PNNL-11470
UC-402, 403, 702

Hanford Site Groundwater Monitoring for Fiscal Year 1996

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February 1997

Prepared by personnel from
Pacific Northwest National Laboratory,
Rust Federal Services Northwest,
CH2M Hill Hanford, Inc., and
IT Hanford Company for the
U.S. Department of Energy under
Contract DE-AC06-76RLO 1830

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PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America

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Abstract

This report presents the results of groundwater and vadose-zone monitoring for fiscal year (FY) 1996 on the Hanford Site, Washington. Hanford Site operations from 1943 onward produced large quantities of radiological and chemical waste that affected groundwater quality on the site.

Characterization and monitoring of the vadose zone during FY 1996 comprised primarily spectral gamma logging, soil-gas monitoring, and electrical resistivity tomography. Spectral gamma logging at past-practices soil-column-disposal and tank farm sites suggests that waste constituents may continue to move at some sites long after termination of disposal activities. Soil-gas concentrations of carbon tetrachloride have declined as a result of remediation.

Water-level monitoring was performed to evaluate groundwater-flow directions, to track changes in water levels, and to relate such changes to evolving disposal practices. Water levels over most of the Hanford Site continued to decline between June 1995 and June 1996. Water levels near the Columbia River increased during this period because the river stage was unusually high from late 1995 through the summer of 1996.

Groundwater chemistry was monitored to track the extent of contamination, to note trends, and to identify emerging groundwater-quality problems. The most widespread radiological contaminant plumes were tritium and iodine-129. Smaller plumes of strontium-90, technetium-99, and plutonium also were present at levels above the U.S. Environmental Protection Agency or State of Washington interim drinking water standards. Uranium concentrations greater than the proposed drinking water standard were also observed. Cesium-137 concentrations did not exceed the drinking water standard, but the well with the highest concentration in 1995 was not sampled in FY 1996. Cobalt-60 concentrations exceeded the drinking water standard in recent years but were below the standard in FY 1996. Derived concentration guide levels specified in U.S. Department of Energy Order 5400.5 were exceeded for tritium, strontium-90, and plutonium. Groundwater in one location had strontium-90 concentrations greater than 10 times the derived concentration guide.

Nitrate, fluoride, chromium, carbon tetrachloride, chloroform, trichloroethylene, and cis-1,2-dichloroethylene were present in groundwater samples at levels above their U.S. Environmental Protection Agency or State of Washington maximum contaminant levels. The nitrate plume is the most extensive. Cyanide concentrations were elevated in one area but were below the maximum contaminant level.

Resource Conservation and Recovery Act of 1976 groundwater monitoring continued at 26 waste management units: 18 were monitored under detection programs during FY 1996 and do not appear to be adversely affecting groundwater, 6 were monitored under groundwater quality assessment or compliance programs to assess possible groundwater contamination, and 2 began new assessment programs in FY 1996.

Groundwater remediation under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* includes pump-and-treat systems in the 100-N Area (strontium-90), the 100-D Area (chromium), and the 200-West Area (separate systems for carbon tetrachloride and technetium-99/uranium).

Three-dimensional, numerical, groundwater models were applied to the Hanford Site to predict contaminant-flow paths and the impact of operational changes on site groundwater conditions. Other models were applied to assess the performance of three separate pump-and-treat systems.

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Summary

This report summarizes the results of fiscal year (FY) 1996 groundwater- and vadose-zone-monitoring activities on the Hanford Site. This report is designed to provide a comprehensive, current interpretation of groundwater conditions on the site and in adjacent areas, including a description of site hydrogeology, groundwater flow, and groundwater contaminant distribution. This report fulfills reporting requirements of the *Resource Conservation and Recovery Act of 1976* (RCRA), Ground-Water Surveillance, Solid Waste Landfill, applicable U.S. Department of Energy (DOE) orders, and Operational Monitoring Programs and summarizes results of groundwater monitoring conducted to assess the effects of remediation or interim measures conducted under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA).

The uppermost aquifer beneath most of the Hanford Site is unconfined and is composed of unconsolidated to semiconsolidated sediments deposited on the basalt bedrock. In some areas, deeper parts of the aquifer are locally confined by layers of silt and clay. Confined aquifers occur within the underlying basalt flows and associated sedimentary interbeds. Groundwater in the unconfined aquifer generally moves from recharge areas along the western boundary of the site eastward and northward toward the Columbia River, which is the major discharge area. However, this natural flow pattern was altered by the formation of groundwater mounds created by large volumes of artificial recharge at wastewater-disposal facilities.

Water levels are monitored across the Hanford Site and to the north and east of the Columbia River. These measurements are used to determine the water-table configuration for the unconfined aquifer and to monitor changes in water-table elevation resulting from site operational and offsite changes. A site water-table map for June 1996 was constructed and used to infer groundwater-flow directions. Water levels over most of the site declined during FY 1996, continuing the trend caused by reduction in liquid effluent disposal. The water table rose in wells near the Columbia River because the river stage was unusually high from late 1995 through the spring and summer of 1996. Water levels are also measured in wells completed in the upper basalt-confined aquifer. No significant changes were observed in FY 1996.

Vadose Zone

Because untreated wastewater is no longer discharged to the ground at the Hanford Site, areas of residual vadose-zone contamination are the most significant sources of possible groundwater contamination. The rate of movement of contaminants to the groundwater depends on contaminant chemistry, stratigraphy, and drainage of water through the vadose zone.

Characterization and monitoring of the vadose zone during FY 1996 were composed primarily of spectral gamma logging, soil-gas monitoring, and electrical resistivity tomography. Spectral gamma logging at past-practices soil-column disposal and tank farm sites provided isotope-specific identification of gamma emitters. Previous gamma logging provided gross gamma information and was unable

to differentiate the various gamma-emitting isotopes. Results of spectral gamma logging suggest that lateral and vertical movement of constituents may continue at some sites long after termination of disposal activities. Soil-gas monitoring shows that remediation near the Plutonium Finishing Plant cribs reduced the carbon tetrachloride concentrations. Vadose-zone investigations near the single-shell tanks and in the 100-K Area indicate that leaking water lines and ponding of surface runoff may mobilize vadose-zone contaminants and transport them to groundwater.

A simulated leak test in the 200-East Area was monitored using electrical resistivity tomography. Results revealed that relatively small leak volumes of a sodium chloride brine moved through the vadose zone relatively rapidly.

Groundwater Contamination

Monitoring wells were sampled during FY 1996 for the Ground-Water Surveillance Project, RCRA, and CERCLA Programs. Approximately 800 wells were sampled during the period.

The extent of major radiological constituents at levels above the interim DWS is shown in Figure S.1. Tritium, strontium-90, technetium-99, iodine-129, and plutonium were present at levels above the U.S. Environmental Protection Agency (EPA) or State of Washington interim drinking water standards (DWSs). Uranium concentrations greater than the EPA's proposed maximum contaminant levels (MCLs) were also observed. Cesium-137 concentrations are elevated near the 216-B-5 injection well. Concentrations did not exceed the 200-pCi/L DWS in FY 1996, but the well with the highest concentration in 1995 was not sampled in FY 1996 (it was sampled in December 1996). Derived concentration guide (DCG) levels were exceeded for strontium-90 in the 100-K, 100-N, and 200-East Areas (near the 216-B-5 injection well). The DCG for tritium was exceeded in one well near cribs that received effluent from the Plutonium-Uranium Extraction (PUREX) Plant. The DCG for plutonium was exceeded in one well in the 200-East Area (near the 216-B-5 injection well). Cobalt-60 concentrations exceeded the 100-pCi/L DWS in recent years but were below the DWS in FY 1996. Results for individual constituents are summarized below.

The extent of major chemical constituents at levels above the MCL is shown in Figure S.2. Nitrate, fluoride, chromium, carbon tetrachloride, chloroform, trichloroethylene, and cis-1,2-dichloroethylene were present in groundwater samples at levels above their MCL. Cyanide concentrations were elevated in wells near the BY cribs but were below the 200-μg/L MCL. Results for individual constituents are summarized below.

Tritium

Tritium was present in many Hanford Site waste streams discharged to the soil column and is the most mobile and most widely distributed radionuclide onsite. As a result, tritium reflects the maximum extent of contamination in the groundwater.

Tritium concentrations greater than the 20,000-pCi/L interim DWS were detected in FY 1996 in portions of the 100-K, 100-N, 100-D, 100-F, 200, 400, and 600 Areas. The highest tritium concentrations in the 200-East Area continued to be found in wells near cribs that received effluent from the PUREX Plant, exceeding the 2,000,000-pCi/L DCG in one well. Tritium continues to be elevated above 100,000 pCi/L in one well in the 100-F Area near a solid waste-burial ground. Tritium contamination in the 100-K Area (some of the highest concentrations on the Hanford Site) was traced to two distinct sources: french drains and leaks in fuel-storage basins.

Tritium in the 400 and 600 Areas can be related to migration from sources in the other operational areas. In particular, tritium migration from sources near the PUREX Plant in the 200-East Area affected that part of the 600 Area downgradient to the east and southeast, the 400 Area, and the 300 Area. This plume discharges to the Columbia River along a stretch extending from the Old Hanford Townsite to the 300 Area. A smaller plume between the 200-East and 200-West Areas has its source near the 200-West Area's Reduction-Oxidation (REDOX) Plant. This plume is moving relatively slowly.

An area near the Old Hanford Townsite formerly had tritium concentrations above 200,000 pCi/L. These concentrations are decreasing because of dispersion and radioactive decay; during FY 1996, tritium declined below 200,000 pCi/L.

Portions of the site north of Gable Mountain and Gable Butte are contaminated with tritium at levels below the DWS. The major sources appear to be the 100 and 200-East Areas.

Cobalt-60

Cobalt-60 is a neutron activation product typically associated with wastes generated by the processing of irradiated fuel or with reactor effluent water. Cobalt-60 is predominantly present as a divalent cation that is strongly adsorbed onto onsite sediments and is rarely observed in groundwater unless complexed by other chemicals. Wells located north of the 200 Areas, in an area that is affected by waste disposed to the BY cribs, consistently show the presence of detectable cobalt-60. In FY 1996, the maximum annual average cobalt-60 detected in this vicinity was below the interim 100-pCi/L DWS. Cobalt-60 in this area appears to be highly mobile, probably because of the presence of a soluble cobalt-cyanide (or ferrocyanide) complex associated with the plume originating in the BY cribs.

Very low levels of cobalt-60 were detected in groundwater downgradient of the PUREX Plant as far as the Old Hanford Townsite. Although levels are far below the interim DWS and are declining, this indicates that cobalt-60 may be mobilized by a complexing agent other than cyanide in some Hanford Site wastes. The moderately short half-life of cobalt-60 (5.3 years) means that its concentration onsite has been decreasing rapidly since production operations ended.

A well between the 200-East Area and Gable Mountain completed in the confined aquifer showed cobalt-60 concentration greater than the DWS in 1995 but that well was not sampled in FY 1996 because of a scheduling error. The well will be sampled in FY 1997. An adjacent confined aquifer well showed no detectable cobalt-60 in 1995 or in the June 1996 sampling event.

Strontium-90

Strontium-90 is produced as a high-yield fission product and is, therefore, present in waste streams associated with fuel processing; it may also be released by fuel-element failures during reactor operations. Strontium-90 is of concern because of its moderately long half-life (28.8 years), its potential for concentrating in bone tissue, and the relatively high energy of the beta decay from its yttrium-90 radioactive decay product. In FY 1996, strontium-90 concentrations exceeded the 8-pCi/L interim DWS in wells in all of the 100 and 200 Areas and near the former Gable Mountain Pond. Strontium-90 concentrations exceeded the 1,000-pCi/L DCG in wells in the 100-K, 100-N, and 200-East Areas. For the first time in recent years, strontium-90 also exceeded the DCG in wells near the former Gable Mountain Pond.

The most widespread, high concentrations of strontium-90 (greater than the DCG) continue to be observed in the 100-N Area. Strontium-90 activity increased in some wells in the 100-N Area because a high water table apparently remobilized contamination formerly sorbed to sediments above the average water-table elevation. The overall extent of the 100-N Area strontium-90 plume is not increasing perceptibly. A pump-and-treat system operates in the 100-N Area to reduce the flux of strontium-90 to the Columbia River.

Strontium-90 concentrations exceeding the DCG were found in a 100-K Area well; changes in concentration may be linked to a leaking water-supply line located within ~4 to 5 m of the well. Strontium-90 concentration continued to exceed the DCG in a well near the 216-B-5 injection well but was slightly lower than in 1995 and was over a factor of two lower than the 1994 maximum. Strontium-90 near the former Gable Mountain Pond is related to past disposal of waste in this area. Concentrations of strontium-90 at or above the interim DWS were detected in two wells in the southern portion of the 200-West Area. Strontium-90 activity was ~7 pCi/L in a well completed in the confined aquifer in the 100-B Area, an increase from the value detected in 1995.

Technetium-99

Technetium-99 is produced as a moderately high-yield fission product and is present in waste streams associated with fuel processing. Technetium is transported in groundwater as a negatively charged species that is highly mobile. Technetium tends to be associated with uranium through the fuel-processing system. However, uranium is less mobile in groundwater on the Hanford Site. Technetium-99 concentrations greater than the 900-pCi/L DWS continue to be observed in the 100-H Area downgradient of the 183-H solar evaporation basins, where fuel-processing waste leaked to the ground. Concentrations of technetium-99 greater than the DWS were also observed in FY 1996 in wells in the 200-West Area, where the largest plume is associated with U Plant and is migrating to the east into the 600 Area. A groundwater pump-and-treat system is operating near U Plant to contain the plume. A technetium-99 plume originating in the northern 200-East Area is migrating toward the gap between Gable Mountain and Gable Butte.

Iodine-129

The presence of iodine-129, a moderately low-activity-yield fission product, in groundwater is significant because of its relatively low interim DWS (1 pCi/L), its long-term releases from nuclear fuel-processing facilities, and its long half-life (16 million years). However, iodine-129's relatively low-fission yield and long half-life limit its activity in Hanford Site groundwater. Iodine-129 is transported in groundwater as the anionic species, which is highly mobile. The main onsite contributor of iodine-129 to groundwater is liquid discharges to cribs in the 200 Areas. Extensive plumes of iodine-129 at levels above the interim DWS are found in the 200 Areas and in downgradient portions of the 600 Area. The major plume extends toward the southeast from the 200-East Area. A smaller arm of the plume is moving toward the north between Gable Mountain and Gable Butte.

Cesium-137

Cesium-137 is produced as a high-yield fission product and is present in waste streams associated with fuel processing, and has been released in reactor areas by fuel-element failures.

In FY 1996, spectral gamma logging at the Waste Management Area (WMA) S-SX single-shell tank farms indicated the presence of cesium-137 in the vadose zone at depths ranging from 18 to 36 m. Low concentrations of cesium-137 were detected in one groundwater well in this area, but it appears that the contamination is dominantly sorbed to particulate matter. It is currently unknown whether the groundwater contamination was transported in or around the well or through the vadose-zone sediments.

Concentrations of cesium-137 in FY 1996 reached 114 pCi/L in a well near the 216-B-5 injection well. The cesium-137 concentration reached a maximum of 1,470 pCi/L in another nearby well in 1995 but that well was not sampled in FY 1996. (It was sampled in December 1996 and results are not available for inclusion in this report.) The interim DWS for cesium-137 is 200 pCi/L.

Plutonium

Plutonium was present in waste streams associated with fuel processing. The DCG for plutonium-239 is 30 pCi/L. There is no explicit interim DWS for plutonium-239; however, the gross alpha MCL of 15 pCi/L is applicable. Alternatively, if the DCG (which is based on a 100-mrem dose standard) is converted to the 4-mrem dose equivalent used for the interim DWS, 1.2 pCi/L would be the relevant guideline. Plutonium generally binds strongly to sediments, so its mobility in groundwater is limited.

The only significant detection of plutonium in FY 1996, as in previous years, is associated with the 216-B-5 injection well in the 200-East Area. The maximum concentration of plutonium-239 and -240 detected near this injection well in FY 1996 was 81.7 pCi/L. Plutonium continues to be detected at very low levels in a well ~150 m northwest of this injection well.

Uranium

There are numerous potential sources of uranium release on the Hanford Site, including fuel fabrication, fuel processing, and uranium recovery from separations activities. Uranium mobility is dependent on both Eh and pH, and its migration is slightly slower than that of tritium and technetium-99. At Eh/pH conditions in the unconfined aquifer, U^{6+} is the most mobile state.

The EPA proposed a 20-μg/L MCL for uranium. Uranium was detected at concentrations above the proposed MCL in the 100-H, 100-F, 200, and 300 Areas. Contamination in the 100-H, 100-F, and 200-East Areas is very localized. The highest concentrations detected in FY 1996 were in the 200-West Area near the 216-U-1 and 216-U-2 cribs, and this plume extends into the 600 Area to the east. Like technetium-99, this plume is being contained by a pump-and-treat system.

Another area of elevated uranium concentrations is observed in the 300 Area, downgradient of the 316-5 process trenches. A pulse of uranium contamination appears to be moving from the vicinity of the process trenches toward the southeast. An expedited response action was performed on the trenches in mid-1991 to reduce the uranium source in that area. Use of the trenches for disposal of cooling water was resumed after the remedial action was completed but discharges ceased in December 1994. Uranium levels decreased sharply after the expedited response action but rose again after 1994, after discharge to the trenches ceased.

Nitrate

Although nitrate is associated primarily with chemical processing liquid wastes, other liquids discharged to the ground also contained nitrate. Nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in decontamination and chemical-processing operations. Like tritium, nitrate can be used to define the extent of contamination because it is present in many waste streams and is mobile in groundwater. However, additional sources of nitrate are located offsite to the west and southwest.

Nitrate was measured at concentrations greater than the MCL (45 mg/L as the NO_3^- ion) in wells in all operational areas except the 100-B Area. Nitrate contamination greater than the MCL in the 100-N Area was restricted to a few, scattered wells. Although elevated nitrate levels were found throughout the extensive plume emanating from the vicinity of the PUREX Plant in the 200-East Area, only proportionally small areas contained nitrate at levels above the MCL. Extensive nitrate contamination extends into the 600 Area from the vicinity of U Plant in the 200-West Area. A large nitrate plume in the 200-West Area is located near T Plant, while smaller amounts of contamination are found near the Plutonium Finishing and REDOX Plants. Two relatively small areas greater than the MCL are observed near the 400 Area and the Washington Public Power Supply System. Nitrate contamination in the Richland North Area apparently has a source off the Hanford Site.

Fluoride

Fluoride was detected above the primary 4.0-mg/L MCL in a small plume near the T Plant waste-disposal facilities in the 200-West Area.

Chromium

A major source for chromium was the sodium dichromate used as a corrosion inhibitor in cooling water for the 100 Area reactors. Chromium was also used for decontamination in the 100, 200, and 300 Areas, and for oxidation-state control in the REDOX process in the 200-West Area. The EPA's MCL for chromium is 100 μg/L and the State of Washington's MCL is 50 μg/L. Chromium was detected above 50 μg/L in groundwater from each of the 100 Areas, but the major plumes are related to operations in the 100-K, 100-D, and 100-H Areas and portions of the 600 Area between. Hexavalent chromium was detected in the Columbia River substrate adjacent to these areas and is a hazard to aquatic life. Therefore, interim remedial measures are planned to pump and treat groundwater in these areas to reduce the amount of chromium reaching the river. The chromium plumes are not well defined in the area east of the 100-K Area and in the area between the 100-D and 100-H Areas. Chromium distribution in the western portion of the 100-D Area was better defined during FY 1996 by data from a series of driven sampling tubes.

Chromium concentrations were also found at levels above the 50- and 100-μg/L MCLs in the 200 Areas. There were no new data on a chromium plume previously observed south of the 200-East Area. The source of this plume was not established.

Cyanide

A cyanide plume is present north of the 200-East Area and is believed to have originated from wastes containing ferrocyanide that were disposed in the BY cribs. Wells containing cyanide often contain concentrations of several radionuclides, including cobalt-60. Cobalt-60 appears to be chemically complexed and mobilized by cyanide or ferrocyanide.

The MCL for cyanide is 200 μg/L. The maximum average annual concentration of cyanide detected in FY 1996 was 140 μg/L. There is some evidence that contamination in this area migrated to some depth in the flow system, including detection of cyanide and cobalt-60 in the confined aquifer near the BY cribs.

Carbon Tetrachloride

As in previous years, carbon tetrachloride contamination was found in FY 1996 above the 5-μg/L MCL beneath much of the 200-West Area. The plume extends beyond the area boundary and forms the most widespread organic contaminant plume onsite. The contamination is principally from waste-disposal operations associated with the Plutonium Finishing Plant, where it was used in

plutonium processing. The 200-West Area carbon tetrachloride plume appears to be spreading gradually to the west and to the south. The total area of the carbon tetrachloride plume in FY 1996 (5-μg/L contour) was ~11,000,000 m^2, unchanged from 1995. A groundwater pump-and-treat system is operating in this area to prevent further movement of the plume.

Chloroform

The 200-West Area chloroform plume appears to be associated with the carbon tetrachloride plume. The chloroform is believed to be a degradation product of carbon tetrachloride. The MCL for chloroform is 100 μg/L (total trihalomethanes). Chloroform above the MCL was detected in FY 1996 in the 200-West Area.

Trichloroethylene

Trichloroethylene (TCE) was commonly used on the Hanford Site between the 1950s and 1970s as a degreasing compound. TCE was detected at concentrations greater than the 5-μg/L MCL in FY 1996 in wells in the 100-K, 100-F and adjacent upgradient 600 Areas, 200-West, and Richland North Areas.

Concentrations of TCE exceeded the MCL in the 200-West Area to the west of T Plant, to the east of U Plant, and in one well near the REDOX Plant. Some TCE at levels above the MCL is also associated with the carbon tetrachloride plume near the Plutonium Finishing Plant.

Concentrations of TCE were also detected in wells near the Solid Waste Landfill but were below the MCL. In recent years, TCE concentrations were greater than the MCL in these monitoring wells.

The 5-μg/L MCL for TCE was exceeded in the northwest point-of-compliance well for the 1100-EM-1 Operable Unit and in other wells near the Siemens Power Corporation and the Horn Rapids Landfill.

cis-1,2-Dichloroethylene

Concentrations of cis-1,2-dichloroethylene are increasing in a well that monitors the bottom of the unconfined aquifer near the 316-5 process trenches. Concentrations in this well exceeded the 70-μg/L MCL in FY 1996. The source of this constituent is believed to be anaerobic biodegradation of TCE.

Ingestion Dose Estimates

Results of groundwater monitoring are compared to the DWSs for individual radiological constituents. These interim DWSs use the methodology set out in 40 CFR 141; 142, and 143 to estimate the concentration in water that could result in a potential radiological dose of 4 mrem/yr from consumption of each individual constituent. Similarly, DCGs provide estimates of concentrations that could result in a 100-mrem/yr dose as set out in DOE Order 5400.5. However, the potential dose is actually the sum

of the doses from the individual constituents. An estimate of this cumulative dose, which could result from consumption of groundwater from different onsite locations, can be calculated from the extent of contamination.

Figure S.3 shows the cumulative dose estimates for ingestion of groundwater from the unconfined aquifer system on the Hanford Site. These estimates were made by summing the interpolated groundwater concentrations for tritium, strontium-90, technetium-99, iodine-129, cesium-137, uranium, and plutonium. Some values were adjusted to preserve the maximum peaks in source areas. Factors to convert concentrations to ingestion dose equivalents were taken from DOE Order 5400.5. The dose presented in Figure S.3 represents the cumulative dose equivalent from all major radionuclides in Hanford Site groundwater.

The dose estimates presented in Figure S.3 show that areas above the 100-mrem/yr dose standard are restricted to localized parts of the 100-K, 100-N, and 200 Areas. Areas above 4 mrem/yr are more restricted than the area above the interim DWS for individual constituents because the dose map used more recent conversion factors than those used in calculating the interim DWSs. Dose estimates for the 100-B,C, 100-K, 100-N, 100-D, 100-F, 200, 300, and 600 Areas exceed 4 mrem/yr.

The volume of unconfined groundwater chemically affected by site activities was estimated to be 1.3 billion m^3 based on the contaminant distributions during FY 1996. The estimate has a high uncertainty because of a lack of knowledge of the vertical extent of contaminant plumes. Plume thickness is estimated to be 20 m, except in the 100, 300, and 1100 Areas where it is estimated to be 5 m. The porosity of the aquifer is not well-characterized; for the purpose of the calculation, the porosity is assumed to be 30%. The estimate does not include water in the vadose zone.

Groundwater Modeling

Numerical simulations of groundwater flow and contaminant movement are used to predict future conditions and to assess the effects of remediation systems. Two sitewide models and several local-scale models were applied on the Hanford Site in FY 1996.

A three-dimensional numerical model representing nine hydrogeologic layers within the unconfined aquifer system was applied to predict the migration of tritium from the Effluent Treatment Facility (ETF), north of the 200-West Area. The model, which was based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code, was also used to predict the future movement of existing tritium and iodine-129 plumes originating in the southeastern part of the 200-East Area. Although results are considered preliminary and calibration and testing of the model are continuing, valuable insight into the three-dimensional movement of contaminant plumes was obtained from the modeling.

A separate modeling effort, with the objective of prioritizing and optimizing environmental restoration activities, was concluded during FY 1996. A two-layer model based on the Variably Saturated Analysis Model in 3 Dimensions with Preconditional Conjugate Gradient Matrix Solvers (VAM3DCG)

code was used to predict the movement of eight radionuclide and chemical contaminant plumes over the next 200 years. This effort supported development of the Hanford Site groundwater remediation strategy.

Additional models based on the Micro-FEM© and FLOWPATH codes were applied to the design of pump-and-treat operations at the 100-NR-2, 200-UP-1, and 200-ZP-1 Operable Units. The models were also used to assess the performance of pump-and-treat operations under current operating conditions and describe the zones of influence for capture and injection wells. Results indicate the plumes are being contained.

Groundwater Monitoring of RCRA Treatment, Storage, and Disposal Facilities

RCRA groundwater monitoring continued at 26 waste management units. At the end of FY 1996, 18 units were being monitored under detection programs and do not appear to be adversely affecting groundwater. The following paragraphs summarize highlights of RCRA monitoring during FY 1996.

Samples from a downgradient well monitoring the 120-D-1 ponds exceeded the critical range for pH in the fall of 1995 and in subsequent verification sampling. An assessment report was prepared and sent to the regulator. The assessment determined the elevated pH is not caused by the RCRA unit itself but is caused by alkaline sediments beneath the ponds.

Samples from a downgradient well that monitors WMA-B-BX-BY single-shell tank farms exceeded the critical mean value for specific conductance in February 1996 and in subsequent verification sampling. In May 1996, the State of Washington Department of Ecology (Ecology) concluded that there was evidence that the WMA-S-SX single-shell tank farms had contaminated groundwater with technetium-99 and had caused an increase in specific conductance. Ecology ordered that this WMA be monitored under an assessment program. Assessment plans were prepared for WMA-B-BX-BY and WMA-S-SX and were submitted to Ecology. The assessment programs are currently collecting data to determine the source, nature, and extent of contamination and the rate of movement. Possible driving forces considered for transporting soil-column contaminants to groundwater include enhanced infiltration of natural precipitation and/or leaking water lines that enter or pass near some of the tank farm areas. Corrective measures under consideration include isolation, removal or rerouting of any remaining water lines in the tank farm areas, and surfacewater controls.

The 183-H solar evaporation basins were monitored under final status regulations during FY 1996. Concentration limits are identified for each of four contaminants of concern (technetium-99, uranium, chromium, and nitrate) in the groundwater-monitoring plan. These limits were exceeded in the fall 1995 sampling set. Subsequent verification sampling confirmed the exceedances. Ecology was notified and monitoring is continuing. Corrective action will be addressed under the CERCLA program.

Background concentrations of indicator parameters were reestablished at several RCRA sites during FY 1996. These were necessary because of 1) a change in monitoring status at the 1324-N/NA surface impoundment/percolation pond, 2) an upward trend in specific conductance in the upgradient well at

the 120-D-1 ponds, and 3) a change in groundwater-flow direction at the WMA-U single-shell tank farm. There is also an upward trend in total organic halogen in the upgradient well at the 216-S-10 pond and ditch. Quarterly sampling was initiated to reestablish background values of total organic halogen.

RCRA groundwater monitoring is no longer conducted for low-level WMA-5 because these burial grounds never received waste and there are no plans to use them in the near future.

One new groundwater-monitoring well was installed in accordance with an agreement with Ecology to combine monitoring programs for the 216-A-10, 216-A-36B, and 216-A-37-1 cribs. The combined program will become effective during FY 1997.

Groundwater Remediation

Groundwater remediation under CERCLA requirements during FY 1996 included pump-and-treat systems in the following operable units:

- 100-NR-2 - Groundwater was extracted from wells near the 1301-N liquid waste-disposal facility, treated to remove strontium-90, and injected into wells near the 1325-N liquid waste-disposal facility. The system is designed to reduce the flux of strontium-90 to the Columbia River. The reduction in flux of strontium-90 to the Columbia River was estimated to be more than 70% based on a real-time water-level-monitoring network and modeled flow conditions. During the 4-month period from September 1995 to January 1996, the pump-and-treat system ion-exchange efficiency was >98%. An upgraded system, with a higher combined pumping volume, is being designed for implementation in FY 1997.

- 100-HR-3 - A pilot-scale treatability test was conducted in the 100-D/DR Area to determine the effectiveness of using pump-and-treat methodology for removing hexavalent chromium from groundwater. Operations began in August 1994 and continued through August 1996. Although the primary objectives of the project were associated with system design and performance, a significant amount of chromium was removed from the aquifer. By November 1995, the system had removed 29.9 kg of hexavalent chromium (9% to 14% of the total mass as estimated by numerical simulation of the plume). Additional chromium was removed prior to shutting the system down in August 1996.

- 200-UP-1 - A pump-and-treat system was designed to contain and treat elevated concentrations of uranium and technetium-99 in groundwater and to provide data for evaluation of the aquifer response resulting from system operation. Carbon tetrachloride is also removed by the system. The treatment system removed >99% of the uranium and technetium-99 from the extracted groundwater.

- 200-ZP-1 - A pump-and-treat system was implemented as an interim remedial measure to prevent further movement of carbon tetrachloride, chloroform, and trichloroethylene from the high-concentration portion of the carbon tetrachloride plume and to reduce contaminant mass.

Interim actions to reduce the potential threat of chromium to aquatic organisms in the Columbia River are planned for the 100-K, 100-D, and 100-H Areas in FY 1997. Groundwater will be extracted from wells in the heart of the chromium plumes, treated to remove the chromium, and injected into wells in the 100-K and 100-H Areas.

Well Maintenance

Several hundreds of well-maintenance activities were carried out during FY 1996. These activities included repairing wells or pumps, routine cleaning and maintenance, and well reconfigurations. Two wells were reconfigured to provide additional contaminant distribution information for the lower unconfined aquifer and upper confined aquifer beneath the Hanford Site and one well was reconfigured in support of a CERCLA limited field investigation. Thirty-six wells were decommissioned.

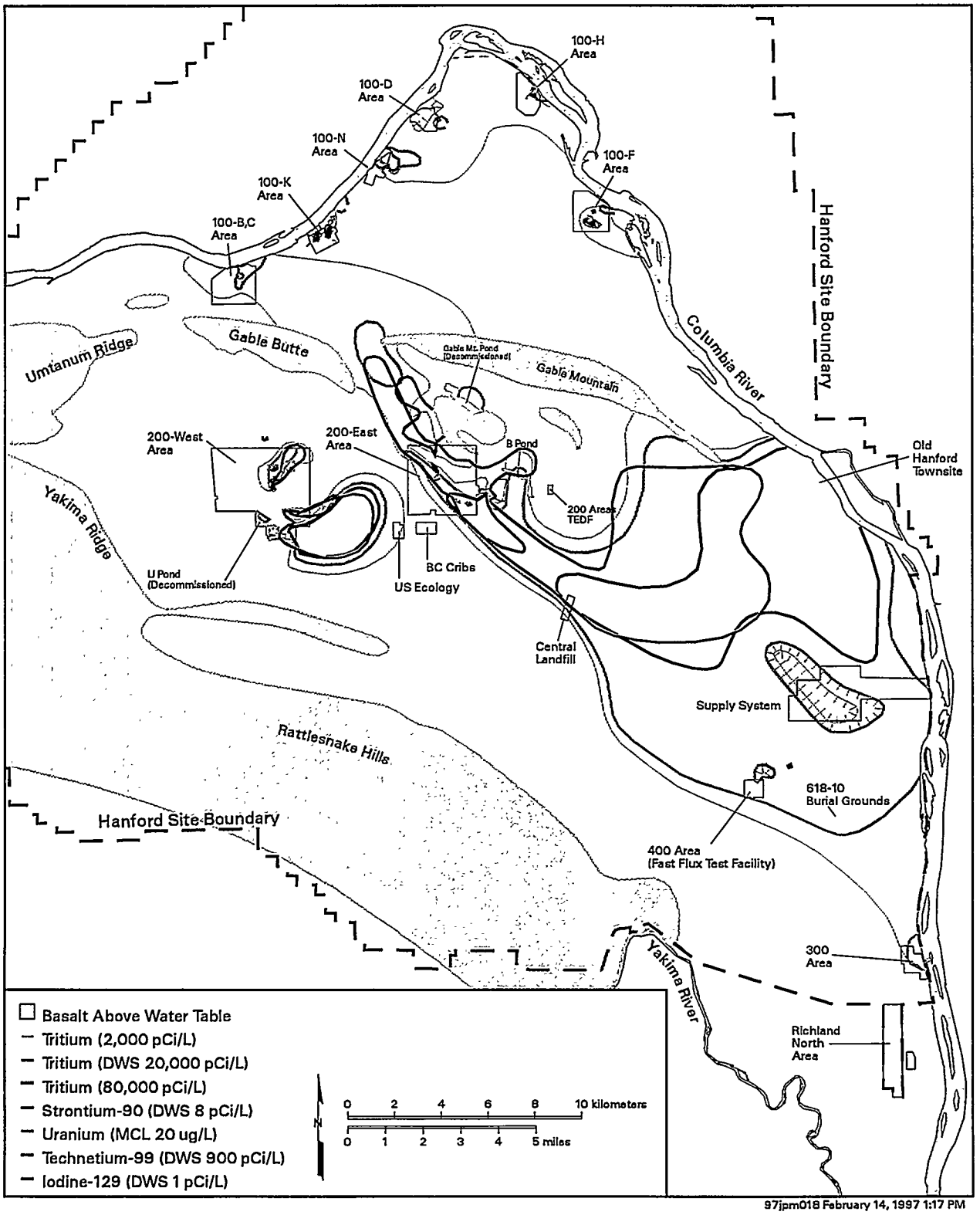


Figure S.1. Distribution of Major Radionuclides in Groundwater at Concentrations Above the Maximum Contaminant Level or Interim Drinking Water Standard, FY 1996

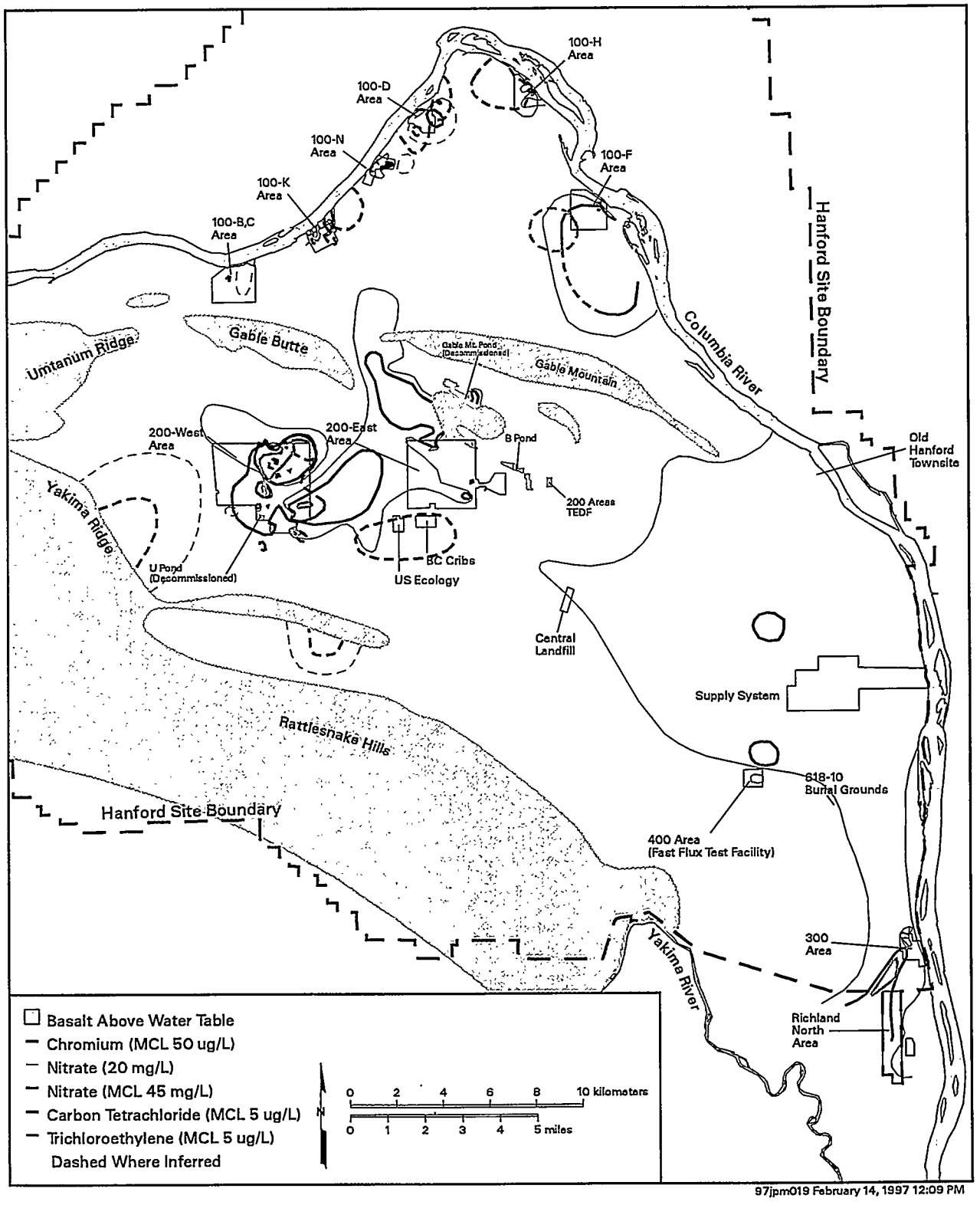
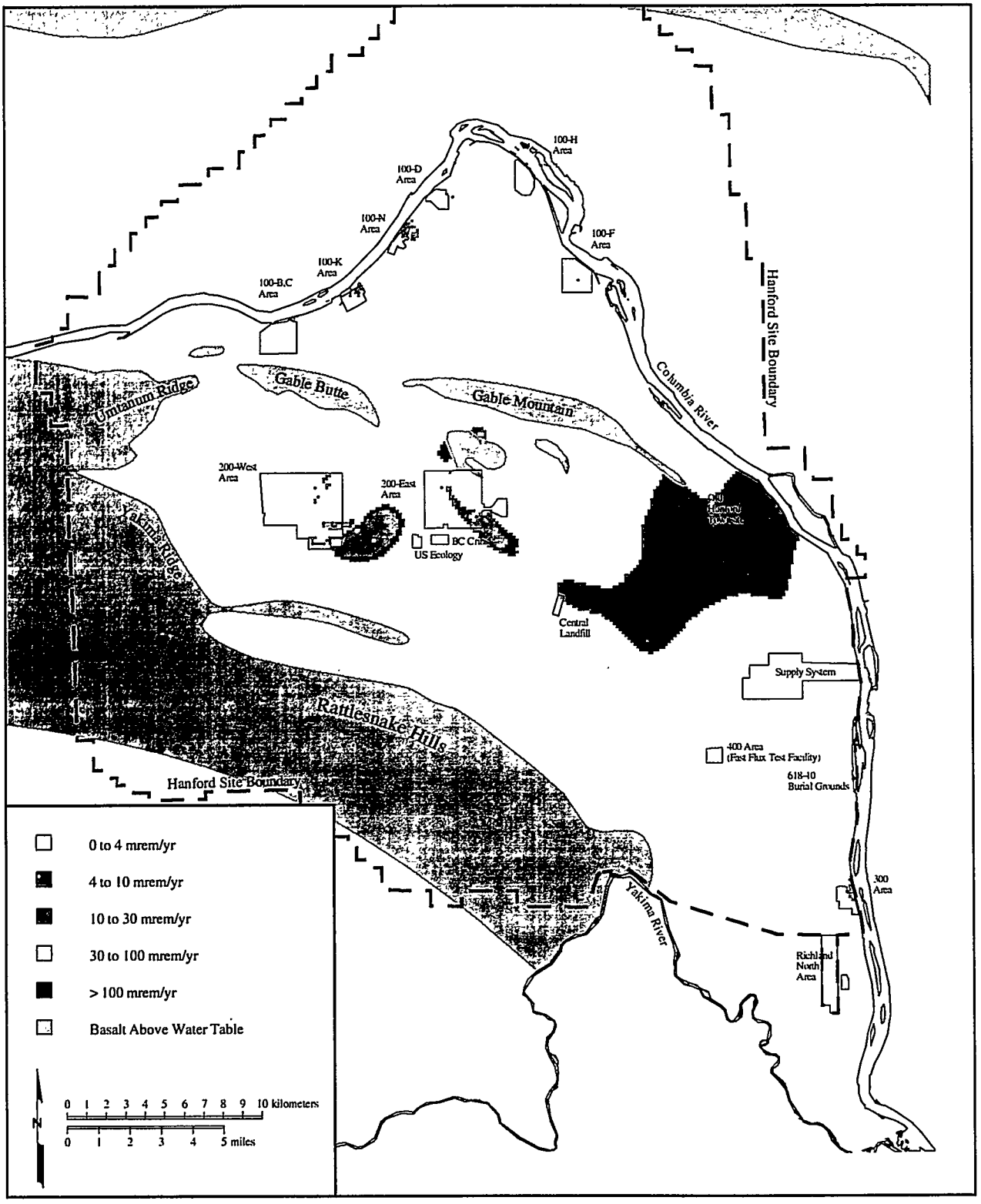


Figure S.2. Distribution of Major Hazardous Chemicals in Groundwater at Concentrations Above the Maximum Contaminant Level, FY 1996



97skw013.eps February 06. 1997

Figure S.3. Potential Dose Estimates from Ingestion of Hanford Site Groundwater, FY 1996

Acknowledgments

The scope and volume of this report increased astronomically and the authors wish to thank the many staff members who contributed to it.

Staff of Pacific Northwest National Laboratory (PNNL), Westinghouse Hanford Company, and Bechtel Hanford, Inc., and its subcontractors scheduled and coordinated collection of samples, measured water levels, and managed analytical results. Bill McMahon (CH2M Hill Hanford, Inc.) and Reed Simpson (IT Hanford Company) provided transducer data. Chris Denslow (IT Hanford Company) provided additional database support. Technical review was provided by Jeff Serne (PNNL). Bruce Ford served as a technical liaison with Bechtel Hanford, Inc. and its subcontractors. Marty Gardner (Rust Federal Services Northwest) contributed information on well maintenance. Tony Knepp (Bechtel Hanford, Inc.) supported the modeling chapter.

Denise Sauer, John McDonald, Steve Teel, and Travis Walters (PNNL) and Rob Hedges (Lockheed Martin Services, Inc.) produced the multitude of graphics. Darrell Newcomer (PNNL), in addition to being an author, and Dave Lanigan (PNNL) tracked down errant figures, references, and missing data when extra assistance was needed. Bill Hanf (PNNL) with the assistance of Dennis Brunson (PNNL) designed the cover.

Report editing and production were the responsibility of PNNL under the direction of Bev Johnston, with the able assistance of Rosalind Schrempf, Teresa Riley, Barbara Wilson, and Viva Metz. Text processing was a major task met by the skill of Kathy Neiderhiser, Jean Cheyney, Laurie Ann Empey, Kay Hass, Lila Andor, Rose M. Watt, Rose Urbina, and Margot White. Duplication of this massive report was expeditiously provided by the ROB and 337 Building duplicating crews.

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1.0 Introduction

M. J. Hartman

1.1 Purpose

Groundwater monitoring is conducted on the Hanford Site under a variety of regulations and programs: *Resource Conservation and Recovery Act of 1976* (RCRA), Ground-Water Surveillance Project, *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA), and Operational Monitoring Program. In the past, each of these produced separate interpretive reports of monitoring results to fulfill U.S. Department of Energy (DOE) orders and regulatory requirements.

In 1996, DOE instructed its contractors to restructure Hanford Site groundwater-monitoring activities. One element of this effort is the combination of these interpretive reports into this *Hanford Site Groundwater Monitoring for Fiscal Year 1996*.

The interpretations contained in this report primarily rely on data from samples collected between October 1, 1995 and September 30, 1996. Data received after November 8, 1996 may not have been considered in the interpretations.

This report is designed to meet the following objectives:

- provide a comprehensive, current interpretation of groundwater conditions on the Hanford Site and adjacent areas (Figure 1.1), including a description of hydrogeology, groundwater flow, and groundwater-contaminant distribution.
- meet the reporting requirements of RCRA, Ground-Water Surveillance, Solid Waste Landfill, and Operational Monitoring Programs.
- summarize the results of groundwater monitoring conducted to assess the effects of remediation or interim measures conducted under CERCLA
- describe the results of vadose zone monitoring
- summarize the maintenance, reconfiguration, and decommissioning of Hanford Site monitoring wells.

During the reporting period, groundwater was monitored under the various programs independently. Sampling and analysis were coordinated if possible to avoid duplication and expense, and data were managed in an integrated database but the programs were designed and implemented separately.

The Ground-Water Surveillance Project was conducted by Pacific Northwest National Laboratory (PNNL) to monitor contaminant distribution in groundwater across the entire Hanford Site.

Westinghouse Hanford Company (WHC) was responsible for the RCRA Program, which includes 18 treatment/storage/disposal units and the Solid Waste Landfill (Figure 1.2). WHC was also responsible for operational groundwater monitoring to evaluate the near-field impact on groundwater from facilities that received radioactive waste. The CERCLA Program, which includes groundwater remediation and groundwater monitoring to characterize contaminant plumes, is the responsibility of the Environmental Restoration Contract team, lead by Bechtel Hanford, Inc. The distribution of wells used to monitor for these programs is illustrated in Figure 1.3.

Combining the groundwater reports produces many benefits, including the following:

- provides the public with a single reference for current groundwater conditions on the Hanford Site
- resolves inconsistencies in interpretations of groundwater flow and contaminant distribution
- reduces redundancy and unnecessary costs associated with producing multiple reports.

1.2 Organization

This report integrates data collected under the various monitoring programs described in Section 1.1. The report is organized by primary subject areas rather than by program to reflect the restructuring of the site's groundwater-monitoring activities. Table 1.1 lists the section numbers where various subjects are discussed for each geographic area. Chapter 2.0 defines the DOE groundwater-protection program and associated requirements for groundwater monitoring. Chapter 3.0 describes the hydrogeology of the Hanford Site by geographic location. Chapter 4.0 presents the results of vadose zone monitoring. Chapter 5.0 describes groundwater flow, and Chapter 6.0 describes groundwater contaminant distribution—both are organized by geographic location. The chapter on groundwater contamination is further divided into discussions of the constituents of concern in each geographic area. Chapter 7.0 presents the results of groundwater modeling, and Chapter 8.0 summarizes well maintenance, reconfiguration, and decommissioning activities. Chapter 9.0 gives the references cited in the text. Additional references are provided in a historical bibliography (Appendix A).

Supporting information is organized in appendixes, some of which are included on a computer disk. Large plate maps are included in the back of this report that show the wells used for monitoring, the Hanford Site water table, and the distribution of widespread groundwater contaminants (tritium, nitrate, and iodine-129) in the uppermost aquifer.

The organization of this report is designed to make it more useful to the reader interested in groundwater and vadose-zone activities at the Hanford Site. Readers interested in specific program results (e.g., RCRA regulators) will find required elements in several chapters. The matrix presented in Table 1.2 is designed to guide the reader interested primarily in the RCRA program. The numbers listed in the table refer to section numbers of this report.

Table 1.1. Organizational Matrix for this Report

Subject Area (listed alphabetically)	Hanford Site	100-B,C Area	100-K Area	100-N Area	100-D Area	100-H Area	100-F Area	200-West Area	200-East Area	400 Area	600 Area	300 Area	Richland North	Confined Aquifer
Drinking water standards	Appendix G Table 6.1-29	6.3.4	6.4.5	6.5.5	6.6.5	6.7.5	6.8.5	6.9.5	6.10.4	6.11.3	6.12.3	6.13.4	6.14.4	6.15
Groundwater Contaminants (data in Appendix H)														
Carbon tetrachloride	NA	NA	NA	NA	NA	NA	NA	6.9.3	NA	NA	6.12.2	NA	NA	NA
Cesium-137	NA	NA	NA	NA	NA	NA	NA	6.9.3	6.10.3	NA	NA	NA	NA	NA
Chloroform	NA	NA	NA	6.5.3	NA	NA	NA	6.9.3	NA	NA	NA	NA	NA	NA
Chromium	6.2	6.3.3	6.4.3	6.5.3	6.6.3	6.7.3	6.8.3	6.9.3	NA	NA	6.12.2	NA	NA	NA
cis-1,2-Dichloroethylene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.13.3	NA	NA
Cobalt-60	NA	NA	NA	6.3.3	NA	NA	NA	NA	6.10.3	NA	NA	NA	NA	6.15
Cyanide	NA	NA	NA	NA	NA	NA	NA	NA	6.10.3	NA	NA	NA	NA	NA
Fluoride	NA	NA	NA	NA	NA	NA	NA	6.9.3	NA	NA	NA	NA	NA	NA
Iodine-129	6.2, Pl. 5	NA	NA	NA	NA	NA	NA	6.9.3	6.10.3	NA	NA	NA	NA	6.15
Nitrate	6.2, Pl. 4	6.3.3	6.4.3	6.5.3	6.6.3	6.7.3	6.8.3	6.9.3	6.10.3	6.11.2	6.12.2	NA	6.14.3	6.15
Plutonium	NA	NA	NA	NA	NA	NA	NA	6.9.3	6.10.3	NA	NA	NA	NA	NA
Specific conductance	NA	NA	NA	6.5.3	6.6.3	NA	NA	6.9.3	6.10.3	NA	6.12.2	NA	NA	6.15
Strontium-90	NA	6.3.3	6.4.3	6.5.3	6.6.3	6.7.3	6.8.3	NA	6.10.3	NA	6.12.2	6.13.3	6.14.3	6.15
Technetium-99	6.2	NA	NA	NA	NA	6.7.3	NA	6.9.3	6.10.3	NA	NA	NA	6.14.3	6.15
Trichloroethylene	NA	NA	6.4.3	NA	NA	NA	6.8.3	6.9.3	NA	NA	6.12.2	6.13.3	6.14.3	NA
Tritium	6.2, Pl. 3	6.3.3	6.4.3	6.5.3	6.6.3	6.7.3	6.8.3	6.9.3	6.10.3	6.11.2	6.12.2	6.13.3	6.14.3	6.15
Uranium	6.2	NA	NA	NA	NA	6.7.3	6.8.3	6.9.3	6.10.3	NA	6.12.2	6.13.3	6.14.3	NA
Groundwater flow	5.2, Pl. 2	5.4.2	5.4.2	5.4.2	5.4.2	5.4.2	5.4.2	5.4.3	5.4.4	5.4.5	5.4.5	5.4.6	5.4.6	5.5
Groundwater remediation	NA	NA	6.4.4	6.5.4	6.6.4	6.7.4	NA	6.9.4	NA	NA	NA	NA	NA	NA
Hydrogeology	3.2	3.3	3.3	3.3.1	3.3.2	3.3.3	3.3	3.4	3.4	3.5	3.5	3.6.1	3.6	3.1.1
Modeling	7.1, 7.2	NA	7.4.2	7.4.2	7.4.2	7.4.2	NA	7.3	7.1.5	NA	NA	NA	NA	NA

Table 1.1. (contd)

Subject Area (listed alphabetically)	Hanford Site	100-B,C Area	100-K Area	100-N Area	100-D Area	100-H Area	100-F Area	200-West Area	200-East Area	400 Area	600 Area	300 Area	Richland North	Confined Aquifer
RCRA	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2	Table 1.2
Regulatory requirements	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
River	NA	5.4.2	5.4.2	5.4.2	5.4.2, 6.6.3	5.4.2, 6.7.3	5.4.2	NA	NA	NA	NA	5.4.6	5.4.6	NA
Sampling and Analysis														
Chemistry	Section 6.1 and Appendix E													
Vadose	Section 4.2													
Water level	Section 5.1													
Vadose zone (unsaturated)	NA	NA	4.4.1	NA	NA	NA	NA	4.3.1, 4.3.2, 4.4.2	4.3.1, 4.3.3, 4.4.2	NA	NA	NA	NA	NA
Well remediation	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

Table 1.2. Organizational Matrix for Required RCRA Elements in this Report

RCRA Site	Regulatory Status[a]	Facility Overview	Hydrogeologic Summary	Well Network and Constituent List	Indicator Parameters and Statistics[b]	Elevated Constituents, Concentration Histories, Distribution	Groundwater-Flow Direction and Rate[c]	Evaluation of Monitoring Network
1301-N, 1325-N, 1324-N/NA	Indicator evaluation	6.5.2	3.3.1	Table 6.1-1, 6.1-2, 6.1-3	6.5.5	6.5.3	5.4.2	6.5.5
120-D-1 Ponds	Indicator evaluation	6.6.2	3.3.2	Table 6.1-4	6.6.5	6.6.3	5.4.2	6.6.5
183-H Basins	Compliance	6.7.2	3.3.3	Table 6.1-5	NA	6.7.3	5.4.2	6.7.5
216-B-3 Pond	Assessment	6.10.2	3.4.7	Table 6.1-18	NA	6.10.3	5.4.4	6.10.4
216-A-29 Ditch	Indicator evaluation	6.10.2	3.4.6	Table 6.1-17	NA	6.10.3	5.4.4	6.10.4
216-A-36B Crib	Indicator evaluation	6.10.2	3.4.5	Table 6.1-15	6.10.4	6.10.3	5.4.4	6.10.4
216-A-10 Crib[b]	Indicator evaluation	6.10.2	3.4.5	Table 6.1-16	6.10.4	6.10.3	5.4.4	6.10.4
216-B-63 Trench	Indicator evaluation	6.10.2	3.4.8	Table 6.1-19	6.10.4	6.10.3	5.4.4	6.10.4
216-S-10 Pond & Ditch	Indicator evaluation	6.9.2	3.4.1	Table 6.1-6	6.9.5	6.9.3	5.4.3	6.9.5
216-U-12 Crib	Assessment	6.9.2	3.4.2	Table 6.1-7	NA	6.9.3	5.4.3	6.9.5
LERF	Indicator evaluation	6.10.2	3.4	Table 6.1-22	6.10.4	6.10.3	5.4.4	6.10.4
LLWMA-1	Indicator evaluation	6.10.2	3.4.4	Table 6.1-20	6.10.4	6.10.3	5.4.4	6.10.4
LLWMA-2	Indicator evaluation	6.10.2	3.4.4	Table 6.1-21	6.10.4	6.10.3	5.4.4	6.10.4
LLWMA-3	Indicator evaluation	6.9.2	3.4.10	Table 6.1-9	6.9.5	6.9.3	5.4.3	6.9.5
LLWMA-4	Indicator evaluation	6.9.2	3.4.10	Table 6.1-10	6.9.5	6.9.3	5.4.3	6.9.5

Table 1.2. (contd)

RCRA Site	Regulatory Status[a]	Facility Overview	Hydrogeologic Summary	Well Network and Constituent List	Indicator Parameters and Statistics[b]	Elevated Constituents, Concentration Histories, Distribution	Groundwater-Flow Direction and Rate[c]	Evaluation of Monitoring Network
LLWMA-5[d]	NA[d]	6.9.2	3.4.10	Table 6.1-11	NA	NA	5.4.3	NA
A-AX-SST	Indicator evaluation	6.10.2	3.4.9	Table 6.1-23	6.10.4	6.10.3	5.4.4	6.10.4
B-BX-BY-SST	Assessment	6.10.2	3.4	Table 6.1-24	6.10.4	6.10.3	5.4.4	6.10.4
C-SST	Indicator evaluation	6.10.2	3.4	Table 6.1-25	6.10.4	6.10.3	5.4.4	6.10.4
S-SX-SST	Assessment	6.9.2	3.4.3	Table 6.1-8	NA	6.9.3	5.4.3	6.9.5
T-SST	Assessment	6.9.2	3.4.3	Table 6.1-12	NA	6.9.3	5.4.3	6.9.5
TX-TY-SST	Assessment	6.9.2	3.4.3	Table 6.1-13	NA	6.9.3	5.4.3	6.9.5
U-SST	Indicator evaluation	6.9.2	3.4.3	Table 6.1-14	6.9.5	6.9.3	5.4.3	6.9.5
316-5 PT	Assessment	6.13.2	3.6.1	Table 6.1-27	NA	6.13.3	5.4.6	6.13.4
NRDWL	Indicator evaluation	6.12.1	3.5	Table 6.1-26	6.12.2	6.12.2	5.4.5	6.12.3

(a) As of September 30, 1996; see also Chapter 2.0.
(b) Indicator evaluation sites only; see also Appendix B.
(c) See also Table 5.4-1.
(d) LLWMA-5 never used; groundwater monitoring ceased during FY 1996.

