7.1 Vadose Zone Characterization

S. P. Reidel and D. G. Horton

This section describes significant vadose zone characterization activities that occurred during 2002. These characterization activities were done to further the understanding of physical and chemical properties of the vadose zone and vadose zone contamination and to help determine the extent of existing vadose zone contamination. During the year, vadose zone characterization activities were completed to evaluate the effectiveness of the remedial actions related to the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) and to characterize existing vadose zone contaminant plumes to help plan future CERCLA remedial actions.

Also during the year, several characterization efforts were performed at single-shell tank waste management areas. At Waste Management Area TX-TY in the 200-West Area, three new characterization boreholes were drilled and sampled to learn more about contaminant distribution, particularly uranium, and contaminant transport mechanisms. The results of extensive geochemical characterization of core samples from Waste Management Area B-BX-BY in the 200-East Area became available during 2002. These data allow comparison of contaminated vadose zone sediment with uncontaminated sediment. In addition, the data are used to determine the leading edge of contaminant plumes beneath single-shell tanks in the waste management area. The same drill cores were used for several laboratory studies to determine the geochemical characteristics of strontium and uranium in the vadose zone at Waste Management Area B-BX-BY.

Finally, characterization of the vadose zone at the location of the proposed Integrated Disposal Site in the 200-East Area continued during 2002 to support the 2005 U.S. Department of Energy (DOE) performance assessment of the site.

A characterization borehole is a boring into the earth where sediment is collected and examined to address a specific question. In addition, the open borehole can then be used as an access way for instruments that can examine the sediment surrounding the borehole.

7.1.1 Vadose Zone Characterization for Remediation at Past-Practice Disposal Facilities

Vadose zone characterization was completed at five operable units in the 200 Areas to support remediation of sites that received waste from past-practice spent-fuel processing. Characterization was completed at the 200-PW-1, 200-TW-1, 200-TW-2, 200-ZP-1, and 200-CS-1 Operable Units. The results of the characterization provide needed information to plan remedial activities in those areas. Characterization also was completed at one site in the 100-F Area to assess the effectiveness of remediation in the reactor areas.

7.1.1.1 Characterization at 116-F-14 Retention Basin

S. W. Clark

Bechtel Hanford, Inc. excavated a test pit in the 116-F-14 retention basins at the 100-FR-1 Operable Unit, 100-F Area during 2000 and 2001. The results of analyses from the excavated sediment became available during 2002. Figure 7.1.1 shows the location of the 116-F-14 retention basins. The full description of the activities can be found in BHI-01613.

The 116-F-14 retention basins received essentially all cooling water effluent from F Reactor when the reactor was operating from 1945 to 1965. The retention basin was

