in a nearby groundwater monitoring well (299-E33-41), with concentration values peaking in 1997. Several studies were undertaken to better understand the chemical factors affecting past and future strontium and uranium migration. Studies were completed as part of the field characterization effort (Appendix B) and by the Groundwater Protection Program Science and Technology Project, which included Pacific Northwest National Laboratory and associated national laboratories and universities, some of which were supported by the EMSP (Appendix D).

Detailed characterization and ion exchange experiments were conducted on borehole 299-E33-46 soils that contain strontium-90. The analytical results show that 25% of strontium-90 is co-precipitated in a carbonate phase and 75% is present in ion exchangeable form on large silicate minerals (including mica, vermiculite, and smectite). The strontium-90 in the carbonate phase will remain fixed in the soil because carbonate phases are stable under normal Hanford soil conditions. Dissolution and strontium-90 release from carbonate phases requires interaction with acidic liquids.

The mobility of the ion exchangeable fraction of the strontium-90 depends on the presence and concentration of competing cations or complexation with chelating agents. Ion exchange experiments were completed with various concentrations of sodium, calcium, and NTA (nitrilotriacetic acid), all of which are constituents that have been presumed present in the

original waste stream. High concentrations of the three constituents significantly reduced strontium-90 sorption and may have played a role in the apparent initially high strontium-90 mobility in the vadose zone, particularly NTA and other organic chelating agents that may have also been present (e.g., EDTA, HEDTA, and citrate). Currently, mobility-enhancing constituents are either present in the soil column at low concentrations (e.g.,  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$ ) or not found (e.g., organic species) and strontium-90 is strongly sorbed by ion exchange. Significant future migration is not expected in the current geochemical environment.

Detailed characterization and dissolution/desorption experiments were also conducted on borehole 299-E33-45 sediments containing uranium. Various state of the art solids characterization techniques were employed to determine uranium speciation, spatial distribution, and mineral association. Measurements from the various techniques indicate that uranium(VI) is the dominant valence state and that uranium is mostly precipitated as a hydrated silicate (uranophane or weeksite). Desorption and solubility experiments were conducted over the pH range of 7.5 to 9.5 in sodium and sodium/calcium electrolytes in equilibrium with atmospheric carbon dioxide. Uranium solubility increased with both pH and carbonate concentration and approached an approximately steady state of  $1 \times 10^{-4}$  mol/L at pH 9.5. The dissolution rate of the precipitated uranium was relatively slow, requiring in excess of 125 days to reach constant values. The experiments performed have not yet been fully analyzed, but the results indicate that the precipitated uranium phases can function as a long-term uranium source to percolating waters. The moisture content, porewater velocity, pH, and carbonate concentration of the porewater will control the extent of uranium dissolution.

Because the T, TX, and TY tank farms have waste streams similar to those in the B, BX, and BY tank farms, the study of uranium mobility will continue. This work will be documented in the field investigation report for WMAs T and TX-TY.

## 6.7 INTERIM MEASURES

Interim measures (e.g., capping boreholes, cutting off inactive water lines, and building barriers) have been implemented in WMA B-BX-BY. This effort is now complete for all the single-shell tank farms. These measures are expected to have some impact on future migration. All boreholes in the waste management area were newly capped in 1999.

There are two water lines serving the waste management area. Testing of the main 8-inch raw water line running to the B tank farm complex revealed no line leaks. A 1 gpm leak, detected through a hose bib on top of the Hanford Barrier demonstration site located adjacent to BY tank farm on its west side, was stopped by closing the valve at the hose bib. The 10-inch potable water line serving the B tank farm complex was abandoned.

Upgradient surface water run-on control measures were installed in the summer of 2002. The items included:

- A 10-inch diameter culvert with a catch basin at the inlet pass water under four abandoned waste transfer lines crossing Baltimore Avenue

- An asphalt road modification to Baltimore Avenue, including an asphalt swale on the west side of the road and a concrete curb and gutter on the east side, plus 2000 feet of new asphalt overlay on the roadway
- Earth berms with gravel armor (2,800 feet) and 4 vehicle cross-overs around B, BX, and BY tank farms
- An 18-inch culvert crossing 12th Street near the intersection with Baltimore Avenue.

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## 7.0 RECOMMENDATIONS

This section provides recommendations for additional investigations to support decisions based on findings from the WMA B-BX-BY vadose zone and groundwater characterization activities or to allow other future decisions. Recommendations for further investigations and decisions are provided for the following:

- Interim measures
- Accelerated corrective measures studies
- Future tank farm operations
- Collection of additional data and information
- Lessons learned.