LERF = 200 Areas Liquid Effluent Retention Facility.
LLWMA = Low-Level Waste Management Area (comprises 5 waste management areas).
NA = Not applicable.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PT = Process Trenches.
SST = Single-shell tanks (comprises 7 waste management areas).

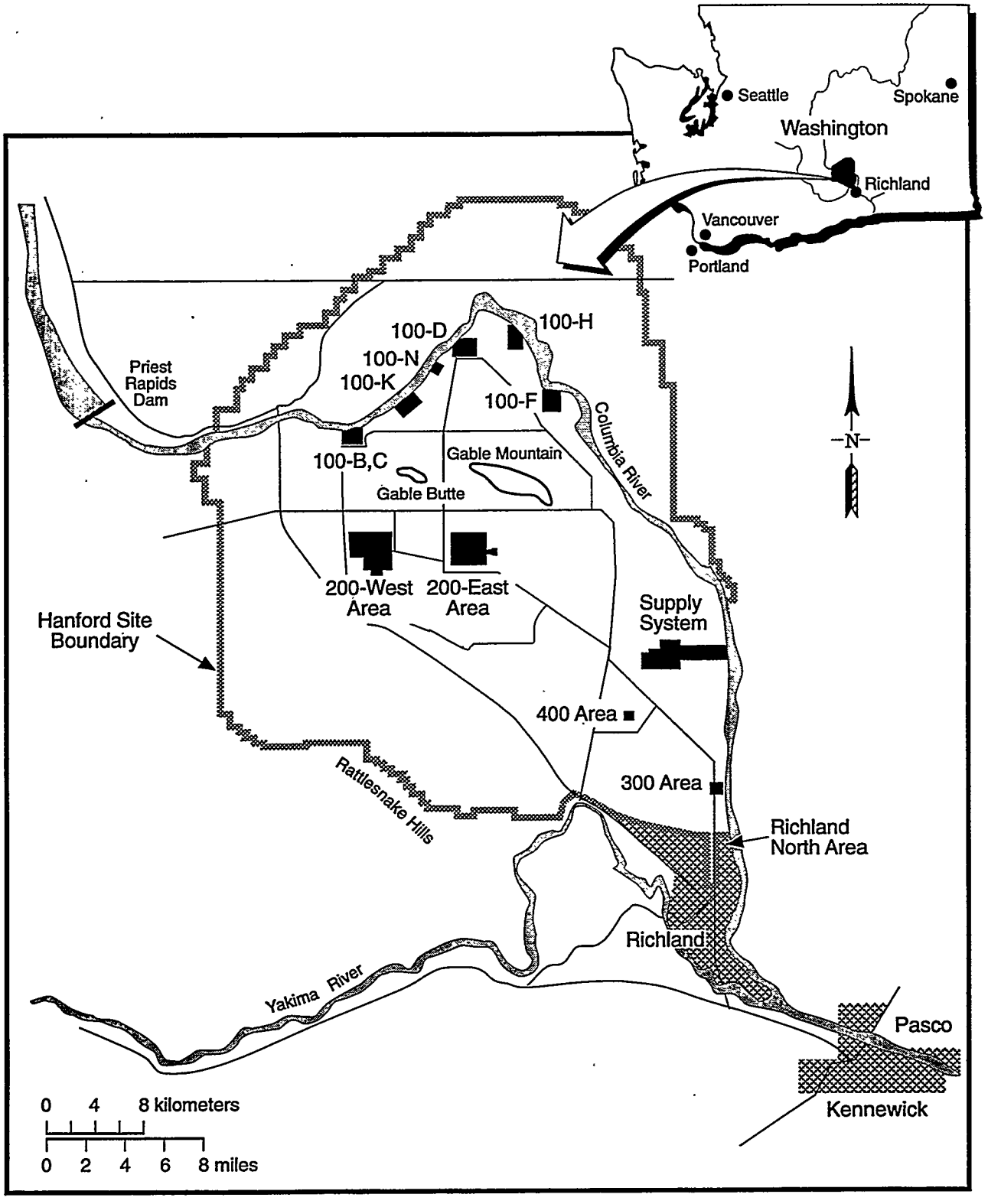


Figure 1.1. Hanford Site Location Map

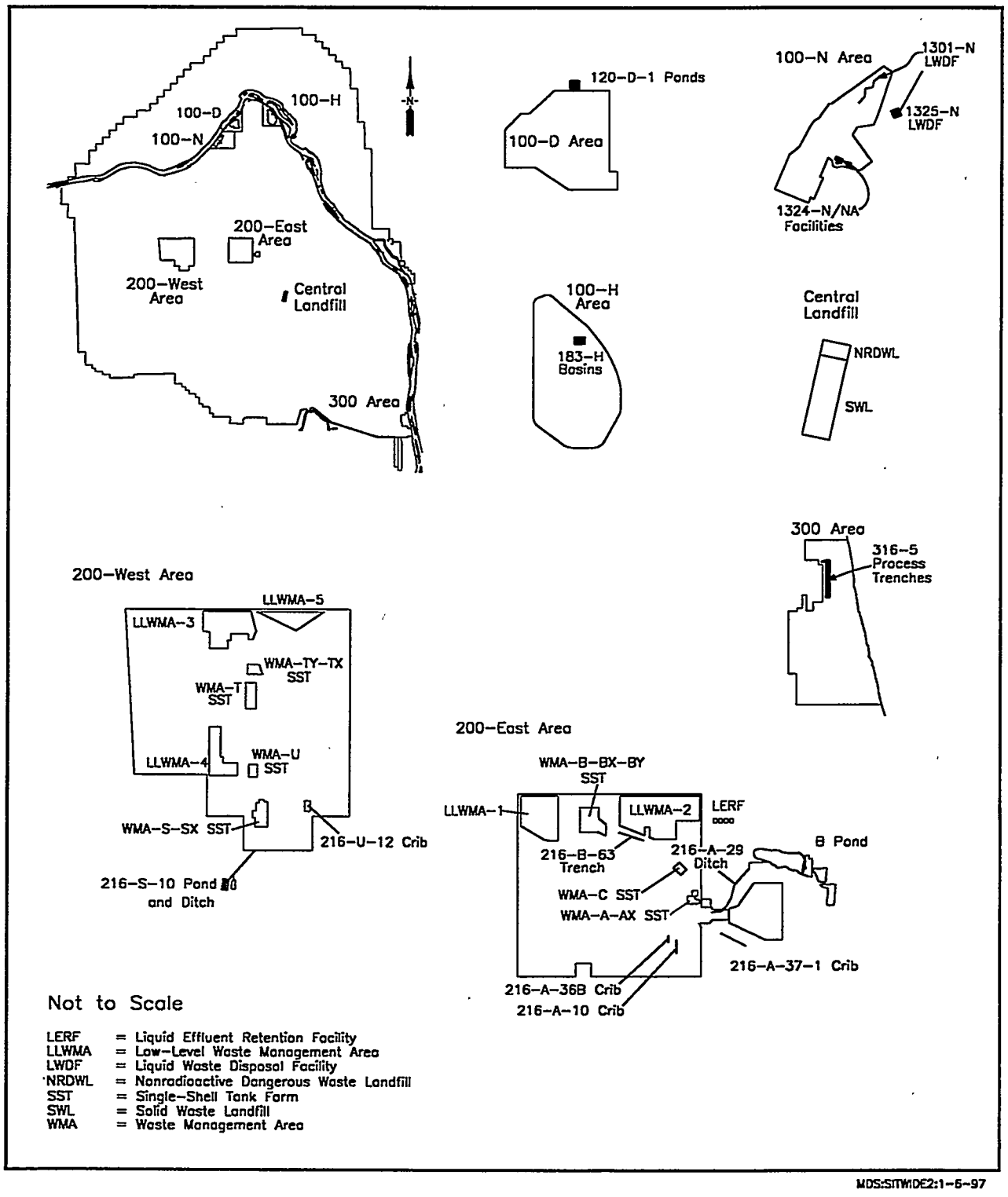


Figure 1.2. RCRA Facilities on the Hanford Site Requiring Groundwater Monitoring

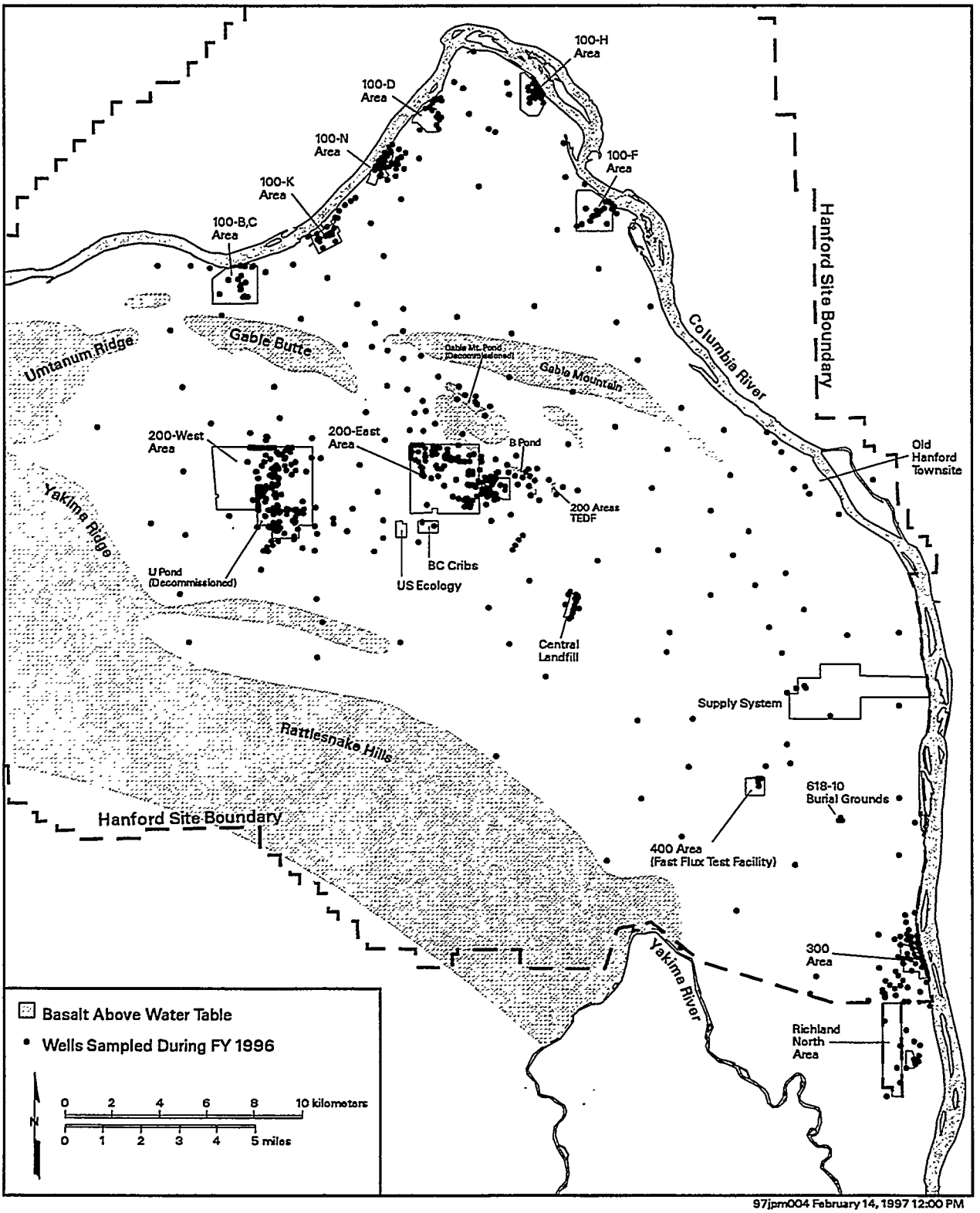


Figure 1.3. Location of Groundwater-Monitoring Wells Sampled in FY 1996

2.0 Groundwater-Monitoring Requirements

B. A. Williams

This chapter describes the regulatory framework governing the Hanford Site's groundwater-protection program. That framework consists of integrated federal and state regulations, orders, and agreements. Pursuant to those regulations, orders, and agreements, the groundwater monitoring performed at the Hanford Site during fiscal year (FY) 1996 is in compliance.

The *Hanford Site Environmental Monitoring Plan* (DOE 1994a) and the *Hanford Site Ground-Water Protection Management Plan* (Barnett et al. 1995a) summarize the groundwater- and program-integration activities and the regulatory reporting requirements for those activities. These plans (Barnett et al. 1995a and DOE 1994a) integrate 1) near-field monitoring at active or inactive waste treatment, storage, or disposal (TSD) facilities to comply with the *Resource Conservation and Recovery Act of 1976* (RCRA), applicable State of Washington regulations, and operational monitoring required by U.S. Department of Energy (DOE) Orders at nuclear facilities and untreated liquid waste-disposal sites and 2) sitewide and offsite groundwater-contaminant migration administered by the sitewide groundwater quality surveillance program required by DOE Order 5400.1. Site-specific groundwater monitoring is also conducted to support groundwater-remediation projects under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) projects.

The following sections discuss the specific regulations in more detail.

2.1 Groundwater Protection

Under the *Atomic Energy Act of 1954*, as amended, DOE is obligated "...to regulate its own activities so as to provide radiation protection for both workers and public."

The environmental standards and regulations applicable for groundwater protection/management are described in DOE Order 5400.1. These environmental protection standards fall into three categories: 1) those imposed by federal statutes, regulations, and requirements; 2) those imposed by state and local statutes, regulations, and requirements applicable to DOE; and 3) those imposed by DOE directives. The objectives of DOE's groundwater-protection projects (as defined in DOE Order 5400.1) are to demonstrate compliance with legal and regulatory requirements imposed by applicable federal, state, and local agencies; to confirm adherence to DOE environmental protection policies; and to support environmental management decisions.

Barnett et al. (1995a) provide a framework for coordinating the existing onsite groundwater-protection activities conducted by DOE's contractors, establish the policy and strategies for groundwater protection/management at the Hanford Site, and propose an implementation plan to meet goals (and milestones). These goals include 1) improved regulatory coordination between the federal and state regulations applicable to groundwater activities, 2) other programmatic groundwater issues (e.g.,

maintaining/achieving regulatory compliance of all groundwater activities), and 3) achieve cost-effective groundwater program administration by DOE and the various contractors. The relationship of this plan (Barnett et al. 1995a) to DOE Order 5400.1 and to the various groundwater-monitoring, remedial activities, and reporting requirements is shown in Figure 2.1.

2.1.1 General Environmental Protection Program, DOE Order 5400.1

Groundwater-monitoring projects are established under this order to 1) meet the requirements of DOE Order 5400.5, which deals with radiation protection of the public and the environment and 2) federal and state regulations. DOE Order 5400.1 requires that groundwater-monitoring projects be designed and implemented in accordance with 40 CFR 264 or 265, Subpart F. DOE Order 5820.2, which deals with radioactive waste management, also applies to the 5400.1 series requirements. The groundwater-monitoring requirements for federal and state regulations are presented in Section 2.3.

Because the Hanford Site has multiple, extensive, and unique groundwater-pollution problems, DOE established an integrated groundwater-monitoring project to deal with radiation protection of the public and the environment. The project also incorporates radiation-management requirements found in DOE Order 5820.2, established to satisfy the groundwater-monitoring objectives listed above. The specific objectives are to:

- verify compliance with other applicable groundwater regulations
- characterize and define hydrogeologic, physical, and chemical trends in the groundwater system
- establish baselines of groundwater quality
- provide a continuing, independent assessment of groundwater-monitoring and -remediation activities
- identify and quantify new or existing groundwater contamination and quality problems.

These projects assess radionuclide and other hazardous effluent-disposal impacts of non-RCRA TSD facilities on groundwater quality and monitors and documents the overall distribution and movement of radionuclides and other hazardous contaminants in groundwater beneath and adjacent to the Hanford Site in accordance with DOE Orders 5400.1 and 5400.5.

2.1.2 Radiation Protection of the Public and the Environment, DOE Order 5400.5

This order establishes standards and requirements for DOE and DOE contractors to operate its facilities and conduct its activities so that radiation exposure to members of the public is maintained within the limits established in the order (e.g., public dose limits and derived concentration guides for air and water) and to control radioactive contamination through the management of real and personal property. In addition, it is DOE's objective to protect the environment from radioactive contamination to the extent practical.

2.2 Hanford Federal Facility Agreement and Consent Order

A key element to Hanford Site compliance is the *Hanford Federal Facility Agreement and Consent Order* (also known as the Tri-Party Agreement) (Ecology et al. 1989). Compliance and waste-cleanup timetables and implementation milestones are established in the Tri-Party Agreement to ensure that cleanup progresses and to enforce environmental protection. Tri-Party Agreement Milestone M-13-81A established the groundwater-protection management plan (Barnett et al. 1995a) as the vehicle to be used to coordinate groundwater-protection and remedial-action efforts and to manage the Hanford Site groundwater resource. The Tri-Party Agreement is a contract between the U.S. Environmental Protection Agency (EPA), State of Washington Department of Ecology (Ecology), and DOE for achieving compliance (enforceable by law) with the remedial action provisions of CERCLA and the TSD unit regulation and corrective action provisions of RCRA.

This annual report contains the results of regulatory-required activities from applicable groundwater-protection, -cleanup, and -monitoring activities as scheduled in the Tri-Party Agreement action plan. Table 2.1 provides a general listing of those applicable major milestones. Details for each milestone are described in the Tri-Party Agreement (Ecology et al. 1989).

2.3 Applicable Federal Regulations

This section describes the federal regulations that govern groundwater monitoring, remedial investigation, and remediation. The institutional and regulatory interfaces are defined by the Tri-Party Agreement and are outlined in Section 2.5.

2.3.1 Comprehensive Environmental Response, Compensation, and Liability Act of 1980/Superfund Amendments and Reauthorization Act of 1986

These Acts establish a federal program authorizing waste cleanup at inactive sites. The Hanford Site was listed on the National Priorities List (40 CFR 300, Appendix B). This was based on the EPA's hazard-ranking system that subdivided the Hanford Site into four National Priorities List sites: 100, 200, 300, and 1100 Areas. Preliminary assessments revealed ~1,400 known waste management units where hazardous substances may have been disposed. The four listed sites were further divided into 74 source and 10 groundwater operable units (i.e., a grouping of individual waste units based primarily on geographic area and common waste sources).

The groundwater operable units currently being studied were selected as a result of the Tri-Party Agreement negotiations. Table 2.2 defines the current groundwater operable unit monitoring projects, listed according to Tri-Party Agreement priority, and also defines the Tri-Party Agreement regulatory unit designation and lead regulatory agency responsible for the operable unit (described more fully in Section 2.5).

The *Hanford Past-Practices Strategy* (Thompson 1991) provides the framework for streamlining the CERCLA remedial investigation process and accelerating remediation of groundwater and

past-practices waste sites through expedited response actions and interim remedial measures. The bias-for-action principles of the past-practices strategy were vigorously pursued in accelerating the groundwater-remediation project through the investigative phases and into pilot-scale treatability studies, both of which gathered important data necessary to begin full-scale remediation activities through implementation of interim remedial measures.

The groundwater interim remedial measures consist primarily of hydraulic containment actions using pump-and-treat technologies and are designed to halt the continued migration of the most-contaminated portions of the plumes into the Columbia River or out of aquifers underlying the 200 Areas. DOE plans to continue the interim remedial measures already under way and to supplement and expand the system, where needed, to meet remediation objectives. The groundwater-remediation strategy (DOE 1995a) establishes that the overall goal of groundwater remediation on the Hanford Site is to restore groundwater to its beneficial uses in terms of protecting human health and the environment and its use as a natural resource. In recognition of the Hanford Future Site Uses Working Group (Drummond 1992) and public values, the strategy establishes that the sitewide approach to groundwater cleanup is to remediate the major plumes found in the reactor areas and to contain the spread and reduce the mass of the major plumes found in the 200 Areas. This strategy is documented in DOE (1995a) and Barnett et al. (1995a).

The scope of this decision process encompasses all contaminated groundwater (CERCLA and/or RCRA past-practices projects) at the Hanford Site. To date, six pilot-scale pump-and-treat projects in five groundwater operable units address the following plumes:

- 100-HR-3 Operable Unit - chromium plume
- 100-NR-2 Operable Unit - strontium plume
- 200-BP-5 Operable Unit - combined plutonium, cesium, and strontium plume and a technetium and cobalt plume (no longer active)
- 200-UP-1 Operable Unit - uranium and technetium plume
- 200-ZP-1 Operable Unit - carbon tetrachloride (and associated organics) plume.

The pilot-scale pump-and-treat systems in the 100-HR-3, 100-NR-2, 200-UP-1, and 200-ZP-1 Operable Units are being expanded to full-scale interim remedial measures (discussed more fully in Chapter 6.0).

Groundwater monitoring is performed at these operable units in support of the pump-and-treat performance assessment and for contaminant monitoring. Individual requirements as defined under CERCLA are described in the work plans and/or records of decision.

Under the EPA's interpretation of CERCLA, contaminated groundwater generally must be cleaned up to meet maximum contaminant levels or maximum contaminant level goals established under the

Safe Drinking Water Act of 1974 if the groundwater, prior to contamination, could have been used at some future date as a drinking water source. Using the EPA's groundwater classification as well as Ecology's highest beneficial use assumption in Washington Administrative Code (WAC) 173-340-720, almost all Hanford Site groundwater is, by definition, a potential future source of drinking water. The classification is based on groundwater-quality characteristics and not related to land-use designations. These cleanup levels are identified in the applicable operable unit's record of decision.

2.3.2 Resource Conservation and Recovery Act of 1976

Regulatory standards for the generation, transportation, storage, treatment, and disposal of hazardous wastes are established in RCRA and relate to ongoing waste-management and permitting at active facilities. The Hanford Facility RCRA Permit was issued by Ecology and EPA in August 1994 (Ecology 1994). Ecology and EPA designated the Hanford Site as a single RCRA facility with over 60 individual liquid and solid waste TSD units. The Tri-Party Agreement recognized that all of the TSD units cannot be permitted simultaneously and set up a schedule for submitting unit-specific Part B RCRA/dangerous waste permit applications and closure plans to Ecology and EPA. Of the 60 TSDs, 26 required groundwater monitoring in FY 1996 to determine if operations are impacting the uppermost aquifer.

The RCRA groundwater-monitoring requirements for the 26 active TSDs fall under one of two categories: interim status or final status. A permitted or closed RCRA TSD unit requires final status groundwater monitoring as specified in 40 CFR 264. Nonpermitted RCRA units require interim status groundwater monitoring as specified in 40 CFR 265. Ecology was authorized by the EPA to implement its dangerous waste program in lieu of the EPA's. Ecology's interim status TSD requirements, established in WAC 173-303-400, invoke 40 CFR 265 governing RCRA groundwater-monitoring activities. RCRA final status TSD facilities follow WAC 173-303-645, which specifies the groundwater-monitoring requirements. Table 2.3 provides a list of the 26 active RCRA units requiring groundwater monitoring and the status of the unit.

This annual report also includes groundwater results for the Environmental Restoration Disposal Facility. This facility is a landfill authorized under CERCLA that is constructed to meet RCRA technical requirements (40 CFR 264). The facility is not a RCRA TSD unit but utilizes a 4-well RCRA-style groundwater network and conducts monitoring in accordance with WAC 173-303-645 as outlined in Weekes et al. (1996).

Both interim and final status groundwater monitoring are conducted under one of three possible phases: 1) indicator parameter/detection, 2) assessment (or final status compliance), and 3) corrective action. Initially, a detection-level program is developed to determine and monitor the impact of facility operations on the groundwater. If the detection-monitoring results indicate a statistical increase in the concentrations of key indicator parameters or dangerous waste constituents in the groundwater, then an assessment (or final status compliance) phase of monitoring and investigation is initiated. If the source of the contaminants is determined to be the TSD unit, and those concentrations exceed maximum contaminant levels as defined in the monitoring program plan or permit, then Ecology may require corrective action to reduce the contaminant hazards to the public and environment. Table 2.3 also

indicates when the site is scheduled for incorporation under the site permit. The comparisons and details of these three phases of groundwater monitoring and the specific requirements of the interim and final status groundwater-monitoring projects are provided in Appendix B.

2.4 Applicable State Regulations

2.4.1 Dangerous Waste Regulations, WAC 173-303

As stated in Section 2.3.2, Ecology was authorized by EPA to implement state groundwater regulations. WAC 173-303-400 and -600 provide the requirements for interim and final status TSD facility standards. The interim status requirements invoke the EPA regulations (40 CFR 265) governing the RCRA groundwater-monitoring activities. RCRA final status TSD facilities follow WAC 173-303-645, which specifies the groundwater-monitoring requirements.

2.4.2 State Waste Discharge Program, WAC 173-216

Non-RCRA TSD facilities are regulated by DOE Orders and the Tri-Party Agreement. These facilities consist primarily of soil-column-disposal facilities that receive cleaned water (treated effluent) derived from liquid waste that was associated with nuclear material processing, refining, and waste-treatment activities. All major discharges of untreated wastewater were terminated in June 1995. In addition, an agreement was reached in December 1991 to include all miscellaneous waste streams and/or any new waste streams discharged to the groundwater under the waste-discharge-permit system defined in WAC 173-216. Groundwater monitoring is conducted at three of the permit sites: 400 Area process pond, 200 Areas treated effluent disposal facility, and 200 Areas effluent treatment facility (Ecology 1995a, 1995b). Monitoring and reporting requirements for the latter two facilities are specified in the monitoring plans (Barnett et al. 1995b; Davis et al. 1996, respectively).

2.4.3 Minimum Functional Standards for Solid Waste Handling, WAC 173-304

The Solid Waste Landfill is a disposal facility that is not a RCRA hazardous waste site and is not addressed under the Tri-Party Agreement. The current operations of this landfill are regulated by WAC 173-304-490. A permit application was submitted to the Benton-Franklin District Health Department in 1991 (DOE 1991a). Responsibility for the site was subsequently assumed by Ecology in 1993 (DOE 1993a). Groundwater-monitoring activities conducted at this landfill comply with requirements stipulated in WAC 173-304-490.

2.5 Regulatory Authority Interface

2.5.1 Regulatory Programs

The RCRA, CERCLA, WAC 173-303 regulations, and DOE Orders that govern groundwater monitoring, remedial investigations, and remediation overlap in many areas. This section clarifies

how, through the Tri-Party Agreement, these programs must interface to achieve an efficient regulatory program to integrate the groundwater projects and to minimize redundancy.

2.5.2 Categories of Waste Units

There are three waste-unit categories and related statutory or regulatory authorities addressed in the Tri-Party Agreement action plan: TSD unit, RCRA past-practices unit, and CERCLA past-practices unit.

The TSD units requiring groundwater monitoring were listed in Table 2.3. TSD units are defined as units receiving a RCRA permit for either operation or postclosure care and must be closed to meet WAC 173-303-610 and the *Hazardous and Solid Waste Amendments of 1984.* These units shall remain classified as RCRA TSD units, rather than CERCLA units, even if they are investigated in conjunction with CERCLA units. All TSD units that undergo closure, irrespective of permit status, must be closed pursuant to the authorized regulations in WAC 173-303-610 (see Section 2.4.1).

The RCRA and CERCLA past-practices units are waste management units wherein hazardous substances from sources (other than TSD units) have been disposed, as addressed by CERCLA, regardless of date of receipt at the past-practices units.

2.5.3 Management of Waste Units

Since the Hanford Site was placed on the National Priorities List (40 CFR 300, Appendix B), Ecology, EPA, and DOE agreed that the units managed as RCRA past-practices units shall address all CERCLA hazardous substances for the purposes of corrective action. An agreement was also made that all of the waste regulated by WAC 173-303 (RCRA) will be addressed as part of any CERCLA response action or RCRA corrective action.

Section 121 of CERCLA requires that remedial actions attain a degree of cleanup that meets applicable or relevant and appropriate federal and state environmental requirements (ARARs). Based on this, the Tri-Party Agreement (Ecology et al. 1989) requires that 1) all state-only hazardous wastes will be addressed under CERCLA and 2) RCRA standards for cleanup or TSD requirements (for applicable RCRA TSD units) will be met under a CERCLA action. This eliminates many discrepancies between the two programs and lessens the significance of whether an operable unit is placed in one program or the other.

All units within an operable unit are designated as either RCRA or CERCLA past-practices units. This designation ensures that only one past-practices program is applied at each operable unit. The corrective action process selected for each operable unit must be sufficiently comprehensive to satisfy the technical requirements of both statutory authorities and the respective regulations.

The authority in CERCLA will be used for operable units consisting primarily of past-practices units (i.e., no TSD units or relatively insignificant units). The CERCLA authority will also be used for past-practices units in which remediation of CERCLA-only materials is the majority of work to be done

in that operable unit. The RCRA past-practices authority generally is used for operable units that contain significant TSD units and/or lower priority past-practices units. Currently assigned RCRA past-practices and CERCLA past-practices designations are shown in Table 2.2.

2.5.4 TSD and Past-Practices Units Interface

There are several cases where TSD units are closely associated with past-practices units, either geographically or through similar processes and waste streams. A procedure to coordinate the TSD unit closure or permitting activity with the past-practices investigation and remediation activity is necessary to prevent overlap and duplication of work, thereby economically and efficiently addressing the contamination. Based on criteria defined in Section 2.5.3, selected TSD groups/units were assigned to corresponding operable units and the information necessary for performing RCRA closures/post-closures within an operable unit is provided in various RCRA facility investigations/corrective measures reports. The initial work plan contains a sampling and analysis plan for the associated RCRA units and outlines the manner in which RCRA closure/postclosure requirements are met in the work plan and subsequent documents. The selected closure/postclosure method and associated design details, submitted as part of the corrective measures report, must 1) meet RCRA-closure standards and requirements, 2) be consistent with closure requirements specified in the sitewide RCRA permit, and 3) be coordinated with the recommended remedial action(s) for the associated operable unit. Each remedial facility investigations/corrective measures reports closure document must be structured such that RCRA-closure/postclosure requirements can be readily identified for a separate review/approval process and so the RCRA closure/postclosure requirements can be incorporated into the RCRA permit.

It was agreed by Ecology, EPA, and DOE that past-practices authority may provide the most efficient means for addressing mixed waste groundwater-contamination plumes originating from a combination of TSD and past-practices units. However, to ensure that TSD units within the operable units are brought into compliance with RCRA and state hazardous waste regulations, Ecology intends that all response or corrective actions, excluding situations where there is an imminent threat to the public health or environment, will be conducted in a manner that ensures compliance with the technical requirements of the State of Washington's *Hazardous Waste Management Act (RCW 70.105)*.

2.5.5 Lead Regulatory Agency Concept

The EPA and Ecology selected a lead regulatory agency approach to minimize duplication of effort and to maximize productivity. Either the EPA or Ecology will be the lead regulatory agency for each operable unit, TSD group/unit, or milestone.

The designated lead regulatory agency for a specific operable unit, TSD group/unit, or milestone is responsible for overseeing the activities covered by the Tri-Party Agreement action plan that relate to the successful completion of the milestone or activities at the operable unit or TSD group/unit, ensuring that all applicable requirements are met. However, the EPA and Ecology retain their respective legal authorities. The lead regulatory agency must advise and obtain any necessary approvals from the agency with regulatory authority in accordance with the Ecology/EPA August 27, 1996 memorandum of understanding. Regulatory oversight activities, including preparation of responses to documents

submitted by DOE, will be performed by the lead regulatory agency for each operable unit. The assignment of the lead regulatory agency for all units/groups and milestones is based on criteria defined in the Tri-Party Agreement. Currently assigned lead regulatory agency designations for groundwater operable units are listed in Table 2.2.

Table 2.1. Hanford Site Groundwater-Management Requirements

Hanford Site Groundwater Program	Tri-Party Agreement Milestones[a]	Regulatory Requirements
	Resource Conservation and Recovery Act of 1976	
RCRA/TSD Unit Monitoring	M-20-00 M-24-00	40 CFR 264 40 CFR 265 40 CFR 257 WAC 173-303-400, -600
	Comprehensive Environmental Response, Compensation, and Liability Act of 1980	
CERCLA Operable Unit Remedial Assessment Monitoring	M-15-00 M-16-00	40 CFR 300
	Atomic Energy Act of 1954	
Sitewide Surveillance and Operational Monitoring		DOE Orders 5400.1, 5400.5, and 5820.2
	Liquid Effluent Disposal Facilities	
Facility-Specific Monitoring (ETF, TEDF)	M-17-00b	WAC 173-216

(a) TPA M-20-00--Submit Part B permit applications or closure/postclosure plans for all RCRA TSD units.

TPA M-24-00--Install RCRA groundwater-monitoring wells at the rate of up to 50/yr (after 1990) as scheduled in interim milestones until all land disposal units and single-shell tanks are determined to have RCRA-compliant monitoring systems.

TPA M-15-00--Complete remedial investigation/feasibility study (or RCRA facility investigation/corrective measures study process for all operable units.

TPA M-16-00--Complete remedial actions for all non-tank farm operable units.

TPA M-17-00B--Complete implementation of best available technology/all known available and reasonable methods of prevention, control, and treatment for all Phase II liquid effluent streams at the Hanford Site.

ETF = 200 Areas Effluent Treatment Facility.
TEDF = 200 Areas Treated Effluent Disposal Facility.

Table 2.2. Hanford Site Groundwater Operable Unit Monitoring Status

Tri-Party Agreement Priority[a]	Groundwater Operable Unit	Monitoring Status	Regulatory Unit Designation	Regulatory Lead Agency
2A	300-FF-5	Contaminant monitoring	CERCLA past practices	EPA
4A	100-HR-3	Assessment monitoring for pump-and-treat containment project in 1997	RCRA past practices	Ecology
6A	100-BC-5	Contaminant monitoring	CERCLA past practices	EPA
7A	100-KR-4	Contaminant monitoring	CERCLA past practices	EPA
9	100-NR-2	Assessment monitoring for pump-and-treat containment project	RCRA past practices	Ecology
10A	100-FR-3	Contaminant monitoring	CERCLA past practices	EPA
13	200-BP-5	Assessment monitoring for pump-and-treat containment project	CERCLA past practices	EPA
20A	200-UP-1	Assessment monitoring for pump-and-treat containment project	RCRA past practices	Ecology
20A	200-ZP-1	Assessment monitoring for pump-and-treat containment project	CERCLA past practices	EPA
20B	200-PO-1	Contaminant monitoring	RCRA past practices	Ecology

(a) Listed from highest to lowest.
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
Ecology = State of Washington Department of Ecology.
EPA = U.S. Environmental Protection Agency.
RCRA = Resource Conservation and Recovery Act of 1976.

Table 2.3. Hanford Site Interim and Final Status Groundwater-Monitoring Projects (as of September 1996)

TSD Units, Date Initiated	Interim Status TSD Unit Groundwater Monitoring		Final Status TSD Unit Groundwater Monitoring		Regulatory Requirements	Associated (CERCLA) Groundwater Operable Units	Year Scheduled for Part B or Closure
	Indicator Parameter Evaluation[a]	Groundwater Quality Assessment, date initiated	Detection Evaluation	Compliance Evaluation			
120-D-1 Ponds, April 1992	X				40 CFR 265.93(b) WAC 173-303-400	100-HR-3	1998[c]
183-H Solar Evaporation Basins, June 1985				X	WAC 173-303-645 (10)	100-HR-3	1995[c]
1301-N LWDF, December 1987	X				40 CFR 265.93(b) WAC 173-303-400	100-NR-2	1999[c]
1324-N/NA Pond, December 1987	X				40 CFR 265.93(b) WAC 173-303-400	100-NR-2	1998[c]
1325-N LWDF, December 1987	X				40 CFR 265.93(b) WAC 173-303-400	100-NR-2	1999[c]
216-B-3 Pond, November 1988		X, 1990			40 CFR 265.93(d) WAC 173-303-400	200-PO-1	2000[c]
216-A-29 Ditch, November 1988	X				40 CFR 265.93(b) WAC 173-303-400	200-PO-1	2000[c]
216-A-10 Crib,[d] November 1988	X				40 CFR 265.93(b) WAC 173-303-400	200-PO-1	>2000[c]
216-A-36B Crib,[d] May 1988	X				40 CFR 265.93(b) WAC 173-303-400	200-PO-1	>2000[c]
216-A-37-1 Crib,[d] 1997		X, 1997			40 CFR 265.93(d) WAC 173-303-400	200-PO-1	1998[c]
216-B-63 Trench, August 1991	X				40 CFR 265.93(b) WAC 173-303-400	200-PO-1	>2000[c]
216-S-10 Pond, August 1991	X				40 CFR 265.93(b) WAC 173-303-400		>2000[c]
216-U-12 Crib, September 1991		X, 1993			40 CFR 265.93(d) WAC 173-303-400	200-UP-1	1998[c]

Table 2.3. (contd)

TSD Units, Date Initiated	Interim Status TSD Unit Groundwater Monitoring: Indicator Parameter Evaluation[a]	Interim Status TSD Unit Groundwater Monitoring: Groundwater Quality Assessment, date initiated	Final Status TSD Unit Groundwater Monitoring: Detection Evaluation	Final Status TSD Unit Groundwater Monitoring: Compliance Evaluation	Regulatory Requirements	Associated (CERCLA) Groundwater Operable Units	Year Scheduled for Part B or Closure
LERF, July 1991	X				40 CFR 265.93(b) WAC 173-303-400		>2000[b]
LLBG WMA-1, September 1988	X				40 CFR 265.93(b) WAC 173-303-400		>2000[b]
LLBG WMA-2, September 1988	X				40 CFR 265.93(b) WAC 173-303-400		>2000[b]
LLBG WMA-3, October 1988	X				40 CFR 265.93(b) WAC 173-303-400		>2000[b]
LLBG WMA-4, October 1988	X				40 CFR 265.93(b) WAC 173-303-400	200-ZP-1	>2000[b]
LLBG WMA-5, March 1992	Discontinued in 1995				40 CFR 265.93(b) WAC 173-303-400		>2000[b]
WMA-A-AX SST February 1990	X				40 CFR 265.93(b) WAC 173-303-400		>2000[c]
WMA-B-BX-BY SST February 1990		X, 1996			40 CFR 265.93(d) WAC 173-303-400		1998[c]
WMA-C SST February 1990	X				40 CFR 265.93(b) WAC 173-303-400	200-PO-1	>2000[c]
WMA-S-SX SST October 1991		X, 1995			40 CFR 265.93(d) WAC 173-303-400	200-UP-1	1998[c]
WMA-T SST February 1990		X, 1993			40 CFR 265.93(d) WAC 173-303-400	200-ZP-1	1998[c]
WMA-TX-TY SST September - October 1991		X, 1993			40 CFR 265.93(d) WAC 173-303-400	200-ZP-1	1998[c]
WMA-U SST October 1990	X				40 CFR 265.93(b) WAC 173-303-400	200-ZP-1	1998[c]

Table 2.3. (contd)

TSD Units, Date Initiated	Interim Status TSD Unit Groundwater Monitoring: Indicator Parameter Evaluation[a]	Interim Status TSD Unit Groundwater Monitoring: Groundwater Quality Assessment, date initiated	Final Status TSD Unit Groundwater Monitoring: Detection Evaluation	Final Status TSD Unit Groundwater Monitoring: Compliance Evaluation	Regulatory Requirements	Associated (CERCLA) Groundwater Operable Units	Year Scheduled for Part B or Closure
316-5 Area Process Trenches,[c] June 1985		X		X (1996 to final status)	WAC 173-303-645 (10)	300-FF-5	1996[c]
NRDWL, October 1986	X				40 CFR 265.93(b) WAC 173-303-400	200-PO-1	1998[c]

(a) Specific parameters (pH, specific conductance, total organic carbon, and total organic halogen) used to determine if a facility is affecting groundwater quality. Exceeding the established limits means that additional evaluation and sampling are required (groundwater quality assessment). An X in the column indicates whether an evaluation was needed or an assessment was required.

(b) Part B permit; TSD unit will operate under final status regulations beginning in year indicated.

(c) Closure/postclosure plan; TSD unit will close under final status.

(d) 216-A-10, 216-A-36B, and 216-A-37-1 cribs will be combined in fiscal year 1997 into one RCRA monitoring unit. RCRA monitoring will be performed according to interim status groundwater quality assessment requirements.

(e) At the end of calendar year 1996, these will move from an interim status assessment monitoring evaluation (required by regulatory consent agreement and compliance order [Ecology and EPA 1986]) to a final status compliance monitoring evaluation.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act of 1980.
LERF = Liquid effluent retention facility.
LLBG = Low-level burial ground.
LWDF = Liquid waste-disposal facility.
NRDWL = Nonradioactive dangerous waste landfill.
RCRA = Resource Conservation and Recovery Act of 1976.
SST = Single-shell tanks.
TSD = Treatment, storage, or disposal.
WMA = Waste management area.
> = Beyond the year 2000.

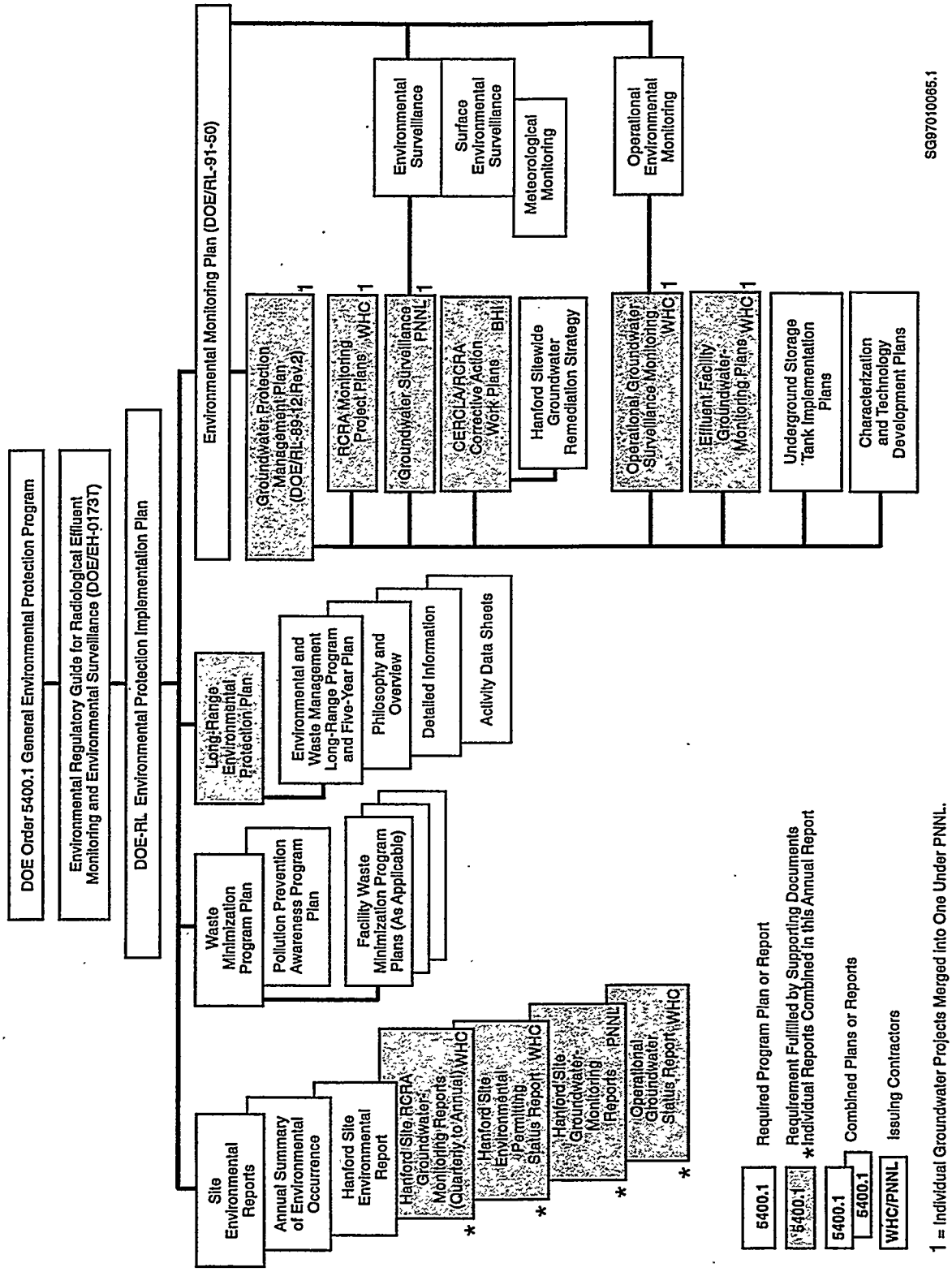


Figure 2.1. Relationship Between Hanford Site Groundwater Protection Management Plan and Other Environmental Protection Programs and Plans

3.0 Hydrogeologic Setting

This chapter provides an overview of the geology and groundwater hydrology of the Hanford Site. Understanding the groundwater-flow system is important in assessing the potential for contaminants to migrate from the site through the groundwater pathway Hydrogeologic information is used in the determination of the designs and locations of the monitoring wells. The information also provides the basis for numerical modeling of groundwater-flow and contaminant plume migration.

3.1 Geologic Setting

S. P. Reidel

The Hanford Site lies in the Columbia Plateau, a broad plain situated between the Cascade Range to the west and the Rocky Mountains to the east. The Columbia Plateau was formed by a thick sequence of Miocene Age tholeiitic basalt flows, called the Columbia River Basalt Group, which erupted from volcanic fissures in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson et al. 1979). The Columbia Plateau is often called the Columbia Basin because it forms a broad lowland surrounded by mountains. In the central and western sections of the Columbia Plateau, where the Hanford Site is located, the Columbia River Basalt Group is underlain by continental sedimentary rocks from earlier in the Tertiary Period.

The basalt and sedimentary rocks have been folded and faulted over the past 17 million years, creating broad structural and topographic basins separated by asymmetric anticlinal ridges. Sediments up to 518 m in thickness accumulated in some of these basins. Basalt flows are exposed along the anticlinal ridges, where they have been uplifted as much as 1,097 m above the surrounding area. Overlying the basalts in the synclinal basins are sediments of the late Miocene, Pliocene, and Pleistocene. The Hanford Site lies within one of the larger basins, called the Pasco Basin, that is bounded on the north by the Saddle Mountains and on the south by Rattlesnake Mountain and the Rattlesnake Hills. Yakima Ridge and Umtanum Ridge trend into the basin and subdivide it into a series of anticlinal ridges and synclinal basins. The largest syncline, the Cold Creek syncline, lies between Umtanum Ridge and Yakima Ridge and is the principal structural basin containing the U.S. Department of Energy's (DOE's) waste management areas. Figure 3.1 shows the surface geology and major structural features of the Pasco Basin. The geology of the Hanford Site is described in detail in DOE (1988).

Figure 3.2 shows the stratigraphic units underlying the Hanford Site. These include, in ascending order, the Columbia River Basalt Group, Ringold Formation, Plio-Pleistocene unit, early Palouse soil, and Hanford formation. A regionally discontinuous veneer of Holocene alluvium, colluvium, and/or eolian sediments overlies the principal geologic units. The various stratigraphic units found within the Hanford Site boundaries are described below.

3.1.1 Columbia River Basalt Group

There are approximately 50 basalt flows beneath the Hanford Site with a combined thickness of more than 3,000 m (DOE 1988). The most recent, laterally extensive basalt flow underlying the Hanford Site is the Elephant Mountain Member of the Saddle Mountains Basalt. However, the younger Ice Harbor Member is found in the southern part of the site (DOE 1988). Sandwiched between various basalt flows are sedimentary interbeds, collectively called the Ellensburg Formation, which includes fluvial and lacustrine sediments consisting of mud, sand, and gravel deposited between volcanic eruptions. Along with the porous basalt flow tops and bottoms, these sediments form basalt-confined aquifers that extend across the Pasco Basin.

3.1.2 Ringold Formation

The Pliocene-aged Ringold Formation sediments overlie the basalts and are overlain by late Pliocene- and Pleistocene-aged deposits. Ringold Formation sediments consist of a heterogeneous mix of variably cemented and compacted gravel, sand, silt, and clay deposited by the ancestral Columbia and Snake Rivers between 8 and 3 million years ago (Fecht et al. 1987; Lindsey 1991; Reidel et al. 1994). The depositional system was a braided stream channel with the two rivers joining in the area of the present White Bluffs. The deposits at the Hanford Site represent an eastward shift of the Columbia River from the west side of the Hanford Site to the east side. The Columbia River first flowed across the west side of the Hanford Site and up Dry Creek, crossing over the Rattlesnake Hills. The river eventually shifted to a course that took it through the gap between Gable Mountain and Gable Butte and south across the present 200-East Area.

Traditionally, the Ringold Formation in the Pasco Basin is divided into several informal units. In ascending order, these units are the 1) gravel, sand, and paleosols of the basal unit; 2) clay and silt of the lower unit; 3) sand and gravel of the middle unit; 4) mud and lesser sand of the upper unit; and 5) basaltic detritus of the fanglomerate unit (Newcomb 1958; Newcomb et al. 1972; Myers/Price et al. 1979; Tallman et al. 1979; Bjornstad 1984; DOE 1988). Ringold strata also have been divided on the basis of facies types (Tallman et al. 1981) and fining upward sequences (PSPL 1982). More recently, Lindsey et al. (1992) described Ringold sediment facies on the basis of lithology, stratification, and pedogenic alteration. The facies types identified include the following:

- fluvial gravel facies - These consist of matrix-supported granule to cobble gravels with a sandy silt matrix and intercalated sands and muds. The facies were deposited in a gravelly fluvial braidplain characterized by wide, shallow, shifting channels.

- fluvial sand facies - These consist of cross-bedded and cross-laminated sands that are intercalated with lenticular silty sands, clays, and thin gravels. Fining upward sequences are common. Strata comprising the association were deposited in wide, shallow channels.

- overbank facies - These consist of laminated to massive silt, silty fine-grained sand, and paleosols containing variable amounts of pedogenic calcium carbonate. Overbank deposits

occur as thin lenticular interbeds in the gravels and sands and as thick, laterally continuous sequences. These sediments record deposition in proximal levee to more distal floodplain conditions.

- lacustrine facies - These are characterized by plane laminated to massive clay with thin silt and silty sand interbeds displaying some soft-sediment deformation. Deposits coarsen downward. Strata were deposited in a lake under standing water to deltaic conditions.

- alluvial fan facies - These are is characterized by massive to crudely stratified, weathered to unweathered basaltic detritus. These deposits generally are found around the periphery of the basin and record deposition by debris flows in alluvial fan settings and in sidestreams draining into the Pasco Basin.

As described by Lindsey (1991, 1995) and illustrated in Figure 3.2, the upper part of the Ringold Formation is composed of interbedded fluvial sand and overbank facies, which are overlain by mud-dominated lacustrine facies. The lower part of the Ringold Formation contains five separate stratigraphic intervals dominated by the fluvial gravel facies. These gravels, designated units A, B, C, D, and E, are separated by intervals containing deposits typical of the overbank and lacustrine facies. The lowermost of the fine-grained sequence units, overlying unit A, is designated the lower mud sequence.

To support development of a layered three-dimensional groundwater-flow and transport model (see Chapter 7.0), the lithofacies defined by Lindsey (1991) were regrouped into 9 hydrogeologic units (Thorne et al. 1993, 1994; Wurstner et al. 1995). Facies were grouped based on similarity in expected groundwater-flow properties, which correlate to texture (grain size and sorting) and degree of cementation. Other geologic factors such as depositional environment, lithologic composition, and time of deposition were not considered in the definition of the model units. The grouping is similar but not identical to that of Lindsey (1991). A comparison of these units with Lindsey's stratigraphic column is shown in Figure 3.2. One difference is the grouping of the lower, predominantly sand, portion of Lindsey's upper Ringold with Unit 5, which includes Lindsey's Hanford gravel units E and C. The predominantly mud facies of Lindsey's upper Ringold was designated as Unit 4. Sandy portions of Lindsey's lower mud unit were assigned to Unit 7, which also includes Lindsey's gravel Units B and D. The remainder of Lindsey's lower mud unit was designated as Unit 6. The gravels of Lindsey's Unit A were designated as Unit 9. Units 2 and 3 correspond to the early Palouse soil and Plio-Pleistocene unit, respectively, which are described below. The Hanford formation combined with the pre-Missoula gravel deposits were designated as Unit 1. These deposits are also described below.

3.1.3 Plio-Pleistocene Unit and Early Palouse Soil

The laterally discontinuous Plio-Pleistocene unit unconformably overlies the Ringold Formation and is found only in the western part of the Hanford Site (DOE 1988). This unit consists of sidestream alluvial deposits and buried soil horizons with significant caliche in some areas and is generally above the current water table.

The Pleistocene-aged early Palouse soil is a buried eolian unit that overlies part of the Plio-Pleistocene unit. The early Palouse soil consists of up to 20 m of massive, brown-yellow, and compact, loess-like silt and minor fine-grained sand (Tallman et al. 1979; DOE 1988). The early Palouse soil is found only in the vicinity of the 200-West Area. The early Palouse soil and the fine-grained and caliche portions of the Plio-Pleistocene unit, both of which are found in the 200-West Area, form a low-permeability layer that may significantly affect migration of water through the vadose zone.

3.1.4 Hanford Formation and Pre-Missoula Gravels

The informally named Hanford formation consists of deposits from a series of Pleistocene cataclysmic floods. The floods occurred when ice dams gave way, releasing water from Lake Missoula, a large glacial lake that formed in the Clark Fork River valley. Flood episodes may have occurred as many as 40 times, with the released water spreading across eastern Washington. The floodwaters collected in the Pasco Basin and formed Lake Lewis, which slowly drained through the gap in the Horse Heaven Hills called Wallula Gap (Allison 1933). Three principal types of deposits were left behind by the floods: 1) high-energy deposits consisting of gravel; 2) low-energy, slackwater deposits consisting of rhythmically bedded silt and sand of the Touchet Beds; and 3) coarse to fine sand deposits representing an energy transition environment. The fluvial pre-Missoula gravels underlie the Hanford formation gravel deposits in the central part of the Hanford Site. The pre-Missoula deposits are difficult to distinguish from the Hanford gravels, so they are usually grouped together.