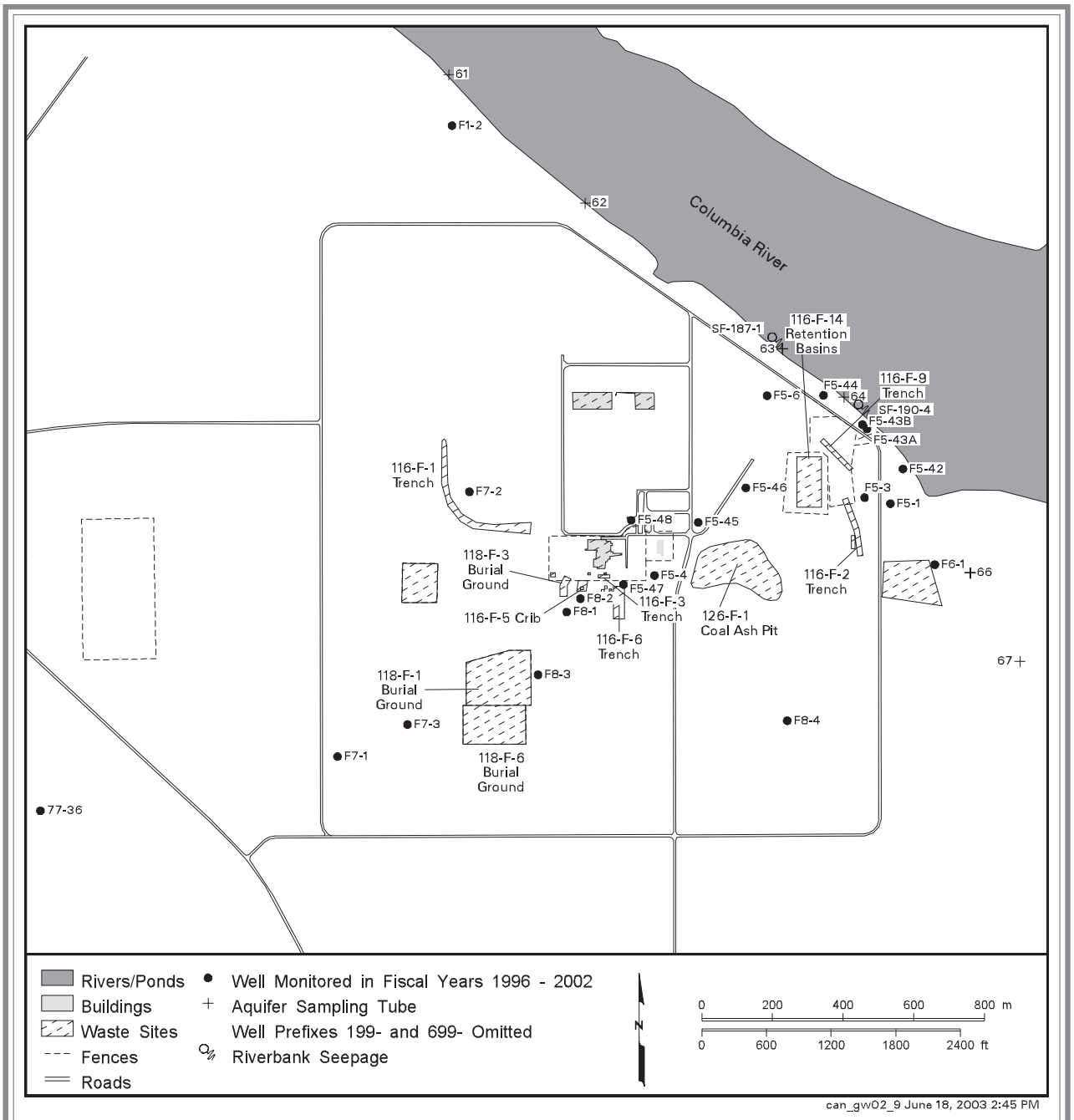

Figure 7.1.1. Groundwater Monitoring Wells Near the F Reactor in the 100-F Area of the Hanford Site

made of reinforced concrete and was divided lengthwise into two chambers to hold the cooling water for a brief period of time, allowing radioactive decay and thermal cooling to occur before the water was discharged to the Columbia River. Numerous instances of retention basin leakage and overflows contaminated the sediment in the immediate vicinity of the basin, including the sediment beneath the basins.

The objective of the excavation and sampling of the test pit was to determine the extent and distribution of contaminants within the vadose zone between the base of the basin and the water table. The test pit was dug in a depression that was the former location of a sump used to transfer process effluent and had formerly been a small, localized zone of contamination.

The sediment data indicate that concentrations of cobalt-60, nickel-63, cesium-137, europium-152, and europium-154, total chromium, hexavalent chromium, lead, and mercury decrease with increasing depth. However, arsenic concentrations were found to increase with depth. The highest concentrations of contaminants were found immediately below the bottom of the retention basin. The same general residual contamination profile has been observed for other remedial action excavations throughout the 100 Areas.

7.1.1.2 Characterization of the 200-TW-1 Operable Unit

M. E. Todd and C. A. Kahler-Royer

Bechtel Hanford, Inc. drilled a borehole through the 216-T-26 crib in the 200-West Area during 2001 to characterize the nature and extent of contamination as part of the remedial investigation for the 200-TW-1 Operable Unit (BHI-01606). The site received waste from uranium recovery and ferrocyanide processes between August 1955 and November 1956 when the crib was deactivated. Data from field screening, geophysical logging, and analytical results from sediment samples became available during 2002 (Figure 7.1.2 shows the location of the crib).

The data indicate that contaminant distribution is influenced by the contacts between sedimentary layers where significant changes in texture (i.e., grain size) occur. These texture changes result in retardation of many contaminants including cobalt-60, cesium-137, and europium-154. Contaminants that typically are not retarded by sediment, including chloride, hexavalent chromium, and nitrate, are able to reach the water table.