### 7.1 INTERIM MEASURES

Interim measures currently implemented at WMA B-BX-BY as described in Section 5 include:

- Groundwater wells have been capped
- Water lines into the B, BX, and BY tank farms have been either cut or leak tested
- Berms and gutters have been constructed around the B, BX, and BY tank farms to lessen potential water run-on.

These three interim measures have now been completed for all single-shell tank farms. Water lines that are deemed necessary should be leak tested on a periodic (e.g., annual) basis.

### 7.2 ACCELERATED CORRECTIVE MEASURE STUDIES

According to HFFACO Milestone M-45-58 (Ecology et al. 1989), a corrective measures study could be conducted after the RFI report is written if a study is determined necessary by Ecology. The date for issuance of the corrective measures study is to be determined.

The major potential corrective measures are the removal of waste, thus eliminating the source, and the mitigation of recharge through run-on controls and decommissioning of leaking water lines (Sections 3.5 and 6.1).

According to the current version of the *Single-Shell Tank Retrieval Sequence and Double-Shell Tank Space Evaluation* (Hohl 2001), tank BY-111 will be the first tank retrieved in WMA B-BX-BY, with retrieval completed in 2008. By the end of 2013, fifteen tanks in this waste management area are to be retrieved, including tank BX-102.

Surface contamination at depths of less than 4.6 m (15 ft) bgs is widespread. Soil removal could not be conducted without considering removal of the ancillary 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. Soil and ancillary equipment removal should be considered as part of the corrective measures studies.

Water lines serving WMA B-BX-BY have been tested and cut and capped as necessary. 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 is the placement of interim barriers. Numerical simulation results summarized in Section 4.2 suggest that, when compared to the base case alternative, placement of an interim surface barrier provides no reduction in peak concentrations of mobile contaminants. This conclusion is expected because the technetium-99 is found so deep in the vadose zone that the technetium will reach groundwater before the interim barrier can be effective. Thus, an accelerated corrective measures study for the WMA B-BX-BY is not recommended at this time. However, plans for the use of an interim barrier in other tank farms are proceeding.

### **7.3 FUTURE TANK FARM OPERATIONS**

Future tank farm operations (i.e., those at WMA B-BX-BY and other tank farm WMAs) can benefit from the information gained from the vadose zone 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.

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

Tank waste retrieval and tank farm closure decisions are partially based on information obtained from past releases that occurred in the SST farm system. The Tank Farm Vadose Zone Project characterization activities quantify vadose zone contaminant characteristics caused by past tank waste operations releases and provide a better understanding of the environmental parameters (both human-made and natural) affecting contaminant migration. This information provides a means for estimating the consequences of other releases that may occur during waste retrieval and after closure. This new knowledge and data are useful for determining the best approaches for waste retrieval and closure to satisfy regulatory requirements and that are cost effective. Other River Protection Project programs are using the data (particularly the data modeling package) for their risk assessments. Greater integration is recommended and projected to occur for the future as waste retrieval and closure activities increase.

### **7.4 COLLECTION OF ADDITIONAL WASTE MANAGEMENT AREA B-BX-BY 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 that could be obtained for WMA B-BX-BY include:

- Perform the near-surface characterization activities defined in Rogers and Knepp (2000)
- Drill and sample one or more new boreholes near tanks BX-101 and BX-102.

As noted in Section 2.2.4.1, the near-surface characterization activities (e.g., cone penetrometer pushes) defined in the work plan have not yet been completed. The field activities should be completed during fiscal year 2003 with laboratory measurements completed soon thereafter. Depending upon the ability to penetrate the tank farm excavation base and the amount of contamination found, such information may provide enhanced understanding of the amount of fluids lost from tank BX-101 in the early 1970s and how those fluids moved through the vadose zone.

As noted in Section 3.3, the amount of fluids lost from tank BX-101 in the early 1970s is uncertain. Also uncertain is how these fluids moved (e.g., whether down borehole 21-02-04, or following the path established by the 1950s metal waste release, or following some combination of paths). Obtaining and analyzing samples from a borehole near tank BX-101 may lead to a better understanding.

## **7.5 LESSONS LEARNED**

The lessons learned from the WMA S-SX characterization and modeling effort were reinforced by the WMA B-BX-BY characterization and modeling efforts. 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 (particularly the database and numerical models) to support tank waste retrieval and tank farm closure.

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