The Hanford formation is divided into a variety of sediment types, facies, or lithologic packages. Recent reports dealing with the Hanford formation (Lindsey 1991; Reidel et al. 1992) recognized three basic facies: gravel, sand, and silt dominated. These facies generally correspond to the coarse gravels, laminated sands, and graded rhythmites, respectively (DOE 1988; Baker et al. 1991; Delaney et al. 1991). The Hanford formation ranges in thickness from less than a meter to more than 100 m.

Gravel-dominated strata consist of coarse-grained sand and granule-to-boulder gravel that display massive bedding, plane to low-angle bedding, and large-scale cross-bedding in outcrop. Matrix commonly is lacking from the gravels, giving them an open-framework appearance. The sand-dominated facies consist of fine- to coarse-grained sand and granules that display plane lamination and bedding and, less commonly, plane and trough cross-bedding in outcrop. Small pebbles and pebbly interbeds (<20 cm thick) may be encountered. The silt content of these sands varies, though where its content is low, an open-framework texture may occur. The silt-dominated facies consist of silt and fine- to coarse-grained sand forming normally graded rhythmites. Plane lamination and ripple cross-lamination are common in outcrop.

The water table lies within the Hanford formation over most of the eastern and northern parts of the Hanford Site. The Hanford formation lies entirely above the water table in the western part of the site and in some other localized areas. Figure 3.3 shows a cross section of the Hanford Site and the location of the water table in 1996. Figure 3.4 is a map view of the hydrogeologic units that contained the water table during 1996.

3.1.5 Holocene Surficial Deposits

Holocene surficial deposits consisting of silt, sand, and gravel form a thin (<5-m) veneer across much of the Hanford Site. In the 200-West Area and southern part of the 200-East Area, these deposits consist dominantly of laterally discontinuous sheets of wind-blown silt and fine-grained sand. They are generally found above the water table.

3.2 Hanford Site Hydrology

P. D. Thorne

This section provides general information on the Hanford Site groundwater-flow system. Additional details concerning hydrogeologic conditions at each of the *Resource Conservation and Recovery Act of 1976* (RCRA) sites is provided in the following sections.

Groundwater is present in both unconfined and confined aquifers at the Hanford Site. The unconfined aquifer is generally located in the unconsolidated to semiconsolidated Ringold and Hanford formations that overlie the basalt bedrock. In some areas, low-permeability mud layers form aquitards that create local confined hydraulic conditions in the underlying sediments. However, these aquitards are not continuous across the Hanford Site, and the entire suprabasalt aquifer is connected on a sitewide scale. Consequently, the entire suprabasalt aquifer is referred to as the unconfined aquifer system in this report. A sequence of basalt-confined aquifers is present within the Columbia River Basalt Group beneath the Hanford Site. These aquifers are composed of sedimentary interbeds and the relatively permeable tops of basalt flows. The dense interior sections of the basalt flows form confining layers. The following discussion focuses on the Hanford Site unconfined aquifer system because, as the uppermost aquifer system, it is the most likely to be affected by contaminants released from Hanford Site sources. Monitoring data confirm that almost all of the groundwater contamination is found within the upper part of the unconfined aquifer system. Additional information on the upper basalt-confined aquifer system is available in DOE (1988), Spane and Vermeul (1994), and Spane and Webber (1995).

The saturated thickness of the unconfined aquifer system is greater than 180 m in some areas but pinches out along the flanks of the basalt ridges. Depth to the water table ranges from <0.3 m near the Columbia River to >106 m near the 200 Areas. Perched water-table conditions have been encountered in sediments above the unconfined aquifer system in the 200-West Area (Airhart 1990; Last and Rohay 1993) and in irrigated offsite areas east of the Columbia River (Brown 1979).

Groundwater in the unconfined aquifer system generally flows from recharge areas in elevated regions near the western boundary of the Hanford Site toward the Columbia River (discussed more fully in Chapter 5.0), which is a discharge zone for the unconfined aquifer on both sides of the river. The Yakima River lies southwest of the Hanford Site and is generally regarded as a source of recharge to the unconfined aquifer system in the southern part of the site and in the Richland area. Groundwater in the basalt-confined aquifers also generally flows from elevated regions at the edge of the Pasco Basin toward the Columbia River (Spane and Webber 1995). However, the discharge zone locations are also influenced by geologic structures that increase the vertical permeability of the confining basalt layers.

3.2.1 Unconfined Aquifer System Recharge and Discharge

Natural recharge to the unconfined aquifer system occurs from infiltration of runoff from elevated regions along the western boundary of the Hanford Site, infiltration of springwater and upwelling of groundwater that originates from the basalt-confined aquifer system, and infiltration of precipitation falling across the Hanford Site. Some recharge also takes place along the Yakima River. Recharge from precipitation is highly variable, both spatially and temporally, ranging from near zero to >100 mm/yr, depending on climate, vegetation, and soil texture (Gee et al. 1992; Fayer and Walters 1995). Recharge from precipitation is highest in coarse-textured soils with little or no vegetation, which is the case for most of the industrial areas on the site. A natural recharge map developed by Fayer and Walters (1995) based on distributions of soil and vegetation types is shown in Figure 3.5.

Since the start of Hanford Site operations in the mid-1940s, artificial recharge from wastewater-disposal facilities has been several times greater than the estimated recharge from natural sources. This caused an increase in the water-table elevation over most of the Hanford Site and the formation of groundwater mounds beneath major wastewater-disposal facilities. However, during the past 5 years, all production activities on the Hanford Site have been curtailed, resulting in a decrease in wastewater disposal and decreases in water-table elevation over much of the site. Additional information on changes in artificial recharge and the resulting water-level changes is presented in Chapter 5.0.

3.2.2 Unconfined Aquifer System Hydraulic Properties

Hydraulic property data for the unconfined aquifer system are derived mainly from well-pumping and slug tests and, in a few cases, laboratory permeameter tests of sediment samples. These results were documented in dozens of published and unpublished reports over the past 50 years. A summary of available data for the unconfined aquifer system was provided in DOE (1988), and an updated summary was provided in Thorne and Newcomer (1992) together with an evaluation of selected pumping test analyses. Additional tests were conducted to support several specific Hanford Site projects. Examples are presented in Swanson (1992), Thorne and Chamness (1992), Williams and Barnett (1993), Swanson (1994), Thorne et al. (1993, 1994), Lindberg (1995), Newcomer et al. (1995), Vermeul et al. (1995), and Peterson et al. (1996).

The distribution of unconfined aquifer transmissivity, which is the product of the vertically averaged horizontal hydraulic conductivity and the aquifer thickness, is shown in Figure 3.6. This distribution was determined from the results of well-pumping tests combined with a flow-model calibration procedure (Wurstner et al. 1995). The model calibration is discussed in more detail in Chapter 7.0. Thickness of the unconfined aquifer system, which includes all the saturated sediments above basalt, is shown in Figure 3.7. Where they are found below the water table, the Hanford formation gravels make up the most-permeable zones of the unconfined aquifer system. The hydraulic conductivity of these sediments is generally 10 to 100 times greater than the hydraulic conductivity of Ringold Formation gravels. In some areas of the Hanford Site including the 200-West Area, the water table is below the bottom of the Hanford formation (see Figures 3.3 and 3.4). The aquifer transmissivity in these areas is generally much lower than the transmissivity in areas where Hanford formation sediments are saturated, which is the case in most of the 200-East Area.

Aquifer specific yield, which is a measure of the volume of water released from aquifer storage in response to a change in the water-table elevation, is more difficult to measure than hydraulic conductivity and generally requires relatively long-duration aquifer-pumping tests with observation wells (Spane 1993) or slug tests with observation wells (Spane and Thorne 1995; Spane 1996). Even for these tests, the calculated specific yield is subject to errors that result from nonideal test conditions such as aquifer heterogeneity, anisotropy, and partially penetrating wells (Spane 1993). Specific yield values calculated from several multiple well tests are listed in Wurstner et al. (1995). These results range from 0.02 to 0.38 and have a mean of 0.15. For an unconfined aquifer, specific yield is approximately equal to effective porosity, which is important in calculating contaminant travel times.

3.3 Hydrogeology of the 100 Areas

M. J. Hartman and P. D. Thorne

The 100 Areas include 6 separate areas where retired plutonium-production reactors and associated support facilities are located. The hydrogeology of these areas is somewhat unique because of their location along the Columbia River in the northern part of the Hanford Site (see Figure 1.1). The uppermost unconfined aquifer in the 100-B, C, 100-K, 100-N, and 100-D Areas is composed of either the Unit E Ringold gravels or Unit E combined with the Hanford gravels, depending on the location of the water table (Peterson et al. 1996). In the 100-H and 100-F Areas, the Ringold Unit E gravel is missing and the Hanford formation lies directly on the upper Ringold mud (Unit C). In most of the 100 Areas, Unit C forms a local aquitard, and the Ringold gravels below this mud are locally confined. Additional information on the hydrogeology of the 100 Areas is presented in Hartman and Peterson (1992), Lindberg (1995), and Peterson et al. (1996).

The water table in the 100 Areas is shallower than in the more-elevated central regions of the Hanford Site. The depth to groundwater ranges from <1 m adjacent to the river to ~ 30 m. Groundwater flow is generally toward the river in these areas. However, in the northeastern part of the 100-D Area and the southern part of the 100-F Area, groundwater flow appears to parallel the river. This may reflect the influence of buried river-channel deposits. Groundwater mounds resulting from previous disposal of wastewater also influenced groundwater flow in some areas in the past. Additional details on the direction of groundwater flow in the 100 Areas and the influence of wastewater-disposal operations is provided in Chapter 5.0.

Changes in Columbia River stage influence water levels measured in 100 Area wells and also cause reversals in the direction of groundwater flow immediately adjacent to the river. When the river stage is higher than the water table in the adjacent aquifer, water moves into the banks of the river, resulting in bank storage. When the river stage drops, this water moves back toward the river, often appearing as riverbank seepage. The distance that water moves into the aquifer from the river depends on the difference in river stage and groundwater elevation, the hydraulic properties of the aquifer, and the duration of the elevated river stage. The reversal of flow adjacent to the river also causes a pressure pulse in the aquifer that affects water levels in wells up to several hundred meters inland. Additional details on the effects of river-stage elevation on water levels in the 100 Areas are provided in Chapter 5.0. The effects of bank storage on contaminant transport in the 100 Areas are discussed in

Chapter 6.0. The following subsections give the hydrogeology of the three liquid- and sludge-disposal sites subject to *Resource Conservation and Recovery Act of 1976* (RCRA) monitoring.

3.3.1 1301-N, 1324-N, 1324-NA, and 1325-N Facilities

The uppermost aquifer beneath the 100-N Area is contained in the sands and gravels Ringold Unit E. The base of the aquifer is believed to be a clay-rich unit ~12 m beneath the water table. Hartman and Lindsey (1993) describe the hydrogeology of the 100-N Area.

3.3.2 120-D-1 Ponds

The uppermost aquifer beneath these ponds is a sand and gravel unit in the Ringold Formation, ~3 to 9 m thick. This unit corresponds to Ringold Unit E. The base of the aquifer is a fine-grained overbank interval, which is ~15 m thick elsewhere in the 100-D Area (DOE 1993b).

3.3.3 183-H Solar Evaporation Basins

The uppermost portion of the unconfined aquifer system in the 100-H Area resides in unconsolidated sands and gravels of the Hanford formation. The saturated portion of these deposits ranges in thickness from 2 to 6 m (Peterson and Connelly 1992). This hydrogeologic unit is underlain by the more-consolidated fluvial sands and overbank deposits of the Ringold Formation. The lower hydraulic conductivity of the Ringold Formation sediments restricts downward migration of contaminants. A comprehensive description of 100-H Area stratigraphy is presented by Lindsey (1992) and Lindsey and Jaeger (1993).

3.4 Hydrogeology of the 200 Areas

D. B. Barnett, R. B. Mercer, J. W. Lindberg, B. A. Williams, and P. D. Thorne

The 200-East and 200-West Areas, jointly referred to as the separations areas, are located on the central plateau of the Hanford Site (see Figure 1.1). The geology and hydrology of these areas have been extensively studied because they contain major sources of groundwater contamination; Graham et al. (1981) studied this hydrology. The hydrogeology of these Areas were described by Connelly et al. (1992a, 1992b, respectively). These documents provide references to many other studies conducted to support specific projects. Groundwater-flow directions within the 200 Areas are discussed in Chapter 5.0.

The depth of the water table in the 200-West Area varies from ~50 to >100 m. The thickness of the saturated portion of Ringold Unit E, the uppermost saturated unit, gravels varies from ~65 to >150 m. The Ringold lower mud forms a local confining unit below the Unit E gravels (see Figure 3.3). However, this mud unit is missing in an area immediately north of the 200-West Area

(Connelly et al. 1992b). As the water table declines, it will probably fall below the top of the lower mud unit in the area east of the 200-West Area, which will affect groundwater-flow patterns and the migration of contaminants from this area.

The 200-East Area is located on the southern flank of the Gable Mountain anticlinal structure. The depth of the water table varies from ~65 to 100 m. Thickness of the unconfined aquifer system in the 200-East Area varies from <10 m in the north to ~80 m in the south.

Groundwater flow in the 200-East and 200-West Areas is strongly influenced by the presence or lack of Hanford formation sediments below the water table. In the 200-West Area, the water table lies in Ringold Unit E gravels and is below the bottom of the Hanford formation (see Figure 3.3). In most of the 200-East Area, the water table lies within the Hanford formation. Therefore, the aquifer transmissivity is generally much higher in the 200-East Area than it is in the 200-West Area. However, groundwater flow in the 200-East Area is complicated by areas where Ringold Unit E gravels, Ringold lower mud unit, and deeper Ringold Unit A gravels rise above the water table, forming lower permeability islands in the saturated Hanford formation sediments. The declining water table in the 200-East Area resulted in its dropping below the bottom of the Hanford formation in some areas during the last few years, which decreased the aquifer transmissivity in this area and altered groundwater-flow patterns (Connelly et al. 1992a).

An area of increased intercommunication between the unconfined aquifer system and the upper basalt-confined aquifer was identified in the area north of the 200-East Area based on chemical and hydraulic head evidence (Graham et al. 1984; Jensen 1987). The increased communication is likely caused by local erosion of the upper basalt-confining layer in this area (Graham et al. 1984). The following subsections give the hydrogeology of the disposal sites subject to RCRA monitoring.

3.4.1 216-S-10 Pond and Ditch

The stratigraphy beneath these facilities includes the following (from upper to lower):

- 52 m of Hanford formation silt and sand
- 1.8 m of Plio-Pleistocene unit composed of silty sandy gravel capped with a 0.3-m layer of caliche
- 14 m of upper Ringold Formation unit sand
- 61 m of Ringold Formation Unit E composed of sandy gravel
- ~15 m of the lower mud unit of the Ringold Formation.

The top of the lower mud is the base of the uppermost aquifer system under this facility. Most of the aquifer system is within Ringold Formation Unit E gravel. However, the water table is in the upper Ringold unit, ~2 m above Ringold Unit E. The depth to the water table varies from 55 to 67 m (DOE 1992a).

3.4.2 216-U-12 Crib

The unsaturated sediments beneath this crib are ~73 m thick and are composed of unconsolidated sandy gravel and sand of the Hanford formation and sandy silt and gravelly sand of the Plio-Pleistocene unit. The unconfined aquifer system lies below and is within the silty, sandy gravels of the middle Ringold unit E gravel. The top of the Ringold lower mud unit is the base of the unconfined aquifer at this crib.

3.4.3 S-SX, T, TX-TY, and U Single-Shell Tank Farms

In general, groundwater monitoring wells in all waste management areas in the 200-West Area are screened mostly in the Ringold Formation Unit E gravels, which contains the water table in these areas. A description of the stratigraphy beneath these tank farms may be found in Ford and Trent (1994), which also contains numerous cross sections through the 200-West Area. Details of stratigraphy beneath these tank farms may be found in Jensen et al. (1989) and Caggiano and Goodwin (1991).

3.4.4 Low-Level Burial Grounds

The 200-West Area burial grounds (Waste Management Areas-1 and 2) are underlain by the Ringold Formation and Hanford formation. The uppermost aquifer is entirely within the Ringold Formation. There are indications that the aquifer is locally semiconfined beneath the northern portions of these burial grounds.

3.4.5 216-A-10 and 216-A-36B Cribs

The uppermost aquifer beneath these cribs is contained mainly in the sandy facies of Ringold Unit E. The water table is located ~97 m beneath ground surface and is near the Hanford/Ringold Formation contact. The aquifer is ~40 m thick (Connelly et al. 1992a).

3.4.6 216-A-29 Ditch

The uppermost aquifer beneath this ditch is contained mainly in the gravelly sediments of Ringold Unit A. The water table is near the Hanford/Ringold Formation contact, ~76 m beneath ground surface (Connelly et al. 1992a).

3.4.7 216-B-3 Pond

The uppermost aquifer beneath this pond system occurs within sediments of the Hanford and Ringold Formations. The vadose zone under most of the facility is composed of Hanford formation

sediments. Ringold Formation sediments here consist of Unit A gravel and the lower mud sequence, which is discontinuous in this area. The Hanford formation consists of silty sand to sand and gravel. The water table is generally near the contact between the Hanford and Ringold Formations, and the aquifer is locally confined in places.

3.4.8 216-B-63 Trench

This trench is underlain by sands and gravels of the Hanford formation, which lie directly over the basalt. The aquifer is 1 to 7 m thick, and the water table varies from 70 to 77 m below ground surface.

3.4.9 A-AX, B-BX-BY, and C Single-Shell Tank Farms

In general, groundwater-monitoring wells for these single-shell tank farms are screened in the Hanford formation. A detailed description of the stratigraphy beneath these tank farms may be found in Ford and Trent (1994), which also contains numerous cross sections through the 200-East Area. Stratigraphic details beneath these single-shell tank farms may be found in Jensen et al. (1989) and Caggiano and Goodwin (1991).

3.4.10 Low-Level Burial Grounds

The uppermost aquifer beneath the 200-East Area low-level burial grounds (Waste Management Areas-3, -4, and -5) is contained in the sands and gravels of the Hanford formation, which directly overlies basalt.

3.5 Hydrogeology of the 400 and 600 Areas

P. D. Thorne

The 400 Area is located in the south-central portion of the Hanford Site (see Figure 1.1) and is the location of the Fast Flux Test Facility and its associated facilities. The 600 Area includes all of the Hanford Site that is not within other designated operational areas. The Nonradioactive Dangerous Waste Landfill (NRDWL) and the Solid Waste Landfill (SWL), is located in the central part of the Hanford Site (also known as the Central Landfill on Figures 1.2 and 1.3), southeast of the 200-East Area. The hydrogeology of the 400 Area and the area around the SWL and NRDWL are summarized in this section. Additional details concerning the geology and the construction of wells near these facilities are provided in Weekes et al. (1987), Fruland and Lundgren (1989), and Tyler (1992).

The NRDWL and SWL are underlain by ~180 m of Hanford and Ringold Formation sediments. The Hanford formation beneath these landfills consists of sands and gravels, with sands dominating near the surface and gravels dominating the deeper portions of the formation. Thin, discontinuous silt layers, as well as clastic dikes, are common in the upper part of the formation (Weekes et al. 1987).

The deepest well at the NRDWL penetrated to a depth of 78 m, bottoming in the top of Ringold Formation Unit E. The upper Ringold Formation contains a thin, clay, silt-rich layer that may be locally confining (Weekes et al. 1987) and the two deep wells are screened immediately above that interval.

The water table in the central Hanford Site, where the NRDWL and SWL are located, is in the Hanford formation gravels (see Figure 3.4). Ringold gravels (Units B, C, and E) lie below the Hanford formation and are in contact with it, except where remnants of the upper Ringold mud (Unit D) are present. This unit has been eroded away over parts of the central Hanford Site. The lower Ringold mud unit is relatively continuous in this area and acts as a local confining unit to Ringold Unit A gravels that overlie the basalt. The depth of the water table in the 400 Area varies from ~45 to 50 m. At the NRDWL and SWL, the depth of the water table varies from ~38 to 41 m.

In the 400 Area, groundwater flows to the east. The flow direction at the NRDWL and SWL is to the east-southeast. More detailed information on the direction of groundwater flow at these facilities is provided in Chapter 5.0. Because of their relatively high permeability, Hanford formation sediments dominate groundwater flow in these areas. As shown in Figure 3.4, transmissivity of the unconfined aquifer system at the landfill areas is particularly high because they are located within the main flow channel of the catastrophic floods that deposited the Hanford formation gravels. At the 400 Area, the Hanford formation consists mainly of the sand-dominated facies, and the water table is located near the Hanford-Ringold Formation contact (Tyler 1992). Therefore, transmissivity of the aquifer at the 400 Area is approximately an order of magnitude lower than at the landfill areas.

3.6 Hydrogeology of the 300 and Richland North Areas

P. D. Thorne and J. W. Lindberg

The 300 and Richland North Areas are located in the southern part of the Hanford Site (see Figure 1.1). The 300 Area is adjacent to the Columbia River and was the site of reactor fuel-fabrication facilities and research-and-development functions. The Richland North Area is an informal designation for the southernmost part of the Hanford Site and northern part of the city of Richland.

3.6.1 300 Area and Process Trenches

The uppermost unconfined aquifer in the 300 Area consists of Hanford formation gravels and sands and Ringold Formation gravels and sands with varying amounts of silt and clay (Swanson 1992). The water table is within the Hanford formation in most of the 300 Area. However, to the west of the 300 Area, the water table is in Ringold Formation gravel deposits (see Figure 3.4), below the bottom of the Hanford formation. The lower Ringold mud is found below the unconfined Ringold gravels and forms a local confining unit for thin Ringold gravel deposits directly above the basalt. Detailed information on the hydrogeology of the 300 Area is provided in Swanson (1992).

Depth to the water table in the 300 Area varies from <1 m near the Columbia River to ~17 m, and groundwater generally flows eastward toward the Columbia River. Changes in river stage influence water levels in wells located near the river and also cause reversals in the direction of

groundwater flow immediately adjacent to the river. When the river stage is higher than the water table in the adjacent aquifer, water moves into the banks of the river. When the river stage drops, this water moves back toward the river. The distance that water moves into the aquifer from the river depends on the difference in river stage and groundwater elevation, hydraulic properties of the aquifer, and duration of the elevated river stage. The reversal of flow adjacent to the river also causes a pressure pulse in the aquifer that affects water levels in wells much farther inland than the actual movement of river water. Additional details on the effects of river-stage elevation on water levels in the 300 Area are provided in Chapter 5.0. The effects of bank storage on contaminant transport in the 300 Area are discussed in Chapter 6.0.

At the 316-5 process trenches (RCRA site), the Hanford formation is 9 to 12 m thick and is composed of gravelly sand and sandy gravel. The Ringold Formation is ~40 m thick and comprises two major facies groups. The upper half is interbedded sandy gravels, gravelly sands, and silty sands of Unit E. The lower half is composed of sandy and clayey silt of the lower Ringold mud unit, which overlies basalt at this location.

The water table at the process trenches is close to the position of the Hanford-Ringold Formation contact but near the river, it rises and falls in response to river stage. During average to low-river stages, groundwater in the unconfined aquifer system converges on the 300 Area from the northwest and southwest, flows through the 300 Area in a west-to-east or northwest-to-southeast direction, and eventually flows into the river. During high-water stages, the water table can be quickly raised above the Hanford-Ringold Formation contact near the river, and groundwater may temporarily flow in a southwesterly or southerly direction. Channeling in the top of the Ringold Formation further complicates the direction and flow rate of groundwater movement in the unconfined aquifer system. Basalt-confined aquifers at depth (below the confining Ringold Formation lower mud unit) display higher hydraulic heads than the overlying unconfined aquifer system, causing any interaquifer flow to be in an upward direction.

3.6.2 Richland North Area

Depth to the water table in this area ranges from ~4 to 17 m. The uppermost unconfined aquifer system in this area consists of Hanford formation gravels and underlying Ringold Formation gravels with varying amounts of sand and silt (DOE 1990a). A layer of sandy clay was identified in several wells at a depth of ~10 m below the water table and within the sandy gravels. This layer forms a local confining unit. Additional details on the hydrogeology of the Richland North Area are available in DOE (1990a) and Liikala (1994).

Groundwater in this area generally flows eastward toward the Columbia River. However, a groundwater mound surrounding the City of Richland's North Well Field and recharge basins influences the water table and flow directions in parts of the Richland North Area. Additional details on the effects of this groundwater mound are presented in Chapter 5.0.

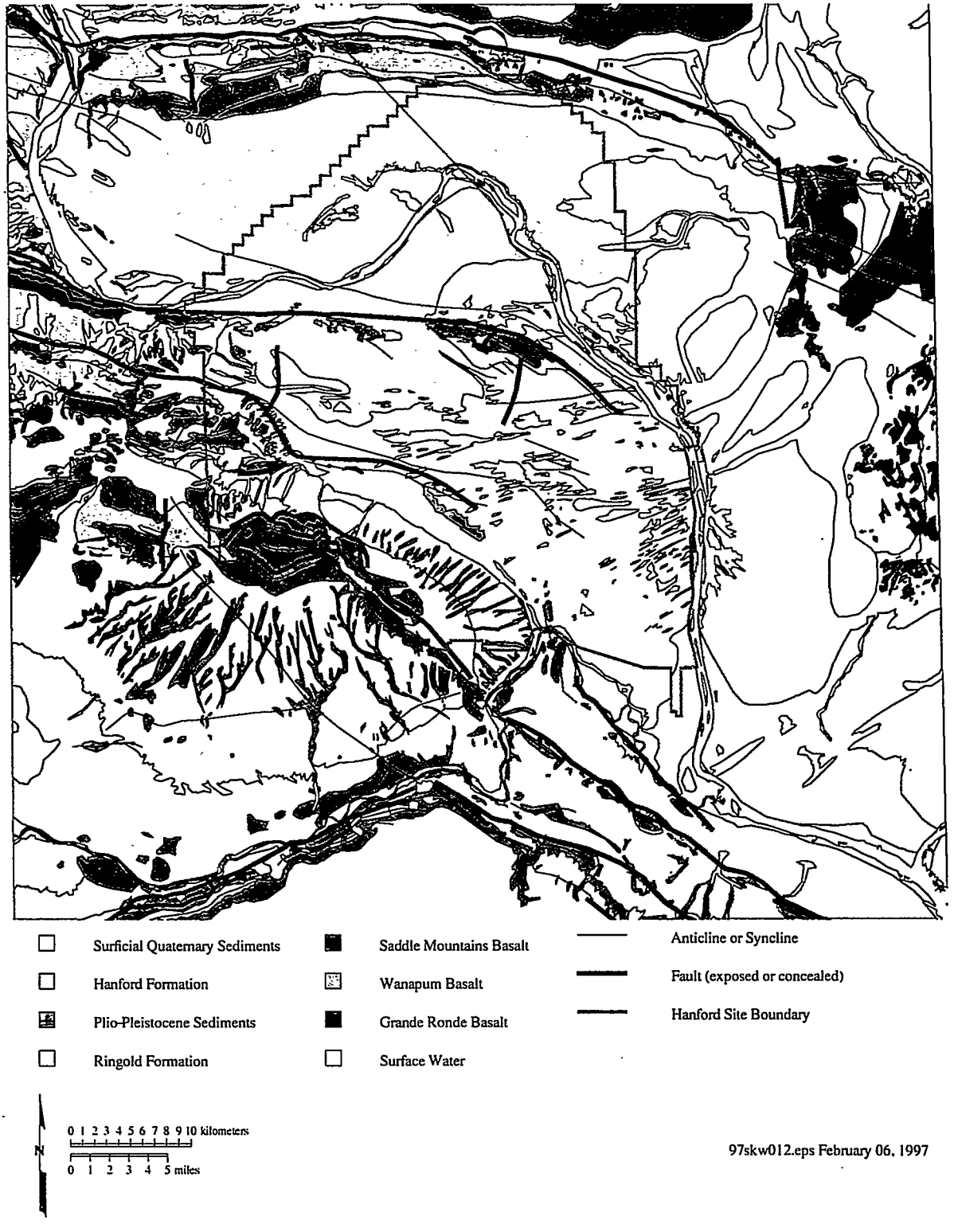


Figure 3.1. Surface Geology and Structural Features of the Pasco Basin (after Reidel and Fecht 1994a, 1994b)

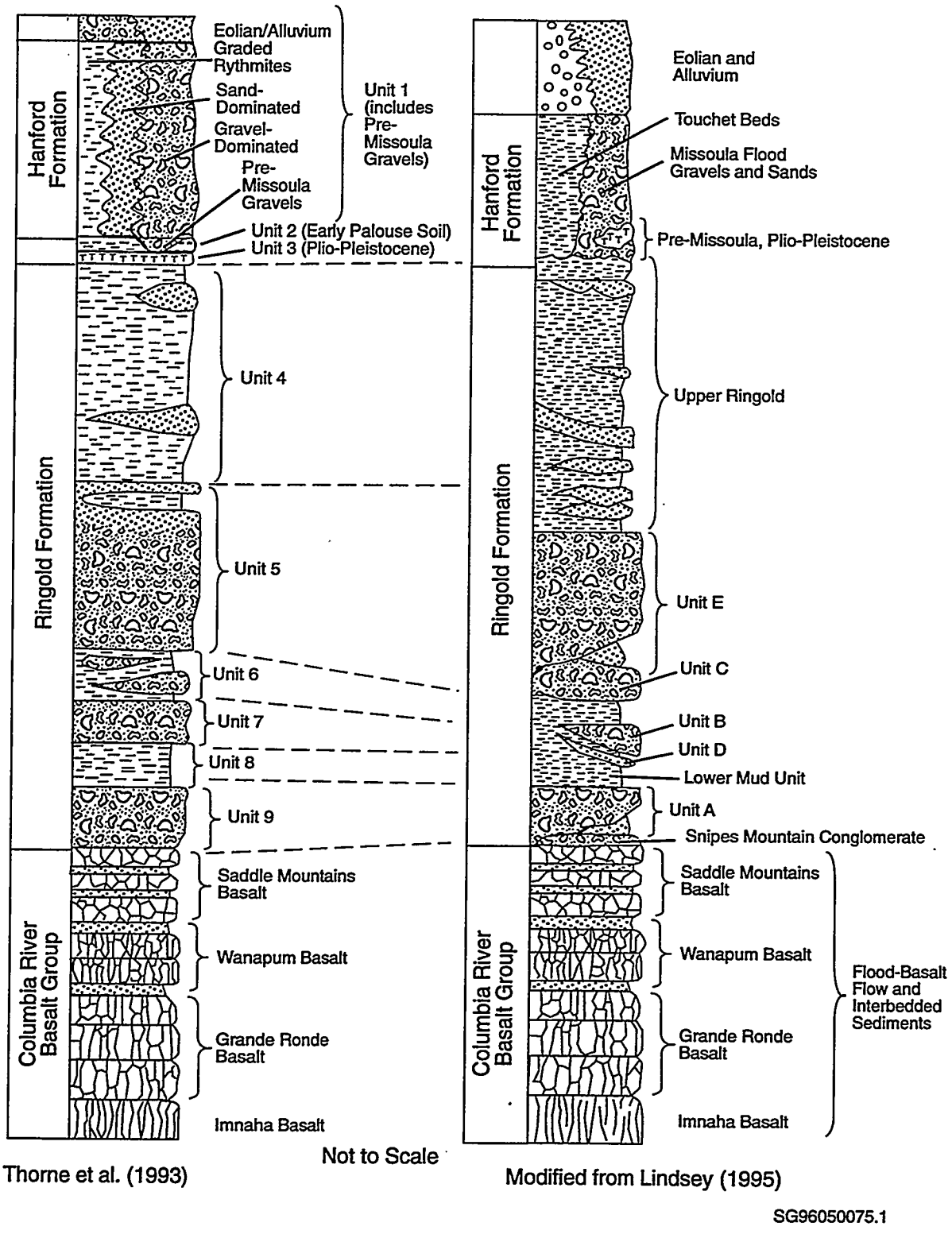


Figure 3.2. Comparison of Generalized Geology and Hydrogeologic Stratigraphic Columns

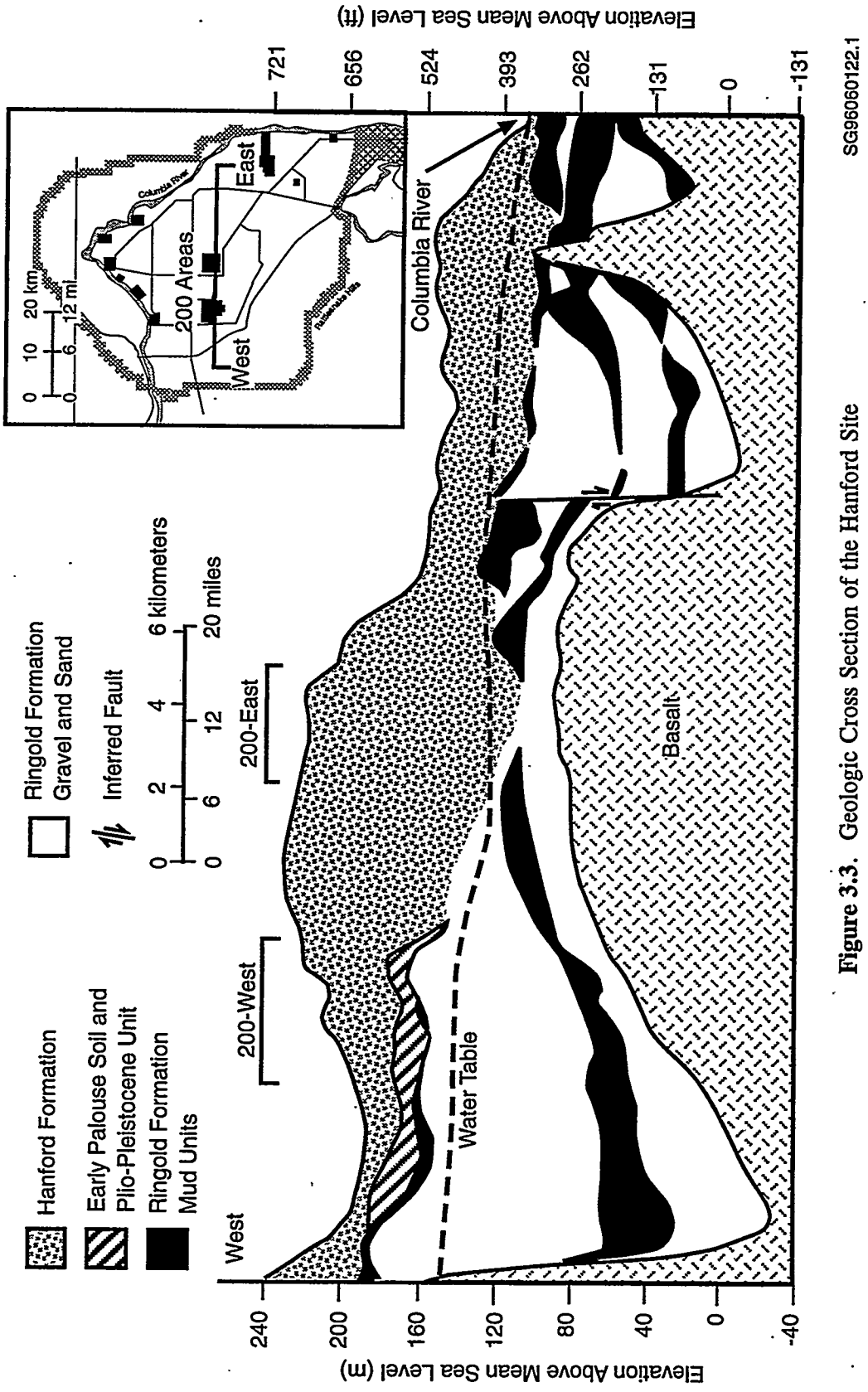


Figure 3.3. Geologic Cross Section of the Hanford Site

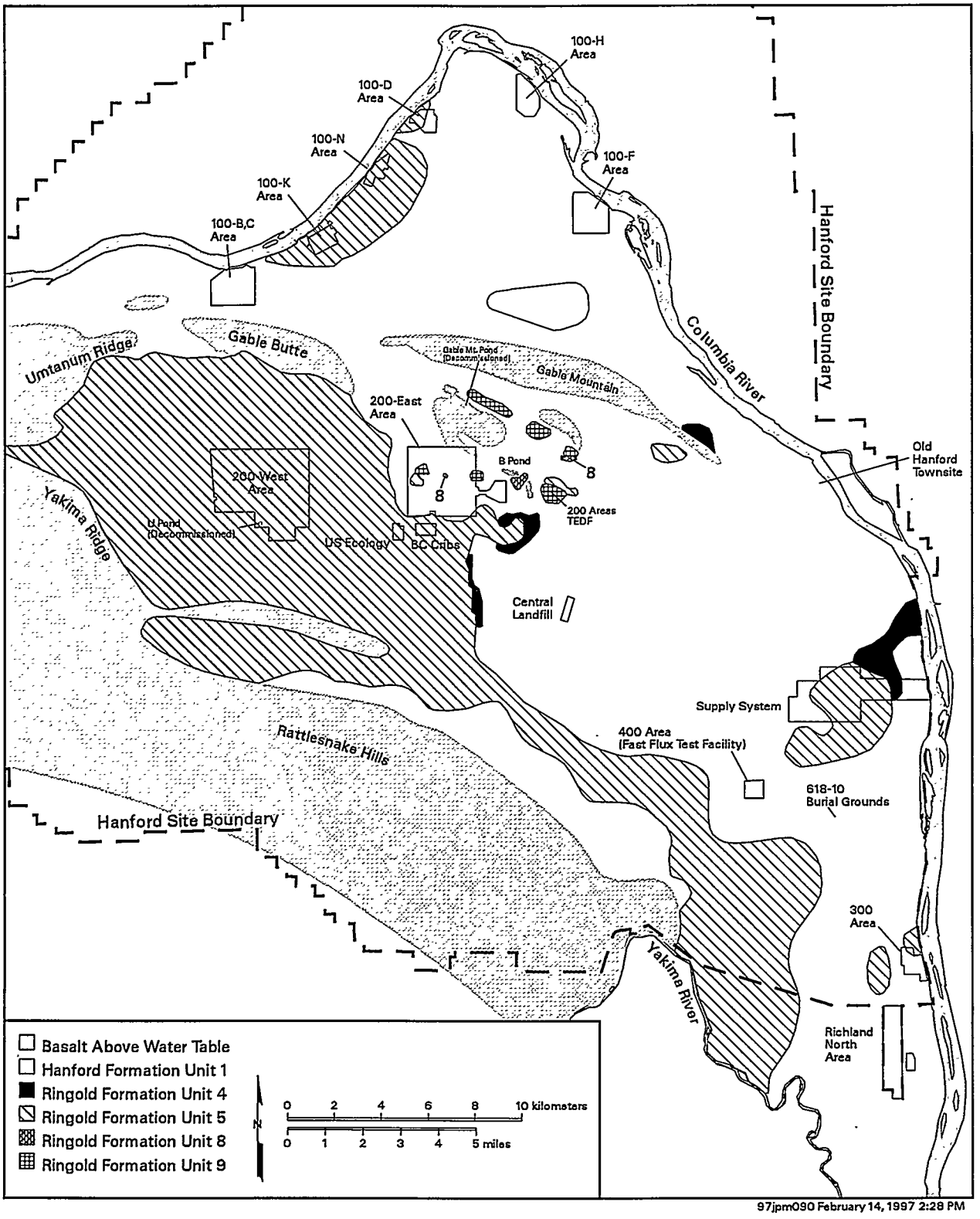


Figure 3.4. Geologic Units Present at the Water Table, June 1996

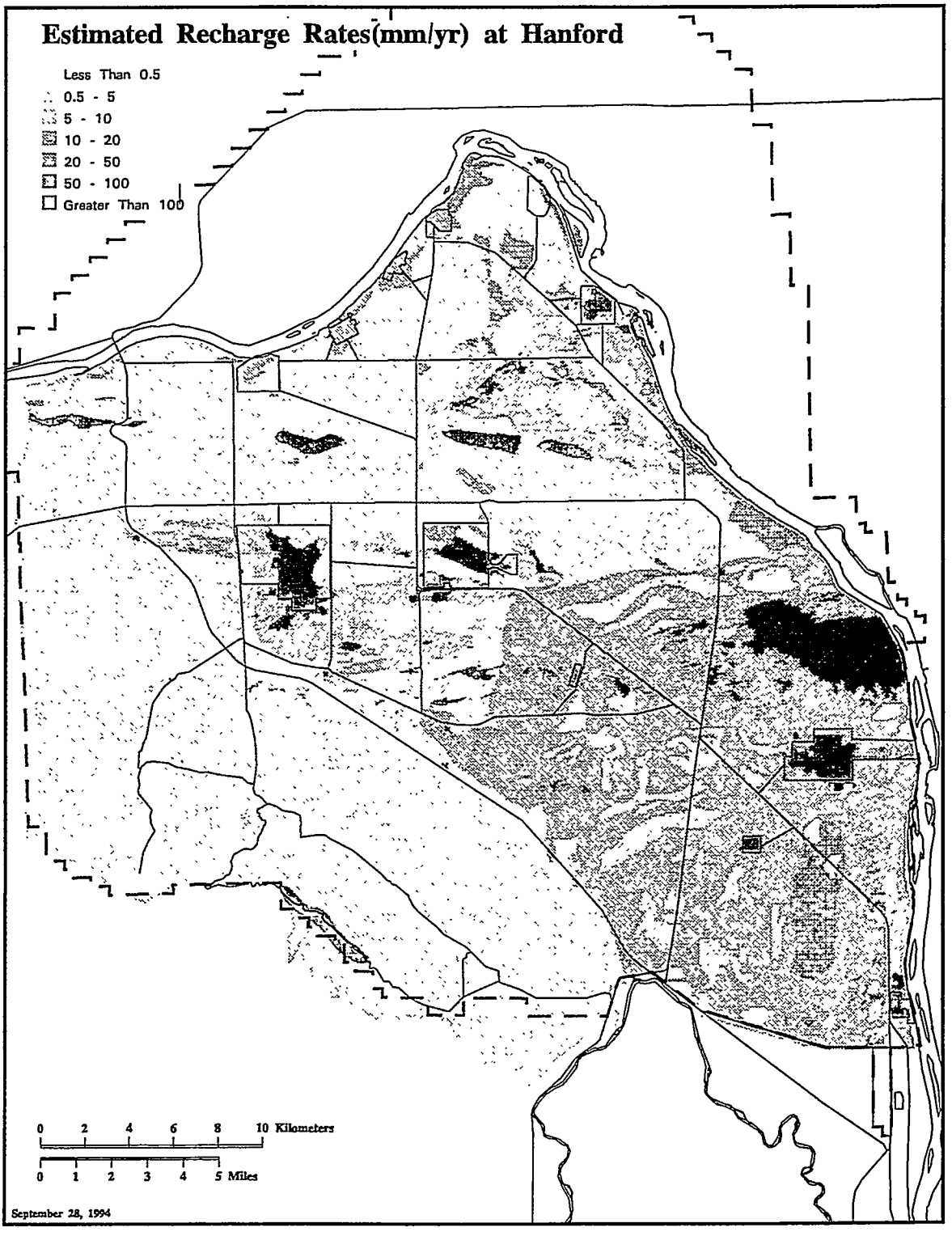
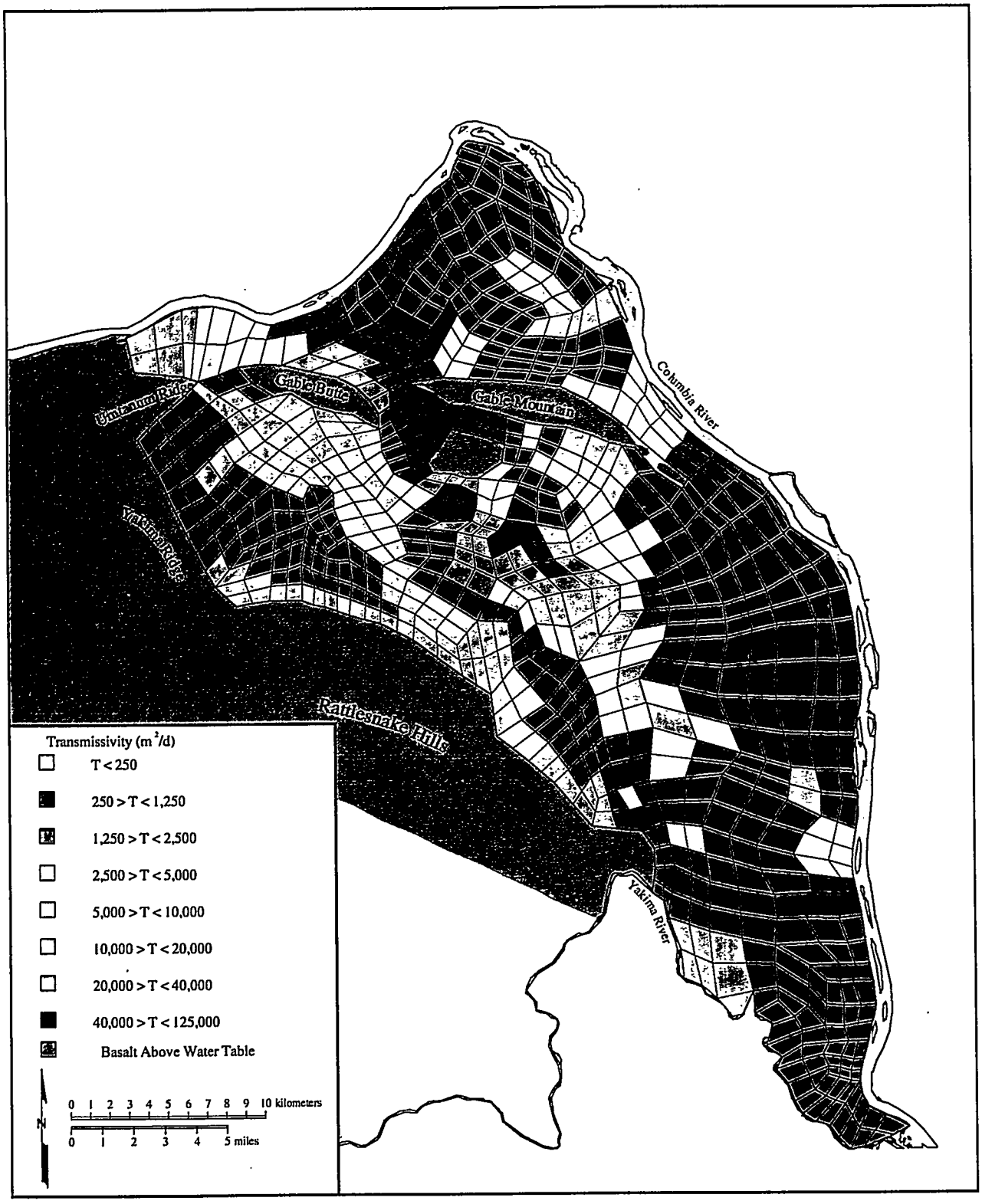


Figure 3.5. Estimated Recharge at the Hanford Site from Infiltration of Precipitation and Irrigation (from Fayer and Walters 1995)



97skw001.eps January 24, 1997

Figure 3.6. Transmissivity Distribution from Model Calibration

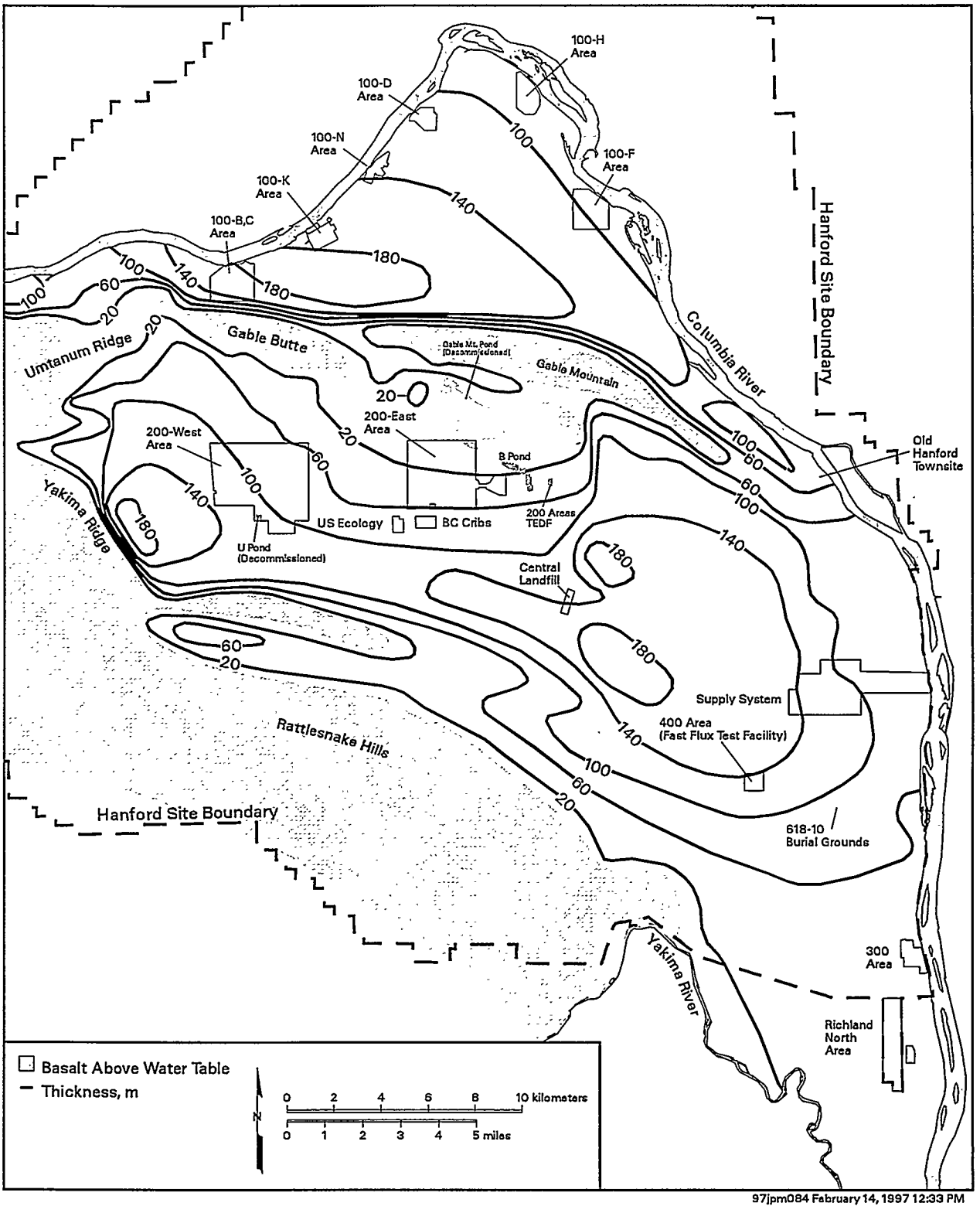


Figure 3.7. Saturated Thickness of Unconfined Aquifer System at the Hanford Site

4.0 Vadose-Zone Contamination

Radioactive and hazardous waste in the soil column, burial grounds, and underground tanks at the Hanford Site are potential sources of continuing groundwater contamination. Subsurface source characterization and monitoring, using spectral-gamma-logging and soil-gas monitoring, was conducted during fiscal year (FY) 1996. Additional characterization studies and field tests were also conducted to evaluate new leak-detection methods, moisture movement, and contaminant-transport processes in the vadose zone. This chapter summarizes major findings from these efforts. The primary focus is on soil contamination associated with single-shell tank farm areas, the spent nuclear fuel-storage basins, and the Plutonium Finishing Plant liquid waste-disposal sites (the major subsurface sources of carbon tetrachloride and transuranics [TRU]). An overview of the major soil-column sources of groundwater contamination is provided as background for a description of methods. The interpretation of monitoring and characterization results is presented in subsequent sections.

4.1 Major Sources

V. G. Johnson

The major soil-column sources of known or potential groundwater contamination are a result of the treatment, storage, and disposal of liquid wastes produced during 1) the initial or first-cycle chemical dissolution of irradiated nuclear fuel elements and 2) subsequent plutonium-refining or -finishing steps. Large volumes of low-activity aqueous waste discharged to soil-column-disposal sites from reactor operations, intermediate processing and waste-handling steps, and leakage of storage-basin water also account for radioactive waste in the soil column. Subsurface disposal and storage sites with the largest contaminant inventories are shown in Figure 4.1-1. Waste characteristics and soil-column-disposal site conditions for these potential sources of groundwater contamination are discussed.

4.1.1 Chemical-Dissolution Waste

Liquid waste (from the nitric acid dissolution of the irradiated nuclear fuel and initial separation steps) typically contained beta-emitting radionuclides at concentrations >100 μCi/mL and very high total salt concentrations (>100 g/L). The primary chemical-waste components were sodium, nitrate, chromate, fluoride, chloride, and phosphate. The relative compositions varied considerably, depending on the process. Agnew (1995) provides a detailed description of these complex and variable mixtures.

After the initial plutonium-separation step, the highly acidic first-cycle waste was neutralized with sodium hydroxide and transferred to underground storage tanks (single-shell tanks). A high pH was maintained by over-addition of sodium hydroxide causing many chemical and radioactive constituents to precipitate and settle to the bottom of the tanks. Typically, the waste flowed, or cascaded, through a series of tanks to remove most of the particulate phases. Early in Hanford's production history, when the bismuth phosphate process was used, the supernatant was discharged to soil-column-disposal sites.

Over 450 million L of liquid waste that cascaded through underground storage tanks was discharged to the vadose zone via cribs, trenches, and french drains (Waite 1991). The estimated total quantity of radioactive waste was 65,000 Ci (decayed through December 1989).

Because of the large volumes discharged, the entire soil column beneath many disposal sites in the 200 Areas became saturated and breakthrough of mobile contaminants (e.g., tritium, iodine-129, technetium-99, nitrate, chromate, and fluoride) from the soil column to groundwater occurred. Although this disposal practice was terminated over 30 years ago, the residual liquid held in soil-pore spaces following drainage of free liquid at these sites can continue to be a long-term source of groundwater contamination, especially if a source of moisture is available to transport the mobile waste constituents (e.g., enhanced natural infiltration from the coarse gravel coverings, removal of vegetation, leaking water lines, etc.).

Leakage from single-shell tanks can also be a source of groundwater contamination under the right conditions (Section 4.4). The estimated total volume of such sources is, however, small (<4 million L) compared to the soil-column-disposal volume (450 million L) of very similar waste. Also, the relatively small volumes associated with individual tank leaks make it less likely for such sources to reach the groundwater. There is growing evidence that downward movement of moisture (and associated mobile contaminants) from small-volume leaks (~100,000 L) may be greater than previously thought (Section 4.4). Small leak sources can also be mobilized if a driving force and/or preferential vertical pathway is present to transport the contaminants through the vadose zone to groundwater. The role of ground-cover type or enhanced natural infiltration and preferential pathways is, thus, a crucial issue in the tank farm areas. Corrective action, consisting of a surface covering to limit infiltration, was initiated at the 216-BY cribs.

4.1.2 Plutonium Finishing Plant Sources

The spent-process solutions from the Plutonium Finishing Plant (formerly known as Z Plant) contained carbon tetrachloride, nitric acid, and isotopes of plutonium and americium (TRU waste). Liquid waste discharges to cribs and trenches in the Plutonium Finishing Plant area resulted in accumulation of an estimated 20,000 Ci of plutonium-239 and americium-241 in the underlying soil column (Rohay and Johnson 1991; Johnson 1993a). Based on relative hazard (e.g., dividing curie quantities of americium-241 and plutonium-239 by the appropriate health/risk standard), the Plutonium Finishing Plant cribs are some of the most significant sources of radioactive contamination in the vadose zone at the Hanford Site.