7.1.1.3 Characterization at the 200-PW-1 and 200-ZP-1 Operable Units

V. J. Rohay and D. G. Horton

Investigations were conducted in the 200-West Area at the Plutonium Finishing Plant and 216-Z-9 trench during 2002 to support carbon tetrachloride remediation efforts (BHI-01631). Near the Plutonium Finishing Plant, a groundwater extraction/monitoring well (299-W15-42) was installed as part of the 200-ZP-1 Operable Unit investigations to evaluate the distribution of carbon tetrachloride and potentially to enhance the work being done for the existing groundwater remediation system (Figure 7.1.2 shows the location of well 299-W15-42). At the 216-Z-9 trench, two existing wells (299-W15-84 and 299-W15-95, Figure 7.1.2) were deepened as part of 200-PW-1 Operable Unit investigations to characterize the distribution of carbon tetrachloride in the vadose zone and groundwater. The deepened wells were completed as soil-vapor extraction wells to enhance vadose zone remediation activities.

Sediment sampling also was conducted at the 200-PW-1 Operable Unit to further characterize the carbon tetrachloride plume.

The results of characterization at the Plutonium Finishing Plant concluded that it is unlikely there is a source of carbon tetrachloride and co-contaminants near well 299-W15-42. Relatively low carbon tetrachloride concentrations in groundwater suggest that the vadose zone is not contaminating the aquifer here. Results suggest that the 216-Z-9 trench or 216-Z-1A tile field at the Plutonium Finishing Plant are the more likely vadose zone sources of groundwater contamination. Furthermore, the data suggest that the two effluent pipelines that carried waste from the Plutonium Finishing Plant to the 216-Z-9 trench had not leaked near the boreholes.

In the 216-Z-9 trench area, carbon tetrachloride was detected in both sediment and soil-gas samples from the Cold Creek unit, a deep sediment layer. However, no artificially produced radionuclides were detected in the sediment samples. The relatively low concentrations of carbon tetrachloride in soil gas suggest that the vapor phase is not a source of groundwater contamination at this location. The data indicate that in 2002 the distribution of carbon tetrachloride is consistent with a conceptual model that suggests the Cold Creek unit would retain more carbon tetrachloride than the overlying and underlying sand and gravel at the well locations.

Soil-Gas Sampling. Characterization of the carbon tetrachloride vadose zone plume was conducted during 2002 as part of the remedial investigation for the 200-PW-1 Operable Unit. The 200-PW-1 Operable Unit waste sites received plutonium-rich and organic-rich waste from the