The TRU concentrations in the soil of >100,000 pCi/g occur beneath the 216-Z-1A crib and extend to depths of 20 to 30 m (Price et al. 1979). Although TRUs are normally expected to be retained in the first few meters, the combination of high acidity and the presence of complexants apparently allowed the TRUs at these sites to penetrate deeper into the soil column. Although the maximum depth of penetration is unknown, the absence of TRUs in groundwater in the immediate vicinity of the 216-Z-1A crib suggests breakthrough beneath this crib has not occurred. Similar conditions exist at the 216-Z-9 trench, which received the same waste stream as the 216-Z-1A crib. An attempt was made to remove much of the TRU-contaminated soil at shallow depths beneath the trench (Ludowise 1978). Low TRU concentrations (<10 pCi/L) were detected in one older groundwater monitoring well

(299-W15-8) adjacent to the trench. Whether the TRU-containing waste liquid traveled through the vadose zone to groundwater or migrated along the outside of the well casing is unknown.

In addition to TRUs, the trench and crib received 570,000 to 920,000 kg of carbon tetrachloride (as both dissolved and as a separate liquid phase) between 1955 and 1973 (Rohay et al. 1994). The discharged contaminated liquid wastes were apparently intended to remain in the soil column; however, carbon tetrachloride was discovered in groundwater near the plant in the mid-1980s and was later found to be widespread in the 200-West Area. In December 1990, planning work began for an expedited response action to reduce the carbon tetrachloride vadose-zone source in the 200-West Area based on concerns that the carbon tetrachloride was continuing to spread to the groundwater. If left unchecked, the carbon tetrachloride would significantly increase the extent of groundwater contamination because of vapor-phase transport through soil-pore space, or by downward migration through the vadose zone as a dense nonaqueous phase liquid. Once in groundwater, the dense nonaqueous phase liquid dissolves slowly, and its status in the vadose zone and groundwater is the subject of ongoing remediation and characterization efforts (Rohay 1996).

4.1.3 Liquid Waste-Disposal Sites

The Hanford Site has more than 330 past-practices liquid waste-disposal facilities. Radioactive liquid waste was discharged to the vadose zone through reverse wells, french drains, cribs, and tile fields. Leakage from fuel-storage basins in the 100 Areas also contributed potentially significant inventories of fission products and TRUs to the soil column (Johnson et al. 1995); thus, both past-practices sites and fuel-storage basin leakage are potential vadose-zone sources.

Even though disposal of untreated wastewater to the ground stopped in 1995 (Schmidt et al. 1996), contaminant movement can still occur in the soil column beneath past-practices sites. Vadose-zone monitoring and characterization is one approach to evaluating the status of possible leaks or remobilization of contaminants caused by enhanced natural or artificial infiltration. The vadose-zone-monitoring methods used at the Hanford Site to assess these possibilities are described in the following sections.

4.2 Description of Vadose-Zone Activities

S. M. Narbutovskih, R. K. Price, and V. J. Rohay

The objectives of vadose-zone monitoring and characterization are to document the location of the contamination and the status of moisture and radionuclide movement in the soil column and to assess the effectiveness of remedial actions. FY 1996 activities involved in situ borehole spectral gamma logging and soil-gas sampling and analysis. Electrical resistivity tomography, another approach for leak detection and tracking moisture movement, was also evaluated at a mock tank leak demonstration site in the 200-East Area. The methods, data handling, and borehole arrays or networks are described in following subsections.

4.2.1 Borehole Spectral Gamma Logging

Borehole spectral gamma logging is an in situ measurement of subsurface gamma-emitting radionuclides obtained through cased monitoring wells that are completed in the vadose zone or extend into the saturated zone. The detector or sensor is a crystal of sodium iodide or germanium and associated electronics. Photons emitted from radionuclides in the formation interact with the detector material, resulting in electronic pulses transmitted to the surface via electrical cables to a digital data-storage system. By periodically recording detector response at various depths, changes over time can be documented. This general type of logging has been conducted at the Hanford Site for over 25 years.

Two organizations performed borehole logging surveys at the Hanford Site in FY 1996. Rust Geotech conducted single-shell tank vadose-zone characterization and Westinghouse Hanford Company conducted vadose-zone monitoring at past-practices liquid waste/soil-column-disposal sites. The equipment, calibration, and operating procedures were equivalent for the two systems, except for administrative and procedural controls for data acquisition and handling, as indicated in the following subsections.

4.2.1.1 Methods

The logging equipment used at past-practices sites was calibrated at the Hanford Site. The calibration facilities were constructed for long-term stability and designed to represent subsurface conditions (Stromswold 1994a; Engelman et al. 1995). The detection systems were calibrated in these facilities and corrections were established for differences between the calibration facilities and Hanford Site borehole-construction conditions (Randall 1994; Price et al. 1996). The subsurface geophysical surveys were acquired in accordance with WHC (1989). The data-reduction method was reviewed (Stromswold 1994b) and performed following the vadose-zone-monitoring plan (Price 1995).

The spectral gamma-ray borehole-logging measurements in the tank farms were conducted in accordance with U.S. Department of Energy (DOE)(1995b).

Depth profiles, or logs, of radionuclide concentrations in all boreholes surrounding a tank are produced and stored electronically. The logs are correlated with tank farm gross gamma-ray log data and historical information about each tank, and a tank summary data report is prepared. The data report documents the results of the logging in relation to tank leak history. An interpretive tank farm report is prepared to provide a complete assessment and correlation of all vadose-zone contamination data to identify sources and to determine the nature and extent of the contamination.

The two logging systems used in the tank farms were calibrated following DOE (1995c). The base calibration was performed using the calibration facilities in Grand Junction, Colorado, and is reported in DOE (1995c). The field calibrations are published biannually, most recently in DOE (1996a).

Data are recorded by the logging system in accordance with procedures outlined in DOE (1995d) and managed as outlined in DOE (1995e). Details on other aspects of the project are provided in DOE (1994b, 1995f, 1995g, and 1996a).

4.2.1.2 Monitoring Networks

Two types of monitoring wells were available for logging: 1) older vadose-zone and groundwater-monitoring wells in and near past-practices sites and 2) single-shell tank farm networks.

Soil-Column-Disposal Sites. Existing groundwater-monitoring wells adjacent to past-practices sites are logged on an as-is basis (Appendix C). Corrections for varying borehole diameters and presence of sealants must be taken into account in these monitoring wells. In addition, a concern with any of the older boreholes is the degree to which contaminants may have migrated down the outside of the borehole casing. Methods to distinguish a distributed source from one at the casing wall are being developed to account for this potential problem. An example of a network of older vadose- and groundwater-monitoring wells is shown in Figure 4.2-1. The example illustrated is for a soil-column-disposal site (216-Z-12) that received liquid waste containing TRUs and carbon tetrachloride. The relatively large number of boreholes were installed for earlier characterization purposes (1970s). Only those sites with significant soil-column contamination were characterized in this manner. These boreholes allow some assessment of downward migration over time by comparing current depth profiles with the previous record of radionuclide depth-distribution based on soil sample results.

Single-Shell Tank Farm. The tank farm vadose-monitoring networks consist of 5 to 7 steel-cased, 15.2- to 20.3-cm-dia. structures arranged around the perimeter of the tanks as illustrated in Figure 4.2-2 (the horizontal distance from the base of the tanks is ~1.5 m). The depths vary from ~22.8 to 38.1 m below ground surface. Most of the single-shell tank-monitoring networks were installed in the late 1960s and early to mid-1970s. In addition, some tank farms included lateral lines that ran horizontally beneath the tanks. The intent of both the vertical and horizontal monitoring facilities was to detect leakage from the tanks and to track movement over time.

4.2.2 Soil-Gas Monitoring

Soil vapor extraction is being used to remove the carbon tetrachloride source from the vadose zone as part of the 200-West Area carbon tetrachloride expedited response action.

Measurements of soil-gas concentrations of chlorinated hydrocarbons were conducted near the soil-vapor extraction sites and from the extraction wells to track the effectiveness of the remediation effort. While such measurements were made for other site-characterization efforts, the primary focus in the following subsections is on the carbon tetrachloride project. The 200-West Area carbon tetrachloride expedited response action is being conducted by the Environmental Restoration Contractor.

4.2.2.1 Methods

To maintain real-time monitoring schedules, constrain costs, and fulfill the requirements for working in a radiologically controlled area, the approach to the carbon tetrachloride remediation maximized the use of field-screening-level data. Since late 1993, contaminant concentrations at the inlets and vent stacks and at individual wells were monitored using a Type 1302™ infrared photo-acoustic spectrometer manufactured by Brüel and Kjaer, Naerum, Denmark. The Brüel and Kjaer

sensors are calibrated annually by the manufacturer and periodically challenged with calibrated gas standards in the field. The detection limit for carbon tetrachloride is 1 part per million by volume (ppmv). A programmable logic controller records the incoming concentrations at each inlet every 15 minutes; the system technicians use these data to establish daily records of representative concentrations.

To monitor concentrations at individual extraction wells, a sampling apparatus is placed in-line at the wellhead to collect a soil-gas sample in a Tedlar™ bag (E. I. du Pont de Nemours & Company, Wilmington, Delaware). The sample is analyzed using the Brüel and Kjaer sensor housed in a trailer at the extraction site.

Shallow soil-gas samples are collected from probes in the network by first purging the system using a 60-cm^3 polyethylene syringe. After the sample tube has been purged, a 1.0-mL soil-gas sample is collected for gas chromatography analysis using a gastight glass syringe. Immediately following sample collection, the sampling syringe needle is sealed by inserting it into a piece of rubber septum material. The sample is then transported to the onsite mobile laboratory for analysis. The subsurface-surface differential pressure at each sample point is measured using a magnehelic gauge immediately before collecting a soil-gas sample. Method detection limits (MDLs) for the gas chromatograph used in 1996 were established at the following concentration levels: 0.070 ppmv for methylene chloride; 0.031 ppmv for chloroform; 0.015 ppmv for trichloroethylene; and 0.015 ppmv for carbon tetrachloride. Practical quantitation limits for each analyte were set at three times the MDL.

4.2.2.2 Monitoring Networks

There are currently 46 drilled wells available for on-line extraction or monitoring (Rohay 1996; Rohay and Tranbarger 1996) (Figure 4.2-3). Thirteen of these wells were drilled during 1992 and 1993 and were completed as vapor-extraction wells with stainless-steel casing and screens; one well was drilled at a 45-degree incline. Thirty-three wells, drilled between 1954 and 1978 and completed with carbon-steel casing, were adapted for vapor extraction by perforating the well casing using mechanical or jet perforators. Seventeen of the 46 available wells have 2 screened or perforated open intervals isolated by downhole packers. Each of the systems extract simultaneously from multiple wells open either above and/or below the Plio-Pleistocene layer; the mix of on-line wells is adjusted periodically to optimize contaminant removal.

There are 125 subsurface-monitoring probes at depths greater than 2 m: 11 cone-penetrometer wells, 104 soil-gas probes, and 10 stainless-steel tubes. A cone penetrometer was used to install 11 extraction or monitoring wells and 104 subsurface-monitoring points at 33 locations at the carbon tetrachloride site in 1993 and 1994. Up to five monitoring screens were installed per location at various depths. Ten stainless-steel tubes were strapped to the outside of the casing of four wells during installation in 1993 to enable monitoring above and below the screened intervals.

There are 73 shallow soil-gas probes at depths ranging from 1.2 to 1.8 m below ground surface (Figure 4.2-4). The probes are attached to a polyethylene tube that runs to the surface. The network was installed between 1991 and 1995.

The combined carbon tetrachloride concentrations from multiple on-line extraction wells are monitored daily at the inlets to the systems (Rohay 1996). Carbon tetrachloride, chloroform, methylene chloride, and methyl ethyl ketone concentrations are monitored monthly at individual on-line extraction wells and quarterly at individual off-line monitoring wells. One "snap-shot" sample is collected at each on-line extraction well. Three samples are collected during an hour of continuous extraction at wells that have been off-line during the month in which quarterly sampling is conducted. The shallow soil-gas network is monitored approximately annually for concentrations of carbon tetrachloride, chloroform, methylene chloride, and trichloroethylene. Selected wellheads and soil-gas probes were monitored twice per week from December 1991 through December 1993 for volatile organic compounds (determined to be primarily carbon tetrachloride) (Fancher 1994).

4.2.3 Electrical Resistivity Tomography

Electrical resistivity tomography is a three-dimensional geophysical imaging technique that can map liquids migrating through the vadose zone. The fluid flow causes changes in the intrinsic resistivity of the soil. The changes are detected by introducing an electrical current into the ground through an electrode pair and measuring the resulting voltage change between another electrode pair (Figure 4.2-5). The measured transfer resistance data are processed using a two- or three-dimensional tomography code (Daily and Owen 1991). This technique relies on detection and mapping of these electrical resistivity variations associated with the migrating fluid.

This technique provides information on leak migration under unsaturated conditions, either two dimensionally in a plane or three dimensionally in a volume. This enables the technique to be used for a variety of applications, from early leak detection beneath hazardous treatment and storage facilities to monitoring steam-injection flow paths to remediate volatile organics in soils. It should be noted that other vadose-zone-monitoring methods provide information at either a point (e.g., time-domain reflectometry, suction lysimeter) or along a line (e.g., borehole-logging methods). Consequently, a contaminant leak has to migrate horizontally to impact the limited region of influence around these sensors. A tomography network, on the other hand, can provide 100% coverage underneath a facility and is capable of detecting moisture changes of only a few percent. Field investigations to assess the capability of this technique to provide early leak detection underneath a facility and to enable plume tracking of vadose-zone contamination migration are discussed. The field tests were conducted at the 200-East Area's 105A mock tank site, shown in Figure 4.2-6.

4.2.3.1 Methods

To perform a survey, several hundred electrical resistance measurements are made between two different electrode pairs. The data are then processed with a tomographic-inversion code to produce a cross-sectional image between the spatial resistivity variations monitored over time. Migrating liquids appear as regions with resistivity changes.

A network can be designed to ring the region of interest, such as the soil beneath a single-shell tank. Tomographic data are collected on one level, enabling a horizontal tomogram to be produced.

This provides 100% coverage beneath the tank. In addition, if greater coverage is required, then this type of network can be used to collect data between horizons to provide a true three-dimensional tomographic image of the volume beneath a tank.

Until 1994, most field applications of this technology were for developmental testing and demonstrations. A transfer of the technique from the developers at Lawrence Livermore National Laboratory to operations at the Hanford Site was conducted. The technology is now available for deployment in operations through the Pacific Northwest National Laboratory.

Field testing of this technology under various subsurface conditions has been ongoing by the developers for 5 years (Daily and Owen 1991; Daily et al. 1992; Daily and Ramirez 1993; Ramirez et al. 1995a). At the Hanford Site, the technology was field tested during FY 1995 to evaluate applicability to leak detection beneath and around single-shell tanks (Ramirez et al. 1993; Daily and Ramirez 1995; Ramirez et al. 1995b).

To illustrate the method, the electrode response to initial (shallow) testing conducted in 1995 near the C tank farm in the 200-East Area is described as follows.

Data were collected during the discharge of 4,160 L of ~0.1 molar sodium chloride solution released continuously over a 5-day period at a rate of 26.5 L/h. This concentration should be considerably more dilute than the actual saturated tank wastes. As can be seen in Figure 4.2-7, the presence of the simulated leak was not only detected at the correct location around the tank but was detected early. In addition, the technology could detect the approximate volume of the leaked liquid. The resulting vadose plume, furthermore, was mapped through time to the maximum depth of the electrode array at 10.7 m. Note that this maximum array depth was reached in 5 days. This implies that if the leakage rate was held constant, then groundwater at a depth of 76.8 m would be impacted in 36 days, with a total leak of only 29,900 L. Lateral spreading resulting from anisotropic impermeability, however, should decrease the estimated rate of movement based on the 10.7-m depth from this test.

During this simulated leak event, data were also collected with a three-dimensional acquisition scheme and processed with a three-dimensional code (Ramirez et al. 1995b). By injecting current through a pair of electrodes on one horizon and measuring the voltage change between electrode pairs on another horizon, the entire soil volume can be monitored. Results from this volume monitoring are presented in Figure 4.2-8. Only resistivity changes greater than 150 ohm-m are displayed in the bottom three tomograms. As can be seen, the shape and volume of the contaminant plume can easily be determined. It is interesting to note that lateral migration occurs at the approximate location of a fine silt layer.

4.2.3.2 Monitoring Network for Initial Test

For single-shell tank leak-detection applications, a monitoring network consists of several electrodes in boreholes surrounding the tank (as illustrated in Figure 4.2-6). At this location, a 15.2-m-dia. steel tank, buried 1.5 m in the ground, was adapted for infiltration tests. A permanent network surrounding the tank provided a quasirealistic environment for leak-detection testing. Boreholes were

augered, dropping the previously constructed electrodes into the hole and backfilling with material on removal of the temporary steel casing. This left the electrodes in contact with the subsurface soils. Each borehole extends to a depth of 10.7 m, with 8 electrodes spaced 1.5 m apart.

4.3 Results

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Results of the vadose-zone characterization, monitoring, and development testing conducted during FY 1996 are summarized as follows.

4.3.1 Borehole Spectral Gamma Logging Results

Spectral gamma logging results for the soil-column-disposal sites and single-shell tank farms are summarized from Schmidt et al. (1996) and DOE (1996b). Some of the soil-column disposal site examples include data collected in prior years in combination with data obtained in FY 1996.

4.3.1.1 Soil-Column-Disposal Sites

During FY 1996, ~75 boreholes were logged by Westinghouse Hanford Company around the inactive liquid waste-disposal facilities on the Hanford Site for identifying and tracking radioactive plumes. The logging surveys of the boreholes identified gamma-emitting radionuclides and quantified the concentration as a function of depth. These data serve as the baseline for any further monitoring to protect the groundwater from additional contamination from these facilities. A listing of boreholes logged is provided in Appendix C. Selected depth-distribution patterns based on these logs, combined with logs acquired previously, are presented in the following subsection. The results suggest that 1) radionuclide movement beneath some disposal sites continues long after termination of liquid input and 2) the lateral extent of movement can be much greater than the physical dimensions of the disposal structure.

Lateral Contaminant Spreading. At least 7 cribs (216-B-43 through 216-B-49) received measurable quantities of potentially mobile radioactive waste from the B-BY-BX single-shell tank farms beginning November 1954 and ending December 1955. The lower vadose-zone sediments contain no widespread low-permeability zones similar to the fine sediments and caliche layers in the 200-West Area that impede downward movement and increase lateral spreading.

Groundwater-monitoring wells 299-E33-38 and 299-E33-40 were constructed outside the projected area of subsurface contamination. Spectral-gamma-ray logs of both wells indicated radioactive contaminants (cobalt-60) to a depth of 58 m in well 299-E33-38. Examination of the drill cuttings identified a 0.3-m-thick fine-grained sand layer in well 299-E33-38 at ~34 m below ground surface. The sediment above and below was sand with slightly higher gravel contents. A plan view of the BY cribs, monitoring-well locations, and gamma surveys of three wells are shown in Figure 4.3-1. The depth-profile survey of well 299-E33-5 shows the interval where horizontal movement was identified at a depth of ~34 m. Information currently available for the cribs is not sufficient to explain the character

of subsurface contaminants and their migration pathways. It can be concluded, however, that the contaminants discharged to the cribs are not localized beneath the crib and horizontal movement does appear to occur.

Another good example of the preferential spreading of radionuclides discharged to the vadose zone is the study of the 216-T-6 crib. This crib was in service from 1946 through 1951, receiving 45 million L of low-salt, neutral-to-basic cell drainage. Records indicate that the crib contains 110 Ci of cesium-137 (decayed through January 1990) and other radioisotopes. Fifteen monitoring boreholes were drilled adjacent to the crib between May 1947 and August 1951. Figures 4.3-2 and 4.3-3 show a plan view and cross section, respectively, of the crib structure, well locations, and maximum extent of contaminant concentrations that range from 10 to 1,000 pCi/g of cesium-137 based on spectral gamma logging results. The irregular shape of the contaminant plume and the extent of lateral spreading beyond the dimensions of the crib suggest the distribution of contaminants discharged to the vadose zone in this area is highly influenced by stratigraphy.

Mobility of Cesium-137 from Contaminated Liquid Discharges. A condition under which cesium-137 can be more mobile than expected is suggested by depth profiles beneath the 216-T-19 crib. This crib received steam condensate, second-cycle supernatant, and cell-drainage waste from September 1951 to July 1980. Monitoring well 299-W15-4 was drilled in January 1956 and was 20 m from the release point. A gamma log survey shows the main contaminant plume at 12 m, with a maximum concentration of 33,000 pCi/g. The survey identified additional cesium-137 contamination at 47 m at concentrations as high as 8 pCi/g, with no indications of contamination being smeared to lower depths by the drilling activity. The maximum in the cesium-137 depth profile (Figure 4.3-4) occurs at the transition from sand to a silt-clay layer. The fine-textured sedimentary layer probably restricted the downward movement of the liquid waste and increased lateral movement in the overlying sand unit. The smaller peak at 47 m suggests there must be other, more-complex pathways that allow movement of cesium-137 to extend to greater depths than expected based on sorption properties alone. The 200-West Area has several stratigraphic interfaces that can promote horizontal spreading and retardation of liquids migrating through the subsurface.

4.3.1.2 Single-Shell-Tank Farm

Spectral gamma logging of 95 vadose-zone-monitoring boreholes (Figure 4.3-5) in the SX tank farm was completed in FY 1996. A comprehensive report was published in 1996 from which the following summary is taken (DOE 1996b).

The boreholes in this tank farm are from 23 to 38 m deep, which is well above the groundwater level at ~64 m below ground surface.

Cesium-137 was found to be the most abundant gamma-emitting radionuclide in the vadose-zone sediments. Other radionuclides detected include cobalt-60, europium-152, and europium-154. They were only detected, however, at or very near the ground surface, except for one borehole where cobalt-60 was detected in one well below the tank base. Depth-profile plots of cesium-137 surrounding tanks SX-108, SX-109, and SX-112 are provided in Figures 4.3-6 through 4.3-8.

The deepest zone of cesium-137 contamination in the SX tank farm is at a depth of 38 m around borehole 41-12-02, which is adjacent to tank SX-112 (see Figure 4.3-8) that is designated as a leaker. High levels of contamination (> 1,000 pCi/g in off-scale shaded zones where detector saturation occurred) have reached the maximum extent of the boreholes. All of the boreholes, however, were drilled using cable-tool-drilling methods, which may leave a gap behind the casing wall that could provide a pathway for vertical movement of contamination. Some contamination, therefore, could have moved down the outside of the borehole casing.

The deep zones of high cesium-137 concentration in borehole 41-12-02 correlate with zones of contamination in surrounding boreholes. Also, the contamination found deep in boreholes 41-09-04 and 41-12-02 was present in the formation when the boreholes were deepened in the mid-1970s, as indicated by sediment samples and gross gamma-ray logs. Finally, gross gamma logs show no evidence of any changes in the activity profiles suggesting that no vertical movement of contamination occurred since the boreholes were drilled.

It was also determined from the SX tank farm vadose-zone-characterization work that movement of liquid beneath tank SX-109 continues to occur. For example, the gross gamma log data from borehole 41-09-09 (see Figure 4.3-7) shows an increasing trend in the activity profile versus time, as shown in Figure 4.3-9. (Tank farm gross gamma logs indicate the upward trend continued until at least mid-1994.)

The impacts of SX tank farms operations on the groundwater were not conclusively defined by the vadose-zone-characterization work. However, groundwater-monitoring data and modeling results (Section 4.4) suggest mobile tank farm contaminants reached the groundwater. This is discussed in detail in Section 4.4. Because the vadose-zone boreholes do not extend deep into the lower vadose zone, the source of the groundwater contamination cannot be determined from an assessment of the vadose-zone contamination. Based on the depth of cesium-137, which is a relatively low-mobility radionuclide, the vadose-zone-characterization results strongly suggest that this tank farm is a source of the mobile technetium-99 found in the groundwater, as discussed in Chapter 6.0.

T Tank Farm. Most of the boreholes surrounding the 12 tanks in the T tank farm were drilled in the mid-1970s and completed with single 15-cm-dia. carbon-steel casing. In the early 1980s, the boreholes were modified by perforating the existing 15-cm casing, inserting a 10-cm casing, and pumping grout in the annulus between the two casings. The configuration of the tank farm boreholes consists of two casings with ~2.5 cm of grout between the casings and an unknown thickness of grout between the outer perforated casing and the formation.

This borehole configuration made quantifying radionuclide concentrations difficult because of the attenuation effects of the double casing and unknown grout thickness. Logging in the tank farm, therefore, was conducted only to establish a baseline against which future logging results could be compared in an effort to detect and quantify changes. This logging was performed around only two tanks that were considered potential leakers and that still have a significant amount of free liquid in them (tanks T-107 and T-110).

The boreholes around tanks T-107 and T-110 also were logged because the ground surface is radiologically clean and access is unrestricted. This was advantageous for the first tests of the new gamma logging systems and served as a preliminary test of the new logging procedures.

Spectral-gamma-log data for tank T-107 indicated the presence of cesium-137 and cobalt-60 contamination at low concentrations just below the base of the tank. Elevated activities were identified by the tank-farm gross gamma-ray-logging system shortly after the boreholes were drilled. This contamination is most likely leakage from the tank. The data acquired from the boreholes surrounding tank T-110 did not reflect subsurface contamination that could be attributed to leakage from this tank.

4.3.2 Soil-Gas-Monitoring Results

During FY 1996, carbon tetrachloride concentrations in extracted soil vapor continued to decline since operation of the extraction systems began in 1992 (Rohay 1996; Rohay and Tranbarger 1996). This is typical and represents removal of the readily available vapor phase of the contaminant in the pore spaces. The most dramatic decrease has been at the 216-Z-9 well field, where carbon tetrachloride concentrations measured at the system inlet declined from ~30,000 ppmv in 1993 to 40 ppmv in June 1996 (Figure 4.3-10a). In comparison, carbon tetrachloride concentrations in soil vapor extracted from the 216-Z-1A wellfield declined from ~1,500 ppmv in 1992 to 25 ppmv in June 1996 (Figure 4.3-10b).

Carbon tetrachloride concentrations measured at individual extraction wells are also decreasing with continued vapor-extraction operations (Rohay 1996). At the 216-Z-9 well field, initial concentrations measured above the Plio-Pleistocene layer were generally an order of magnitude higher than those measured below; after ~6 months, concentrations measured above and below the Plio-Pleistocene layer had reached comparable levels (Figure 4.3-11a). At the combined well fields, concentrations measured at intervals open above the Plio-Pleistocene layer have been the same order of magnitude as those measured below the Plio-Pleistocene layer throughout extraction operations (Figure 4.3-11b).

The concentration of chloroform has been proportional to the carbon tetrachloride concentration (Rohay 1996) (Figure 4.3-12). The ratio between carbon tetrachloride and chloroform is relatively constant for carbon tetrachloride concentrations between 25,000 and 1,000 ppmv. The concentration of methylene chloride tends to be higher than that of chloroform. At carbon tetrachloride concentrations $< 1{,}000$ ppmv, two different linear trends between carbon tetrachloride and chloroform are apparent.

4.3.2.1 Shallow Soil-Gas-Sampling Results

The shallow network was sampled in May 1996 for comparison with previous surveys. The shallow soil-gas results show that carbon tetrachloride has declined significantly since extraction operations began. For example, the highest carbon tetrachloride concentration observed in 1992 at the 216-Z-9 extraction site was 72.7 ppmv; the highest carbon tetrachloride concentration observed in 1996 was 0.17 ppmv.

4.3.2.2 Wellhead Field-Screening Data

Field screening of wellhead concentrations at the vapor-extraction site twice per week between 1991 and 1993 generally confirm the results of the extraction-system monitoring. Carbon tetrachloride concentrations exceeding 10,000 ppmv were observed at wells open above the Plio-Pleistocene layer north/northeast of the 216-Z-9 trench. By contrast, maximum carbon tetrachloride concentrations observed at wells open above the Plio-Pleistocene layer in the combined well field site were an order of magnitude lower. Carbon tetrachloride concentrations exceeding 1,000 ppmv were observed at wells open below the Plio-Pleistocene layer in both sites (Rohay et al. 1994).

4.3.2.3 Other Monitoring Well Observations

Carbon tetrachloride (mostly measured as total chlorinated hydrocarbons) has been detected using field-screening instruments in wells under construction throughout much of the 200-West Area since January 1987. These wellhead measurements are strongly affected by barometric pressure changes and are used to examine the distribution of carbon tetrachloride vapors, either above or below the Plio-Pleistocene layer. Most of the reported detections have been from below the Plio-Pleistocene layer, often in the capillary fringe zone just above the water table. Carbon tetrachloride has been detected in wells drilled adjacent to the carbon-tetrachloride-disposal facilities, and in some wells drilled west and south of the 216-Z-18 site. Carbon tetrachloride (as chlorinated hydrocarbons) has been detected both above and below the Plio-Pleistocene layer in wellheads located outside the maximum extent of the groundwater plume (Rohay et al. 1994).

4.3.3 Mock Tank Leak (Deep) Test Results

The discussion in Section 4.2.3 on electrical resistivity tomography, as illustrated with initial testing at the mock tank site, involved relatively shallow (10.7 m) electrodes. Results for deeper electrode installations tested in FY 1996 are presented here. The deeper installations were tested to evaluate the method over a greater depth interval and to develop an inexpensive electrode-deployment method.

4.3.3.1 Deployment of Probes

Westinghouse Hanford Company, in conjunction with Lawrence Livermore National Laboratory and Applied Research Associates, Inc., designed vertical electrode arrays that could be installed with cone penetrometers. After initial bench testing of several designs, field studies were conducted at the 200-East Area 105A mock tank site. Four arrays were placed to a depth of 30.4 m, each with 20 electrodes spaced every 1.5 m (Figure 4.3-13).

4.3.3.2 Simulated Leak Rate

A controlled 12-day infiltration test was conducted in which 11,140 L of 0.08 molar sodium chloride brine water were released. The release rate was varied from 30 to ~38 L/h. This concentration of salt is considered a conservative tracer for tank leak studies.

4.3.3.3 Imaging

The tomographic images produced between arrays B-2785 and B-2787 are shown in Figure 4.3-14. The distance between B-2785 and B-2787 is 9.14 m. It should be noted that the vertical image plane in Figure 4.3-14 is 8.2 m from the leakage point on the side of the tank. These images indicated no changes before initiating the leak, confirming a stable subsurface resistivity structure. The tomograms continued to show no change during the first 2 days of the simulated spill (May 30, 1996 and May 31, 1996) because of the time it took for the solution to migrate the 8.2 m (horizontally) to this vertical plane.

Small resistivity decreases appear near the top-central part of the image at a depth of 6 m after 3,650 L had been released on June 3, 1996. Between June 4, 1996 and June 10, 1996, these decreases grew stronger and extended deeper. By June 10, 1996 after 10,900 L of brine had been released, the plume reached depths of 21.3 m displaying distinct images of plume migration. Taking into account the 2 days for lateral migration of the plume, an estimate of the time for the plume to reach groundwater at 76.8 m is 36 days for a total release of 52,700 L.

A study of tomographic technical limitations, major safety issues, and logistical requirements was conducted to determine the possibility of installing a network of electrodes around a single-shell tank (Narbutovskih et al. 1996). For dry, arid regions, tomography can be very sensitive, detecting moisture changes as low as a few percent by volume (Daily et al. 1992; Daily and Ramirez 1995), making the potential for detecting or mapping small saturation changes viable.

4.4 Potential for Impacts to Groundwater

V. G. Johnson

This section discusses evidence for breakthrough, or transport, of residual soil-column contaminants to groundwater and possible driving forces. Much of the evidence for continuing impacts on groundwater from vadose-zone contamination is discussed in Chapter 6.0. The evaluation depends, to a large degree, on a synthesis of vadose-zone and groundwater-monitoring data to present a comprehensive picture of contaminant fate and transport. The significant results are summarized here but the bulk of the data is presented and discussed in Chapter 6.0.

4.4.1 Enhanced Mobilization of Strontium-90 in the 100 Areas

Elevated strontium-90 levels in groundwater noted from the 100-K and 100-N Areas in FY 1996 are apparently related to increased mobilization of material sorbed to sediments in the vadose zone. As discussed in Chapter 5.0, water levels have declined in much of the site. Thus, constituents that sorbed to sediments remain trapped in the vadose zone. Sorbed strontium-90 may be remobilized under certain conditions.

An increase in strontium-90 noted in the 100-N Area near the Columbia River is related to high-river stage that occurred during much of FY 1996. It is believed that the increase in water table near

the river caused by the high stage resaturated contaminated sediments, remobilizing strontium-90. Thus, though the strontium-90 flux to the river is expected in general to decline with time, considerable variation may be caused by changing conditions.

Highly variable concentrations of strontium-90 in groundwater were detected in well 199-K-109A, located near disposal facilities that received contaminated water from the KE reactor fuel-storage basin. As discussed in Chapter 6.0, the high levels of strontium-90 appear to be related to infiltration of water from a nearby leaking fire hydrant. The leak apparently remobilized vadose-zone contamination. In addition, ponding of surface runoff may also increase infiltration and mobilization of the vadose zone contamination. These two mechanisms probably occur at other parts of the site, leading to enhanced transport of other contaminants. It is likely that many of the water and sewer lines on site leak because of their age and construction method.

4.4.2 Single-Shell Tanks

The vadose-zone spectral gamma logging results for the single-shell tank farms previously discussed, as well as reevaluation of existing S-SX tank farms groundwater data, suggested that tank farm-related contaminants continue to migrate. The presence of indicators of tank waste in groundwater (e.g., technetium-99) beneath the S-SX tank farms also suggested that transport through the vadose zone to groundwater may occur. An occurrence report suggesting this possibility was issued in late 1995 for these tank farms. This section summarizes initial efforts to correlate vadose-zone-monitoring and -characterization data, source-chemical characteristics, and groundwater-monitoring data. Although the following discussion is focused primarily on the SX tank farm, similar conditions could exist for all of the single-shell tanks and related waste-handling systems, as well as for past-practices sites.

4.4.2.1 Vadose-Zone Gamma-Log Data

As discussed in Section 4.3.1, initial spectral gamma logging was conducted in the southern portion of the SX tank farm, where the largest recorded volume of tank-related leaks are known to have occurred. Spectral-gamma logs indicated that cesium-137 was the most readily detectable waste constituent and was present in several monitoring wells along the southwest side of the farm. Cesium-137 was also detected at the 38-m depth of several vadose-zone-monitoring wells in this area.

The initial spectral-gamma-log results prompted reevaluation of existing gross gamma log and groundwater data. The historical gross gamma log data revealed that at least one vadose-zone borehole (41-09-09, Figure 4.3-9) showed a regular pattern of increasing gamma-ray intensity over time from 1984 to the present. This pattern suggested that some type of continuing movement of tank waste in the soil or vadose zone was occurring at this location. Because cesium-137 is expected to migrate more slowly than the more-mobile waste constituents (e.g., nitrate and pertechnetate), the preliminary vadose-zone results suggested that the constituents could be at much greater depths. In addition, the occurrence of an anomalous pattern of technetium/uranium ratios in groundwater-monitoring wells, both within and adjacent to the tank farm, suggested that a source could exist from somewhere within the tank farms (Figure 4-4.1). The ratio of these two constituents, both of which are equally mobile in natural water, should be approximately uniform, regardless of their absolute concentrations, if they are

both from the same source. In addition, because fractionation occurred in different waste streams, the magnitude of the ratio should reflect different sources. As indicated in Figure 4.4-1, a narrow zone of anomalously high technetium/uranium ratios occurs immediately beneath the S-SX tank farm. The groundwater from adjacent monitoring wells and wastewater discharged to cribs surrounding this tank farm have relatively low ratios (average ratios for each adjacent crib are shown in open boxes next to each location as depicted in Figure 4.4-1). The technetium/uranium ratio in water-wash fractions of sludge samples from the S-104 tank were very high (>300), suggesting that a tank source should have a relatively high ratio. The highest ratio in groundwater was 200 and occurred in well 299-W23-1 near the S-104 tank. The wells with the high technetium/uranium ratios are also the wells with the highest technetium concentrations (up to 8,000 pCi/L).

4.4.2.2 Spatial Correlation Between Groundwater and Vadose-Zone Anomalies

The spectral gamma logging results for the SX tank farm (see Section 4.3.1.2) indicated that near-surface contamination approximated the area that includes the 10 tanks with known or suspected leaks. The highest near-surface soil contamination appeared to be located between the center and the south-west corner of the SX tank farm. The latter location includes the tanks with the largest-known leak volumes (SX-112 and SX-115) (see Section 4.3.1.2 for details). The highest subsurface contamination appeared to be near the west-central area of the SX tank farm (i.e., between tanks SX-108 and SX-109).

The identified soil-contamination zones only partially overlap the anomalous technetium/uranium ratios in groundwater. No groundwater-monitoring wells are present, however, along the west side of the SX tank farm. Distribution lines enter the S-SX tank farms from the east side; therefore, leakage from transfer lines and or distribution boxes would be the more likely influence beneath the east side of these farms. More information is needed to evaluate relationships between past tank leaks, vadose zone sediments, and groundwater contamination in these tank farms.

Nevertheless, based on available knowledge and expected behavior of mobile constituents, the following hypothetical pathways and transport processes are proposed.

4.4.2.3 Pathways and Causal Force

Hypothetical sources and migration pathways beneath the S-SX tank farms are illustrated in Figure 4.4-2. Pathways that could bypass the normal movement of moisture or liquid through the soil column are indicated in Figure 4.4-2a. Such paths are referred to as preferential pathways and could involve both natural features (such as clastic dikes) and more direct paths (such as along unsealed monitoring wells). Five such wells are located inside the tank farm fenceline, two of which are immediately adjacent to single-shell tanks. Clastic dikes are common in the 200-West Area and consist of silt and sand infillings with clay boundaries of variable width that pass vertically through the horizontal sedimentary layers. These features have been shown to be capable of transmitting liquids more rapidly than the adjacent sediments or soil column through which they pass (Fecht et al. 1994; Fecht and Weeks 1996).

Direct infiltration of natural precipitation can also serve as a driving force (indicated by downward vertical arrows above ground surface in Figure 4.4-2a and b). Calculations of natural infiltration rate, which is enhanced by the coarse gravel cover over the tank farms, suggest that an average rate of 10 cm/yr or more is possible. Localized infiltration in the soils near the tank perimeter could be greatly enhanced by runoff from the impermeable tank top (dome) that could tend to concentrate the infiltrating volume along the perimeter of the tank. This process could magnify the infiltration rate significantly in the immediate vicinity of tank leaks. The effective infiltration rate from this process could be several times greater than a uniform areal infiltration rate of 10 cm/yr. Surfacewater runoff moving over or through the tank-leak sites could then be carried into the older, unsealed, vadose-zone-monitoring wells or the adjacent groundwater-monitoring wells and thereby provide a more rapid transport to groundwater. If the mobilized tank waste followed a more direct path to groundwater, most of the fractionation caused by different migration rates would occur in the saturated zone (as indicated in Figure 4.4-2a). A more diffuse pathway through the entire soil column without a preferential pathway would involve fractionation with depth or distance (as suggested in Figure 4.4-2b). The latter instance would present more opportunity for ion-exchange reactions to occur between waste constituents in the migrating fluid and the soil. Major cationic-waste components, such as sodium, could be exchanged for the naturally occurring cations present in the soil column, depicted as follows:

$$2\ Na^{+} + Ca,Mg\text{-}[Soil] = Ca^{2+}, Mg^{2+} + 2\ Na\text{-}[Soil]$$

Given enough time (path length) for the exchange process, the replacement could be nearly complete by the time a hypothetical waste-/moisture-front mixture reaches groundwater. If so, then even though sodium is a major chemical constituent in tank waste, little, if any, may be present in the waste mixture that reaches groundwater. In addition, contaminants that migrate to groundwater under unsaturated flow conditions are more likely to be present at the very top of the aquifer.

4.4.2.4 Tank Waste Chemical Considerations

The first-cycle, aqueous waste stream generated from the reduction-oxidation process, was a multimolar sodium nitrate/nitric acid mixture containing sodium dichromate and permanganate to control the oxidation state of plutonium. After extraction of the uranium and plutonium, the concentrated nitric acid process stream was neutralized with sodium hydroxide and routed to the S-SX tank farm as "R" waste (Figure 4.4-3). The waste was highly radioactive and generated enough heat to boil. The vapor, containing most of the tritium generated in the process, was condensed and routed to the adjacent 216-S-3, 216-S-4, and 216-S-21 cribs. In addition to the in-tank phase-separation caused by boiling, high pH resulted in formation of precipitates of metal hydroxides, including uranium. Also, transfers within the tank farm and transfers from other tank farms included phosphate, which very likely contributed to the formation of insoluble uranium phosphates.

Because the chemistry of tank contents varies, predicting the chemical form of waste constituents is difficult. A reasonable alternative is to use the relative composition of the easily soluble fraction of tank-sludge samples (wash fractions) as an indicator of the mobile constituents and relative amounts. Both earlier tank-sampling efforts and more recent tank-characterization studies included tanks in the S-SX tank farms. The water-wash fraction of the sludge samples recovered from these tanks consists

of water-soluble constituents that include sodium (Na^+), nitrate (NO_3^-) chromate (CrO_4^{2-}), sulfate (SO_4^{2-}), aluminate (AlO_2^-), technetium-99 (TcO_4^-), traces of uranium (U[VI] complexes) and plutonium, large amounts of cesium-137 (Cs^+), and strontium-90 (Sr^{2+}) at concentrations of ~1/10 to 1/100th of the cesium-137 concentration (most of the strontium-90 was associated with the solid phase). These soluble constituents are assumed to have been available to migrate through the soil column from a tank leak. The vertical distribution in the soil column would depend on the affinity of the constituents for the soil matrix through which the aqueous waste migrated. As indicated in Figure 4.4-2b, for example, cesium-137 would be expected to travel more slowly than strontium-90, which should migrate more slowly than the highly mobile constituents.

The high pH and high temperature of the tank waste make dissolution of silica (in the portion of the soil column that initially contained the leak volume) likely to have occurred. Such reactions can also result in a gelatinous precipitate that could have impeded moisture migration through the original contaminated soil volume. This type of waste-form soil-matrix effect was indicated in Figures 4.4-2a and 4.4-2b as the initial soil volume occupied by the leak (shaded waste area immediately beneath and adjacent to the tank). The permeability of such a mass is unknown but should be less than the unaltered sedimentary material. Some fraction of the mobile constituents associated with the original leak volume, however, should be available for transport with any water or moisture movement through or adjacent to the mass.

The timing of the leaks may also be important because leaks that occurred early in the life of a tank would be less subject to additional chemical changes from tank transfers. In this regard, tanks SX-109 through SX-115 were of similar design and all are thought to have failed or leaked soon after they were placed into service.

4.4.2.5 Occurrence of Mobile Constituents in Groundwater

If the conceptual model of waste migration through the soil column to groundwater (see Figure 4.4-2) is correct, the hypothesized mobile tank-waste constituents should be present in groundwater beneath the tanks or downgradient from the tank farm. Based on the water-wash fraction of sludge samples from the S-SX tank farms, the most abundant mobile components that would appear in groundwater include sodium (or ion-exchange products, such as calcium and magnesium), nitrate, technetium-99, tritium, and chromate. The recent concentration history of these constituents in the nearest downgradient Resource Conservation and Recovery Act-monitoring well located near suspected tank-leak sources in the SX tank farm is shown in Figure 4.4-4. As suggested by this figure, the most likely major mobile constituents are present.

In addition to the above, preliminary numerical modeling for the S-SX waste management area assessment plan (Caggiano 1996a) of mobile constituent transport beneath the SX tank farm suggests that breakthrough to groundwater is possible due to enhanced infiltration and liquid density effects. The timing of the predicted peak concentrations of technetium-99 and nitrate is consistent with the observed concentration-time patterns shown in Figure 4.4-4. While the preliminary numerical modeling results are qualitative, they do suggest tank waste-related constituents in the soil column beneath the SX tank farm could have reached groundwater. If so, the observed downgradient contaminant

concentrations, as discussed in Section 6.9, are surprisingly low, considering the magnitude of the source(s) in the soil column beneath the tank farm. Reports documenting results of the modeling and other studies conducted for the S-SX groundwater quality assessment are due to Ecology in June 1997.

4.4.2.6 Enhanced Strontium-90 Mobility

If the divalent calcium ion is mobilized as a result of the sodium-exchange mechanism, strontium-90, which is chemically similar to calcium, could also be mobilized and migrate to a greater extent than expected under low-salt conditions. Serne and Legore (1996) demonstrated that the sorption of strontium-90 by Hanford Site sediments was greatly reduced with increasing calcium concentrations. Because groundwater-sediment interactions for calcium and strontium are quite similar, this ion-exchange enhanced mobility for calcium should also apply for strontium-90, and, thus, strontium-90 might be detectable in groundwater. However, strontium leakage from single-shell tanks such as in the SX tank farm may have been immobilized in the sediments immediately surrounding the leak before the higher concentration calcium "front" developed in the migrating liquid. Reactions that could immobilize the strontium-90 before the ion-exchange enhanced mobility becomes effective include precipitation of hydroxide/carbonates in the very alkaline near-tank environment and adsorption onto aluminum hydroxide precipitates also expected to form near the tank region. Adsorption onto hydrous oxides such as aluminum hydroxide is less affected by high ionic strength than clays and other aluminosilicates that constitute the primary adsorbents in natural soils. Nevertheless, the hypothetical possibility of enhanced transport of strontium-90 caused by the sodium-exchange mechanism may require additional evaluation.

4.4.2.7 Tritium

Tritium would be present in any tank leak and should be covariant with the other mobile constituents. Tritium, however, seems to deviate from this expectation. The plot shown in Figure 4.4-4(c) suggests that tritium in downgradient well 299-W23-15 could have peaked earlier than the other mobile constituents. This would require tritium, as the tritiated water molecule, to migrate faster than the other constituents. Because tritium can move through the vadose zone as a vapor phase, as well as by liquid-phase movement, perhaps the net movement is greater as a result of both processes. If so, then this could explain what otherwise appears to be a discrepancy in the expected covariance of mobile contaminants from single-shell tanks or related waste sources.

4.4.2.8 Utility Line Leaks

Corrosion of older iron pipes used for sanitary water and raw-water distribution occurs industry-wide. The proximity of such lines to single-shell tank farms and the periodic water-line repairs provide at least circumstantial evidence that potential water-line leaks could have occurred near past tank leak locations. Such sources would force movement of waste to groundwater. A sinkhole, for example, caused by a leaking sanitary water line developed in the south-central area of S tank farm. The water line causing the sinkhole was taken out of service in 1994. The leak rate and duration are unknown. Until surface indications appear, such leaks could go undetected for years.

This situation, combined with recently discovered (1994-1995) water-line leaks overlying past waste sites in the 100-K Area, which apparently resulted in transport of strontium-90 to groundwater, suggests utility-line leaks could be common at the Hanford Site. The consequences of a water-line leak can be significant if it occurs in the vicinity of past-practices sites, spills, or tank waste leak sites.

Older, carbon-steel, utility lines can leak as a result of either chemical corrosion or electrolysis or by freezing. The latter typically occurs at fire hydrants during winter. In addition, recent experience with iron releases to the treated effluent-disposal facility adds credence to the idea that the older cast-iron water-distribution lines at the Hanford Site undergo significant corrosion. During 1995 and spring 1996, for example, elevated iron concentrations (up to 3 ppm) occurred periodically in grab samples of effluent discharged to the 200 Areas treated effluent-disposal facility (Chou and Johnson 1996). This was in part attributed to corrosion of sanitary water lines that had been flushed after a period of nonuse. Tens of kilometers of water-distribution lines cross the Hanford Site and many are near or pass over waste sites. Considering the age of most of these lines, leaks are likely to occur.

4.4.3 Plutonium Finishing Plant Disposal Sites

As previously indicated in Section 4.1.2, both carbon tetrachloride and TRUs in the soil column beneath cribs and trenches that received liquid wastes are a concern as future and/or continuing sources. Evidence for a connection between soil-column sources and occurrences of these two major contaminants in groundwater are reviewed as follows.

4.4.3.1 Carbon Tetrachloride

Three major pathways for transport of carbon tetrachloride in the vadose zone to groundwater are possible: 1) sinking and lateral spreading of a heavier-than-air gas or vapor phase down to the top of the aquifer; 2) settling of a liquid phase or dense nonaqueous phase liquid down through the vadose zone over time, which eventually reaches the water column, dissolves, and settles through the saturated zone to an unknown depth; and 3) transportation of carbon tetrachloride dissolved in the aqueous phase either through disposal of aqueous waste or by contact between infiltrating recharge and residual dense nonaqueous phase liquid (Rohay et al. 1994). A schematic representation, or conceptual model, of the subsurface behavior of carbon tetrachloride beneath the 216-Z-9 trench is shown in Figure 4:4-5.

Piepho (1996) developed a numerical model to simulate the primary transport processes shown in Figure 4.4-5 using local stratigraphy and published input parameters for the source term and soil properties. Results of initial simulations suggested that over two-thirds of the added carbon tetrachloride could still be retained in the soil column (less the amount that has been removed) and that a dense nonaqueous phase liquid will continue to drain slowly through the vadose zone and settle in the underlying aquifer for years into the future. The initial modeling results indicated that the dense nonaqueous phase liquid dissolved in the groundwater and the depth of penetration was dependent on groundwater-flow rate. Additional modeling is needed to assess the influence of effective porosity and groundwater velocity. Nevertheless, the modeling results support the conceptualization of the

liquid-phase transport illustrated in Figure 4.4-5. The vapor-phase results were less definitive but suggested that gas-phase transport is secondary to dense nonaqueous phase liquid as a groundwater-contamination pathway.

Vertical and areal distribution of dissolved carbon tetrachloride discussed in Chapter 6.0 is consistent with a dense nonaqueous phase liquid-transport mechanism. If the Piepho (1996) numerical model predictions are correct, for example, slowly dissolving carbon tetrachloride distributed with depth in the aquifer should continue to emanate from the point of origin over time, with the highest concentrations at the source, and should result in dissolved carbon tetrachloride distributed with depth in the aquifer. If vapor-phase transport were a primary pathway, the top of the aquifer should have the highest concentrations and should decline rapidly with depth over a 1- to 2-m interval.

The plume map and vertical profiles shown in Figure 4.4-6 suggest there is a continuing groundwater source that produces somewhat uniform carbon tetrachloride concentrations with depth in the aquifer. A sinking dense nonaqueous phase liquid that drains slowly through the vadose zone and down through the aquifer could produce such a pattern. One alternative explanation for the depth-distribution pattern is that a secondary source of water passing near or through an area containing a dense nonaqueous phase liquid and soil-gas carbon tetrachloride could absorb this slightly soluble chlorinated hydrocarbon and carry it into the aquifer under saturated flow conditions. This would theoretically drive the contaminated water deep into the aquifer. Additional investigation of soil-gas-extraction dynamics and groundwater interactions is planned for FY 1997 and is expected to help resolve these issues. This information will be used to decide if soil-gas extraction should be continued or if an alternative remediation approach to remove more of the residual source remaining in the soil column should be designed to attenuate the predicted long-term dense nonaqueous phase liquid drainage to groundwater.

4.4.3.2 Transuranics

As previously indicated, liquid-waste streams associated with plutonium-process streams contained both carbon tetrachloride and isotopes of plutonium and americium. A complexing agent, tributyl phosphate, was used to extract plutonium from an aqueous phase (nitric acid) into an organic phase (carbon tetrachloride). A subsequent step involved back-extracting the plutonium into dilute nitric acid. When the tributyl phosphate became degraded (converted to dibutyl phosphate), the dibutyl phosphate-bound plutonium remained in the organic phase. When degradation reached this point, the process liquids were discharged to soil-column-disposal sites, primarily the 216-Z-1A crib and the 216-Z-9 trench. The liquid-waste streams thus discharged to these facilities were highly acidic and contained both carbon tetrachloride with plutonium (and americium) as an organometallic complex. In this form, the TRUs may have moved with the carbon tetrachloride phase.

The 216-Z-1A crib was designed as a specific retention crib intended to hold or contain the liquid waste in the vadose zone. The general policy for specific retention cribs was to restrict the disposal volume to 10% of the calculated void space in the soil column directly beneath the crib. Although the trench received the same waste stream as the crib, the volume of liquid waste discharged exceeded the calculated soil-column pore space by ~40%. Considering the chemistry of the TRUs, and the

predicted distribution of the dense nonaqueous phase liquid shown in Figure 4.4-5, it is likely that the TRUs could have been transported to groundwater at least beneath the trench.

An extensive soil-column characterization (Price et al. 1979) was conducted at the 216-Z-1A crib in the mid-1970s and revealed that plutonium and americium were distributed at high concentrations (>100,000 pCi/g) to depths of 20 to 30 m (Figure 4.4-7). The status of the TRUs beneath this crib and the trench is unknown. It is clear, however, that the complexed plutonium and americium were not as mobile as the major cocontaminant, carbon tetrachloride. Detectable TRUs in groundwater, for example, have been found in only one well (299-W15-8) near the Plutonium Finishing Plant cribs. Detectable but relatively low concentrations (<8 pCi/L) of americium-241 and lesser amounts of plutonium-239 have been measured in this well (spectral-gamma logs of this well confirmed the presence of TRUs to depths down to ~39.6 m and a maximum soil plutonium concentration of 300,000 pCi/g).

One possibility for the apparent low mobility of TRUs in the dense nonaqueous phase liquid/complexant mixture is that the complexing agents, tri- and dibutyl phosphates, readily degrade in the soil column. If so, then the americium and plutonium would be adsorbed by the soil after degradation. Alternatively, other soil-chemical reactions may have occurred (Price et al. 1979, Serne et al. 1996). Because these alpha emitters also emit gamma rays, their presence can be detected using high-resolution spectral gamma logging equipment. Evidence of movement, thus, can be checked over time by periodic borehole logging in the available vadose-zone-monitoring structures. Spectral-gamma logs obtained in 1992 demonstrated that the americium and plutonium were detectable by high-resolution spectral gamma logging methods. More complete or continuous spectral-gamma profiles, however, are needed for comparison with previous depth-profile data to determine if changes have occurred over time. With this information, some assessment of the mobility status of the americium and plutonium could be made. It should also be noted that a coarse gravel cover was placed over the 216-Z-1A crib in 1992. Consequently, as previously discussed for the single-shell tank farms, enhanced infiltration of natural precipitation through the gravel covers could cause some downward movement of residual mobile contaminants.

4.5 Discussion

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The vadose zone contamination and related transport processes considered in this chapter influence the interpretation of current groundwater contaminant data in Chapter 6.0 and numerical modeling of long-term groundwater quality at the Hanford Site in Chapter 7.0. The most significant findings, based on the foregoing results and considerations, follow.

Implications of spectral gamma logging results. Spectral gamma-ray logging observations at past-practices soil-column-disposal and tank farm sites suggest that:

- gamma-emitting radionuclides (e.g., cesium-137 and cobalt-60) can extend (laterally) well beyond the disposal site

- radionuclide movement can apparently continue at some sites long after termination of disposal activities.

The extent of lateral movement (several tens of meters from the point of release in some cases) depends on the particle or grain-size variation with depth. The greatest lateral movement occurs at disposal sites where the point of release occurs in coarse sand and gravel underlain by a fine sand or silt layer. Improvements in vadose-zone contaminant transport modeling can be made by inclusion of this type of stratigraphic detail. Lateral contaminant spreading may also be an important consideration in setting compliance boundaries for groundwater-monitoring wells. In the latter case, wells set too close to a disposal structure may intersect vadose-zone contaminants or may miss the zone where wastewater mixes with ambient groundwater.

Vadose zone gamma log monitoring data also indicate there is some type of continuing movement of cesium-137 at a depth of ~20 to 25 m beneath some single-shell tanks in the SX tank farm. Possible driving forces considered to account for this movement include leaking utility lines and enhanced infiltration of natural precipitation. Preliminary numerical modeling results suggest it is possible for mobile constituents to have reached groundwater as a result of enhanced natural infiltration.

Subsurface moisture dynamics. A simulated tank leak in the 200-East Area using electrical resistivity tomography methods indicate that relatively small volumes (<50,000 L) can percolate to depths of >30 m in a relatively short time (tens of days). These observations suggest there may be textural or stratigraphic discontinuities that enhance downward vertical movement (preferential flow or "fingering") through the coarse sand unit (Hanford formation) in which the test was conducted. The observations increase our understanding of moisture movement through the vadose zone and underscore the importance of textural features in controlling contaminant transport through the vadose zone to groundwater in Hanford Site waste management areas.

Stability of TRUs in the soil column. The relatively deep (~30 to 40 m) and large inventory of TRU radionuclides released to Plutonium Finishing Plant soil-column-disposal sites in a complexed form until the mid-1970s is apparently stabilized in the soil column. This suggests degradation of the complexing agent (dibutyl phosphate) or some other chemical reactions occurred that immobilized the initially mobile TRU organic complex. Evaluation of the sorptive status of TRUs beneath these cribs would be needed to differentiate among plausible immobilization hypotheses.

Status of carbon tetrachloride in the soil column. Numerical modeling results suggest that long-term drainage of a dense nonaqueous liquid phase of carbon tetrachloride through the soil column may continue tens of years following termination of input. This scenario is supported by the continuing presence of high dissolved carbon tetrachloride in groundwater in the immediate vicinity of the Plutonium Finishing Plant soil-column-disposal sites 20 years after termination of disposal operations. A dense nonaqueous-phase liquid source that drains slowly through the vadose zone to groundwater will continue to be one of the most significant groundwater-contaminant sources in the 200 Areas. However, as suggested by soil-gas-monitoring results, there is a significant decline in soil-gas concentrations, and associated mass reduction, of carbon tetrachloride in the vicinity of the Plutonium Finishing Plant cribs as a result of the remediation efforts in this area.

Continuing sources of water in the vadose zone. Artificial sources of water such as leaking fire hydrants, leaking utility lines, and ponding of surfacewater runoff were identified in the 100-K Area and in some of the single-shell tank farm areas. Such occurrences may be indicative of possible driving forces at other waste sites that are close to utility lines. In addition, enhanced infiltration of natural precipitation by the use of coarse gravel covers over waste sites can also contribute to continued transport of residual (mobile) contaminants to groundwater.

Vadose zone contaminant sources and transport processes discussed for the selected waste-storage and -disposal sites in this chapter should be relevant at other Hanford Site past-practices and regulated waste-disposal sites that were not reviewed at this time (e.g., low-level waste burial grounds). The rate of movement of residual soil-column contaminants beneath any vadose zone waste site will depend on contaminant chemistry, stratigraphy, and drainage through the vadose zone. These factors will now become the primary controls on any remaining vadose-zone sources of groundwater contamination because untreated wastewater discharges to the ground were terminated in 1995.

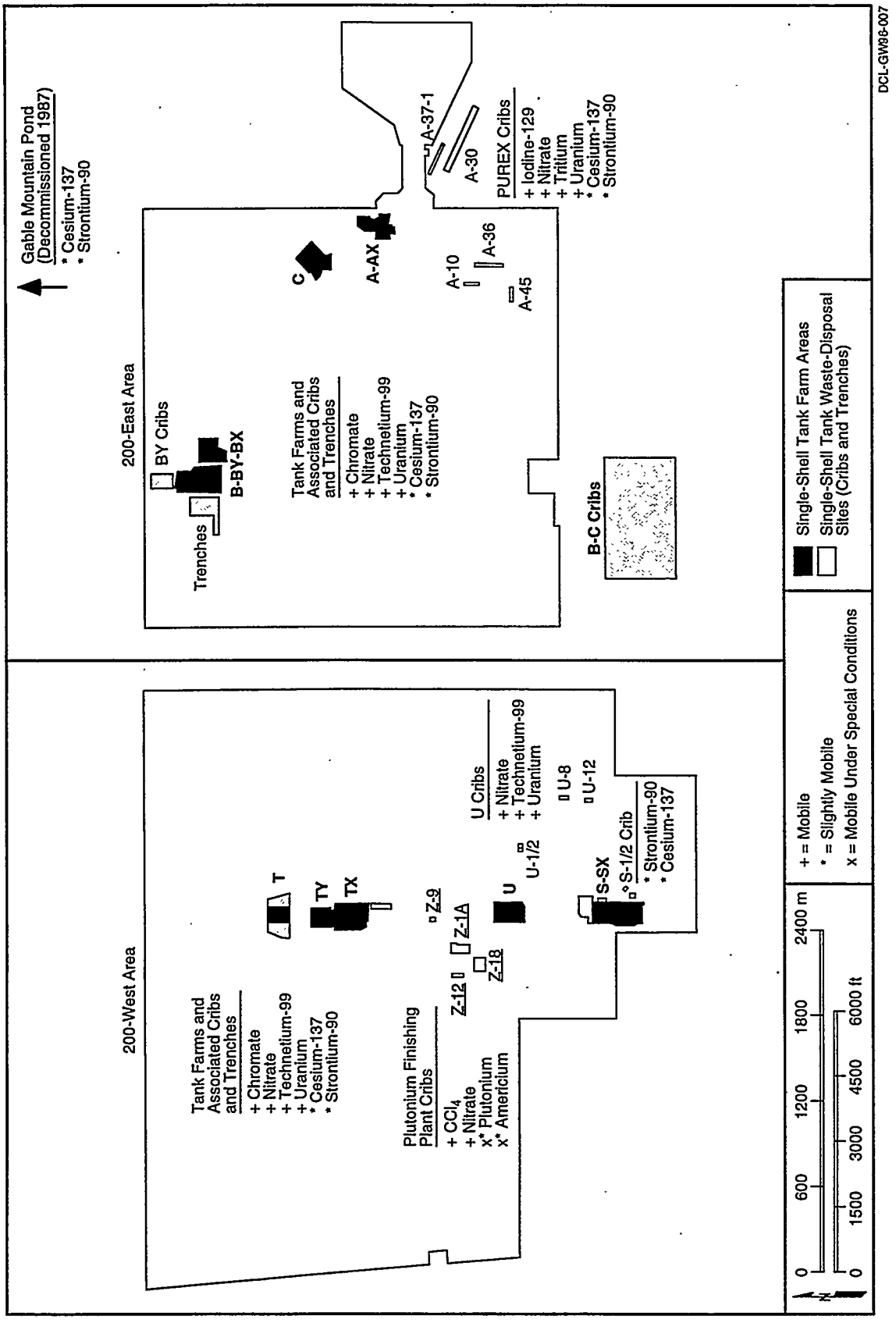


Figure 4.1-1. Major Vadose-Zone-Contamination Sites

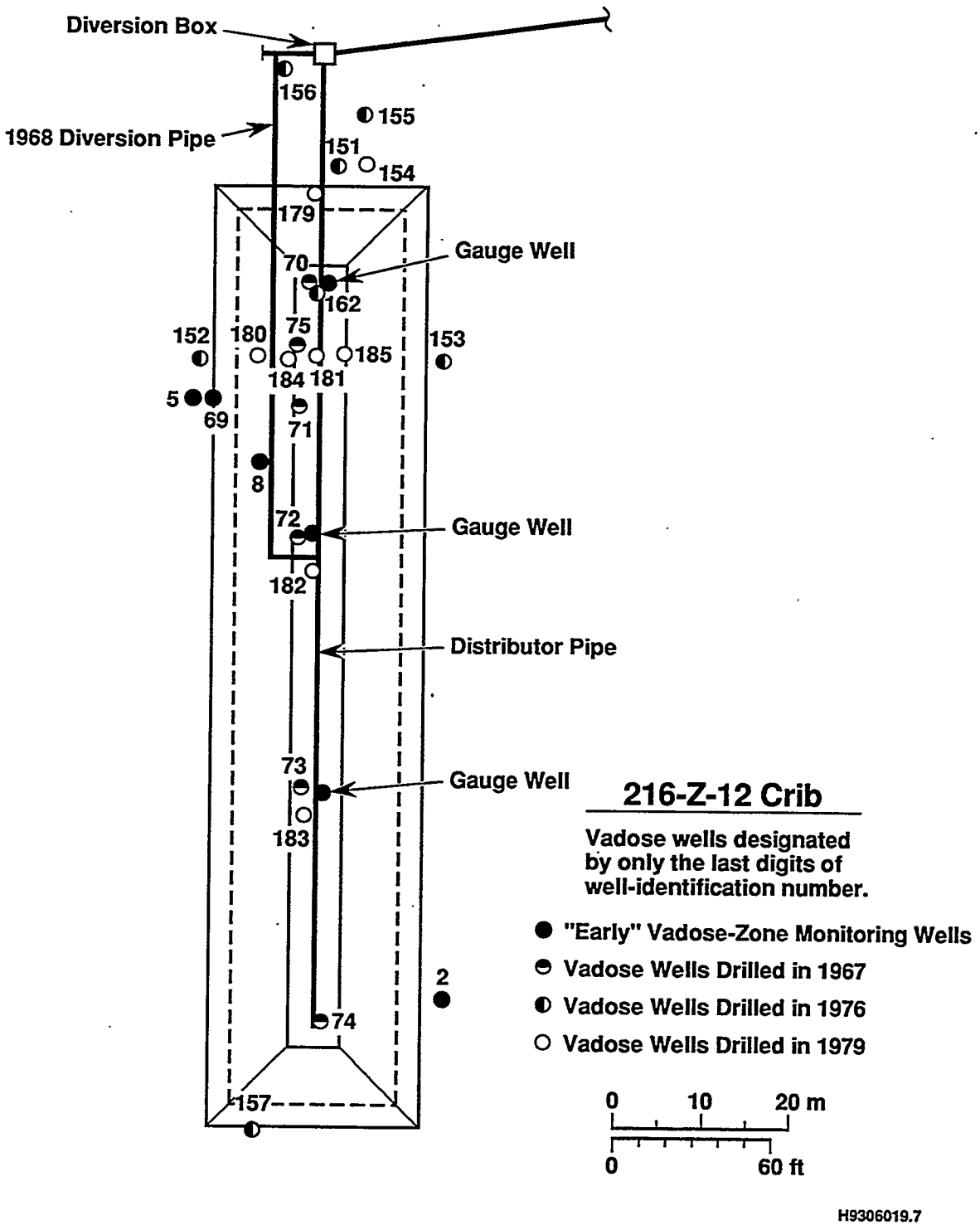


Figure 4.2-1. An Array of Older Type Vadose-Zone Wells

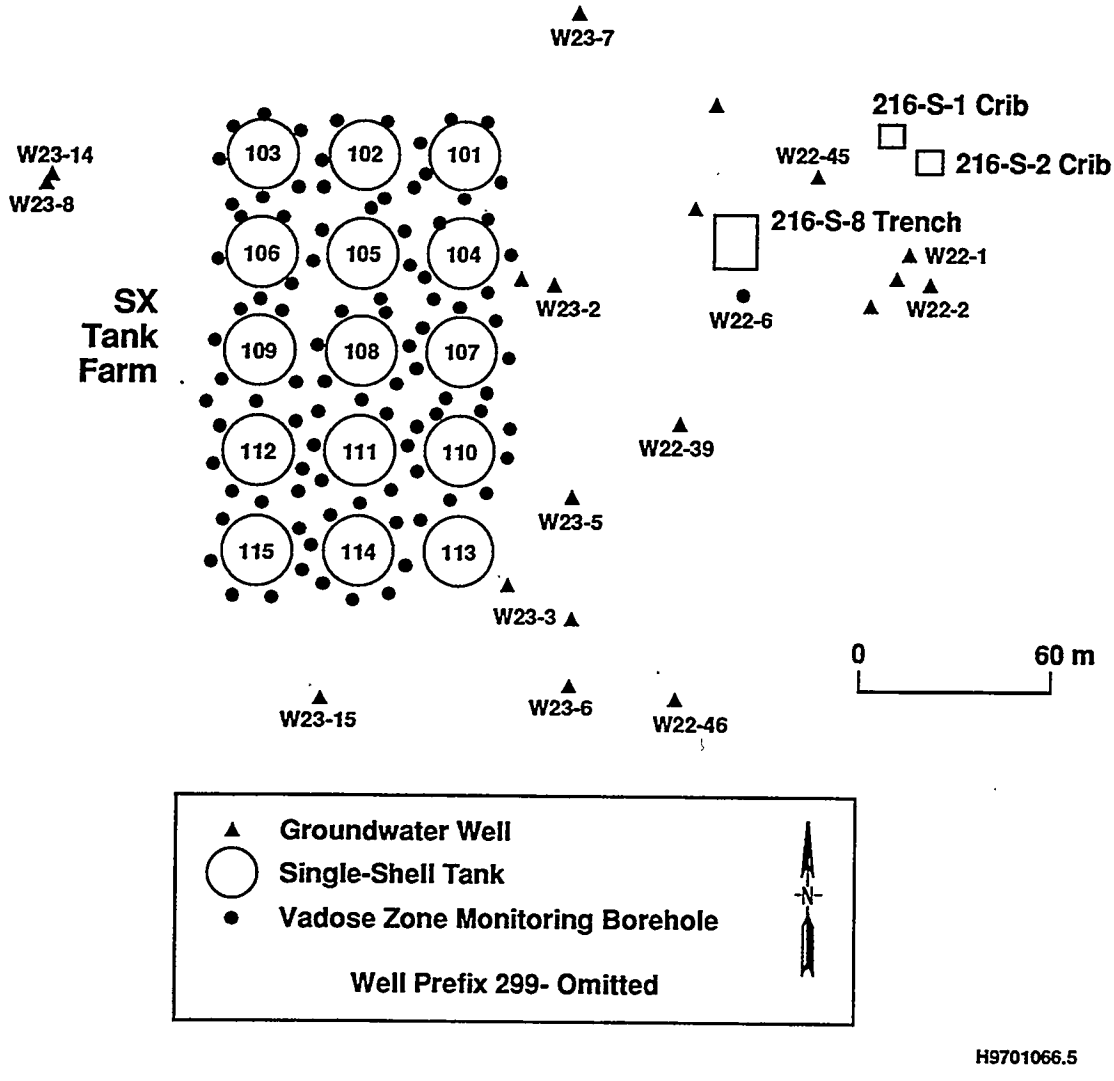


Figure 4.2-2. Map of the SX Tank Farm Area

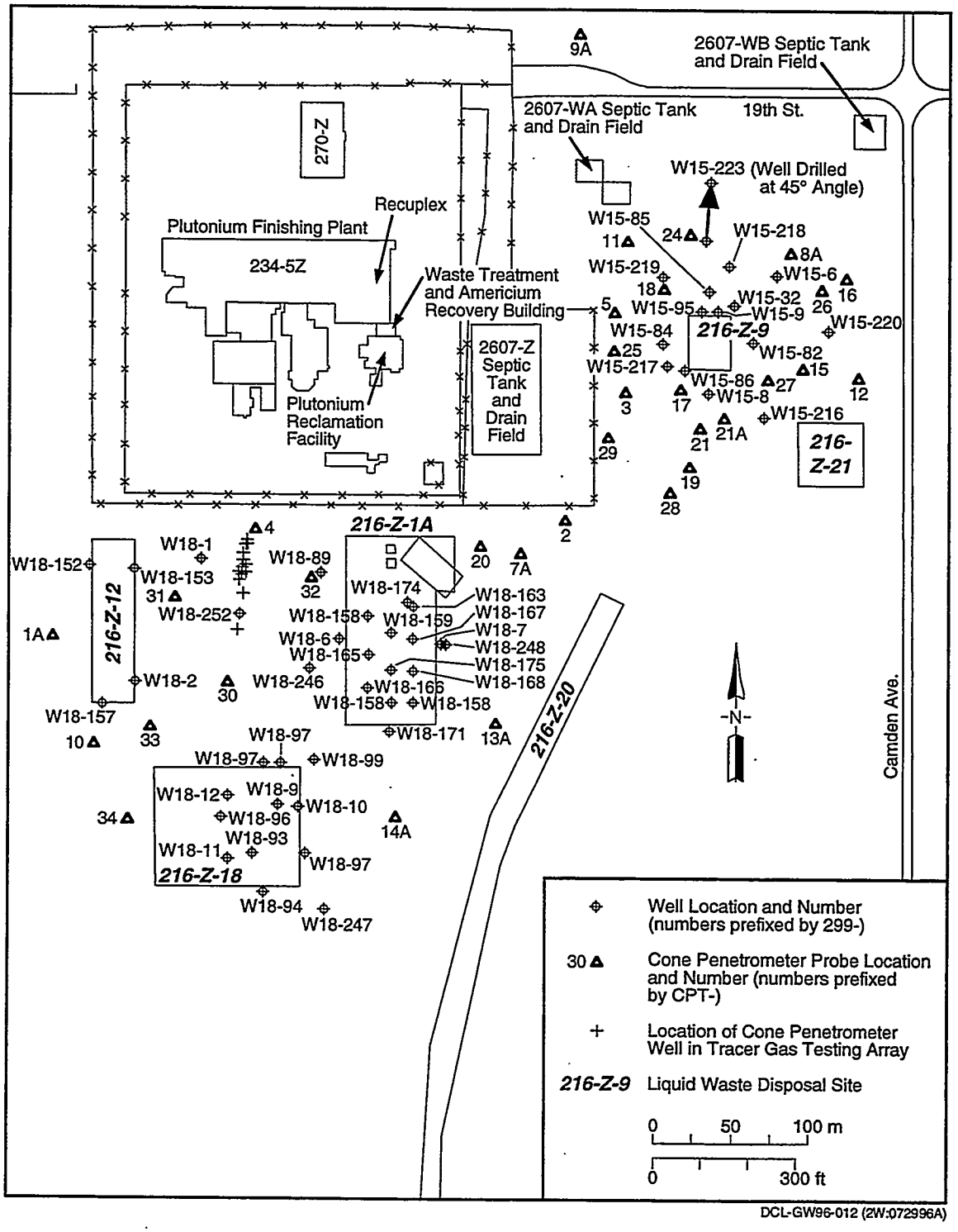


Figure 4.2-3. Location of Wells and Deep-Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site

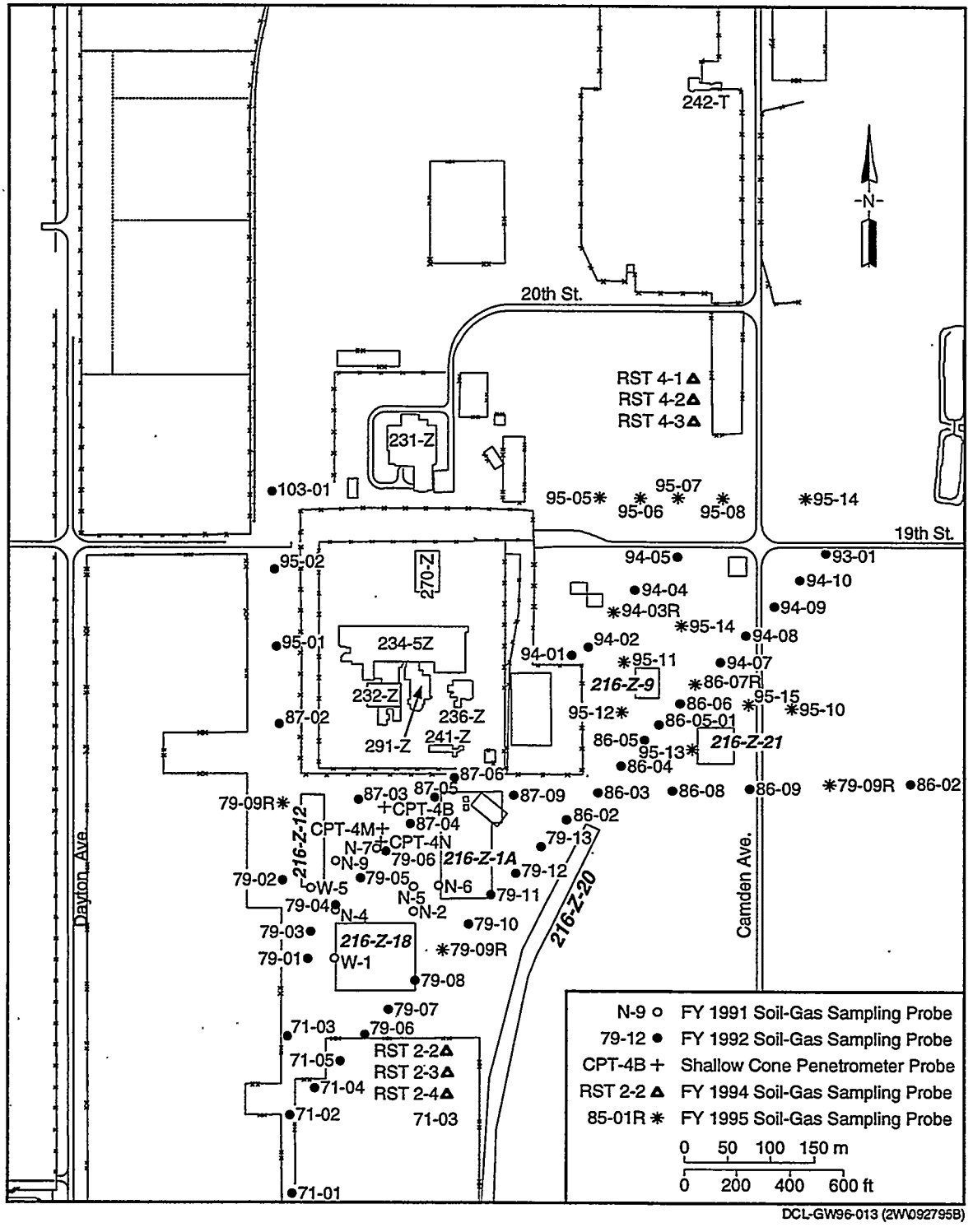


Figure 4.2-4. Location of Shallow Soil-Gas Probes at the Carbon Tetrachloride Vapor-Extraction Site

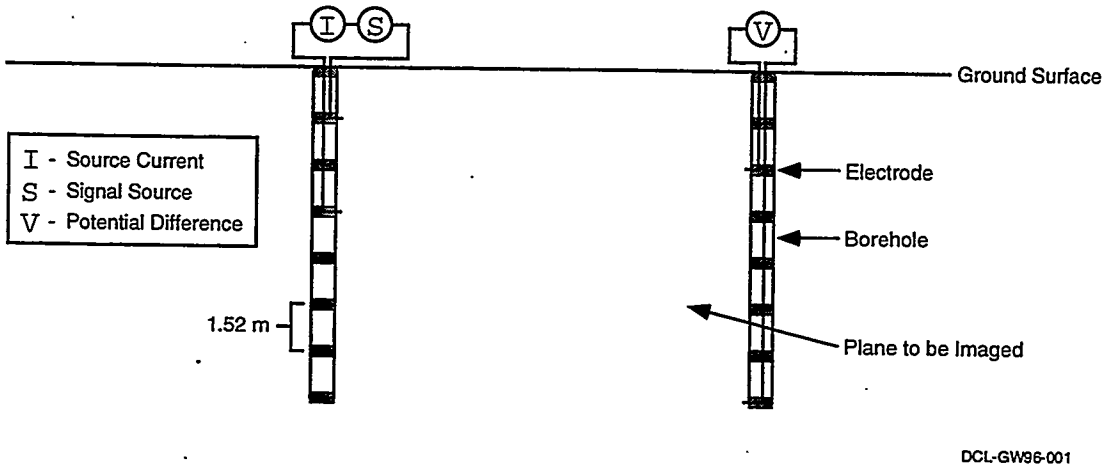


Figure 4.2-5. Schematic of an Electrical Resistivity Tomography System (after Ramirez et al. 1993)

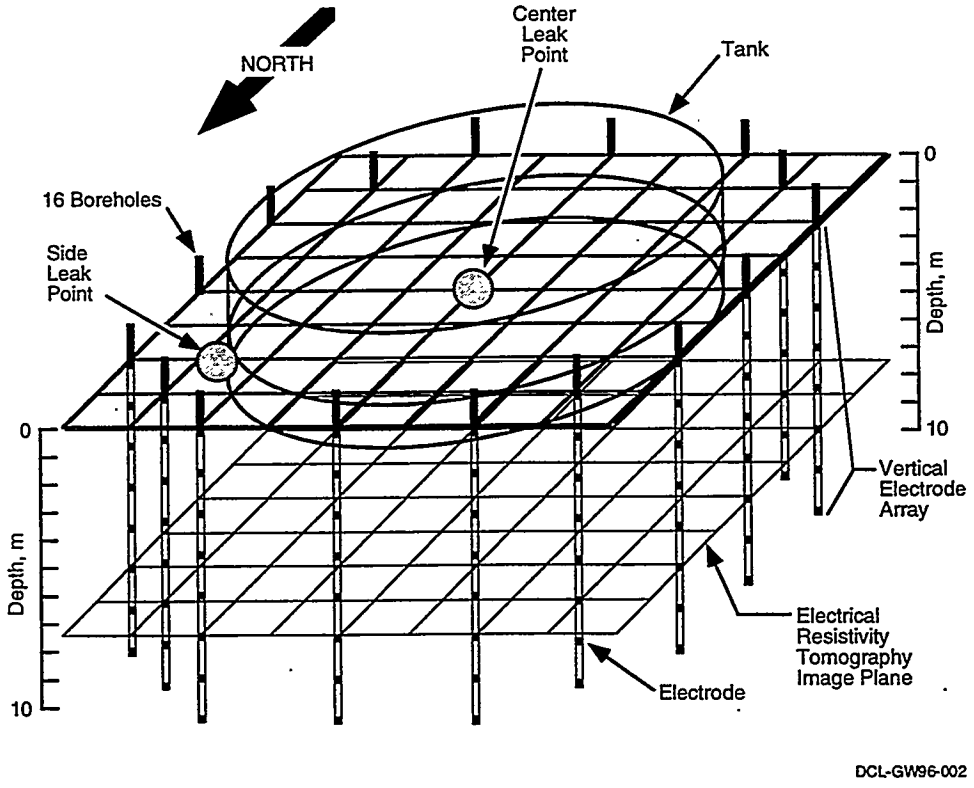


Figure 4.2-6. Schematic of the 200-East Area 105A Mock Tank Site (after Ramirez et al. 1995a). This site consists of a 5-m-dia. steel tank with the lower 2 m below ground surface. The tank contains two built-in leak points, one on the side and one in the center. Sixteen vertical electrode arrays surround the tank, each array having 8 electrodes spaced < 1.52 m apart.

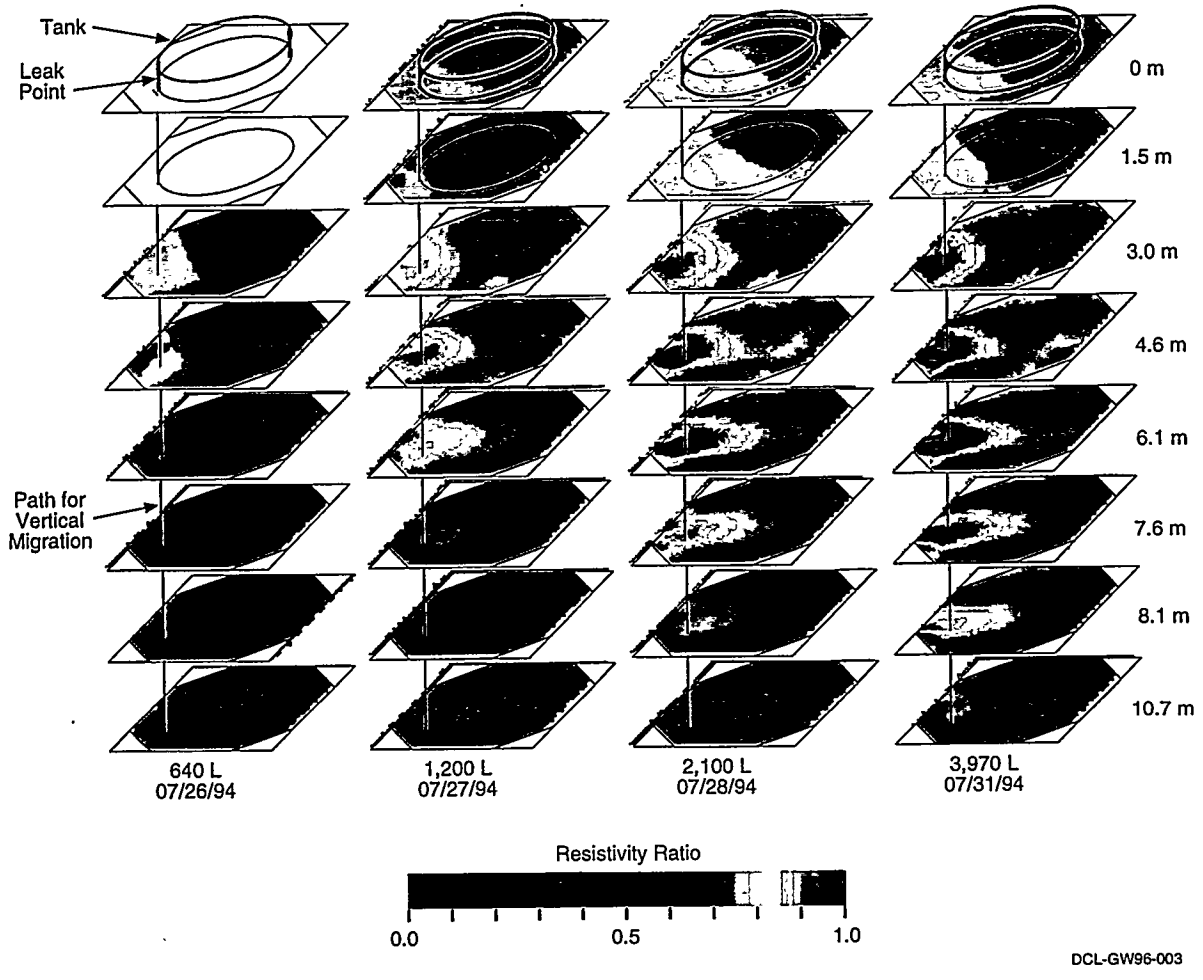


Figure 4.2-7. Time Series of Horizontal Two-Dimensional Tomographs (after Ramirez et al. 1995a). The tomograph columns show how the electrical resistivity of the soil decreased during the leak located at the side of the tank. The red color indicates portions of the images that remained unchanged. The cooler colors, to the left of red on the color scale, indicate portions of the subsurface where the leak was migrating through the soils. A vertical black line indicates the trajectory the liquid would have to follow if it moved straight down.

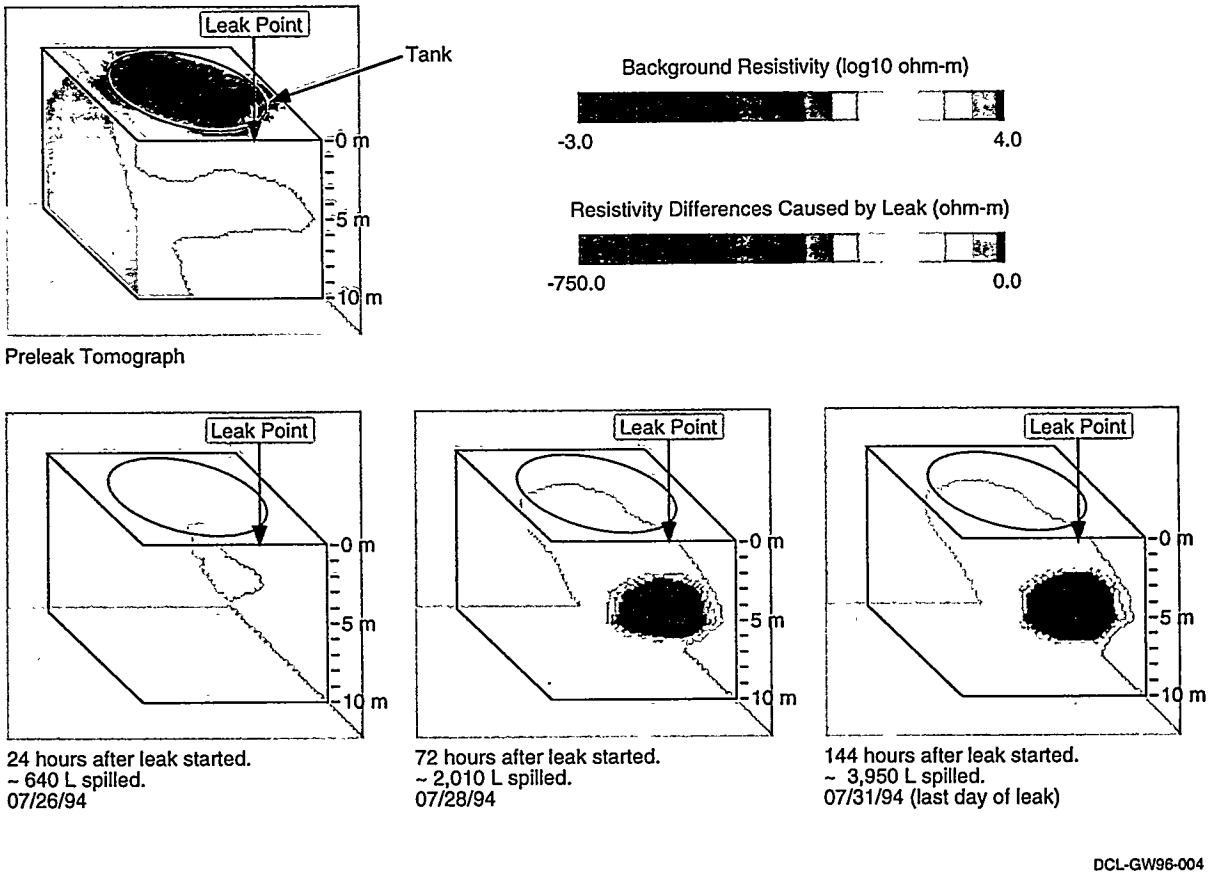


Figure 4.2-8. Tomograms Imaging the Three-Dimensional Resistivity Changes Caused by the Side Leak (after Ramirez et al. 1995a). The bottom three images are transparent where observed resistivity differences were less than 150 ohm-m. Cooler colors, to the left of red on the scale, indicate the portions of the image that had resistivity decreases associated with the leak.

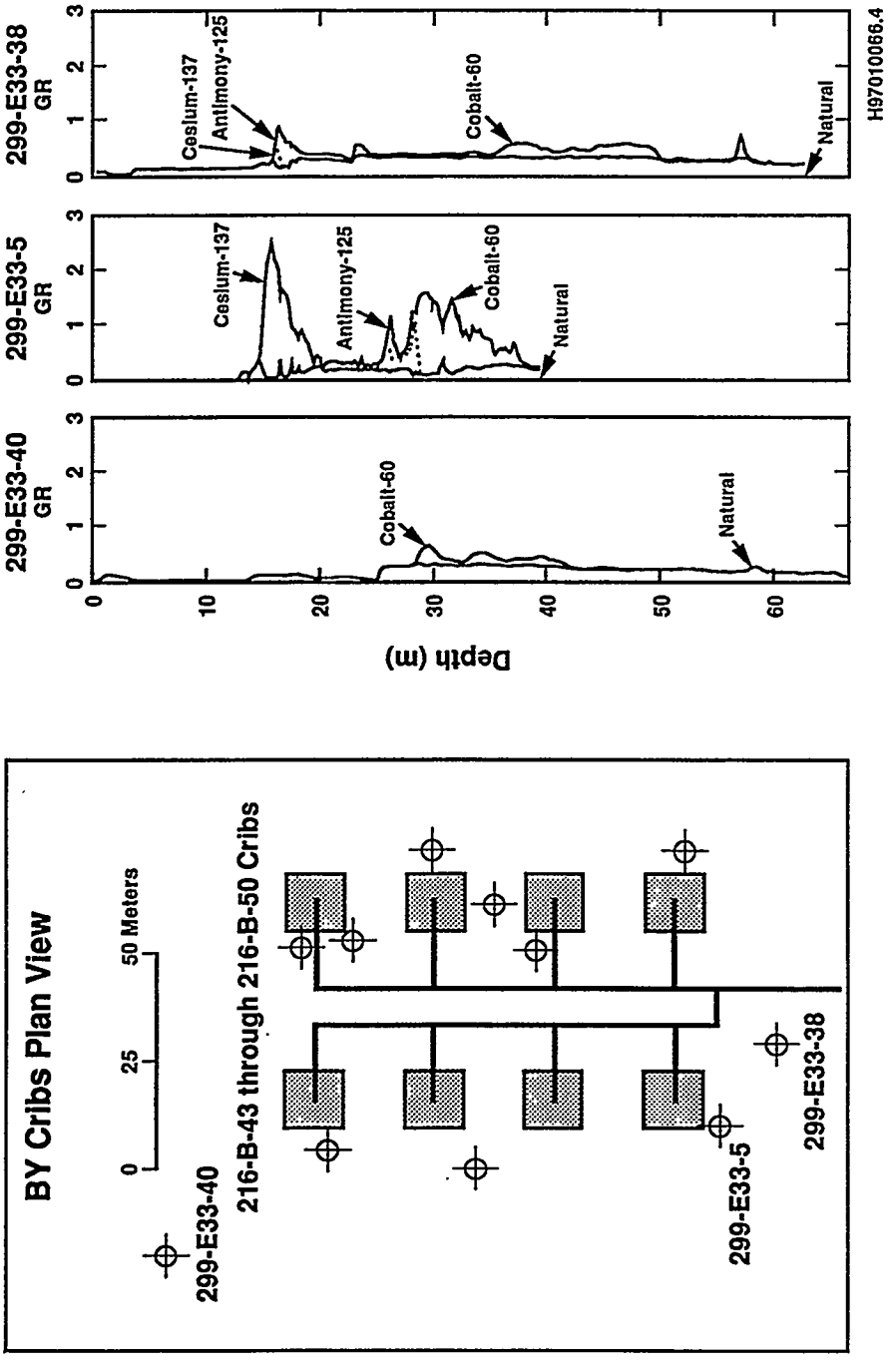


Figure 4.3-1. Gamma Log Survey of BY Cribs Monitoring Wells 299-E33-5, 299-E33-38, and 299-E33-40 (bottoms of cribs are ~4.5 m)

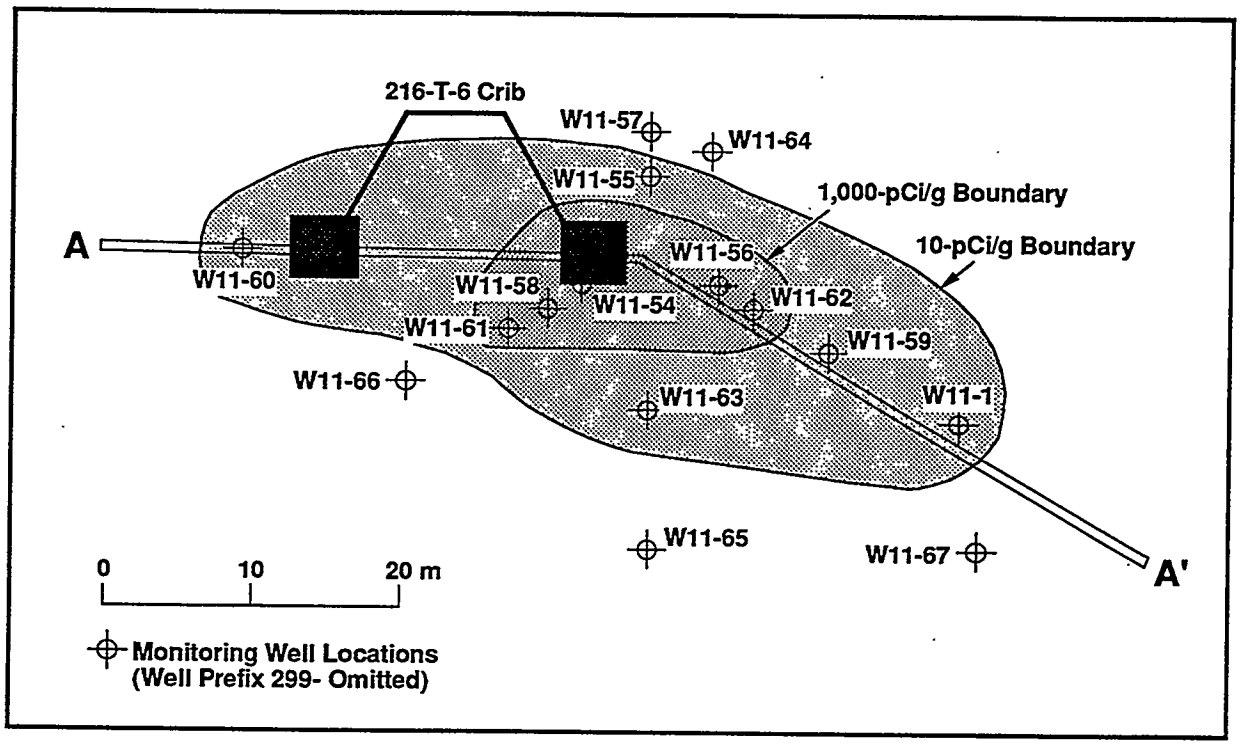


Figure 4.3-2. Contamination (Cesium-137) Associated with 216-T-6 Crib (plan view)

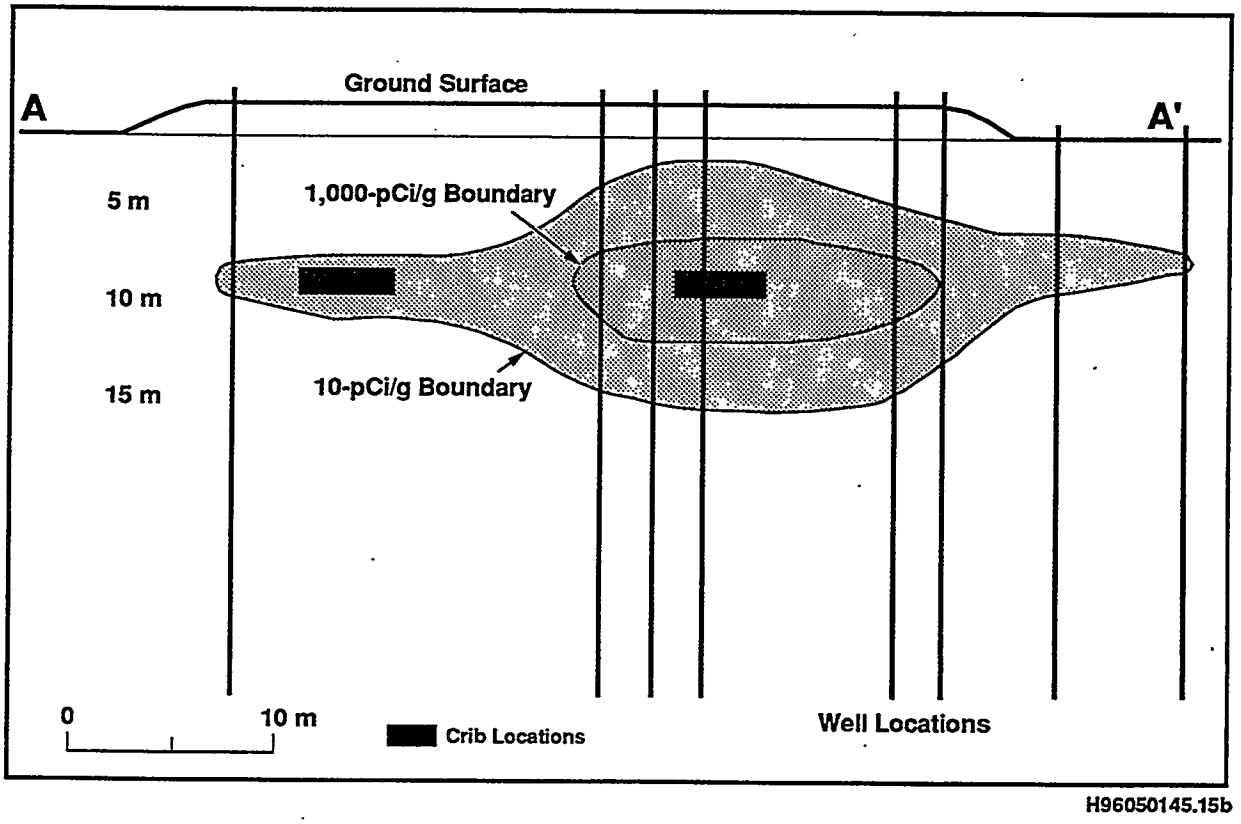


Figure 4.3-3. Contamination (Cesium-137) Associated with 216-T-6 Crib (vertical cross section)

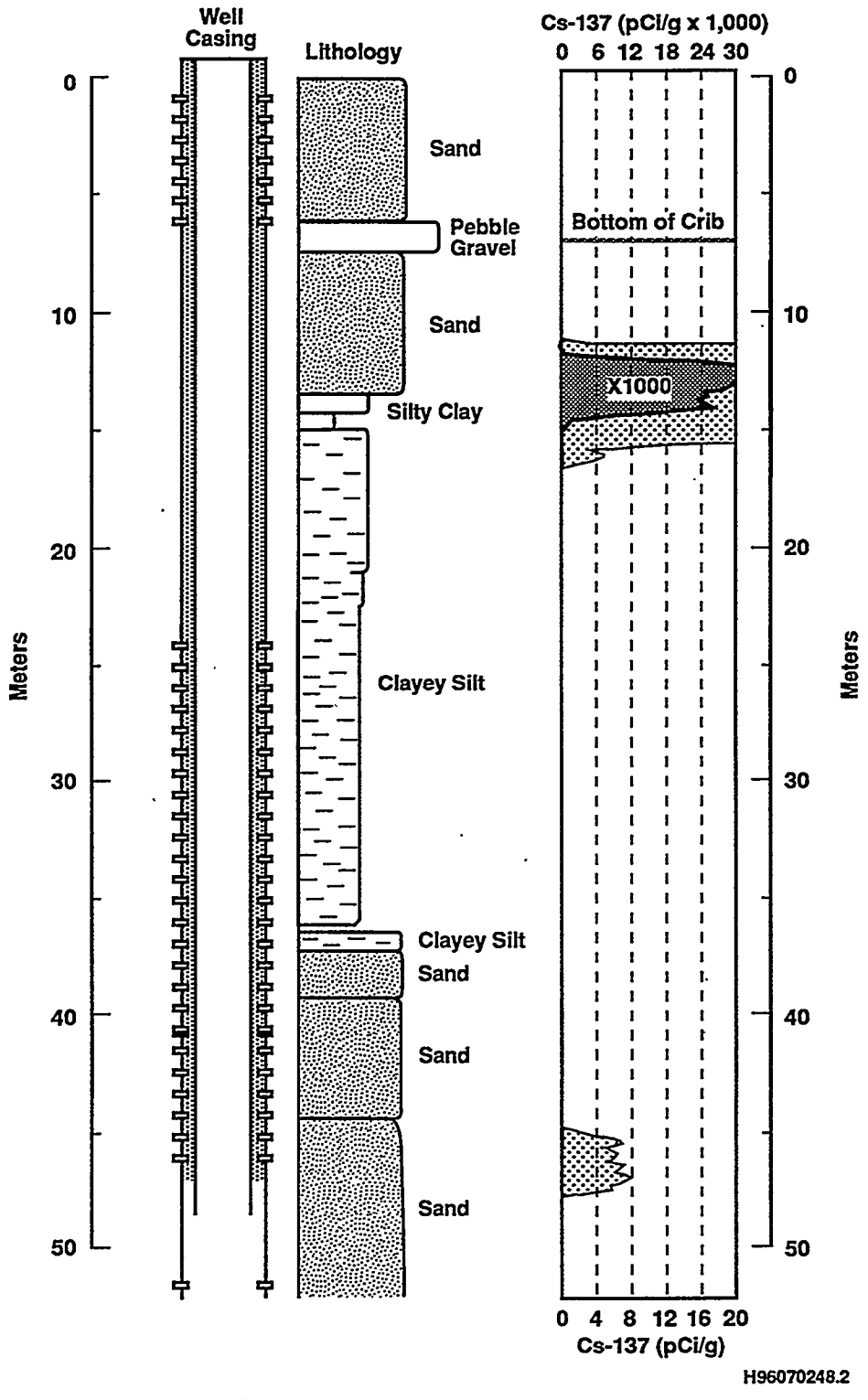


Figure 4.3-4. Stratigraphy and Gamma Log Survey Plot for the 216-T-19 Crib (Well 299-W15-4)

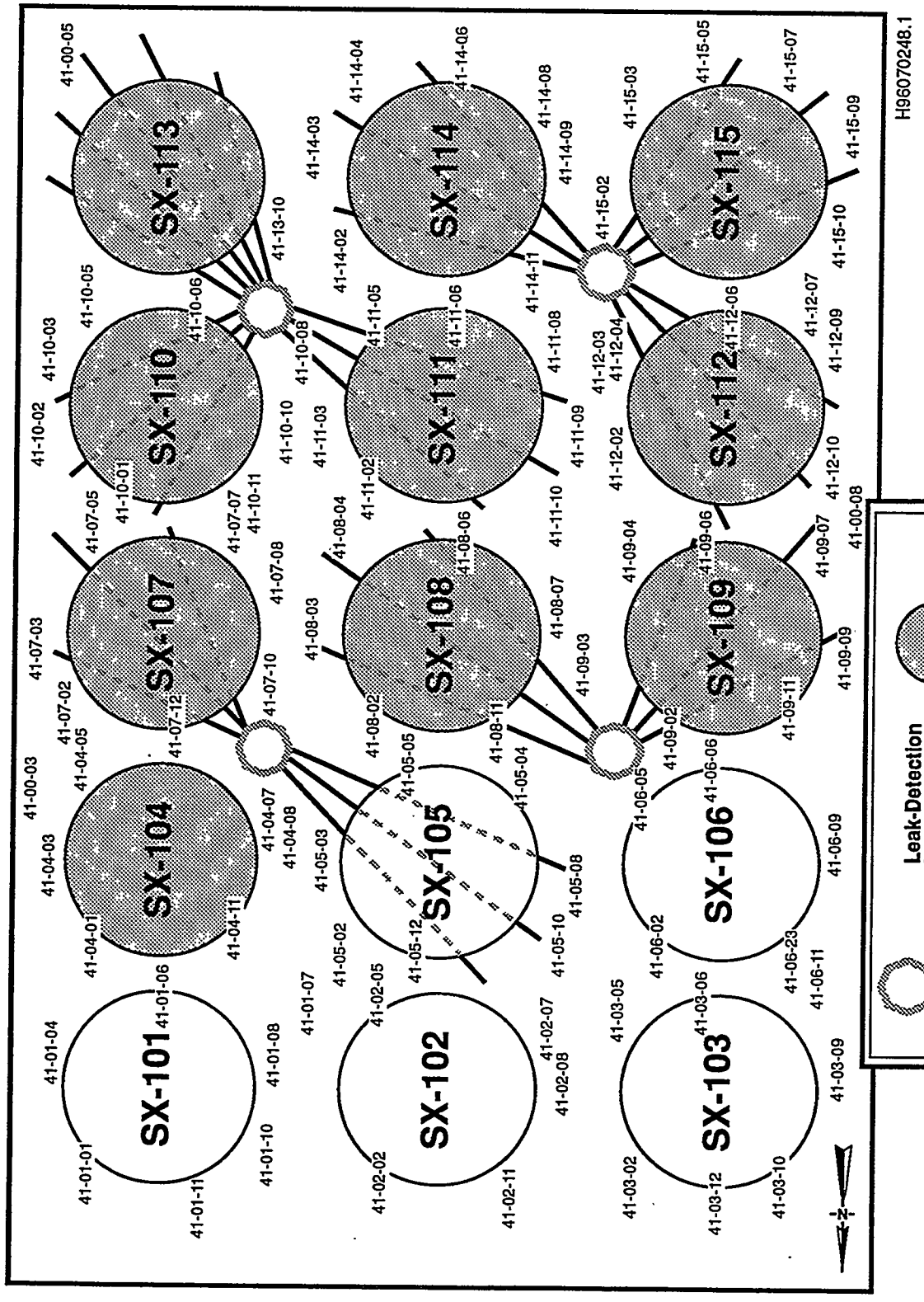


Figure 4.3-5. Plan View of the SX Tank Farm Showing Locations of Boreholes and Laterals