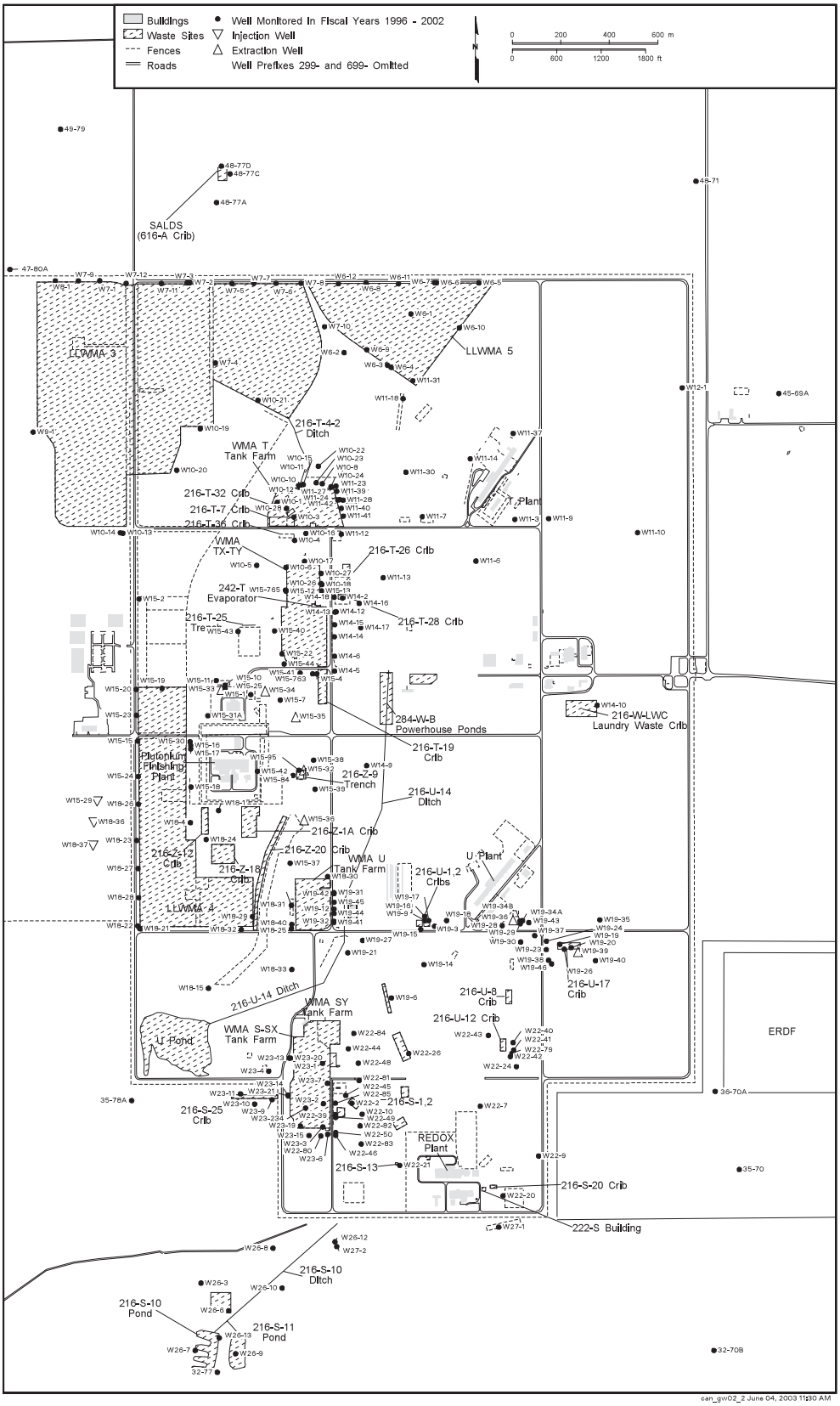

Figure 7.1.2. Groundwater Monitoring Wells in the 200-West Area of the Hanford Site

Plutonium Finishing Plant complex. A primary component of the organic-rich waste was carbon tetrachloride. The objective of the vadose zone investigation was to locate and characterize the sources of carbon tetrachloride contamination that presently affect groundwater, as well as known and suspected release sites with the potential to affect groundwater in the future.

Soil-gas sampling and analysis were used to explore the upper vadose zone in the vicinity of the Plutonium Finishing Plant as Step I of the remedial investigation into the dispersed carbon tetrachloride plume in the vadose zone at that location. The sampling was conducted at engineered structures (e.g., liquid waste discharge pipelines, liquid waste discharge sites, and solid waste burial ground trenches) that had the potential to release carbon tetrachloride to the vadose zone.

- **Liquid waste discharge pipelines**. Soil-gas samples were collected along six liquid discharge pipelines to investigate potential leaks of carbon tetrachloride-bearing waste from the pipelines. The six pipelines connected the 234-5Z and 231-Z Buildings with various disposal facilities.

  Low concentrations of carbon tetrachloride were detected in some samples collected along the waste discharge pipelines leading to cribs and ditches that are known to have received carbon tetrachloride in liquid waste. The low concentrations detected along the pipelines suggest that any pipeline leaks were small or were naturally remediated (e.g., by diffusion or evaporation) since the pipelines were last used. Carbon tetrachloride was not detected in samples collected along a pipeline to the 216-Z-9 trench, which is known to have received large volumes of carbon tetrachloride.
- **Liquid waste discharge sites**. Soil-gas samples were collected at eleven liquid waste discharge sites to investigate discharge of waste containing carbon tetrachloride to the sediment column at those sites. Low concentrations of carbon tetrachloride were detected in some samples collected at liquid waste discharge sites. Carbon tetrachloride was not detected in samples collected at the 216-Z-9 trench or 216-Z-18 crib, which are both known to have received large volumes of waste containing carbon tetrachloride.
- **218-W-4C Burial Ground**. Sampling in the 218-W-4C burial ground was conducted in three phases. During the first phase, vapor samples were collected from 27 vent risers generally aligned with the centers of the trenches. During the second phase, the GeoProbe® was used to collect samples at 12 locations in the vadose zone. During the third phase, a cone penetrometer was used to collect samples at 5 of the 12 locations sampled using the GeoProbe®.