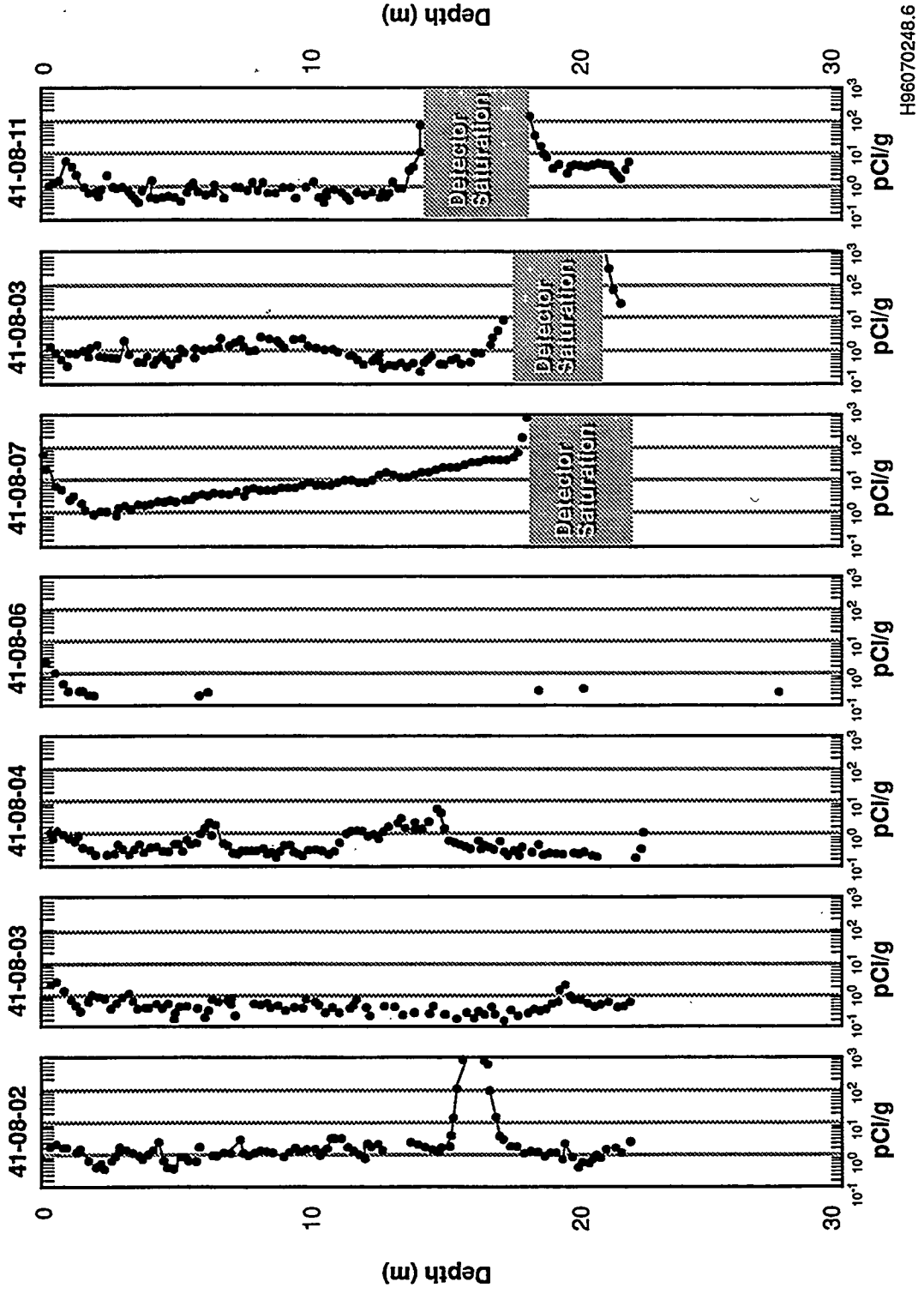


Figure 4.3-6. Cesium-137 Contamination in Boreholes Around Tank SX-108

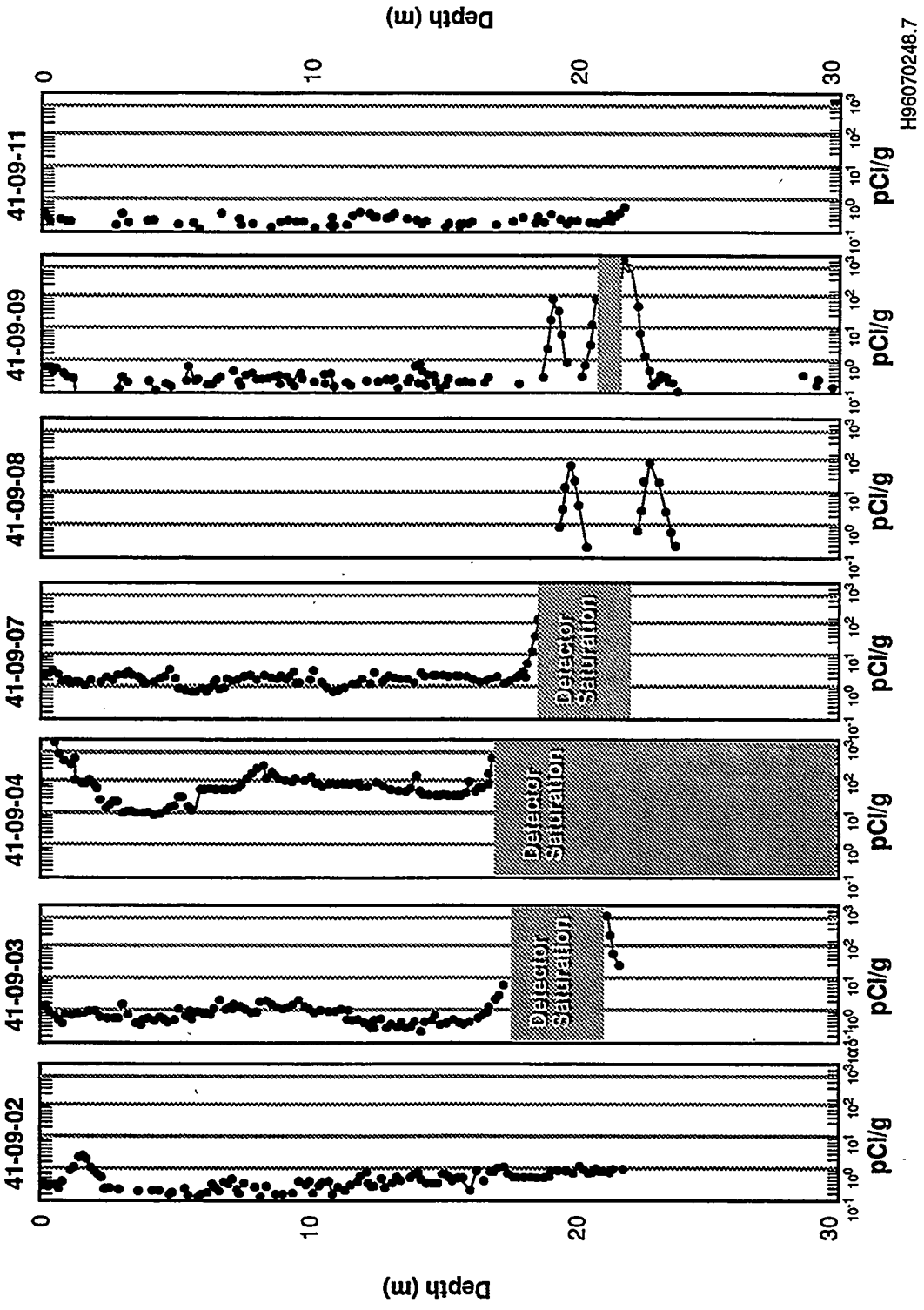


Figure 4.3-7. Cesium-137 Contamination in Boreholes Around Tank SX-109

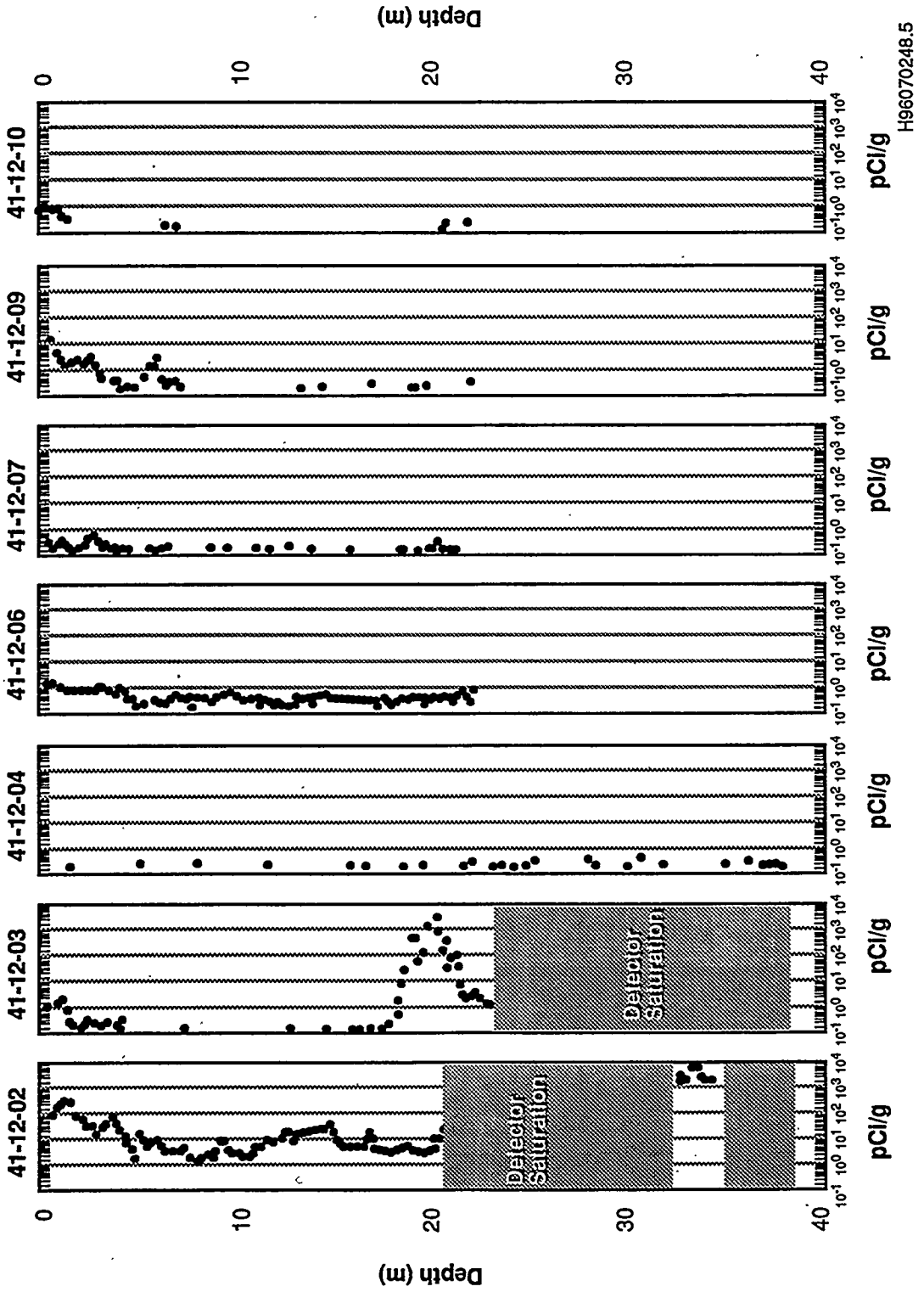


Figure 4.3-8. Cesium-137 Contamination in Boreholes Around Tank SX-112

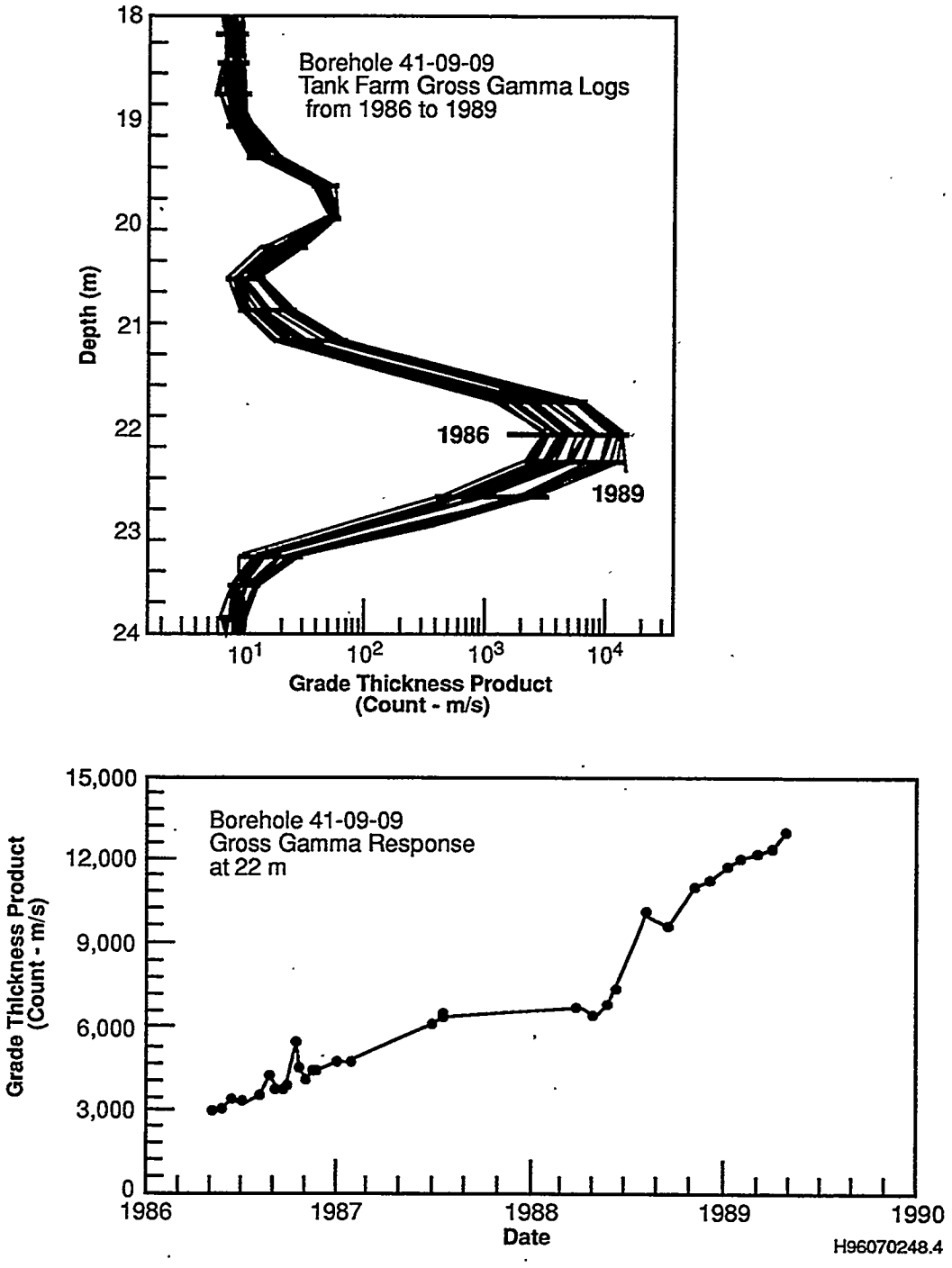


Figure 4.3-9. Gross Gamma-Log History Summary for Borehole 41-09-09 (after DOE 1996b)

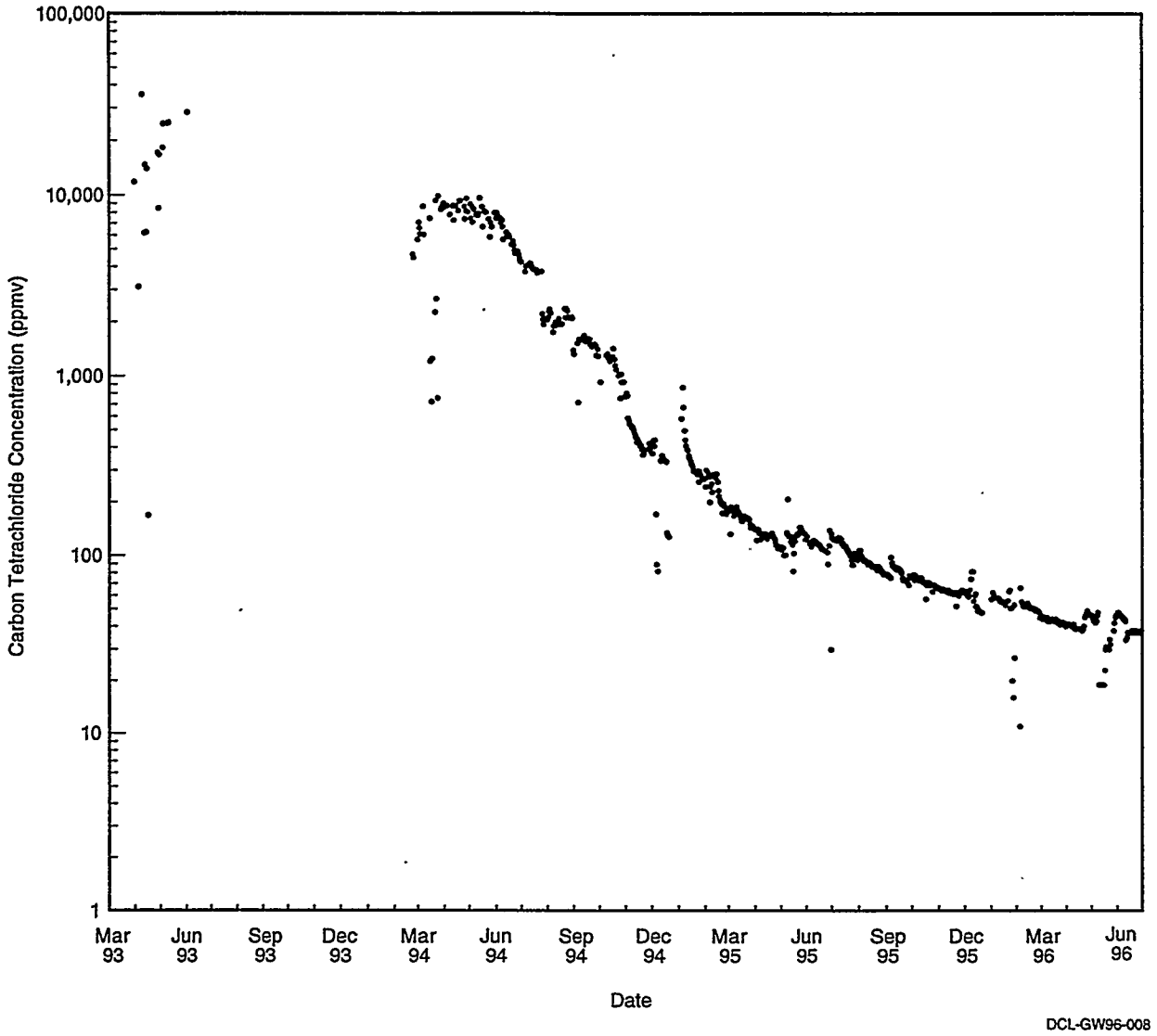


Figure 4.3-10a. Carbon Tetrachloride Concentrations in Soil Vapor Extracted from 216-Z-9 Well Field, March 1993 - June 1996

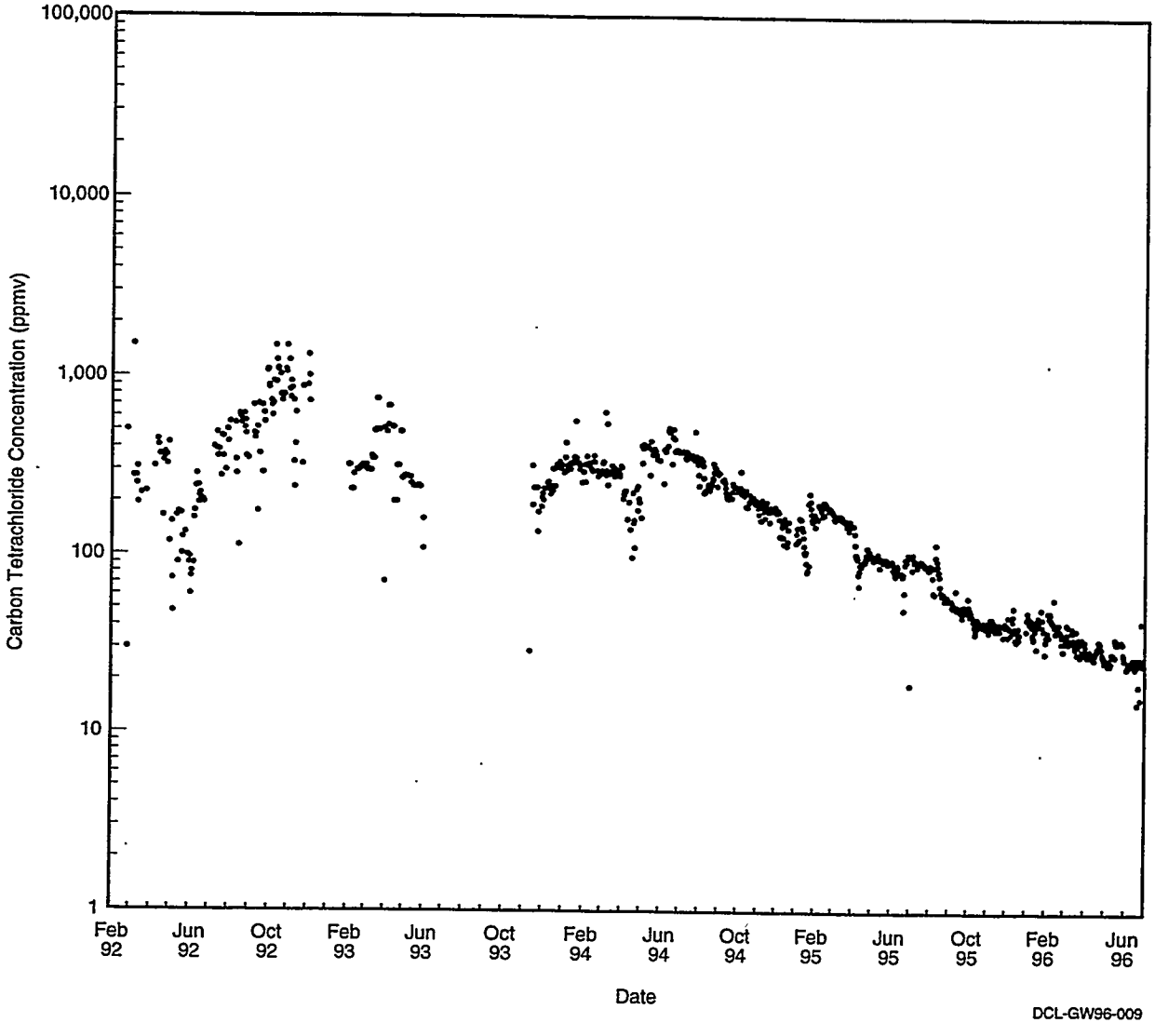


Figure 4.3-10b. Carbon Tetrachloride Concentrations in Soil Vapor Extracted from 216-Z-1A Well Field, February 1992 - June 1996

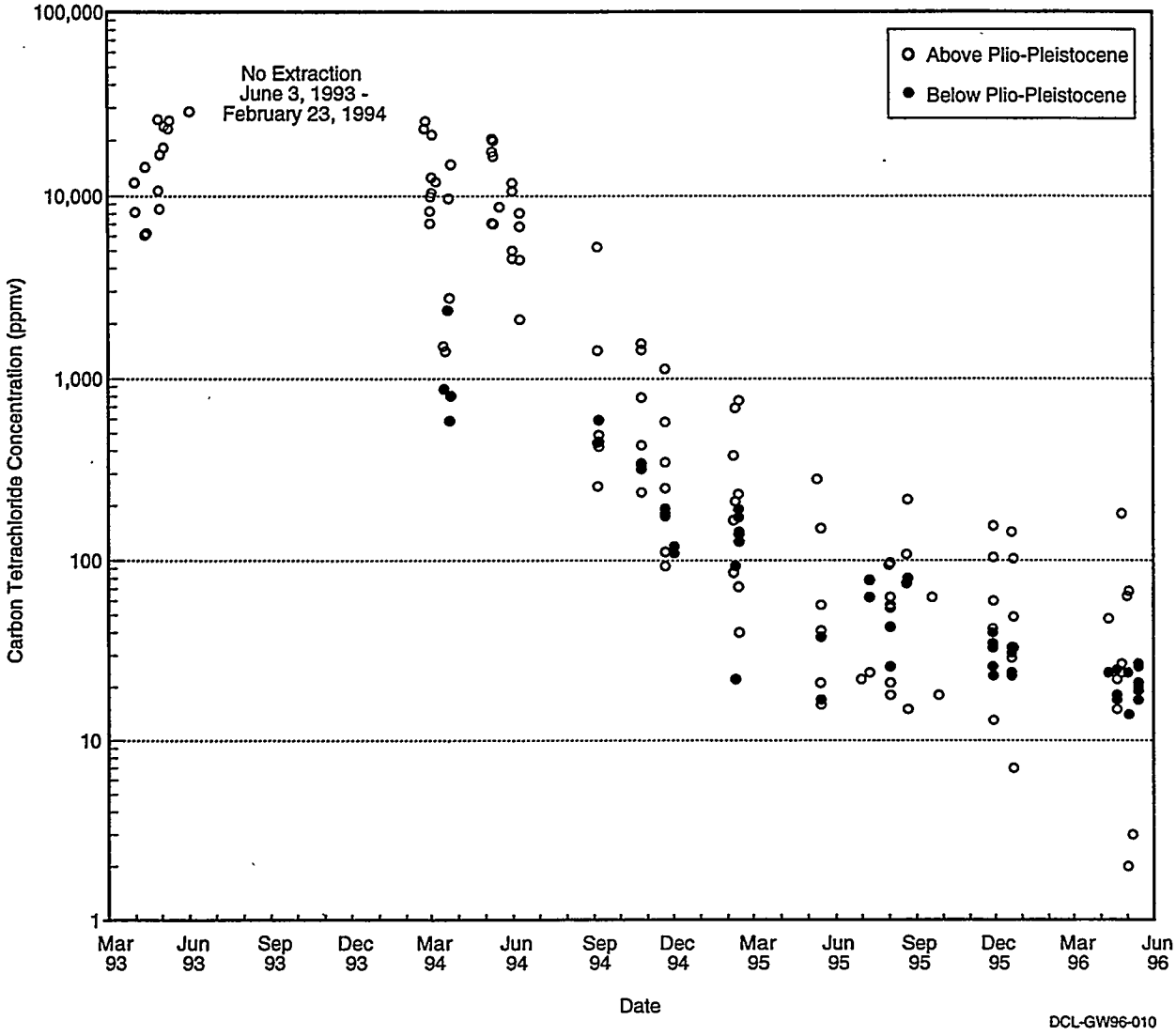


Figure 4.3-11a. Carbon Tetrachloride Concentrations in Extraction Wells in 216-Z-9 Well Field, March 1993 - June 1996

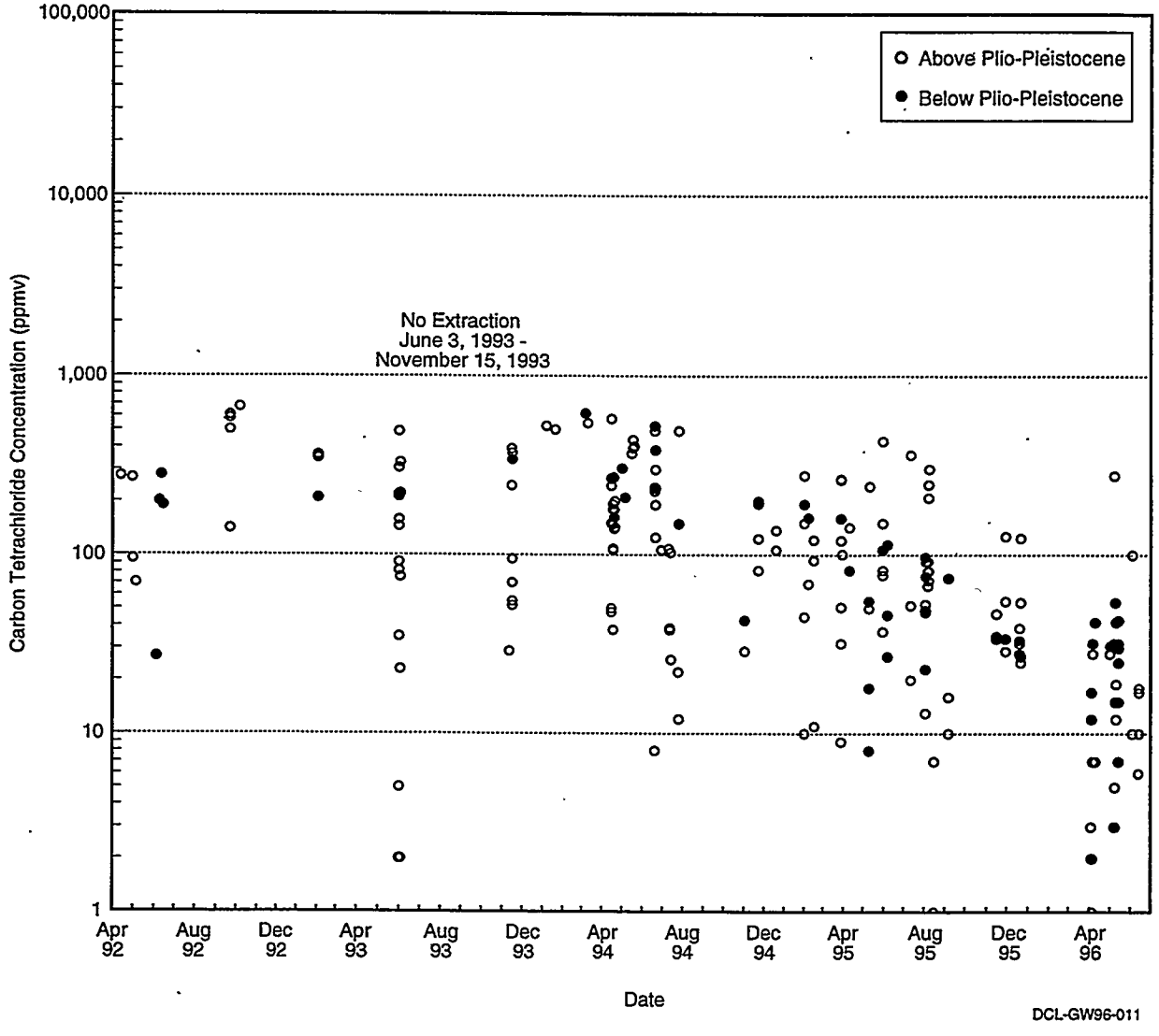


Figure 4.3-11b. Carbon Tetrachloride Concentrations in Extraction Wells in Combined 216-Z-1A/216-Z-12/216-Z-18 Well Field, April 1992 - June 1996

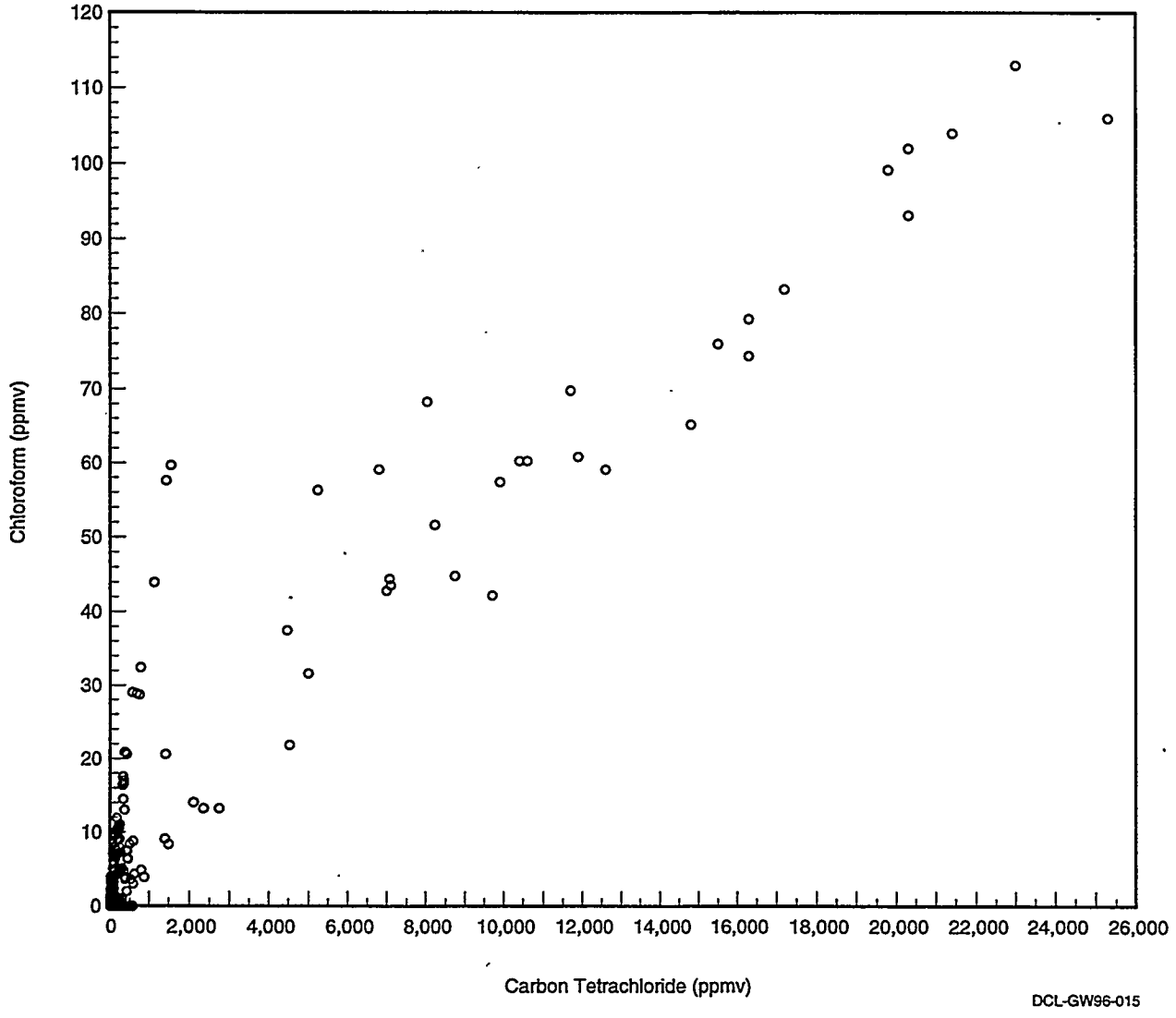


Figure 4.3-12. Relationship Between Concentrations of Carbon Tetrachloride and Chloroform at All Extraction Wells

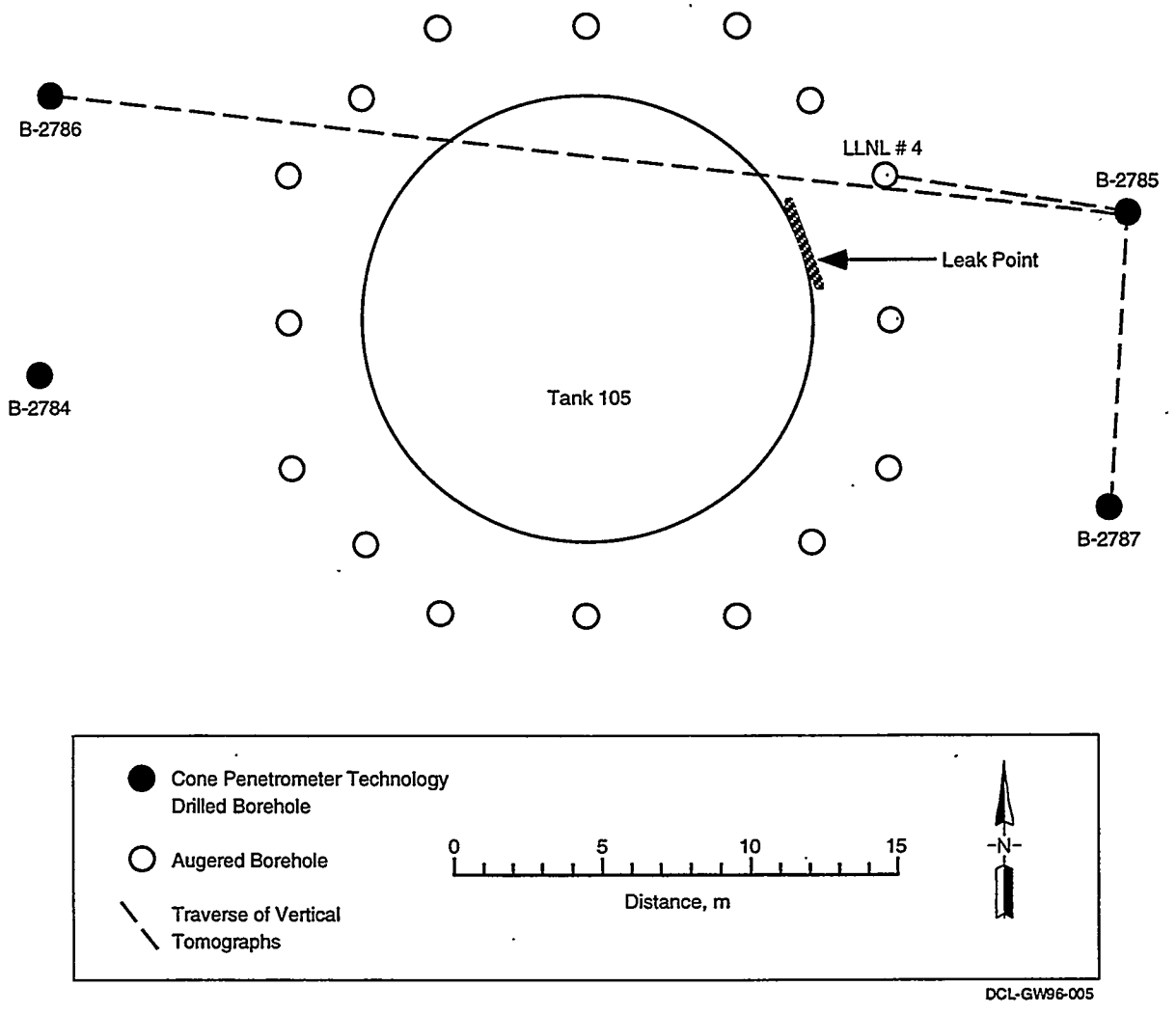


Figure 4.3-13. Schematic Diagram of Vertical Electrode Arrays in Cone Penetrometer-Drilled Boreholes (with respect to the tank and those arrays previously placed in augered boreholes [after Narbutovskih et al. 1996]). The dashed lines indicate paired arrays between which tomographic data were collected.

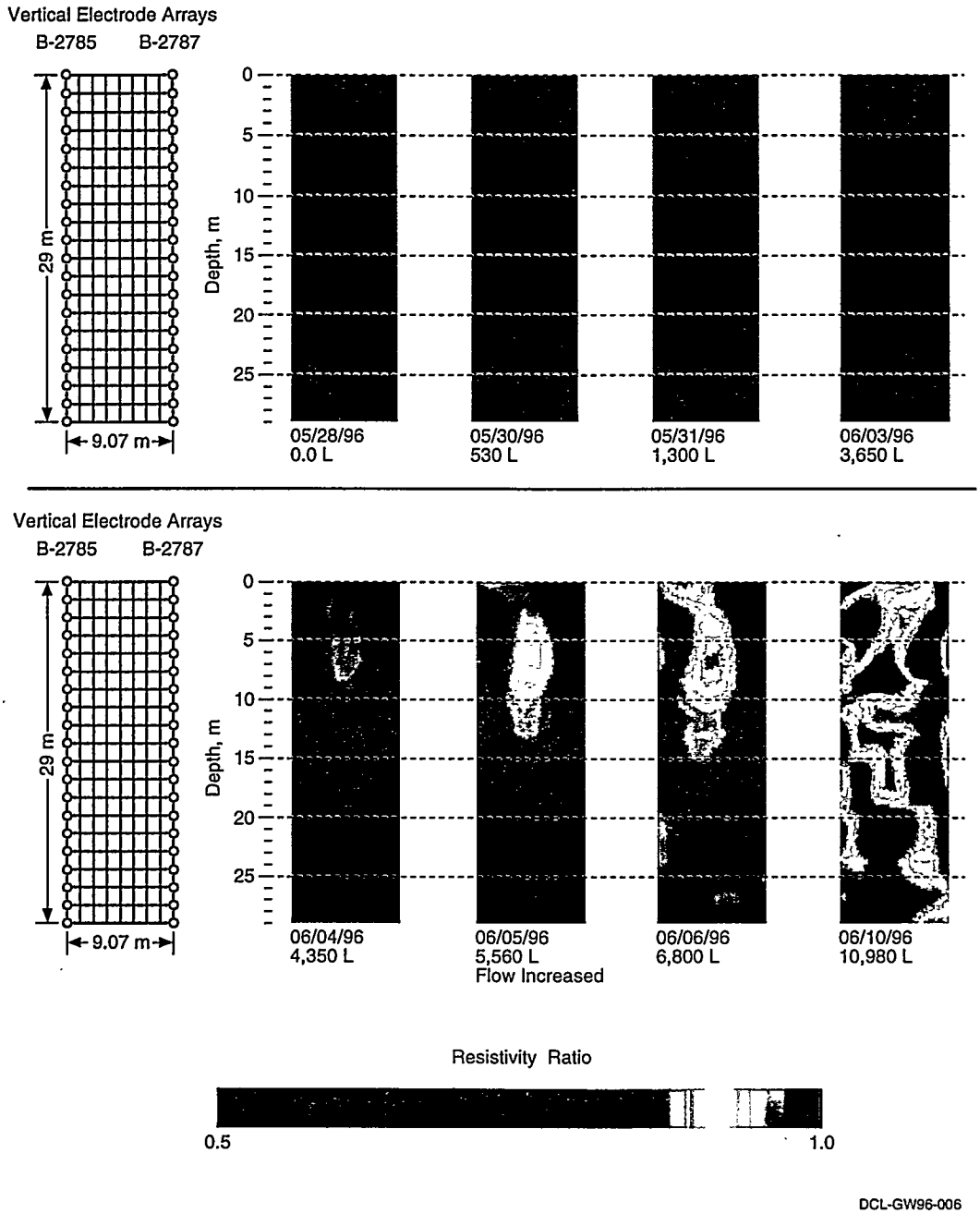
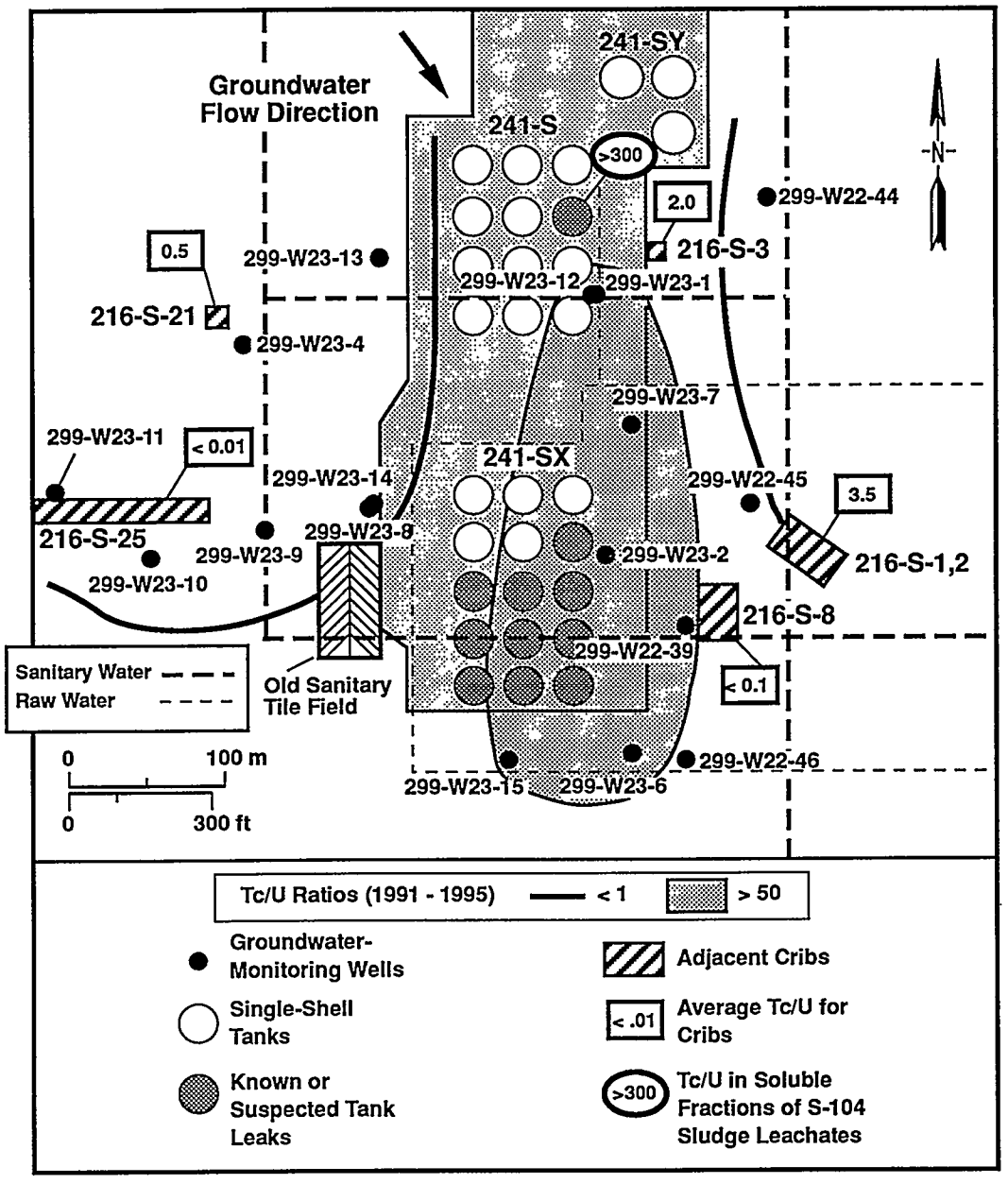


Figure 4.3-14. Vertical Resistivity Tomograms Calculated from Data Collected Between Vertical Electrode Arrays B-2785 and B-2787 (after Narbutovskih et al. 1996). The inversion grids on the left have electrode locations as red circles. Cooler colors, to the left of red on the scale, indicate where resistivity decreased over time. A distinct resistivity decrease after 4,350 L had been leaked indicates movement of the brine plume to a depth of 21 m by the twelfth day after the leak began.



Reference H96020243.11
H96070262.2

Figure 4.4-1. Technetium/Uranium Ratio in Groundwater Near S-SX Tank Farms

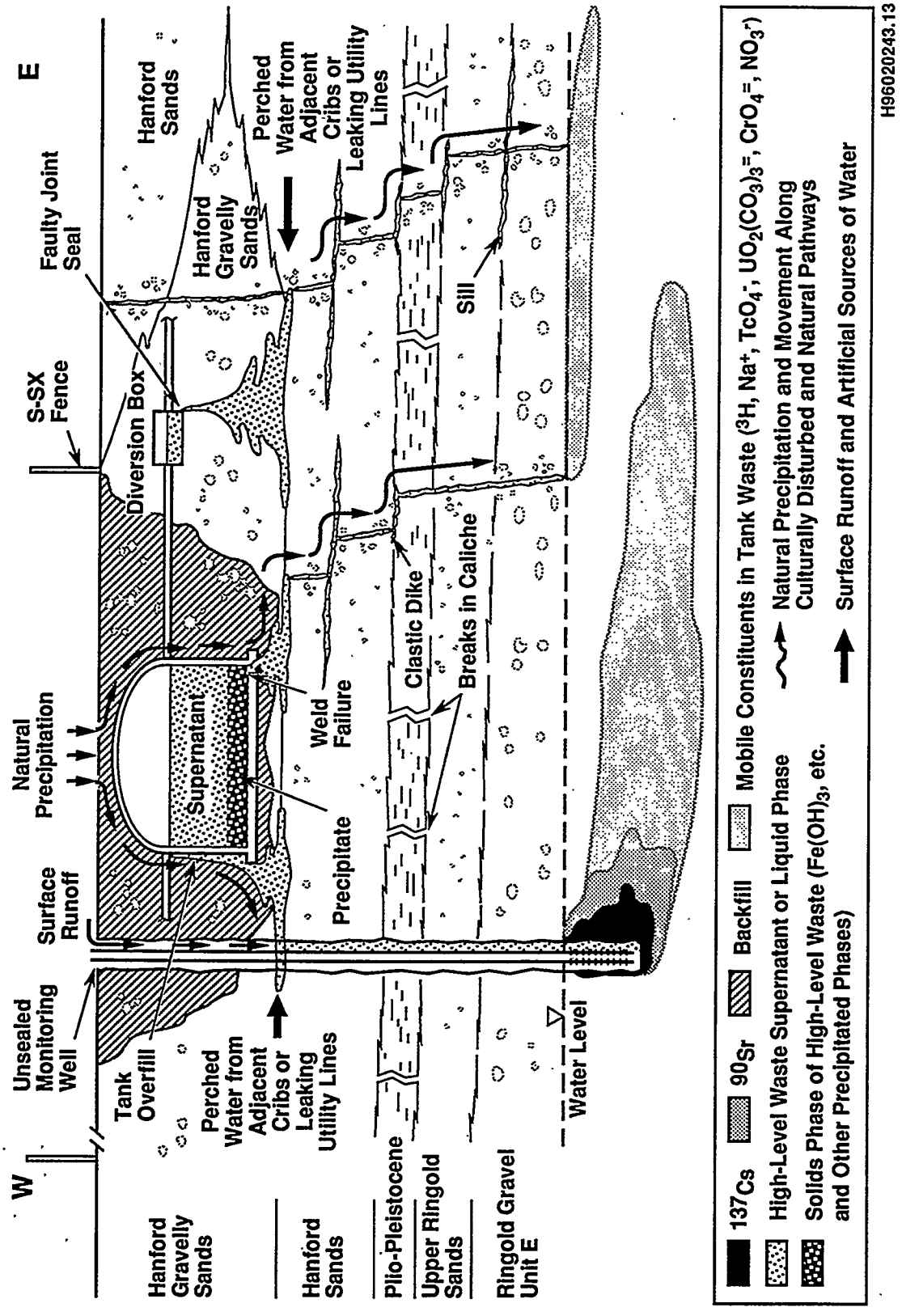


Figure 4.4-2a. Hypothetical Preferential Pathways to Groundwater in S-SX Tank Farms

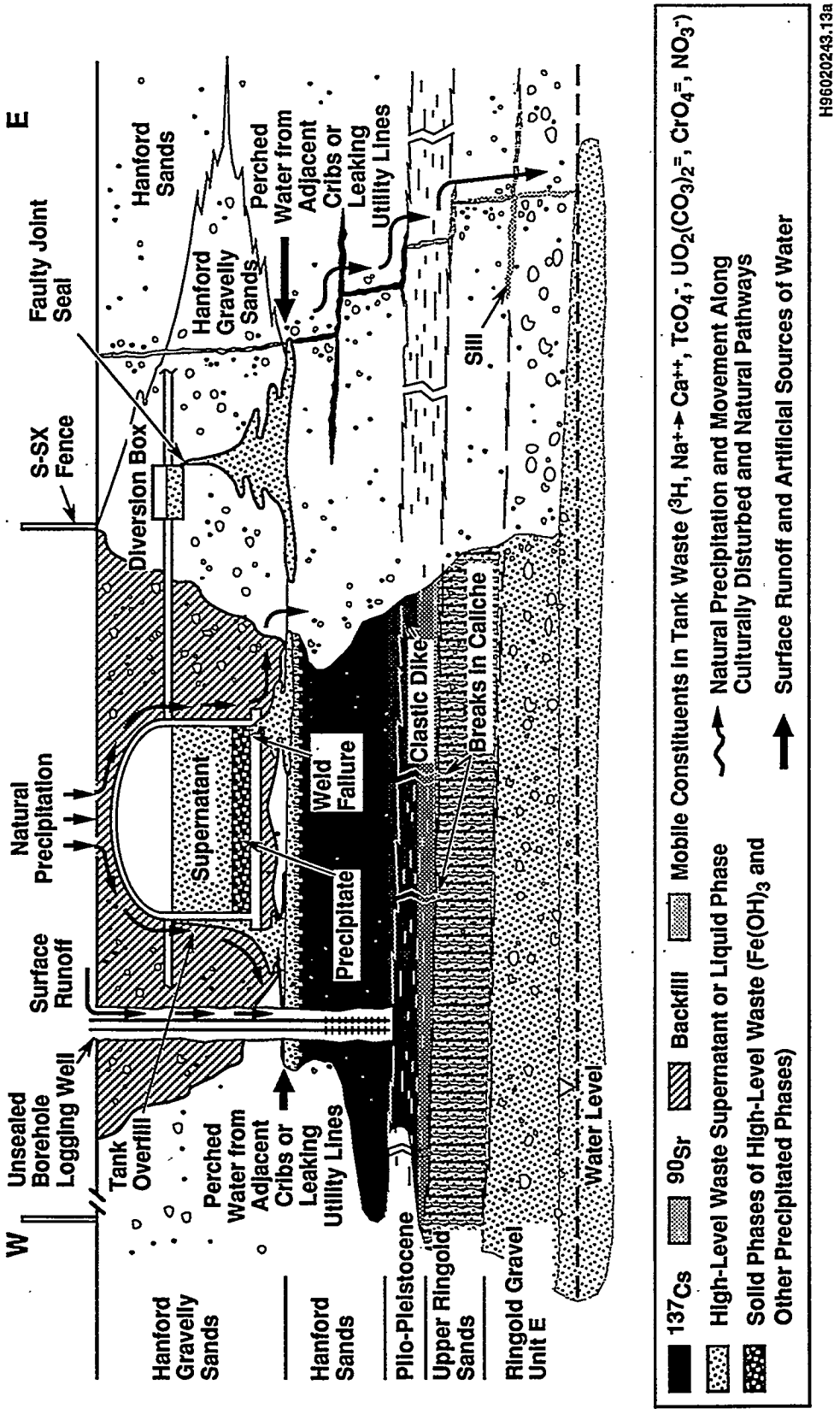


Figure 4.4-2b. Hypothetical Movement of Contaminants Through the Soil Column Beneath S-SX Tank Farms

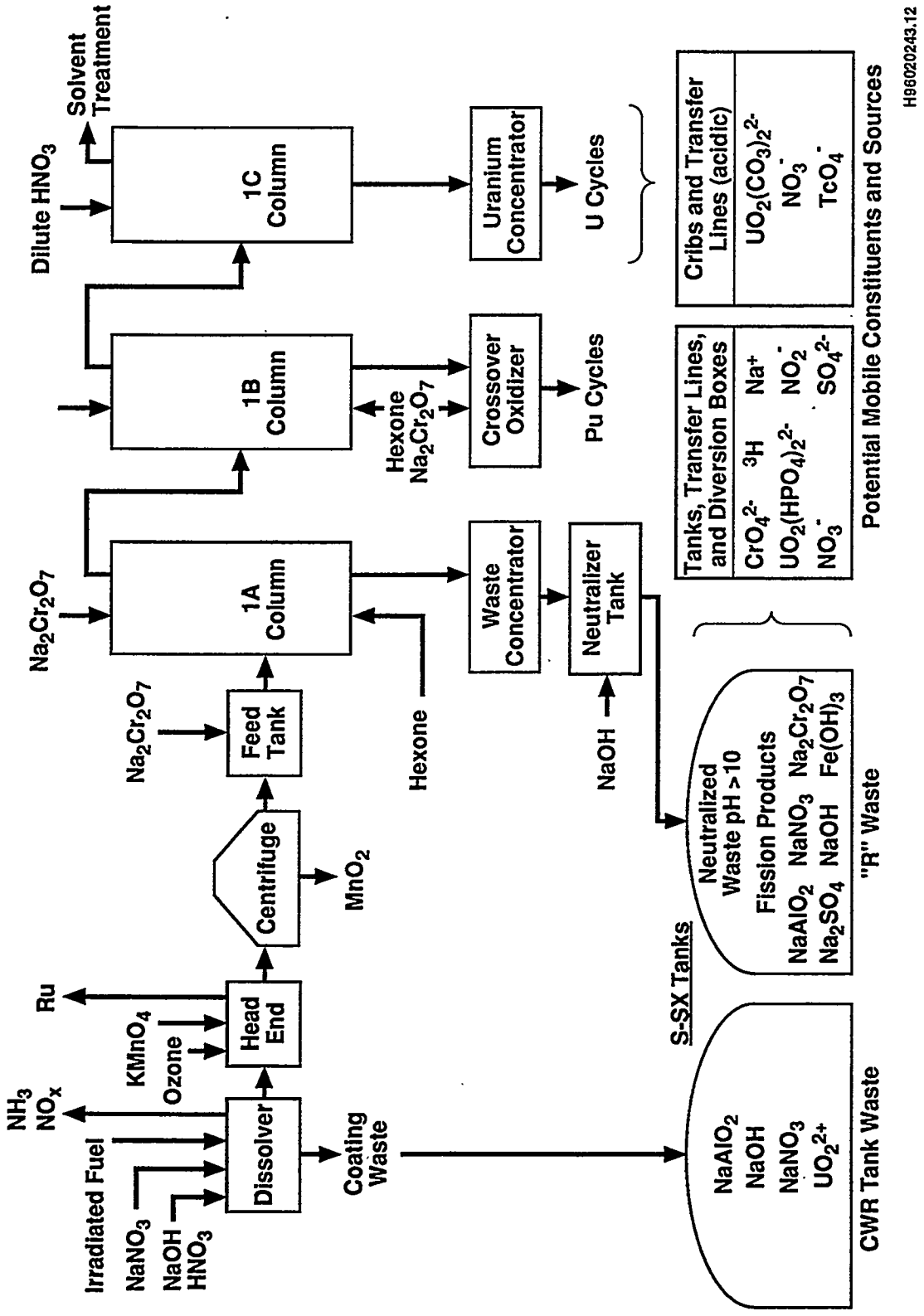


Figure 4.4-3. Reduction-Oxidation Chemical Separations Process and Main Waste Constituents Generated