  During the first phase of the investigation, carbon tetrachloride was detected at all but one of the 27 vent risers sampled. During the second phase, carbon tetrachloride was detected in soil-gas samples collected at 5 of the 12 locations. During the third phase, carbon tetrachloride samples were collected near the location of the highest concentration measured from the second phase.

7.1.1.4 Characterization of the 200-TW-2 Operable Unit

M. E. Todd and C. Trice

Boreholes were drilled through the 216-B-38 trench and 216-B-7A crib during 2001 by Bechtel Hanford, Inc. to characterize the nature and vertical extent of contamination as part of the remedial investigation for the 200-TW-2 Tank Waste Group Operable Unit, 200-East Area (BHI-01607). The results of the investigation became available during 2002. The 200-TW-2 waste sites received tank waste from first- and second-cycle decontamination processes associated with the bismuth-phosphate process at the B and T Plants. The locations of the 216-B-38 trench and the 216-B-7A crib are shown in Figure 7.1.3.

The 216-B-38 trench is located north of B Plant and west of the BX Tank Farm. The trench received 1.43 million liters (378,000 gallons) of high-salt, neutral/basic waste from tanks 241-B-110, 241-B-111, and 241-B-112. The trench was deactivated in October 1982.

To determine the best location for a characterization borehole at the 216-B-38 trench, five test holes were drilled in the areas of greatest contamination. The test holes were installed along the length of the trench. They were logged with both spectral gamma and neutron-moisture tools to identify the area of highest radiological contamination and moisture content. The test holes were then backfilled and decommissioned.

The geophysical logs from the test holes showed the greatest contamination occurred in the test hole closest to the head end of the trench where the characterization borehole ultimately was drilled.

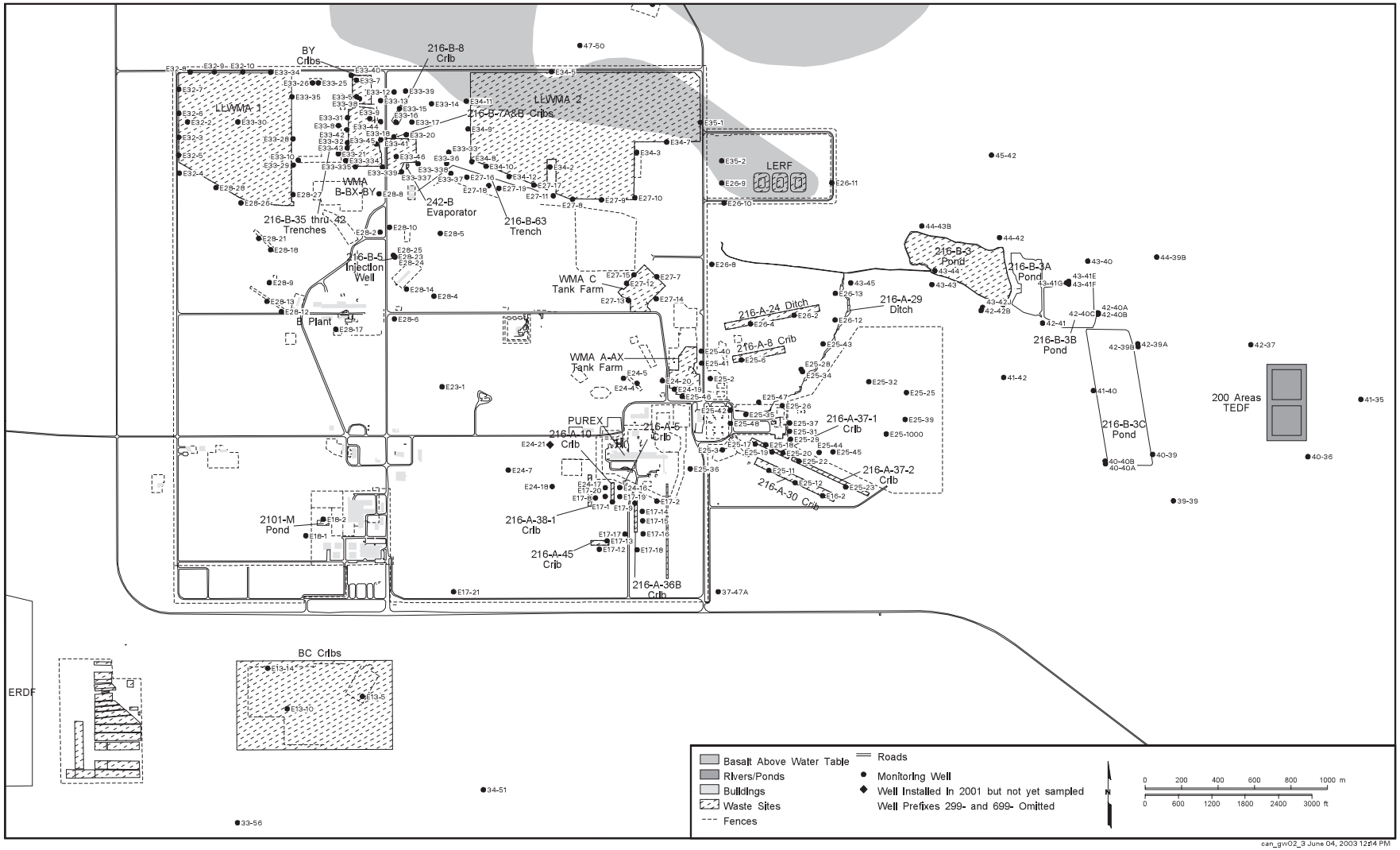

Figure 7.1.3. Groundwater Monitoring Wells in the 200-East Area of the Hanford Site

The analytical results and the geophysical logs at the 216-B-38 trench show that most of the radionuclides occur in the original backfill of the crib and immediately below it. Cesium-137, plutonium, and uranium appear to be concentrated just below the backfill but chemical constituents (e.g., ammonium, cadmium, chromium, copper, lead, nickel, and sulfate) did not penetrate deeper than the backfill.

The 216-B-7A and 216-B-7B cribs are located north of the B Tank Farm. The cribs operated from September 1946 to May 1967 and received a total volume of 43.6 million liters (11.5 million gallons) of waste. The waste included liquid from the 221-B Building from tanks 241-B-202 through 241-B-204, lanthanum/fluoride process waste, cell drainage, and other liquid waste from cells 5 and 6 in the 221-B Building. The cribs were deactivated during 1967, and the area was covered with clean backfill.

The radionuclides (cesium-137, americium-241, and plutonium) observed in the characterization borehole at the 216-B-7A crib are concentrated in the original backfill and immediately below it. The anions and some metals (chromium, copper, and lead) show a bimodal distribution with depth; they occur in the backfill and in the underlying sediments. Metals and anions appear to have reached the water table at this location.

7.1.1.5 Characterization of the 200-CS-1 Operable Unit Test Pits

C. S. Cearlock and D. L. Bowers

Test pits were excavated by Bechtel Hanford, Inc. during 2002 to characterize the vadose zone at the 216-A-29 ditch and the 216-B-63 trench, 200-East Area (Figure 7.1.3 shows the locations of the facilities). Both waste sites are *Resource Conservation and Recovery Act* (RCRA) treatment, storage, and disposal units and part of the 200-CS-1 Operable Unit.

The primary manmade radionuclides detected were strontium-90, cesium-137, and plutonium-239/240. Cesium-137 was detected at the 216-A-29 ditch and at the 216-B-63 trench. Strontium-90 was detected at the 216-A-29 ditch along with plutonium-239/240, americium-241, and uranium.

All observed metals, anions, organic compounds, semi-volatile organic compounds, and volatile organic compounds exceeding background concentrations were well below the Washington State *Model Toxics Control Act* (WAC 173-340) Method C direct exposure cleanup values.

7.1.2 Vadose Zone Characterization and Technical Studies at Single-Shell Tank Farms

New characterization boreholes were drilled and sampled at Waste Management Area TX-TY (200-West Area) and the results of geochemical characterization of core samples from boreholes at Waste Management Area B-BX-BY (200-East Area) became available during 2002. Results from the analysis of core samples allow comparison of contaminated and uncontaminated sediment in the area, which helps delineate the leading edge of vadose zone plumes beneath the B, BX, and BY Tank Farms. These results are summarized in this section.