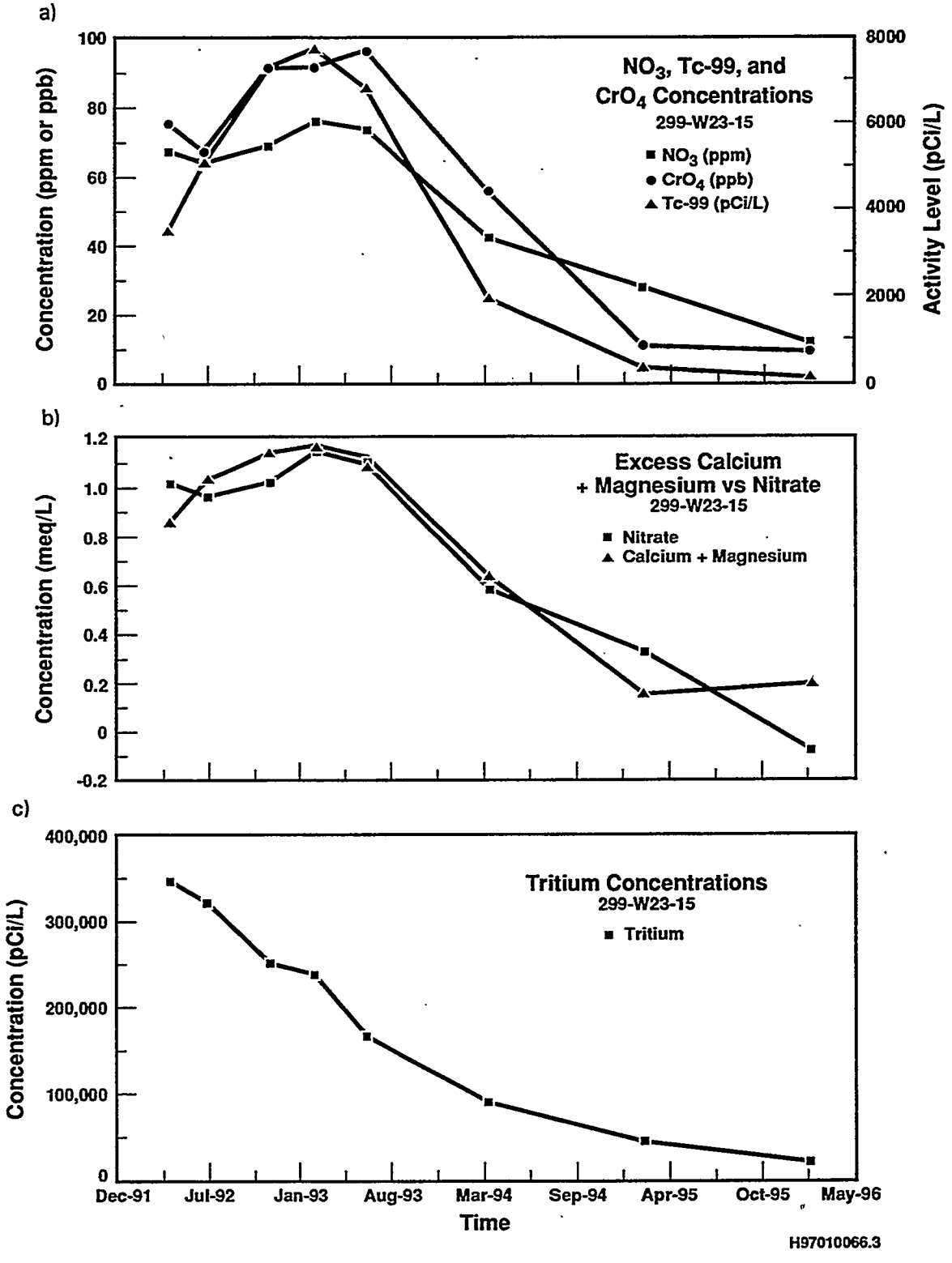


Figure 4.4-4. Mobile Cocontaminant Concentrations Versus Time in Groundwater Downgradient from the SX Tank Farm

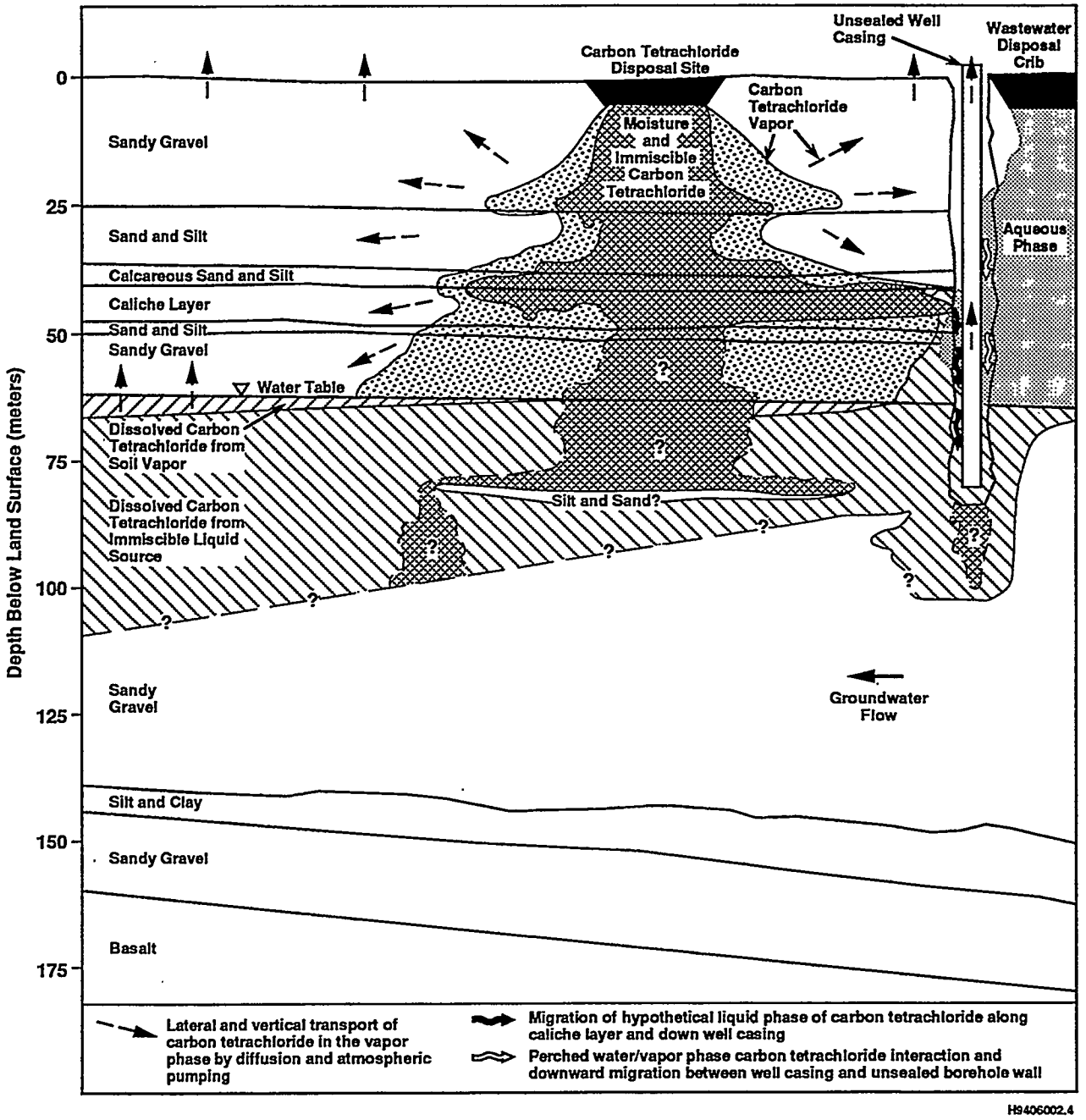


Figure 4.4-5. Schematic Illustration of Carbon Tetrachloride and Wastewater Migration Beneath the 216-Z-9 Trench

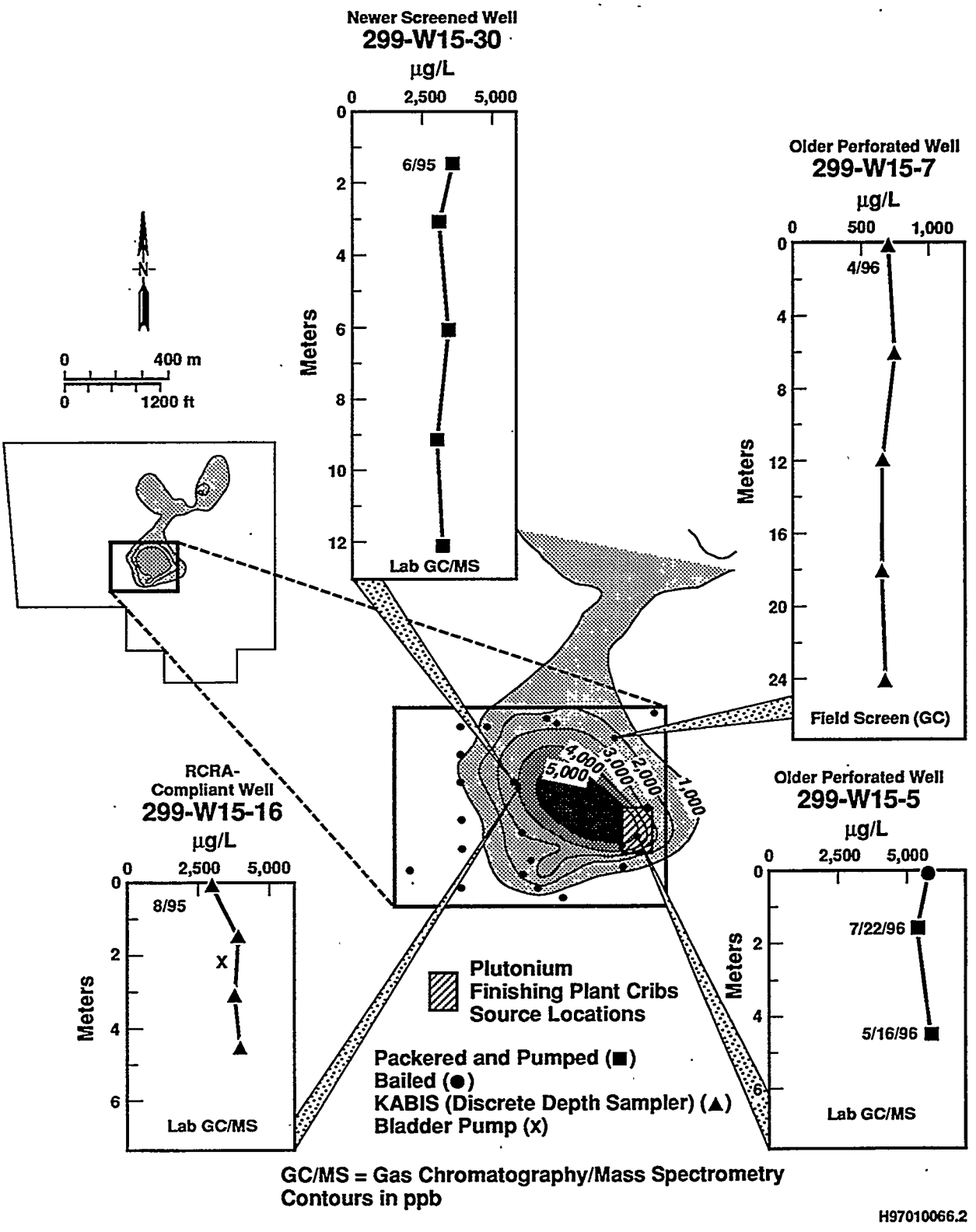


Figure 4.4-6. Depth Distribution of Carbon Tetrachloride in Selected Plutonium Finishing Plant-Monitoring Wells

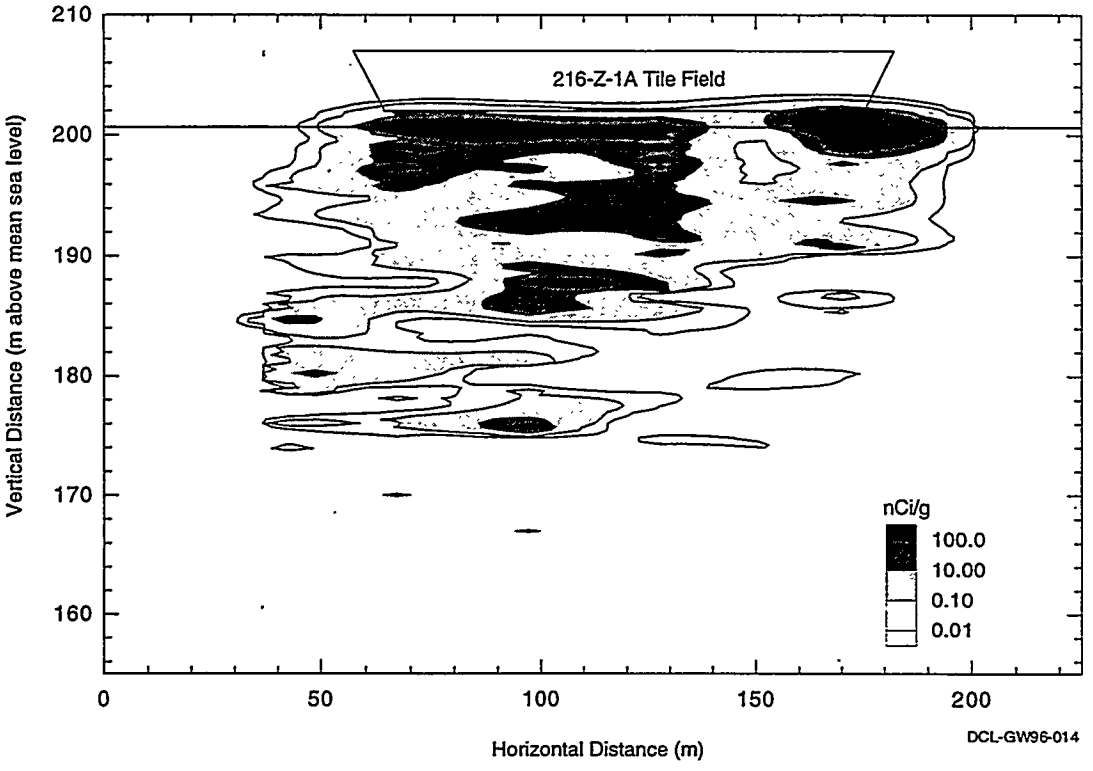


Figure 4.4-7. Cross Section of 1977 Plutonium-239,-240 Concentrations in Unsaturated Zone Under 216-Z-1A Tile Field

5.0 Groundwater Flow

This chapter describes groundwater flow beneath the Hanford Site within the unconfined and upper basalt-confined aquifers. The primary focus is the unconfined aquifer system because it is the aquifer most impacted by onsite wastewater discharged to the ground and by irrigation practices offsite and is the most likely path for offsite migration of contaminants in groundwater. An assessment of a facility's impact on the uppermost aquifer is required for *Resource Conservation and Recovery Act of 1976* (RCRA) groundwater compliance. Groundwater-flow-system dynamics discussed in this chapter are used in the determination of groundwater-flow directions, interpretation of contaminant plume distribution (Chapter 6.0), and in groundwater-flow and contaminant-transport modeling (Chapter 7.0).

A description of the Hanford Site water-level-monitoring programs is given in Section 5.1. Groundwater flow in the unconfined aquifer system is discussed in Sections 5.2 through 5.4. Groundwater flow within the upper basalt-confined aquifer is discussed in Section 5.5. Water-level data are presented in electronic form in Appendix D.

5.1 Description of Water-Level-Monitoring Program

D. R. Newcomer, W. D. Webber, and M. J. Hartman

Water-level data are used to delineate groundwater-flow patterns and to evaluate flow-system dynamics in the unconfined aquifer and upper basalt-confined aquifers. During fiscal year (FY) 1996, water levels were measured to meet the objectives of the Ground-Water Surveillance Project (GWSP), the RCRA and Operational Monitoring (ROM) Program, and the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) Program. The results of these water-level-monitoring programs are presented in this chapter.

Water levels are measured in June of each year in selected wells completed in the unconfined aquifer system beneath the Hanford Site and outlying areas. The purpose of the measurements is to monitor changes in water-table elevation that affect the direction and velocity of groundwater flow and transport of associated contaminants. More frequent measurements are made at a few of the same wells to monitor seasonal variations. Water-table maps are produced annually for the GWSP. In the past they have also been produced semiannually (June and December) for the ROM Program. Serkowski et al. (1996) contains maps for December 1995.

Water levels are also measured in the upper basalt-confined aquifer to monitor changes in elevation of the potentiometric surface for this aquifer. Changes in elevation of the potentiometric surface can affect the direction and velocity of groundwater flow within the upper basalt-confined aquifer and its potential for hydraulic communication with the overlying unconfined aquifer system.

Groundwater-monitoring plans for individual RCRA sites specify requirements for water-level monitoring. These data aid in determining the direction of groundwater flow beneath the RCRA units

and in determining if the monitoring network is adequate. Sampling frequency varies from monthly to semiannually, depending on factors such as the site's groundwater gradient and the variability of water levels.

In addition to the water-level measurements described above, water levels are measured before wells are sampled for any onsite monitoring program. Water-table maps of the unconfined aquifer beneath the Hanford Site have been prepared for selected times since 1944 (see Appendix A).

5.1.1 Monitoring Network

Locations of groundwater wells are shown in Plate 1. Wells north and east of the Columbia River that are numbered by the U.S. Geological Survey's (USGS) well-numbering system are not shown in Plate 1 but can be located by well name, which includes the township, range, and section numbers. The areas where basalt lies above the water table were identified by comparing the top-of-basalt topographic surface with the 1996 water-table surface.

During June 1996, water levels were measured in more than 600 wells completed in the unconfined aquifer system beneath the Hanford Site and in 30 wells completed in the unconfined aquifer system north and east of the Columbia River in Grant, Adams, and Franklin Counties. Monitoring wells used to measure water levels for the unconfined aquifer system were selected using the following criteria:

- well monitors only the uppermost (15-m) part of the aquifer
- screened interval does not exceed 15 m and water table intersects the screened interval
- well location and elevation are accurately known.

Exceptions were made where no alternative wells exist and vertical gradients are small relative to horizontal gradients. In some areas, not all wells that met these criteria were selected because an adequate number of nearby wells exist.

In addition to water levels measured in wells across the Hanford Site, water levels were measured at more closely spaced wells in the vicinity of the Hanford Site operational facilities and the Richland North areas. These areas include the vicinities around RCRA sites, the decommissioned 216-U-10 pond (also referred to as U Pond) in the 200-West Area, and around the City of Richland's North Well Field. Artificial recharge to the unconfined aquifer system in these areas resulted in groundwater mounding that influences groundwater flow.

Water levels were also measured in wells completed in the upper basalt-confined aquifer system, which is defined as the groundwater occurring in basalt fractures and joints, interflow contacts, and intercalated sedimentary interbeds in the upper Saddle Mountains Basalt (see Chapter 3.0). During June 1996, water levels were measured in 36 wells completed in the upper basalt-confined aquifer beneath the Hanford Site and outlying areas. Monitoring wells used to measure water levels in the

upper basalt-confined aquifer system are completed in stratigraphic units within the upper Saddle Mountains Basalt (Rattlesnake Ridge Interbed, Elephant Mountain interflow contact, Levey Interbed).

5.1.2 Methods

Procedures developed in accordance with the techniques described by the American Society for Testing and Materials (1988), the U.S. Environmental Protection Agency (EPA 1986a), Garber and Koopman (1968), and USGS (1977) were followed to measure water levels in piezometers and wells across the Hanford Site. Water levels were measured with steel tapes or laminated steel electric sounding tapes that were standardized by comparison to a calibrated steel tape. Only those standardized steel tapes that deviated in length from the calibrated steel tape by <0.03 m for at least 85 m were used. Water levels are reported as elevations above the National Geodetic Vertical Datum (NGVD29). The more recent North American Datum of 1988 (NAD88) is not used because many of the wells have not been surveyed to this datum and to simplify comparison with historical water-table and potentiometric maps. In general, NAD88 is ~ 1 m greater than NGVD29 but the conversion is not precisely the same at all locations across the site.

A few wells completed in the upper basalt-confined aquifer are under artesian flowing conditions; that is, the potentiometric surface is above the top of the well or piezometer. For these wells, which are pressure sealed from the atmosphere, a pressure gauge or transducer is used to measure the equivalent head above the top of the surveyed elevation.

Pressure transducers and data loggers are used to measure the heads in some wells where water levels change rapidly (e.g., near the Columbia River and near groundwater-extraction or -withdrawal wells). Pressure transducers are also used to measure river stage. The pressure data are generally recorded at 1-hr intervals.

5.1.3 Data Quality

The procedures developed for measuring water levels were designed to ensure the most representative data possible. Interpretation of water-level data assumes that the measurements are spatially representative. However, various sources of error and uncertainty limit the accuracy of the data:

- temporal variations in water table caused by natural external stresses (e.g., barometric pressure fluctuations, earth tides, changes in river stage or recharge) or man-made activities (e.g., wastewater disposal)
- differences in well depths or lengths of screened intervals
- well deviations from vertical
- errors in surveyed elevations of measuring points
- limits of measuring tape precision.

To reduce the effect of seasonal and other long-term water-level changes, water-level measurements for the site water-table map were made within a 1-month period (June 1996). The most significant short-term water-level changes that occurred within this period were in wells influenced by fluctuations in Columbia River stage. Water-level fluctuations in wells influenced by river stage may introduce errors in representing the water-table surface adjacent to the river. Therefore, the water-table-elevation contours adjacent to the river have a greater uncertainty than other contours.

The effects of well depth on water levels depends on the vertical gradient in a given area. For the scale and contouring interval of the site map and of most local maps, any well screened within 6 m of the water table is acceptable (see Section 5.1.1).

The other sources of error listed above generally are only significant in areas of very flat gradients (e.g., the 200-East Area). In some of these areas, water-level data alone are insufficient to determine the direction of groundwater flow and other information (e.g., contaminant plume configuration or groundwater-flow meters) must be employed.

Data from pressure transducers were compared to manual measurements to evaluate and correct for transducer drift or other problems. Water-level data were screened for outliers before producing the water-table maps presented in this report. Depth-to-water measurements were manually screened to identify measurements that were not in agreement with historical trends. Outliers were not plotted in Plate 2 but are included in the data tables of Appendix D. Outliers were generally included on trend plots unless they were off the scale of the plot.

5.1.4 Data Management

The Hanford Environmental Information System (HEIS) database is used to store and maintain manual hydraulic head measurements. In FY 1996, ~2,460 hydraulic head measurements were entered into this database. The hydraulic head data are made available to federal and state regulators for retrieval. Transducer data are stored in project databases.

5.1.5 Interpretive Techniques

The June 1996 water-level measurements were used to construct contour maps that show the elevation of the potentiometric surface for the unconfined aquifer system. The potentiometric surface of the unconfined aquifer system is referred to as the water table. The water-table-contour map primarily represents groundwater head conditions in the upper part of the unconfined aquifer system. The contour maps can be used to determine lateral groundwater-flow potential. Assuming isotropic hydraulic conductivities, uniform fluid density, and no vertical flow, the direction of groundwater flow is perpendicular to contours of equal potentiometric surface elevation. In addition, potentiometric surface maps can be used to

- identify recharge and discharge areas
- evaluate the influence of wastewater discharges on groundwater-flow patterns

- determine the hydraulic gradient, which can be used to estimate the average linear velocity of groundwater and contaminants
- provide information required to calibrate groundwater-flow and contaminant-transport models
- improve the design of the monitoring well network.

A map showing the June 1996 water-table-elevation contours for the unconfined aquifer system is presented in Plate 2. The contour map was constructed by manually contouring the values of water-level elevations (i.e., hydraulic heads). The contour intervals are 2 m on the Hanford Site west and south of the Columbia River. The inset maps of operational areas use smaller contour intervals to show detail. A 50-m contour interval was used north and east of the river because the water-table gradients are much steeper. Selected FY 1996 water-level data, including the measured depth to water, the reference-point elevation, and the calculated water-table elevation for each well are presented in Appendix D.

Because water-table elevations north and east of the Columbia River are much greater than on the Hanford Site and water-level changes are small relative to the regional water-table gradient, water-level measurements are not collected in all offsite monitoring wells each year. Contours of the water-table surface in these areas were constructed based on June 1995 and June 1996 water-level measurements. The elevation of the water-table surface in this area is strongly controlled by the basalt surface and topography and, thus, does not change significantly from year to year.

A map showing the June 1996 potentiometric surface contours for the upper basalt-confined aquifer system is presented in Figure 5.1-1. The map was constructed by manually contouring the values of water-level elevations. The contour intervals are 3 m on the Hanford Site west and south of the Columbia River and are variable north and east of the river.

The RCRA regulations require an annual determination of the direction and rate of groundwater or contaminant movement for sites in assessment or compliance monitoring (40 CFR 265.94[b][2] and WAC 173-303-645[10][e]). For most of the RCRA sites described in this chapter, the rate of groundwater flow is estimated using a form of the Darcy equation

$$v = \frac{Ki}{n_e} \qquad (5.1)$$

where v = average linear groundwater velocity (m/d)
K = hydraulic conductivity (m/d)
i = hydraulic gradient
n_e = effective porosity.

Representative values of hydraulic conductivity, porosity, and current hydraulic gradient are selected for each site. In some cases, other methods are used to estimate groundwater- or contaminant-flow rates, including the migration of contaminant plumes or use of a groundwater-flow meter, which measures flow rate and direction in a well.

5.2 Interpretation of Water-Table Data

D. R. Newcomer and W. D. Webber

The June 1996 water-table map for the Hanford Site is shown in Figure 5.2-1 and Plate 2. Figure 5.2-1 also shows the water table north and east of the Columbia River. Plate 2 includes inset maps of onsite operational areas. This section describes general groundwater-flow patterns on the Hanford Site. Details on various locations are included in Sections 5.4 and 5.5.

The water table for the unconfined aquifer beneath the Hanford Site is generally located in the unconsolidated to semiconsolidated Ringold and Hanford formations, which have vastly different hydrologic properties (see Figure 3.4). Water-table elevations decrease while approaching the Columbia River from either side, indicating that groundwater flow converges and discharges at the river. Steep gradients in the western region of the Hanford Site result from groundwater recharge at the western edge of the Pasco Basin combined with lower hydraulic conductivities than the eastern region of the site. Possible sources of recharge include infiltration of runoff from rain and snowmelt at higher elevations and irrigation of offsite agricultural land in the Cold Creek Valley. Steep gradients north and east of the Columbia River are attributed to recharge associated with irrigation of agricultural land with Columbia River water.

Wastewater discharge to the ground associated with Hanford Site operations resulted in groundwater mounding and significantly affected the groundwater-flow system on the Hanford Site. Past discharges at U Pond and smaller discharges to other 200-West Area disposal facilities are apparent from the shape of the contours passing through the 200-West Area. The steep gradient just east of the 200-West Area results partially from this groundwater mounding and partially from the relatively low transmissivity of the aquifer in this area. The hydraulic gradient decreases abruptly between the 200-West and 200-East Areas. This change in gradient corresponds to an increase in transmissivity caused by the presence of the highly permeable Hanford formation sediments below the water table. The steep gradient in the gap between Umtanum Ridge and Gable Butte results partially from recharge coming from Cold Creek Valley and groundwater mounding in the 200-West Area and partially from restriction of the unconfined aquifer system by the underlying basalt to a thin, narrow zone in the gap.

The water table in the central portion of the Hanford Site south of Gable Mountain is relatively flat, except for the groundwater mound around B Pond where process cooling water and other liquid wastes are discharged to the ground. The presence of highly permeable sediments of the Hanford formation below the water table results in a relatively flat water table in spite of the large discharges in past years. For the past several years, the annual volumes of discharges to the soil column resulting from 200-East Area operations is significantly higher than discharges from 200-West Area operations.

A local groundwater mound exists ~2 km north of Gable Mountain (between Gable Mountain and the 100-F Area). The area of elevated groundwater levels was reported by Jenkins (1922), long before the Hanford Site was established, and persists to the present. Data suggest that this mound is associated with a subsurface topographic "high" of low-permeability sediments (primarily clay) of the Ringold Formation. Although there may be some current recharge to the groundwater mound, the most likely source of recharge is conveyance losses associated with past seasonal irrigation use of the Hanford Canal that transversed the groundwater mound area between 1908 and 1943. The slow dissipation of the recharge water is attributed to the presence of significant thicknesses of clay in the Ringold Formation sediments. There is insufficient information to distinguish whether the groundwater is perched or is part of the active groundwater-flow system.

The elevation of the water table in the region between the Yakima and Columbia Rivers is lower than the Yakima River stage elevation, which is ~122 m above mean sea level at Horn Rapids Dam. This implies that infiltration from the Yakima River may recharge the unconfined aquifer system in this area. During the summer, leakage from the Horn Rapids Ditch and Columbia Canal, which originate from the Yakima River at Horn Rapids Dam, and irrigation in offsite areas east of the Yakima River may also recharge the unconfined aquifer system in this area. Operation of the City of Richland's North Well Field recharge basins has resulted in a groundwater mound in the Richland North Area.

5.3 Changes in Hanford Site Water Levels

W. D. Webber

This section describes changes in the water table over the periods 1944-1979, 1979-1995, and 1995-1996. 1944 was chosen to illustrate the water table before it was affected by Hanford Site effluent discharges. 1979 is representative of maximum, steady volumes of effluent discharge. The 1995-1996 changes are discussed to illustrate the most recent variations in Hanford Site water-table elevations.

Between 1944 and 1979, water-level elevations at the Hanford Site increased in most areas, with the greatest increases occurring near facilities where wastewater was discharged to the ground (Figure 5.3-1). Groundwater mounds associated with wastewater discharge to the ground formed in the 100, 200, and 300 Areas and in parts of the 600 Area. The two most prominent groundwater mounds formed near U Pond in the 200-West Area and near B Pond in the 200-East Area. Figure 5.3-2 shows the volume of wastewater discharged to the ground in each of the major Hanford Site operational areas and net recharge (infiltration less pumping) of Columbia River water at the City of Richland's recharge basins from 1944 through 1995. Figure 5.3-2 indicates that, in the past, the largest volumes discharged to the soil column occurred in the 200-East and 200-West Areas, which corresponds to the two most prominent groundwater mounds. These mounds altered the natural flow pattern of the unconfined aquifer system. Water levels in the unconfined aquifer system changed continually during Hanford Site operations because of variations in the volume and location of wastewater discharged to the ground. Consequently, the movement of groundwater and its associated constituents also changed with time. Figure 5.3-3 shows the discharge locations of the major waste streams at the Hanford Site.

As the Hanford Site's mission changed to include environmental cleanup and restoration and through the efforts of the Waste Minimization and Pollution Prevention Program (DOE 1991c), the volume of wastewater discharged to the soil column has been greatly reduced. For example, ~34 billion L of liquid effluents were discharged to the soil column in 1985, ~14 billion L were discharged to the soil column in 1990, and ~6.9 billion L were discharged to the soil column in 1995. The reduction of wastewater discharge to the ground was accompanied by elimination of many discharge sites, including U Pond in the 200-West Area (decommissioned in 1985) and Gable Mountain Pond north of the 200-East Area (decommissioned in 1984-1988). By the end of 1995, only 18 of the original 33 liquid effluent streams identified in Stordeur and Flyckt (1988) were still active. During FY 1996, disposal of wastewater from these 18 remaining waste streams was consolidated to the 216-B-3C lobe of B Pond, the 200 Areas treated effluent-disposal facility (located east of B Pond), the 200 Areas effluent treatment facility (also known as the C-018H facility located just north of the 200-West Area), the 400 Area process ponds that discharge to the soil column, and the 300 Area treated effluent-disposal facility (located north of the 300 Area) that discharges to the Columbia River.

Reduced wastewater discharge to the soil column resulted in declining water levels for most of the Hanford Site. Figure 5.3-4 indicates that the greatest water-level-elevation decline from 1979 through 1995 occurred in the 200-West Area near the decommissioned U Pond. The trend of declining water levels in most areas of the Hanford Site continued from June 1995 through June 1996, with the area of greatest water-level-elevation decline persisting in the southern part of the 200-West Area near the former location of U Pond (Figure 5.3-5). The Columbia River ran unusually high throughout most of FY 1996, resulting in rising water levels near the river.

5.4 Groundwater Flow

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T. L. Liikala, J. W. Lindberg, R. B. Mercer,
S. M. Narbutovskih, D. R. Newcomer, M. D. Sweeney,
W. D. Webber, and B. A. Williams

This section describes groundwater flow in the uppermost aquifer in various parts of the Hanford Site in greater detail. It is divided by geographic region and subdivided into sections corresponding to RCRA units, which require estimation of groundwater-flow rate and direction. The major geographic areas include the upper Cold and Dry Creek Valleys, 100 Areas, 200-West Area, 200-East Area, 400 and 600 Areas, 300 Area and Richland North Area, and the area north and east of the Columbia River. Water-table maps and hydrographs are presented to show the appropriate levels of detail for each geographic region or RCRA unit. The local direction and rate of groundwater flow for each RCRA unit are reported in Table 5.4-1.

5.4.1 Upper Cold and Dry Creek Valleys

Zimmerman et al. (1986) postulated that the water table in the western part of the Hanford Site responded to irrigation practices in the upper Cold Creek Valley. Figure 5.4-1 shows a hydrograph of well 699-43-104, located downgradient from the irrigated fields in upper Cold Creek Valley. The

hydrograph indicates that the water table has declined steadily since ~1988. The water level declined 0.39 m between June 1995 and June 1996. The declining water level in this well may result from decreased recharge resulting from changes in irrigation practices at Ste. Michelle Vineyards, upgradient of the site. Between 1982 and 1983, the vineyards converted their irrigation system from sprinkler to drip, which reduced consumption between 40% and 50% (Newcomer 1990). Declining water levels in the unconfined aquifer system may also be associated with decreases in the hydraulic heads of the underlying confined aquifers in this area. It is estimated that the hydraulic heads in the confined aquifer system dropped more than 55 m in the Cold Creek Valley since the early 1900s (DOE 1988). Thus, the upward gradient from the confined to the unconfined aquifer system is not as strong as it once was. Other factors not related to irrigation may also affect water levels in well 699-43-104. This well may be within the influence of the U Pond groundwater mound from the 200-West Area (see Figures 5.3-1 and 5.3-4). Well construction may also be a factor: this well originally was open to both the unconfined and the upper basalt-confined aquifers (1957 to 1978). In 1978, a cement plug was placed in the well, but it was removed sometime before 1994.

5.4.2 100 Areas

The 100 Areas are located along the Columbia River in the northern portion of the Hanford Site and contain nine inactive nuclear reactors. Very little liquid effluent is currently discharged to the ground in the 100 Areas. The active and inactive effluent sources are discussed in Chapter 6.0.

Groundwater flows into the 100 Areas from the south, through the gaps between Umtanum Ridge, Gable Butte, and Gable Mountain, and discharges to the Columbia River (see Figure 5.2-1 or Plate 2). The area of increased water-table elevations resulting from wastewater disposal in the 200 Areas extends north of the gap between Gable Mountain and Gable Butte. Water levels in this area are ~3 m higher than they were in 1950 (Zimmerman et al. 1986). Groundwater flow is predominantly to the north at the 100-B,C and to the northwest at the 100-K and 100-N Areas. Near the 100-D Area, the groundwater-flow direction is northwestward and northward adjacent to the river and changes to northeastward across the horn of the Columbia River toward the 100-H Area. At the 100-H and 100-F Areas, located on the eastern side of the horn, flow is predominantly toward the east and southeast.

The most significant influence on groundwater flow in the 100 Areas is the Columbia River. River stage is controlled by flow through dams upstream of the Hanford Site. Water levels commonly fluctuate up to 2 m in a single day and up to 3 m over a year. Periods of sustained high-river stage reverse the average water-table gradient and create a potential for river water to flow into the aquifer and for groundwater to flow up to several hundred meters inland until the gradient returns to normal.

The Columbia River ran unusually high from December 1995 (usually a time of low-river stage) through the summer of 1996. The river stage during the first half of 1996 was ~2 m greater than in recent years. Figure 5.4-2 shows hydrographs constructed from pressure transducer data for the 100-B,C, 100-N, 100-H, and 100-F Areas.

Groundwater-level data from the 100 Areas indicate a reversed gradient was present throughout the period of high-river stage (see Plate 2). There was a potential for river water to flow into the aquifer during this time. The river stage decreased during the summer of 1996, and groundwater flowed toward the river again beneath the 100 Areas.

Groundwater extraction also influences groundwater flow in the 100 Areas. During the past year, groundwater was withdrawn from pumping wells in the 100-N and 100-D Areas as part of pump-and-treat remediation efforts (discussed in Sections 6.5 and 6.6).

5.4.2.1 100-N RCRA Sites

There are 4 RCRA units in the 100-N Area: 1301-N liquid waste-disposal facility, 1325-N liquid waste-disposal facility, 1324-NA percolation pond, and 1324-N surface impoundment (see Figure 1.2). The 1324-N and 1324-NA facilities are monitored with a single network because of their proximity, and the facilities are described in Chapter 6.0. When the 100-N Area RCRA units were active, the water table in the entire area was elevated by up to 7 m (see Figure 3.13 in Hartman and Lindsey 1993). Discharge to all the facilities ceased by 1991, resulting in a sharp water-table decline in the early 1990s and stabilization by 1994. The water table fluctuated up to 2.5 m beneath the 100-N Area RCRA sites during the past year in response to changes in river stage (Figure 5.4-3).

Groundwater normally flows toward the northwest (toward the river) beneath the 1301-N and 1324-N/NA facilities and toward the north beneath the 1325-N facility. During the past year, however, high-river stage changed the gradient beneath all three RCRA units. In June 1996, the gradient was toward the east beneath the 1301-N facility and toward the northeast beneath the 1324-N/NA and 1325-N facilities (see Plate 2). Estimated groundwater-flow rates in FY 1996 ranged from -0.48 m/d (reversed gradient) to 0.25 m/d (see Table 5.4-1). These linear velocity estimates are an order of magnitude smaller than in previous years because of the high-river-stage influence.

A pump-and-treat system was active in the 100-N Area during the past year. Water is extracted from wells near the 1301-N facility and reinjected into a well or wells near the 1325-N facility. Details of the pump-and-treat system, including a summary of drawdown and capture-zone information, is included in Section 6.5.

Vertical gradients are not well known in the 100-N Area. Wells adjacent to the Columbia River show an upward gradient in the uppermost aquifer (Hartman and Lindsey 1993, p. 13). Farther inland there is no significant difference in head between wells completed at the water table and wells completed at the base of the aquifer, which are ~6 m deeper. Limited data prevent a clear comparison of vertical heads in the unconfined and shallowest locally confined Ringold Formation aquifers.

5.4.2.2 120-D-1 Ponds

These ponds are a small RCRA site that was formerly used for disposal of effluent from a water-treatment plant in the 100-D Area (see Figure 1.2) and is described in Chapter 6.0. Water levels in the four wells that monitor these ponds are plotted in Figure 5.4-4. The water table responded to changes

in river stage and fluctuated up to 2 m during the past year. During times of high-river stage, the head in the "downgradient" wells is higher than in "upgradient" well 199-D5-13. A pump-and-treat system was active in the 100-D Area until the summer of 1996; it is located upgradient of the ponds and does not appear to influence water levels at the ponds. The general direction of groundwater flow beneath the ponds is toward the north or northwest (toward the Columbia River). However, the prolonged period of high-river stage in FY 1996 influenced groundwater flow in the area, creating a potential for groundwater to flow toward the east or southeast beneath the ponds (see Plate 2). Maximum estimated groundwater-flow rates ranged from 0.32 m/d during low-river stage to -0.44 m/d (reversed gradient) during high-river stage (see Table 5.4-1). Hartman (1994) estimated an upward vertical gradient that ranged from 0.007 to 0.02 between wells 199-D8-54A and 199-D8-54B. Well 199-D8-54A is completed across the water table, and well 199-D8-54B is completed 22.6 m deeper than well 199-D8-54A in a thin layer of silty sand that is confined beneath 15 m of clay.

5.4.2.3 183-H Solar Evaporation Basins

The 183-H solar evaporation basins were used to treat and dispose RCRA waste during the 1970s and 1980s and are described in Chapter 6.0. Water levels in three of the wells that monitor the basins are plotted in Figure 5.4-5. The water table responded to changes in river stage and fluctuated up to 2.7 m during the past year. When river stage is very high (e.g., June 1996), the head in the "downgradient" wells is higher than in "upgradient" well 199-H3-2A. The general direction of groundwater flow beneath the basins is toward the east (toward the Columbia River), as inferred from average water-table maps and contaminant-plume configurations (Hartman 1995, p. 3.3-3.5). The prolonged period of high-river stage in 1996 influenced groundwater flow in the area, creating a potential for groundwater to flow toward the southeast, parallel to the river (see Plate 2). Maximum estimates of groundwater-flow rates during FY 1996 ranged from 3.5 m/d during low-river stage to -1.1 m/d (reversed flow direction) during high-river stage (see Table 5.4-1).

5.4.3 200-West Area

Groundwater flows into the 200-West Area from the basalt ridges and Cold Creek Valley to the west of the Hanford Site and flows out primarily to the north and east (see Plate 2). The water table in the 200-West Area is dominated by the groundwater mound associated with the decommissioned U Pond. Water-level data, beginning in 1948 for well 699-39-79 located near the decommissioned U Pond, indicate that elevations rose steadily until 1957, then fluctuated somewhat until 1985, after which they began to decline steadily (Figure 5.4-6). The maximum elevation of this mound, which occurred in 1984, was ~146 m above mean sea level, ~20 m above preoperational conditions. Water levels in FY 1996 remained over 10 m above preoperational levels, and continued to decline because of reduced discharges to cribs and unlined trenches. Groundwater withdrawal and injection at pump-and-treat systems in the 200-West Area affected water levels locally. These systems are discussed in Section 6.9.

5.4.3.1 216-S-10 Pond and Ditch

The water-table elevation for the unconfined aquifer system beneath this facility during June 1996 is illustrated in Plate 2, indicating that groundwater flow is east to southeast. The vertical groundwater gradient in the vicinity of wells 299-W27-2 and 299-W26-12 was estimated to be slightly downward in June 1995 (i.e., head in well 299-W27-2 was ~137.92 m; head in well 299-W26-12 was ~138.04 m). Water levels declined 0.40 m on average in the vicinity of the 216-S-10 facility in FY 1996 (Figure 5.4-7). Groundwater velocities beneath the facility were estimated at 0.019 to 3.04 m/d (see Table 5.4-1).

5.4.3.2 216-U-12 Crib

Water levels declined over 0.61 m during the past year under this crib (Figure 5.4-8). FY 1996 water-level measurements continue to reveal an increasing rate of decline over the past years. The water table beneath the crib during June 1996 is illustrated in Plate 2, indicating that groundwater flow is east to southeast, a conclusion that is supported by the distribution of contaminants from the site. The rate and direction of groundwater flow beneath the crib were relatively unchanged from 1995 to FY 1996. The average gradient measured in FY 1996 was 0.0019. Estimates of linear velocity range from 0.06 to 0.1 m/d (see Table 5.4-1). There are no data available to determine vertical gradients in this area.

5.4.3.3 Single-Shell Tanks

The water-table mound, which developed beneath the former U Pond, provides a northerly component to the local velocities at Waste Management Area (WMA) T and TX-TY single-shell tank farms. The direction of groundwater flow beneath these tank farms is to the northeast (see Plate 2). At WMA-T, the water-level gradient is 0.0007. At WMA-TX-TY, the gradient decreased from 0.0009 in 1995 to 0.0005 in FY 1996. The groundwater-flow direction is northeast, and the velocity is 0.04 to 0.27 m/d (see Table 5.4-1). With further decline of the U Pond mound, the direction of groundwater flow may shift to the regional west-to-east direction.

Trends of water-level elevation for WMA-T and TX-TY can be seen in Figures 5.4-9 and 5.4-10. Although the decline is not the same for all wells because of local differences in permeability, hydrographs show sharp increases in the rate of water-level drop. At WMA-T, the rate of decline in 1995 was 56 cm/yr; the average rate beneath WMA-TX-TY was 57 cm/yr. Using 12-month data through August 1996, the average rates are 1.2 m/yr for WMA-T and 1.3 m/yr for WMA-TX-TY. These average values show that the rate of decline more than doubled since 1995 when discharges of effluent to the ground ceased.

The strongest influence on groundwater levels and flow directions at the WMA-S-SX and -U single-shell tank farms has been historically the water-table mound beneath U Pond. The water-table elevations in the vicinity of WMA-U have fallen rapidly since the decommissioning of U Pond in 1985. Figure 5.4-11 is a hydrograph for well 299-W23-4, located ~90 m west of the WMA-S-SX boundary, indicating a 7.3-m drop in the water table between 1984 and 1995. Hydrographs of the WMA-S-SX

monitoring wells, illustrating the water-level decline and the elevation relationships between the wells, are presented in Figure 5.4-12. Figure 5.4-13 is a hydrograph for well 299-W19-1, located ~50 m southeast of the WMA-U boundary, indicating a 7.6-m drop in the water table between 1984 and 1995. A map of the top of the water table in the vicinity of WMA-U, based on June 1996 data, is included in Plate 2.

The shutdown of U Pond resulted in increased effluent discharge to other sites, particularly the 216-Z-20 crib. The result of the discharge to this crib was a shift in the peak of the declining groundwater mound northward toward the crib, thus changing the groundwater-flow direction under WMA-S-SX from approximately west to east to its present direction of southeast.

Groundwater flow under WMA-U changed from slightly north of east to its present direction of slightly south of east. The result of several large discharges to the 216-U-14 ditch (located west of U Plant) in 1991 and 1993 (Singleton and Lindsey 1994) was to slow the rate of decrease in the water table. In the case of the 1993 discharge, the influx temporarily reversed the direction of groundwater flow beneath the tank farm so that it flowed toward the northwest (Caggiano 1996b). This reversal of flow directions was probably possible because of the greatly reduced discharge to the 216-Z-20 crib at that time (Johnson 1993b).

The effect of discharge to the 216-U-14 ditch is complicated because of the existence of perched water beneath the ditch. Figure 5.4-14 shows hydrographs of two wells (299-W19-91 and 299-W19-92) that monitor the perched water beneath the ditch. The result of the 1993 discharge was a rapid 6-m rise in the level of the perched water table. The effect of this discharge is apparently spread out as water drains downward from the perched water table; however, the gradient reversal resulting from this discharge is illustrated in Figure 5.4-15, which shows hydrographs for wells 299-W18-25 and 299-W19-32. The water-table elevations in well 299-W19-32 rose above those of 299-W18-25 in mid-1993, reversing the up- and downgradient relationships within the monitoring network. In late-1995, water levels in well 299-W18-25 moved higher, reestablishing the original relationship.

It is uncertain how groundwater-flow directions will change as the U Pond groundwater mound decreases and migrates; however, there will probably be a period of changing flow directions before the groundwater assumes its pre-Hanford west to east flow.

Average linear velocity estimates beneath WMA-S-SX ranged from 0.004 to 0.55 m/d (see Table 5.4-1). The estimates of hydraulic conductivity used to calculate these velocities are believed to be low; therefore, they should be considered lower limits to actual flow velocities (Caggiano 1996b). Estimates of groundwater velocity beneath WMA-U range from 0.02 to 0.71 m/d (see Table 5.4-1).

5.4.3.4 Low-Level Burial Grounds

Low-Level Waste Management Areas (LLWMA) -3, -4, and -5 are located in the 200-West Area (see Figure 1.2). Groundwater flow beneath each of these LLWMAs is discussed below.

LLWMA-3 is located in the north-central portion of the 200-West Area, and the groundwater-flow direction is generally northward with a slight eastward component, which increases to the east (see Plate 2). The eastward component is increasing with time, as expected, resulting from the decreased liquid disposal in the 200-West Area. The rate of groundwater flow beneath LLWMA-3 is estimated to be ~0.0002 to 0.1 m/d (see Table 5.4-1).

Water-level data from the two groundwater wells that monitor the base of the unconfined aquifer indicate that the vertical groundwater gradient in this area is downward. The water levels in downgradient shallow well 299-W7-2 are consistently greater than those in nearby deep well 299-W7-3, by ~0.3 m (this results in a downward gradient of 0.0038). Water levels in upgradient shallow well 299-W10-13 are generally 0.15 m greater than in deep well 299-W10-14, for a downward gradient of 0.0026.

LLWMA-4 is located in the south-central portion of the 200-West Area. The groundwater-flow direction has been primarily to the west, trending to northwest in the northern portions and possibly slightly to the southwest in the extreme southern portion (Mercer 1996). This flow direction is the result of past disposal practices in the 200-West Area. The groundwater mound created by liquid disposal has been declining in recent years, and the flow direction beneath LLWMA-4 is uncertain. Water-level measurements in upgradient and downgradient wells are within the limits of error, and until a definite change in groundwater-flow direction is confirmed, the flow will be assumed to continue in the west-to-northwest direction. The startup of Phase II of the 200-ZP-1 Operable Unit carbon tetrachloride pump-and-treat program, which began in August 1996, further complicates the groundwater-flow regime. Extraction wells 299-W15-33, 299-W15-34, and 299-W15-35 to the east and injection well 299-W15-29 to the west of LLWMA-4 are expected to impact the RCRA groundwater-monitoring wells in the near future. More information on the pump-and-treat system, including a summary of its effects on groundwater flow, is included in Section 6.9.

Without being able to determine a definite groundwater-flow direction beneath LLWMA-4, calculation of flow velocity is highly subjective. The best estimate for flow velocity reported in Mercer (1996) was 0.17 m/d (see Table 5.4-1). Knowing that the gradient diminished in FY 1996, the velocity would also be lower but a reliable estimate cannot be made.

The vertical groundwater gradient in the unconfined aquifer system in this area is downward, based on water levels from the wells that monitor the base of the unconfined aquifer (wells 299-W15-17 and 299-W18-22). The water levels in these wells are consistently lower than the nearby wells monitoring the top of the unconfined aquifer. The differences are ~0.07 m between wells 299-W15-16 and 299-W15-17 and ~0.06 m between wells 299-W18-21 and 299-W18-22. Downward gradients of 0.00056 and 0.00054, respectively, can be calculated for the paired wells.

LLWMA-5 is located in the north-central portion of the 200-West Area. RCRA monitoring was discontinued in FY 1996 because the burial ground had never been used. Some water-level measurements were made at these groundwater-monitoring wells for other projects. The groundwater-flow direction beneath LLWMA-5 is to the northeast (see Plate 2). The hydraulic gradient in June 1996 was 0.0016, and the groundwater-flow velocity is estimated at 0.19 m/d (see Table 5.4-1).

The vertical groundwater gradient in the unconfined aquifer system in this area is downward. Water levels in well 299-W6-3, which monitors the base of the unconfined aquifer, are generally 0.2 m less than water levels in shallow well 299-W6-4. The difference in water-level measurements from shallow/deep paired wells (299-W6-6 and 299-W6-7) is smaller: 0.02 m. These values translate into downward gradients of 0.0024 for the upgradient pair (299-W6-3 and 299-W6-4) and 0.00046 for the downgradient pair (299-W6-6 and 299-W6-7).

5.4.4 200-East Area

Groundwater flows into the 200-East Area from the west and flows out primarily to the northwest through Gable Gap and to the southeast toward the Columbia River (see Plate 2). The water table in the 200-East Area and vicinity is nearly flat, except for a groundwater mound associated with wastewater discharge to B Pond. Because of the high transmissivity of the Hanford formation, the water table in the 200-East Area slopes very gently. There is a broad hydraulic low area between westward-flowing water from the B Pond mound and the regional eastward gradient.

Water-level data beginning in 1949 for well 299-E26-1, located in the northeastern portion of the 200-East Area, indicate that water levels rose until 1965, declined slightly from 1972 to 1983, rose to a maximum elevation in 1988, and declined steadily from 1988 through 1995 (Figure 5.4-16). Because wastewater discharges to disposal facilities in the 200-East Area and B Pond were reduced in 1988, the water table has been declining. During FY 1996, however, this decline in water-table elevation has slowed or ceased, as indicated by the hydrographs of wells 299-E32-2 (northwestern corner of the 200-East Area) and 299-E34-2 (northeastern corner of the 200-East Area) (Figure 5.4-17).

5.4.4.1 216-B-3 Pond

Groundwater flows essentially radially outward from the groundwater mound, the apex of which is approximately located in the vicinity of the 216-B-3B lobe of B Pond (see Plate 2). Based on June 1996 water-level measurements, the horizontal component of hydraulic gradient near B Pond varies from ~0.003 east of the mound apex to 0.006 west-southwest of the former location of the main pond. The mound was created by large volumes of wastewater recharging the uppermost aquifer and significantly altered the original groundwater-flow pattern of the area. In the past, the mound was even more extensive than at present because of larger volumes of effluent discharge to the system. The maximum elevation of the mound was ~130 m above mean sea level at well 699-42-40A in 1988 (~13 m above preoperational conditions) and corresponds with the maximum wastewater discharge to B Pond (Figure 5.4-18). As the rate of effluent discharge decreased, water levels in wells within the influence of the mound generally declined with time.

In FY 1996, water levels in wells monitoring B Pond generally showed little change or had decreased slightly from June 1995 levels. Wells showing the greatest decline in water level during this period were 699-42-40A (-0.33 m) and 699-42-41 (-0.2 m). Water levels in most of the other wells were down slightly, but six wells showed a slight increase in water level relative to June 1995. The water level in well 699-43-40 rose 0.12 m from June 1995 to June 1996, and represents the greatest departure from the trend of decline.

On a broader time scale, most wells in the network showed a pronounced decline in water level until late 1993 or early 1994, and thereafter decline less rapidly, level off, or even rise. Notable exceptions to this trend are wells near the western end of the main pond (e.g., 699-43-43 and 699-44-43B). The water-level decline in these wells accelerated since late 1993, when discharge to the main pond ceased. A composite hydrograph, typical of wells in the B Pond network, is shown in Figure 5.4-19.

Estimates of groundwater-flow rates near the B Pond system are mostly based on numerical modeling and by the tracking of tritium migration from the 200-East Area operations to the Columbia River (Freshley and Graham 1988; Freshley and Thorne 1992). The average horizontal groundwater-flow rate determined by these methods is estimated at 0.2 to 2.7 m/d (see Table 5.4-1).

The vertical hydraulic gradient was calculated for four well pairs in the network, representing deep and shallow completions. All four pairs indicate a definitively downward hydraulic gradient. Because the screens in each of these wells are open to several meters of aquifer thickness, potentiometric measurements used for the calculations should be considered approximations. The well pairs and the calculated approximate vertical hydraulic gradients for June 1996 are, respectively: wells 699-40-40A/B, 0.06; wells 699-42-39A/B, 0.01; wells 699-43-43E/G, 0.07; and wells 699-43-42J/699-42-42B, 0.13.

5.4.4.2 216-A-29 Ditch

Groundwater flow beneath this ditch is currently to the southwest and is strongly influenced by the nearby B Pond groundwater mound (see Plate 2). Water levels continued to decline in response to reductions in effluent discharges to 200-East Area facilities (Figure 5.4-20). The ditch is positioned above the southwest flank of the B Pond groundwater mound and continues to have an appreciable groundwater gradient with respect to the rest of 200-East Area. The gradient for the lower end (nearest B Pond) is 0.0045 and was calculated using wells 699-43-43 and 299-E25-34. The velocity for the lower end of the ditch is 0.63 m/d (see Table 5.4-1). Determination of velocity and gradient for the head (southwest) end of the ditch is more problematic because the water table is very flat. Groundwater gradients on this end of the ditch are generally on the order of 0.00020 (Connelly et al. 1992a). This produces a velocity of 0.028 m/d (see Table 5.4-1).