7.1.2.1 Tank Farm Vadose Zone Project – Drilling and Sampling

D. A. Myers

The Tank Farm Vadose Zone Project conducted characterization activities in the TX Tank Farm during 2002. Three boreholes were drilled, sampled, and then decommissioned. The location of one borehole was based on a potentially large metal-waste contamination zone between tanks TX-101 and TX-105. Vadose zone monitoring equipment was installed during decommissioning of the borehole to provide information on the behavior of infiltrating water in the tank farm environment. The location for a second borehole was based on an extensive and fairly well-defined contaminant zone from a past leak. The third borehole was drilled to define the leading edge of contamination released from tank TX-107 and/or tank TX-104 (RPP-7578). Analyses of samples from these boreholes are scheduled to be completed during 2003.

7.1.2.2 Characterization at Waste Management Area B-BX-BY

R. J. Serne, B. N. Bjornstad, G. W. Gee, H. T. Schaef, D. C. Lanigan, C. W. Lindenmeier, R. D. Orr, V. L. Legore, R. E. Clayton, M. J. Lindberg, I. V. Kutnyakov, S. R. Baum, K. N. Geiszler, M. M. Valenta, T. S. Vickerman, and L. J. Royack

Geochemical examination of drill cores from three boreholes (RCRA well 299-E33-338, borehole 299-E33-45, and borehole 299-E33-46) at Waste Management Area B-BX-BY was completed during 2002 to characterize vadose zone contamination. Well 299-E33-338, was located southeast of the B Tank Farm in an uncontaminated area. Characterization data from this well are thought to represent natural background in the area of Waste Management Area B-BX-BY. A second borehole, 299-E33-45, was located east of tanks BX-101 and BX-102, and drilled through a uranium plume. This borehole was drilled to evaluate concentrations of mobile contaminants, primarily technetium-99 and nitrate, assumed to co-exist with uranium. A third borehole, 299-E33-46, was located northeast of tank B-110. This borehole was drilled to characterize contamination from a leak in a transfer line to tank B-110.

All three boreholes encountered essentially the same stratigraphy and were sampled for moisture content and logged with a neutron-moisture tool. High moisture zones were found to occur in finer grained sands, at the contact between sands underlying gravel, and within the Cold Creek unit, a deep sediment layer.

An extensive set of chemistry analyses of water extracts was completed on samples from natural background borehole 299-E33-338 and serves as a baseline against which to compare results of analyses of contaminated samples from the other two boreholes.

In the contaminated boreholes, elevated pH and increases in electrical conductivity above background were found at selected depths. In addition, a primary indicator of tank waste is the occurrence of elevated nitrate. Elevated nitrate was found in both contaminated boreholes.

Among the cations, elevated sodium concentrations are primary indicators of tank fluid in the sediment column. Sodium concentrations are elevated in both contaminated boreholes. Calcium, magnesium, and potassium show a distinct concentration pattern with depth in both contaminated boreholes that indicates sodium in the sediment was exchanged for the other natural cations in the sediment. The high sodium fluids push the other cations deeper in the sediment column.

Analyses of selected radionuclides and trace metals also were done on samples from the two contaminated boreholes. The dominant radionuclides in the first contaminated borehole were technetium-99 and uranium. The radionuclides identified in the second were uranium, strontium-90, and technetium-99. Strontium-90 was the primary radionuclide released from tank B-110 transfer lines. The uranium concentrations suggest that there is process uranium from Hanford Site activities at low concentrations in the sediment.

7.1.2.3 Strontium Adsorption, Desorption, and Transport in Pristine and Contaminated Sediment

J. M. Zachara

The Hanford Science and Technology Project was initiated during 1998 as part of the Groundwater Protection Program (formerly the Groundwater/Vadose Zone Integration Project). The project's goal was to coordinate and perform scientific research to support decision making for environmental cleanup at the Hanford Site. The results of the Science and Technology Project's investigation of strontium-90 geochemistry and transport at single-shell tank B-110 were to support the Waste Management Area B-BX-BY Field Investigation Report (RPP-10098). The key results from 2002 that are summarized here are from four separate but related studies by several principal investigators from Pacific Northwest National Laboratory, Los Alamos National Laboratory, and Lawrence Livermore National Laboratory. Some of key findings as described in the field investigation report (RPP-10098) are listed below:

- The vadose zone strontium-90 plume currently appears stable and immobile.

- The primary mechanism for holding strontium-90 in Hanford sediment is isotopic exchange with stable isotopic strontium.
- Bicarbonate solutions enhanced ion exchange adsorption of Sr^{2+}.
- Approximately 75% of the sorbed strontium-90 is present in an ion exchangeable state and 25% was precipitated in a high magnesium-calcite. Re-wetting of the sediment can remobilize ion exchangeable strontium-90.

7.1.2.4 Uranium Speciation and Dissolution from BX-102 Sediment

J. M. Zachara

Uranium speciation and dissolution in sediment from Waste Management Area B-BX-BY was investigated during 2002. The results of those investigations provide insights into uranium distribution and future migration of the vadose zone plumes, and support decision making for environmental cleanup at Waste Management Area B-BX-BY. The key results summarized here are from five separate but related studies by several principal investigators from Pacific Northwest National Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, and Stanford University. The following are some of the key findings from those studies as described in the field investigation report (RPP-10098):

- Uranium exists as uranium(VI) in samples and as a uranium silicate phase within the uranophane – boltwoodite mineral series.
- The precipitated uranium(VI) can dissolve from the sediment if water is added and the pH is above 8.5.
- The amount of precipitated uranium(VI) that will dissolve appears predictable, and is most dependent on pH, bicarbonate/carbonate concentration ratio, and water content.
- The precipitated uranium(VI) phases in the sediment are sufficiently soluble and reactive to function as long-term source terms to infiltrating waters if allowed. Water management will be key to limiting further contamination.

7.1.3 Characterization for Integrated Disposal Site

D. G. Horton

Waste from plutonium production and separation processes is currently stored underground in 149 single-shell tanks and 28 double-shell tanks. DOE plans to retrieve tank waste, separate it into low- and high-activity fractions, and immobilize it using a vitrification process. The low-activity waste will then be disposed in near-surface burial facilities at the Hanford Site 200-East Area.

The results of geochemical and mineralogical characterization of borehole samples from the vadose zone at the location of the proposed Integrated Disposal Site became available during 2002. The information from that characterization effort will support the Integrated Disposal Site performance assessment during 2005.

A study of iodide sorption onto sediment from the proposed Integrated Disposal Site was completed during 2002.

7.1.3.1 Borehole 299-E24-21 Geochemistry

D. G. Horton, H. T. Schaef, R. J. Serne, M. M. Valenta, T. S. Vickerman, I. V. Kutnyakov, S. R. Baum, K. N. Geiszler, and K. E. Parker

Borehole 299-E24-21 was drilled at the northeast corner of proposed Integrated Disposal Site during 2001. Near-continuous core was collected from the borehole from below ground surface to the water table. The purpose of the borehole was to obtain characterization data to support the Integrated Disposal Site performance assessment during 2005 and to serve as a groundwater monitoring well for future RCRA monitoring. Details of the drilling and sampling can be found in BHI-01531 and in PNNL-13652.

The data collected included particle size distribution data, moisture content, bulk composition (as measured by x-ray fluorescence), total carbon content, inorganic carbon, and organic carbon (by difference), x-ray diffraction analysis, major cations and anions in 1:1 water extracts. These data are similar to other data collected from the sand-dominated portion of the Hanford formation.

7.1.3.2 Sorption Linearity and Reversibility of Iodide

W. Um and R. J. Serne

A performance assessment of the proposed Integrated Disposal Site investigated the effects of the planned disposal on long-term environmental conditions and human health. The investigation showed that technetium-99, iodine-129, uranium-233, uranium-235, neptunium-237, and uranium-238 pose the most potential health risks at the proposed disposal site. Because of its long half-life and high mobility in the subsurface environment, the sorption/desorption characteristics of radioactive iodine were investigated. During 2002, sorption onto sediment and reversibility were determined using iodine-125 as a radioactive tracer for iodine-129 on a typical Hanford formation sand from the second Integrated Disposal Site borehole in 200-East Area. Because iodine-129 is one of the key risk drivers at the Hanford Site, predictions for the fate of iodine-129 using simple transport models are technically defensible. However, since iodide desorption is slower than adsorption and only partially reversible, the concentration of iodide will not drop as fast as predicted and the time for iodide to leave the system may be longer than the time predicted by simple transport theory.