Although water-level data indicate groundwater flows toward the southwest beneath the ditch, tritium and technetium-99 plumes in the 200-East Area suggest that groundwater near the ditch may have a southeasterly component. This flow-direction change more closely reflects the regional trend of groundwater flow from west to east.

5.4.4.3 216-A-10 and 216-A-36B Cribs

Water levels continue to decline in all of the wells that monitor these cribs but the rate of decline decreased since discharges to the cribs ceased in 1988. The average water-level decline from 1988 to 1991 was ~0.37 m/yr; from 1991 to 1993, ~0.21 m/yr; and from 1994 through FY 1996, ~0.06 m/yr.

Groundwater flow in the vicinity of the cribs is poorly defined because the local hydraulic gradient is extremely low. The water-table elevations suggest that local groundwater flow is generally toward the south to southeast. However, the cribs may also be influenced by groundwater flowing from the northeast from the vicinity of B Pond. The tritium plume map (see Plate 3) also indicates that groundwater flow in the southern half of the 200-East Area is directed to the southeast.

The rate of groundwater flow is difficult to estimate because of the very low gradient (0.0001 to 0.0002) (Connelly et al. 1992a). Groundwater-flow velocities may range from 0.06 to 0.2 m/d (see Table 5.4-1).

5.4.4.4 216-B-63 Trench

Water-table elevations reveal a westward flow direction that is approximately parallel to this trench (see Plate 2). Groundwater flow is controlled by the B Pond groundwater mound to the east of the trench. In general, groundwater levels continued to decline beneath the trench in FY 1996 (Figure 5.4-21).

The horizontal groundwater gradient in the unconfined aquifer under the trench is very flat, ~0.000066 between wells 299-E27-9 and 299-E33-33 in FY 1996. Estimated groundwater velocity is ~0.06 m/d (see Table 5.4-1).

Well 299-E33-36 continues to exhibit a significant groundwater-elevation difference from the two adjoining wells (299-33-33 and 299-33-37) (Figure 5.4-22). The wells were resurveyed in FY 1996; the report indicates that survey error is not a significant contributing factor in the elevation discrepancy. Well-construction and stratigraphic effects are now being considered because of the erratic behavior exhibited by well 299-E34-8. This well is located east of 299-E33-36 and has similar problems with groundwater-elevation readings.

5.4.4.5 200 Areas Liquid Effluent Retention Facility

Groundwater beneath this facility generally flows from east to west (see Plate 2). In general, the water table continues to decline beneath the facility (Figure 5.4-23) in response to a decline in the groundwater mound beneath B Pond. The horizontal groundwater gradient in the unconfined aquifer is ~0.0054 between wells 299-E26-9 and 299-E26-11. The average linear groundwater velocity is estimated at 3.3 m/d (see Table 5.4-1).

5.4.4.6 Single-Shell Tanks

The directions of flow at WMA-A-AX, -B-BX-BY, and -C single-shell tank farms are not easily determined because the water table is very flat (see Plate 2). The difference in hydraulic head across these smaller areas ranges from <1 to 5 cm.

Historical water-level trends can be seen in the hydrographs in Figures 5.4-24, 5.4-25, and 5.4-26. From 1995 through FY 1996, the elevation of the water table continued to decline slightly beneath the

200-East Area because of reduced discharges to cribs, unlined trenches, and B Pond. FY 1996 decreases in water level at WMA-A-AX and -C are ~3 to 6 cm. Beneath WMA-B-BX-BY, water-level changes are less consistent, displaying increases for some wells. Investigations are under way to determine measurement and barometric effects on these data, and will allow more accurate analysis of tank farm groundwater flow in assessing compliance.

Groundwater flow across WMA-A-AX is generally from the east to west. The hydraulic gradient calculated from August 1996 data is ~0.0002, a decrease from 0.0005 in 1995. Groundwater flow across WMA-C is also to the west. The hydraulic gradient calculated from August 1996 data is ~0.00005; also a decrease from 0.0003 in 1995. Groundwater flow across WMA-B-BX-BY in the past was generally toward the west. However, as can been seen from Plate 2, the true direction of groundwater flow in the northern part of the 200-East Area is difficult to determine. The hydraulic gradient calculated from August 1996 water-level data is the same as 1995 (0.00008). Estimates of the groundwater velocities are given in Table 5.4-1.

5.4.4.7 Low-Level Burial Grounds

LLWMA-1 and -2 are located in the northwest and northeast corners, respectively, of the 200-East Area (see Figure 1.2).

The groundwater-flow direction in the area of LLWMA-1 is difficult to determine using only water-level data from the monitoring wells around the burial ground because the groundwater gradient in this area is extremely low.

An interpretation of the groundwater-flow direction from Plate 2 is inconclusive. A better estimate of the groundwater-flow direction can be inferred from contaminant plume maps (e.g., Plates 3 and 4). The contamination distribution suggests that the general direction of flow is to the northwest beneath LLWMA-1. Estimates of groundwater-flow velocities are given in Table 5.4-1. Calculated groundwater-flow velocities are highly subjective; however, they represent the best estimate of the actual conditions beneath LLWMA-1.

As with LLWMA-1, water-level data from LLWMA-2 monitoring wells do not present a clear picture of groundwater flow. The groundwater-flow direction in this area is primarily from east to west. Groundwater flow is affected by the basalt high located north and east of LLWMA-2 and the continued presence of a groundwater mound associated with B Pond.

The groundwater gradient beneath LLWMA-2 is low, on the order of 0.00004. The average linear velocity of groundwater is estimated to be between 0.15 and 0.7 m/d (see Table 5.4-1).

5.4.5 400 and 600 Areas

The Hanford Site water-table map in Plate 2 shows the groundwater-level contours for the 400 and 600 Areas. The 400 Area contains the Fast Flux Test Facility in its south-central portion. Groundwater flows from west to east beneath the 400 Area. The 600 Area, the largest area on the site,

encompasses all land on the Hanford Site that is not bound by operational areas. The two waste sites located in the 600 Area southeast of the 200 Areas are discussed in this section.

5.4.5.1 Solid Waste Landfill

This landfill lies in a zone of very high transmissivities (Jacobson and Freshley 1990) and, as a result, there is a very low hydraulic gradient across the site. A map of the water table in the vicinity of the site, based on June 1996 data, is presented in Figure 5.4-27. This map illustrates the low hydraulic gradients in the vicinity of the landfill. The zone of high transmissivities, which includes the landfill, extends to the northwest beneath the southeast corner of the 200-East Area. Groundwater flows into this zone from the B Pond mound to the north and from the U Pond mound and Cold Creek recharge areas to the west. The principal source was apparently the input to B Pond, which strongly affects the water-table elevations over a wide area, including the vicinity of the landfill.

The water table has dropped more than 1.3 m since December 1988, apparently as a result of decreased water input to B Pond, a trend that essentially stopped during FY 1996. This variation in the water table is illustrated in Figure 5.4-28, which depicts hydrographs of monthly water-level measurements in wells that monitor the landfill. These hydrographs indicate the low hydraulic gradient across the site.

Groundwater-flow directions beneath the landfill are inferred from the water-level measurements and by the paths of nitrate and tritium plumes that originate in the 200-East Area that pass beneath the landfill (see Plates 3 and 4). The nitrate and tritium plumes (see Plates 3 and 4) indicate that the principal direction of groundwater flow is ~125 degrees east of north (Hodges 1991a), a value that has remained relatively constant since 1990. The difference in water-table elevation across the site is commonly on the order of 1 cm, within the error expected from well-surveying and water-table-elevation measurements. However, flow directions based on water-table elevations agree to some extent with the flow direction indicated by the plumes.

The rate of groundwater flow beneath the landfill is highly uncertain because of the flat water table. On the basis of site-specific aquifer testing and the observed hydraulic gradients, the expected groundwater velocities should be on the order of 1.2 to 1.8 m/d. However, more direct indicators of velocity yield values that range from 3 m/d to in excess of 30 m/d (see Table 5.4-1). Additional information on flow rate is provided by the recent decrease in nitrate and tritium concentrations across the site. Nitrate and tritium, which have upgradient sources, exhibit nearly identical time-concentration variation in certain upgradient and downgradient well pairs with quarterly sampling. This correspondence indicates that the time required for the contaminants to traverse the site is on the order of 3 months. This traverse time indicates groundwater-transport rates of ~5.5 m/d. The actual transport rate is probably near 6 m/d and is controlled by zones of very high groundwater velocity within the Hanford formation that are missed or averaged out in normal aquifer testing (see Table 5.4-1).

5.4.5.2 Nonradioactive Dangerous Waste Landfill

This landfill is contiguous with the Solid Waste Landfill discussed above, and groundwater flow is similar (see Figure 5.4-27). Estimates of groundwater-flow rates for this landfill are the same as provided above for the Solid Waste Landfill.

The water table in the vicinity of this landfill apparently dropped ~1.5 m since December 1988; however, the exact decrease is difficult to estimate because of the scatter in water-level data. Data from the Solid Waste Landfill, which shows much less scatter, indicate a considerable slowing in water-table decrease and a drop of ~1.4 m over the same time interval. This decrease in water-table elevation, apparently a result of decreased water input to B Pond, is illustrated in Figure 5.4-29.

The reason for the degree of scatter in the water-level data is uncertain. Water levels are measured using the same equipment and techniques as at the Solid Waste Landfill, where there is much less scatter; therefore, error does not seem likely. The case against measurement error is reinforced by the much lower variability in the two deep wells (699-25-33A and 699-26-35C) at the landfill that are measured at the same time.

Hydraulic gradients across the landfill are on the order of 0.0001, yielding water-level differences that are within standard surveying and measurement error. In past years, it was possible to make estimates of average groundwater-flow directions on the basis of water-level measurements; however, the large scatter in groundwater-elevation data made this impossible for 1994, 1995, and FY 1996.

Groundwater-flow directions, previously calculated from regular water-level measurements for wells 699-25-34B, 699-26-33, and 699-26-35A, provided a relatively consistent average flow direction toward the northeast (see Table 5.4-1). The nitrate and tritium plumes that pass through the area and the regional plume map suggest groundwater flow is toward the southeast (see Plates 2, 3, and 4).

Two well pairs (699-25-33A/699-25-34A and 699-26-35A/699-26-35C) sample the top of the unconfined aquifer and the top of the Ringold Formation. The lack of a detectable head difference in these well pairs indicates that any vertical gradient within the upper portion of the aquifer is quite small.

5.4.6 300 and Richland North Areas

Groundwater beneath these areas generally flows from west to east between the Yakima and Columbia Rivers. Plate 2 includes the June 1996 water-table-elevation contours for these areas.

5.4.6.1 300 Area

Groundwater flows into the 300 Area from the northwest, west, and southwest and converges as it flows toward the Columbia River (see Plate 2). This is caused by the regional flow with the additional influences of recharge from the Yakima River and irrigation of offsite agricultural land to the west and the City of Richland's North Well Field recharge basins located ~3 km south of the 300 Area. The

presence of highly permeable, gravel-filled channels that intersect the Columbia River in the 300 Area (Lindberg and Bond 1979; Swanson 1992) also contributes to the convergence of groundwater flow in this area.

The primary influence on groundwater-elevation changes in the 300 Area is the fluctuation in Columbia River stage (Figure 5.4-30). River-stage elevation is influenced by operation of up- and downstream dams. Changes in Columbia River stage elevation can be correlated to changes in water-level elevations at wells as far as ~360 m from the river (Campbell et al. 1993). River stage was unusually high during FY 1996, rising in December 1995 (which is usually a period of low-river stage) and remaining elevated until late summer 1996.

The water table beneath the 300 Area was also influenced by recharge from process effluent. In the past, discharge of wastewater to the ground created a groundwater mound beneath the 300 Area. During 1994, the process trenches received the largest volume of wastewater in the 300 Area, 291,000 m^3; however, discharge to the trenches ceased in December 1994 (WHC 1995).

The groundwater-flow direction in the unconfined aquifer in the immediate vicinity of the 316-5 process trenches was primarily to the south or southeast during FY 1996 (see Plate 2). This direction is slightly different than in previous years because of high-river stage. When the river stage is lower, groundwater in the vicinity of these process trenches is generally to the southeast or east (Lindberg 1996). When the river stage is high and sustained, there is enough bank storage to change the flow direction in the 300 Area to the south or even to the southwest. This change in flow direction is readily apparent in a contour map of the water table that was developed from water-level data collected in June 1996 (see Plate 2). The river stage was elevated with enough bank storage to cause a gradient to the south.

The flow rate in the top of the unconfined aquifer was ~10.6 m/d near the process trenches, based on data from a tetrachloroethylene spill that occurred while the trenches were in use (see Table 5.4-1). Because the process trenches artificially recharged groundwater, the water table was steeper when this estimate was made than it is now. The gradient (and hence, groundwater velocity) decreased after discharge to the trenches ceased. In FY 1996, the water table was flatter than normal because of the long period of high-river stage. Velocity estimates based on the December 1995 and June 1996 gradients were 0.17 m/d (see Table 5.4-1).

There is a vertical head difference, with the gradient in an upward direction, between the unconfined aquifer above the Ringold Formation lower mud unit and the gravels beneath the lower mud unit. At wells 399-1-17A (106.39 m) and 399-1-17C (114.70 m), the head difference is ~8.3 m in June 1996. Well 399-1-17C is screened ~42 m deeper than 399-1-17A; thus, the vertical gradient is 0.2 upward.

5.4.6.2 Richland North Area

South of the 300 Area in the Richland North Area, the City of Richland's North Well Field is the primary influence on groundwater-elevation changes. At this well field, water is pumped from the

Columbia River into a system of basins (ICF Northwest 1987) that recharge the unconfined aquifer system. Water is then pumped from the aquifer via the well field to supplement the City of Richland's water supply. This system is primarily used when the city's filtration plant is shut down for annual maintenance between January and March and during the summer months. Historical data indicate that the ratio of recharge to discharge varied from 2:1 to 4:1 (Liikala 1994). Because the volume of water pumped into the recharge basins is much larger than the volume of groundwater removed, a water-table mound formed around this facility. The variable net recharge to the aquifer causes the elevation of the groundwater mound to rise and fall each year. The hydrograph of well 699-S40-E14 (Figure 5.4-31), which is located immediately west of the well field, illustrates the effect of pumping river water to the recharge basins and the resultant water-table fluctuations.

Operation of this well field affects water-table elevations in wells throughout the Richland North Area. Liikala (1994) identified wells up to at least 1.6 km north and south of the well field that responded to the net recharge to the aquifer. As expected, hydrographs of wells near the well field show the highest correlation with operation of the well field (see Figure 5.4-31). The amplitude of water-level response decreases with distance from the well field (i.e., well 699-S32-E13A, located ~2.5 km to the north), decreasing more rapidly to the west and east than to the north and south. The water-level responses to the west and east are likely dampened by the horizontal hydraulic gradient (Liikala 1994). The water-level changes at well 699-S43-E7A, located north of Highway 240, may result from operation of this well field, pumping of agricultural wells, irrigation of agricultural land, and activities at the potato-processing plant to the south. At well 699-S27-E14, located near the southern boundary of the 300 Area, water-level changes appear to be dominated by river-stage fluctuations.

In 1989, ~1 km^2 of agricultural land was irrigated in the area between the Yakima River and the Richland North Area; by 1991, ~30 km^2 were being irrigated. Irrigation water is pumped primarily from the Columbia River and, to a lesser extent, from shallow irrigation wells (Liikala 1994). Increasing water levels in the area northwest of the Richland North Area, resulting from irrigation, are apparent in the hydrograph of well 699-S31-1 (Figure 5.4-32). Well 699-S31-1 is ~3 km west of the Horn Rapids Landfill along the northern perimeter of the irrigated fields. The water level at this well rose 0.15 m between June 1995 and June 1996, which is consistent with the trend observed since 1991.

5.4.7 Areas East and North of Columbia River

Water-level elevations north and east of the Columbia River are much greater than on the Hanford Site. As indicated in Figure 5.2-1, the water-table elevation to the east of the Columbia River is currently from 50 to 150 m higher than the water-table elevation on the Hanford Site. The dominant pattern of groundwater flow in the unconfined aquifer system north and east of the Columbia River is from basalt ridges that form the northern and eastern edges of the Pasco Basin toward the Columbia River. The water-table configuration in these areas is heavily influenced by recharge from irrigation with Columbia River water. The irrigated areas are part of the South Columbia Basin Irrigation District of the Columbia Basin Irrigation Project. Recharge to the unconfined aquifer system in this area is caused by leakage from canals, wasteways, and ponds and by seepage from irrigated fields (Ebbert et al. 1991). Pumping from wells that tap the unconfined aquifer system is mostly for

domestic, stock, and irrigation purposes, but yield is commonly low (Bauer et al. 1985). For this reason, pumping from the unconfined aquifer system in this area has little influence on the configuration of the water-table surface.

The water-table map (see Figure 5.2-1) shows a steep hydraulic gradient along the eastern bank of the Columbia River east of Gable Mountain in the area known as White Bluffs. A similar steep gradient is seen in the area east of the river and north of the 300 Area. Because of the abrupt change in land-surface elevation between the Columbia River and White Bluffs, the increased elevation of the water table from irrigation caused the formation of a series of springs discharging from the bluffs.

Water-table maps by the USGS (Drost et al. 1989, 1993; Ebbert et al. 1995) indicate that the elevation of the water table north of the Columbia River, extending from Wahluke Slope southeast to Columbia Flat, is controlled by the topography of the land surface and the underlying basalt. Comparison of water-level data indicates that the water-table elevation in this area did not change significantly between 1989 and FY 1996. Water-table-elevation contours in the nonirrigated portion of Wahluke Slope north of the Columbia River are inferred because data are limited (i.e., there are few wells for measuring water levels). The sources of information used to infer the contours include the elevation of water in ponds and seeps in the Saddle Mountain National Wildlife Refuge across the Columbia River from the 100-N and 100-K Areas. These data, used in conjunction with topographic elevations, indicate that the 150-m contour extends south and east of the ponds (see Figure 5.2-1). Along the northeastern border of the Hanford Site, contour flexures are inferred from topographic elevations.

5.5 Groundwater Flow in the Upper Basalt-Confined Aquifer System

D. B. Barnett, F. A. Spane, and W. D. Webber

The upper basalt-confined aquifer system is defined as the groundwater occurring within basalt fractures and joints, interflow contacts, and intercalated sedimentary interbeds within the upper Saddle Mountains Basalt (see Figure 3.2). Groundwater is confined by the dense, low-permeability interior portions of basalt flows and by Ringold Formation silt and clay units overlying the basalts.

Hydraulic head distribution and flow dynamics of the upper basalt-confined aquifer system were evaluated by Spane and Raymond (1993), who identified several prominent hydrologic features, including the following:

- a broad recharge mound extending northeastward from Yakima Ridge in the 200-West Area
- a small recharge mound immediately east of the 200-East Area in the vicinity of B Pond
- a hydrogeologic barrier (i.e., an impediment to groundwater flow), believed to be related to faulting, near the mouth of Cold Creek Valley
- the presence of a region of low hydraulic head (potential discharge) in the Umtanum Ridge and Gable Mountain structural area

- a region of high hydraulic head to the north and east of the Columbia River that is associated with recharge attributed to agricultural activities.

The groundwater-flow system imposed by these features is presented schematically in Figure 5.1-1. Figure 5.1-1 presents the potentiometric map for the upper basalt-confined aquifer system based primarily on June/July 1996 water-level measurements. (Note: offsite well-water levels are based on 1993 measurements reported in Spane and Raymond 1993). With few exceptions, the potentiometric map features shown in Figure 5.1-1 for 1996 are nearly the same as those shown for 1993 in Spane and Raymond (1993). Minor differences in the 1996 map, in comparison to 1993, include increases in hydraulic head for selected monitoring wells near the Columbia River and minor decreases in hydraulic head for monitoring wells in the 200-West Area and for the region north of the 200-East Area.

Two confined-aquifer-monitoring wells near the Columbia River (199-B3-2P and 699-42-E9B) exhibited increases in water level of ~1 m between March 1993 and mid-1996. These increases coincide with head increases in the unconfined aquifer, which reflect the high-river stage in the spring and into the summer of 1996, but may also be related to the continued increases in hydraulic head in this region as a result of recharge associated with offsite agricultural activities located north and east of the Columbia River.

Water levels in confined-aquifer-monitoring wells north, east, and south of the 200-West Area show a continuing slow decline of ~0.08 to 0.15 m/yr. Wells in the area between Gable Mountain and the northern boundary of the 200-East Area experienced steadily declining water levels since 1987, with a total decline of 0.6 to 0.9 m. Based on FY 1996 measurements, this decline appears to have ceased and is even reversing slightly in some wells.

Recharge to the upper basalt-confined aquifer system is believed to result from natural recharge from precipitation and surfacewater infiltration where the basalt and interbeds are exposed at land surface. Recharge also may occur through the unconfined aquifer system, where there is artificial recharge associated with offsite irrigation and wastewater discharge from Hanford Site facilities. Hydraulic communication with overlying and underlying aquifers is believed to cause the region of low hydraulic head found in the Umtanum Ridge-Gable Mountain structural area. Spane and Raymond (1993) discuss these relationships in more detail.

Table 5.4-1. Estimates of Groundwater-Flow Rates

RCRA Site	Direction of Flow	Rate of Flow (m/d)	Method	Input to Darcy Equation: Hydraulic Conductivity (m/d)	Input to Darcy Equation: Effective Porosity[a]	Input to Darcy Equation: Gradient	Comments
1301-N LWDF	NW (low river) SE (high river)	-0.0026 to -0.048 (March 1996)	Darcy	6.1 to 36.6 (Gilmore et al. 1992)	0.1 to 0.3	-0.00013 (March 1996)	Gradient calculated between wells 199-N-34 and 199-N-75. Reversed gradient in March.
1325-N LWDF	N	0.0033 to 0.059 (March 1996)	Darcy	6.1 to 36.6 (Gilmore et al. 1992)	0.1 to 0.3	0.00016 (March 1996)	Gradient calculated between wells 199-N-27 and 199-N-50.
1324-N/NA LWDF	NW	0.014 to 0.25 (March 1996)	Darcy	6.1 to 36.6 (Gilmore et al. 1992)	0.1 to 0.3	0.00067 (March 1996)	Gradient calculated between wells 199-N-72 and 199-N-25.
120-D-1 Ponds	NW (low river) SE (high river)	0.0032 to 0.32 (October 1995) -0.0044 to -0.44 (June 1996)	Darcy	1.2 to 40 (Hartman 1992a)	0.1 to 0.3	0.00080 (October 1995) -0.0011 (June 1996)	Gradient calculated between wells 199-D5-13 and 199-D8-4. Reversed gradient in June 1996.
183-H Solar Evaporation Basins	E (low river) W (high river)	0.125 to 3.5 (October 1995) -0.04 to -1.1 (June 1996)	Darcy	15 to 140 (Liikala et al. 1988)	0.1 to 0.3	0.0025 (October 1995) -0.0008 (June 1996)	Gradient calculated between wells 199-H3-2A and 199-H4-12A. Reversed gradient in June 1996. Flow meter in wells 199-H4-7 and 199-H3-2A (Hartman 1996a).
		0.65 to 4.9	Flow meter				
216-S-10 Pond and Ditch	E or SE	0.019 to 3.04	Darcy	10 (Williams and Barnett 1993) 12 to 152 (Kipp and Mudd 1973)	0.1 to 0.3	0.00057 to 0.002 (June 1996)	
216-U-12 Crib	E-SE	0.06	Darcy	6.2	0.2	0.0019	Hydraulic conductivity is geometric mean of values in Goodwin (1990).
		0.1	Plume migration				
216-B-3 Pond	Radial	0.2 to 2.7	Numerical modeling; plume migration	NA	NA	NA	Freshley and Graham (1988) and Freshley and Thorne (1992).
216-A-29 Ditch	SW	0.63 (lower end of ditch) 0.028 (head end)	Darcy	35 (Kasza 1992)	0.25 (WHC 1990a)	0.0045 (lower) 0.0002 (head)	Gradient for lower end of ditch calculated between wells 699-43-43 and 299-E25-34. Gradient for head end of ditch from Connelly et al. (1992).

Table 5.4-1. (contd)

RCRA Site	Direction of Flow	Rate of Flow (m/d)	Method	Input to Darcy Equation: Hydraulic Conductivity (m/d)	Input to Darcy Equation: Effective Porosity[a]	Input to Darcy Equation: Gradient	Comments
216-A-36B 216-A-10	S to SE	0.06 to 0.2	Darcy	150 to 300	0.25	0.0001 to 0.0002	Connelly et al. (1992).
216-B-63 Trench	W	0.06	Darcy	182	0.2	0.000066	Gradient calculated between wells 299-E27-9 and 299-E-33-33.
200-Areas LERF	W	3.3	Darcy	122 (Graham et al. 1981)	0.2	0.0054	Gradient calculated between wells 299-E26-11 and 299-E26-9.
WMA-A-AX	W	0.007 to 0.07	Darcy	7.3 to 33.5 (Newcomer et al. 1990)	0.1 to 0.2	0.0002 (June 1996)	Gradient calculated between wells 299-E25-2 and 299-E24-19.
WMA-B-BX-BY	W	0.04 to 0.08	Darcy	97.5 (Newcomer et al. 1990)	0.1 to 0.2	0.00008 (June 1996)	Gradient calculated between wells 299-E33-33 and 299-E33-32.
WMA-C	W	0.01 to 0.06	Darcy	48.7 to 119 (Newcomer et al. 1990)	0.1 to 0.2	0.00005 (June 1996)	Gradient calculated between wells 299-E27-7 and 299-E27-12.
WMA-S-SX	SE	0.004 to 0.55	Darcy	0.43 to 27.4 (Newcomer et al. 1990)	0.1 to 0.2	0.002	Lower bound for hydraulic conductivity and velocity.
WMA-T	NE	0.04 to 0.07	Darcy	10.1 (Newcomer et al. 1990)	0.1 to 0.2	0.0007 (June 1996)	Lower bound for hydraulic conductivity and velocity. Gradient calculated between wells 299-W10-16 and 299-W11-27.
WMA-TX-TY	NE	0.04 to 0.27	Darcy	15.2 to 54.8 (Newcomer et al. 1990)	0.1 to 0.2	0.0005 (June 1996)	Lower bound for hydraulic conductivity and velocity. Gradient calculated between wells 299-W15-22 and 299-W10-17.
WMA-U	E	0.02 to 0.26 <0.01 to 0.71	Darcy Flow meter	6.1 to 36.6 (Newcomer et al. 1990)	0.1 to 0.2	0.0007	Lower bound for hydraulic conductivity and velocity. Flow-meter results reported in Caggiano (1996b).
LLWMA-1	NW	0.04 to 0.5	Darcy	73 to 762 (Last et al. 1989)	0.1	0.00006	Direction inferred from plume maps. Gradient very low; rate uncertain.
LLWMA-2	W	0.15 to 0.7	Darcy	427 to 2,042 (Last et al. 1989)	0.1	0.00004	Direction inferred from plume maps. Gradient very low; rate uncertain.
LLWMA-3	N to NE	0.00024 to 0.12	Darcy	0.02 to 9.8 (Last et al. 1989, p. 6.18)	0.1	0.00118	

Table 5.4-1.. (contd)

RCRA Site	Direction of Flow	Rate of Flow (m/d)	Method	Input to Darcy Equation: Hydraulic Conductivity (m/d)	Input to Darcy Equation: Effective Porosity[a]	Input to Darcy Equation: Gradient	Comments
LLWMA-4	W to NW (currently uncertain)	0.17	Darcy	23.8 (Last et al. 1989, p. 6.18-19)	0.1	0.00072	Estimated for 1995 by Mercer (1996). Gradient decreased in 1996; velocity lower.
LLWMA-5	NE	0.19	Darcy	11.9 (Mercer 1993a, 1993b)	0.1	0.00164	
SWL	125° E of N (plume maps) 96 +-28° E of N to 139 +-15° E of N (water levels)	1.2 to 1.8 3 to 4.3 >30 6	Darcy Plume movement through 1983 Tracer tests Recent plume movement	NA	NA	NA	For direction of flow, Hodges (1991a, 1992a, 1993a, 1994a, 1995). For Darcy velocity, Weekes et al. (1987). For plume movement, Wilber et al. (1983). For tracer tests, Bierschenk (1959) (note hydraulic gradient was higher than today).
NRDWL	62 to 90° E of N (water levels); 125° E of N (plume maps, regional water table)	See estimates above	NA	NA	NA	NA	For direction of flow, Hodges (1991b, 1994b) and Weekes et al. (1987).
316-5 Process Trenches	S to SE (high river); SE to E (average river)	10.6 (Schalla et al. 1988a) 0.165 to 100.6	Movement of PCE spill Darcy	150 to 15,240 (Schalla et al. 1988a)	0.1 to 0.3	0.00033 (December 1995) 0.00066 (June 1995)	

(a) Effective porosity assumed to be between 0.1 and 0.3, a representative range for the unconfined aquifer system.

LLWMA = Low-level waste management area.
LWDF = Liquid waste-disposal facility.
NA = Not applicable.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PCE = Tetrachloroethylene.
SWL = Solid Waste Landfill.
WMA = Waste management area.

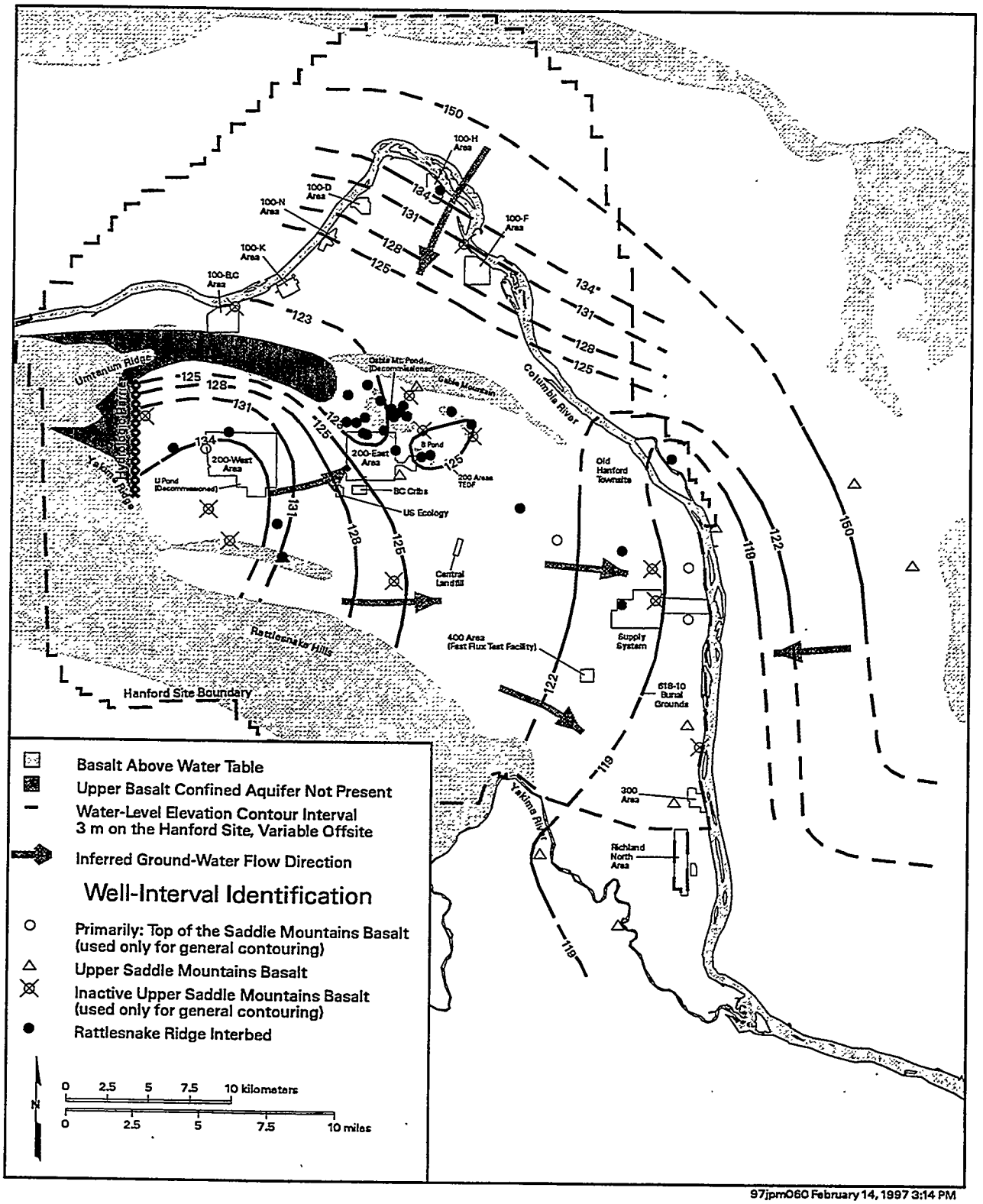


Figure 5.1-1. Potentiometric Map of the Upper Basalt-Confined Aquifer System, June 1996

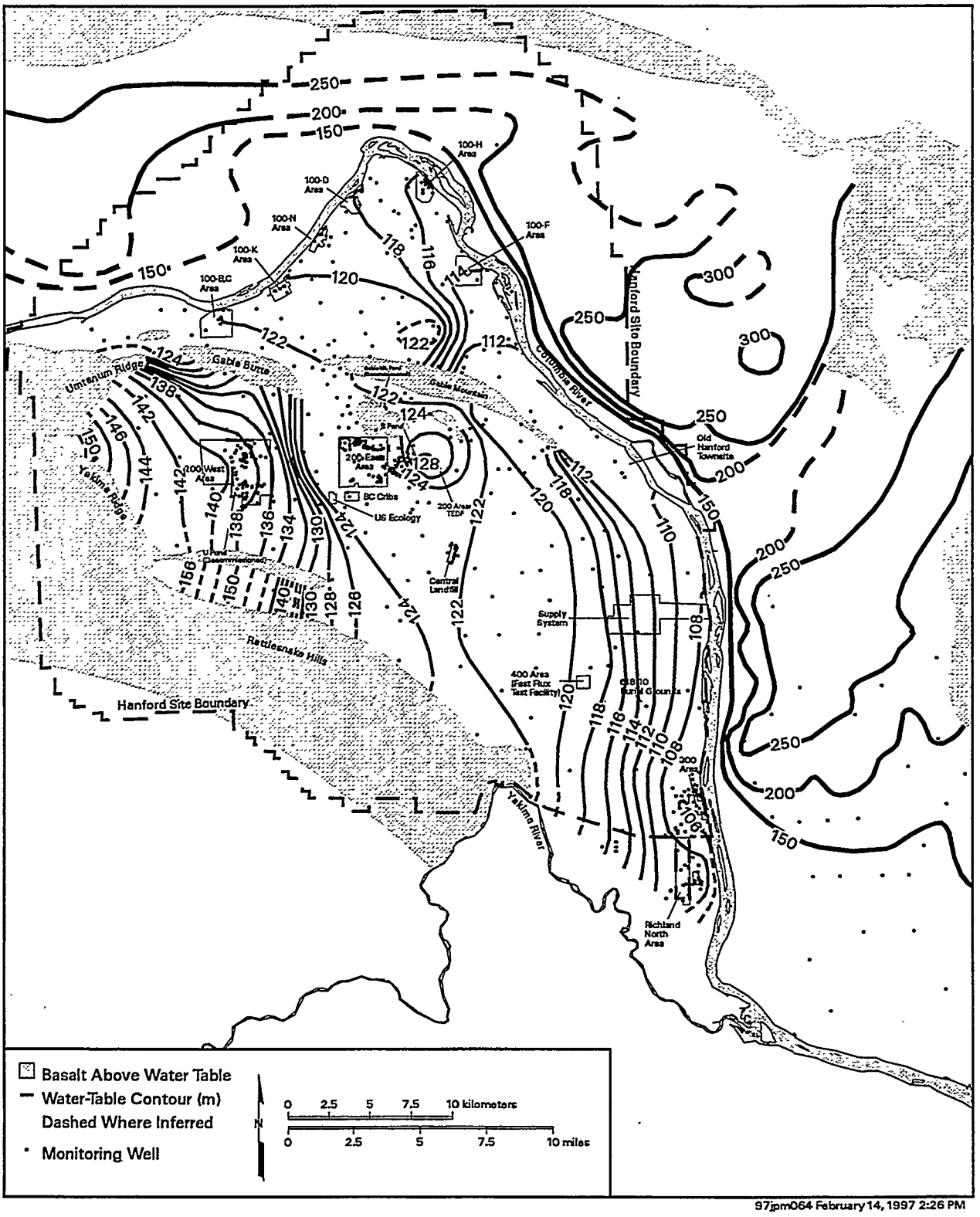


Figure 5.2-1. Hanford Site and Outlying Areas Water-Table Map, June 1996

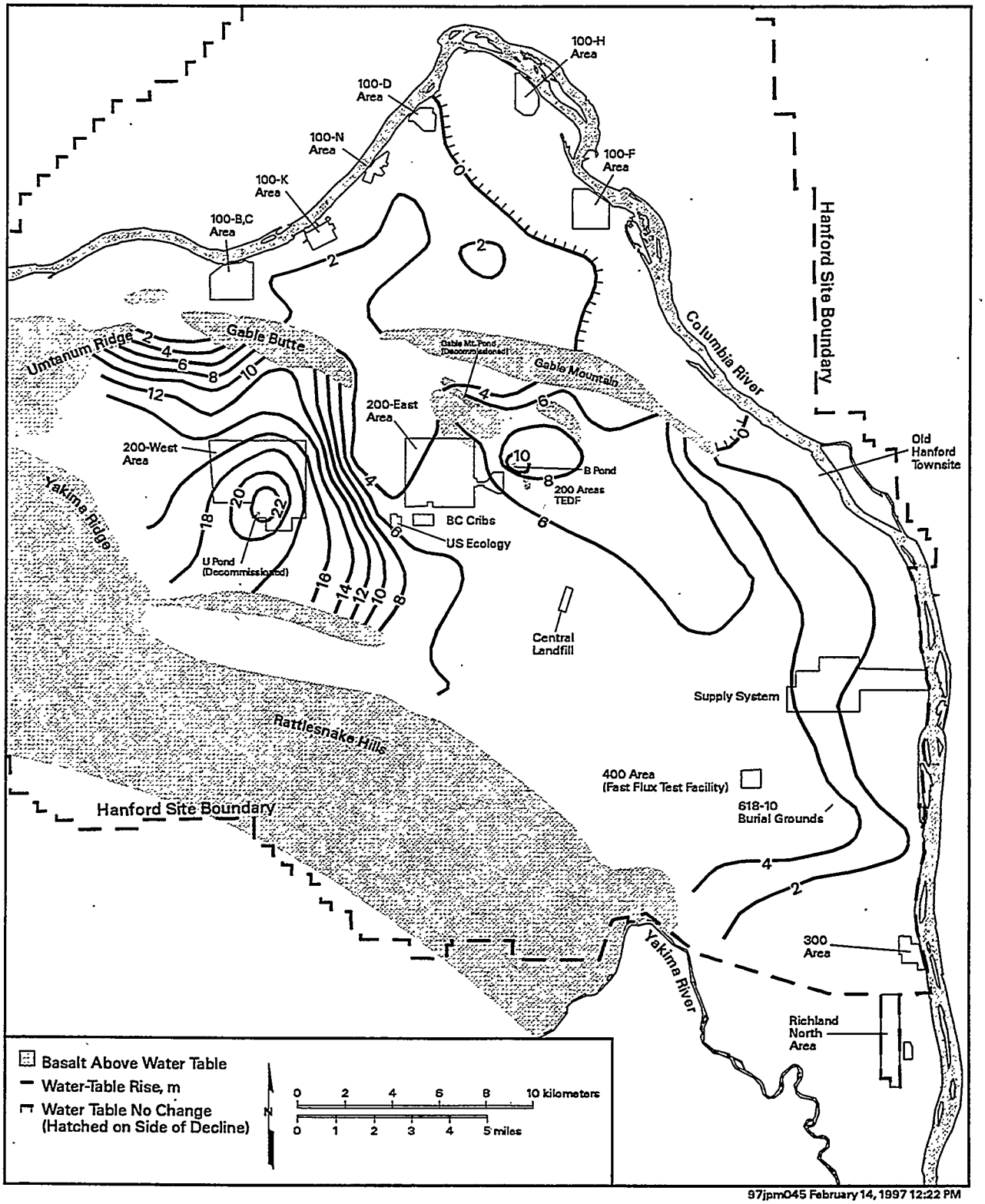


Figure 5.3-1. Changes in Water-Table Elevations on the Hanford Site, 1944 Through 1979

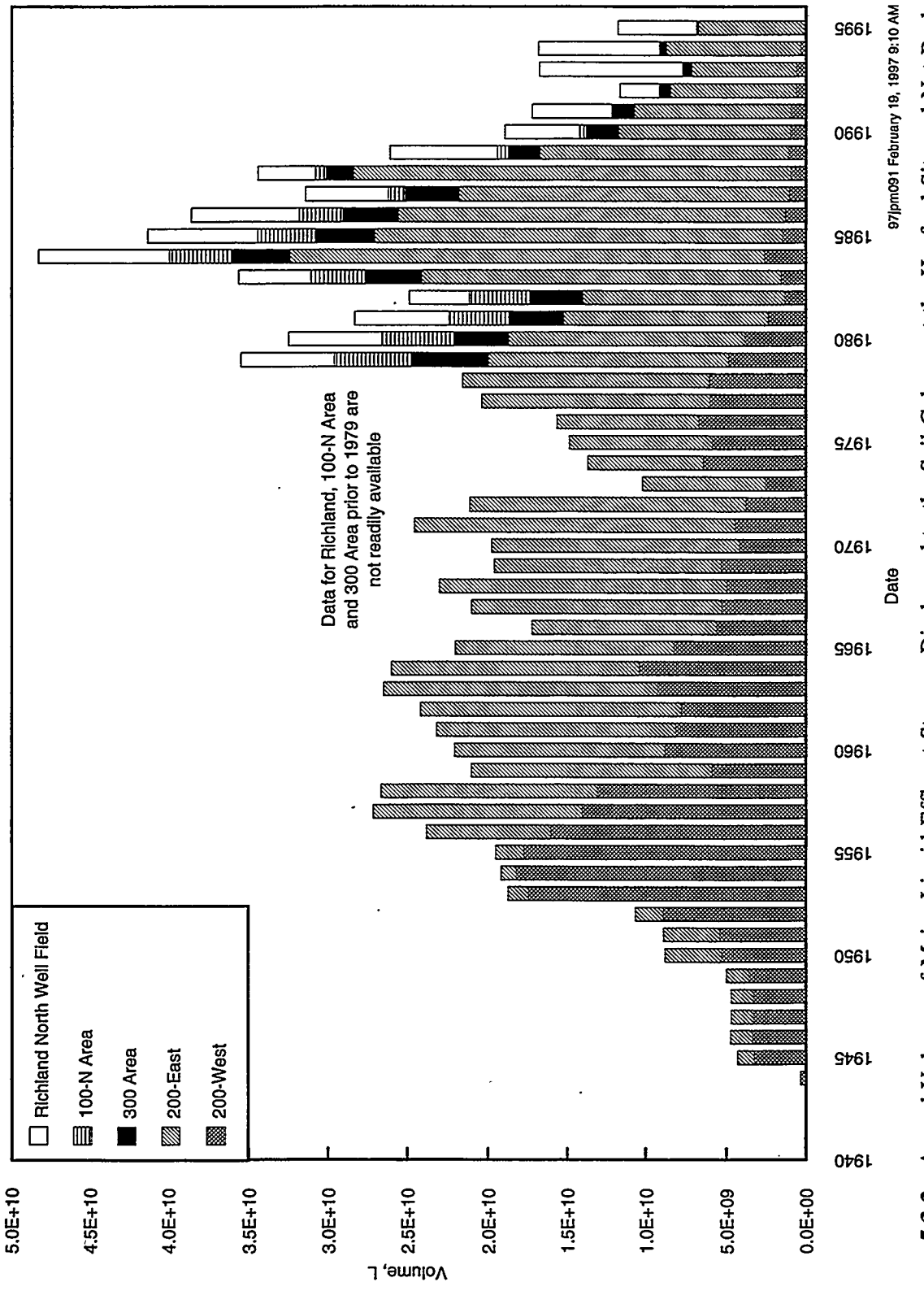


Figure 5.3-2. Annual Volumes of Major Liquid Effluent Streams Discharged to the Soil Column at the Hanford Site and Net Recharge at the City of Richland's North Well Field

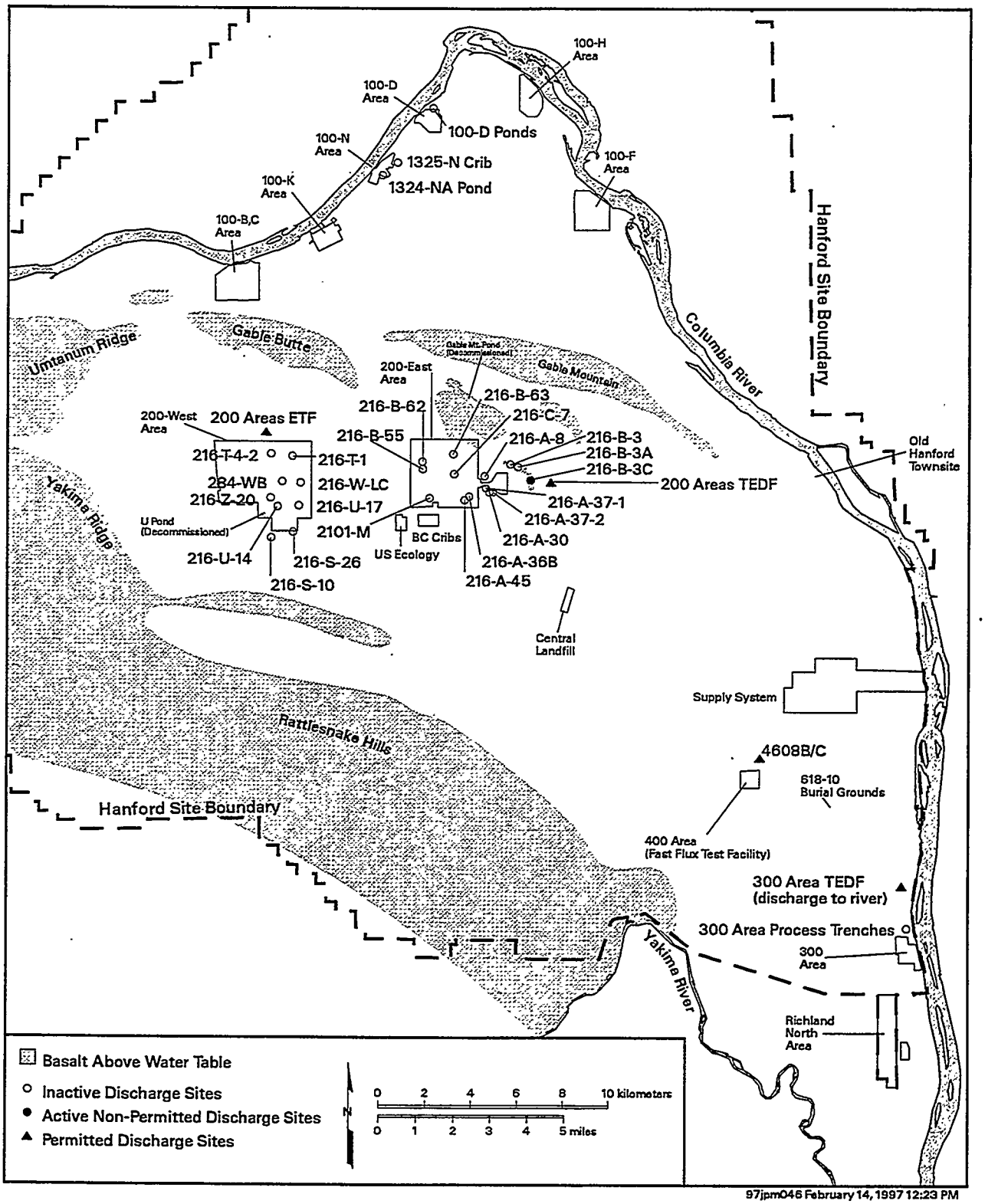


Figure 5.3-3. Discharge Sites for 33 Major Liquid Effluent Streams on the Hanford Site

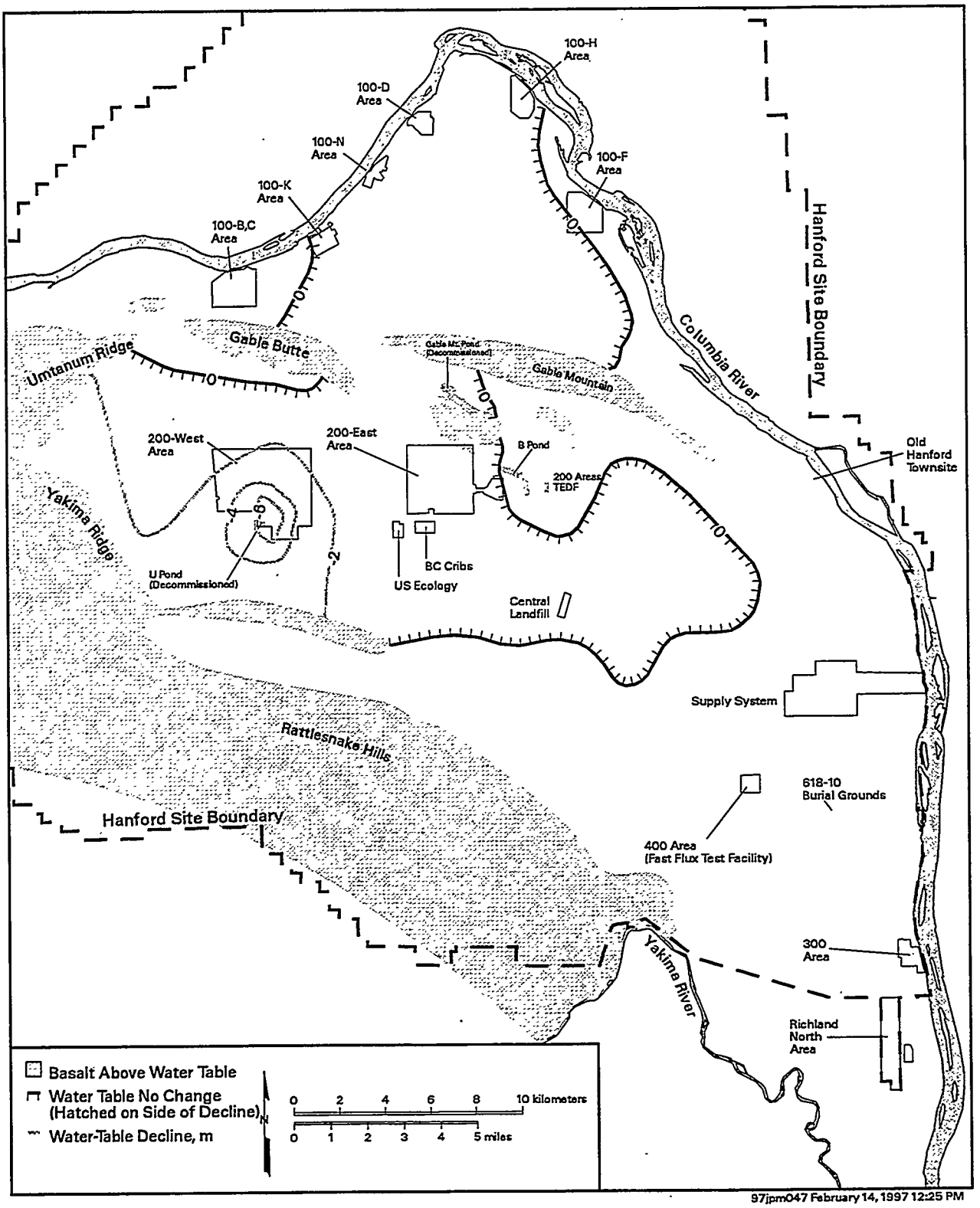


Figure 5.3-4. Changes in Water-Table Elevations on the Hanford Site, 1979 Through 1995

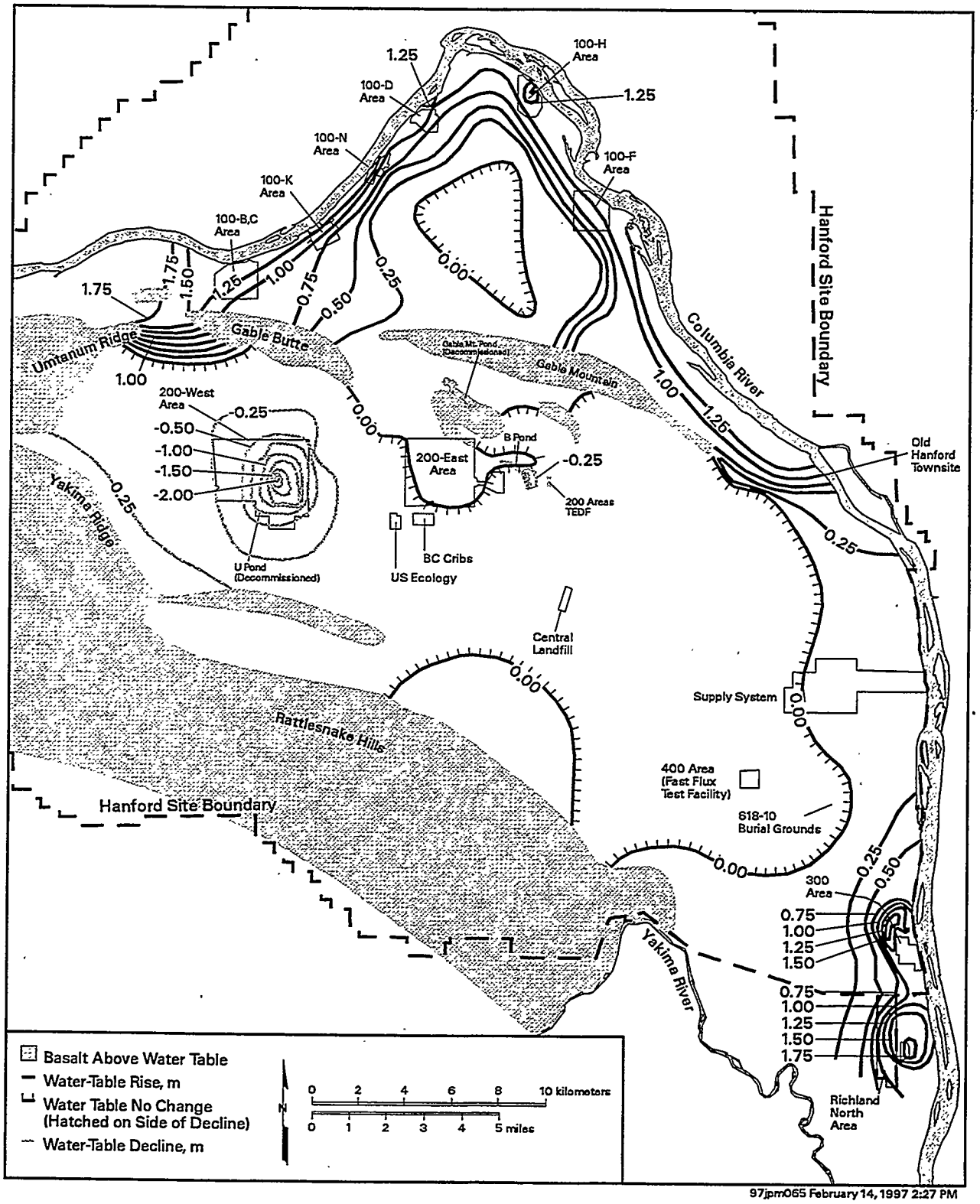


Figure 5.3-5. Changes in Water-Table Elevations on the Hanford Site, 1995-1996

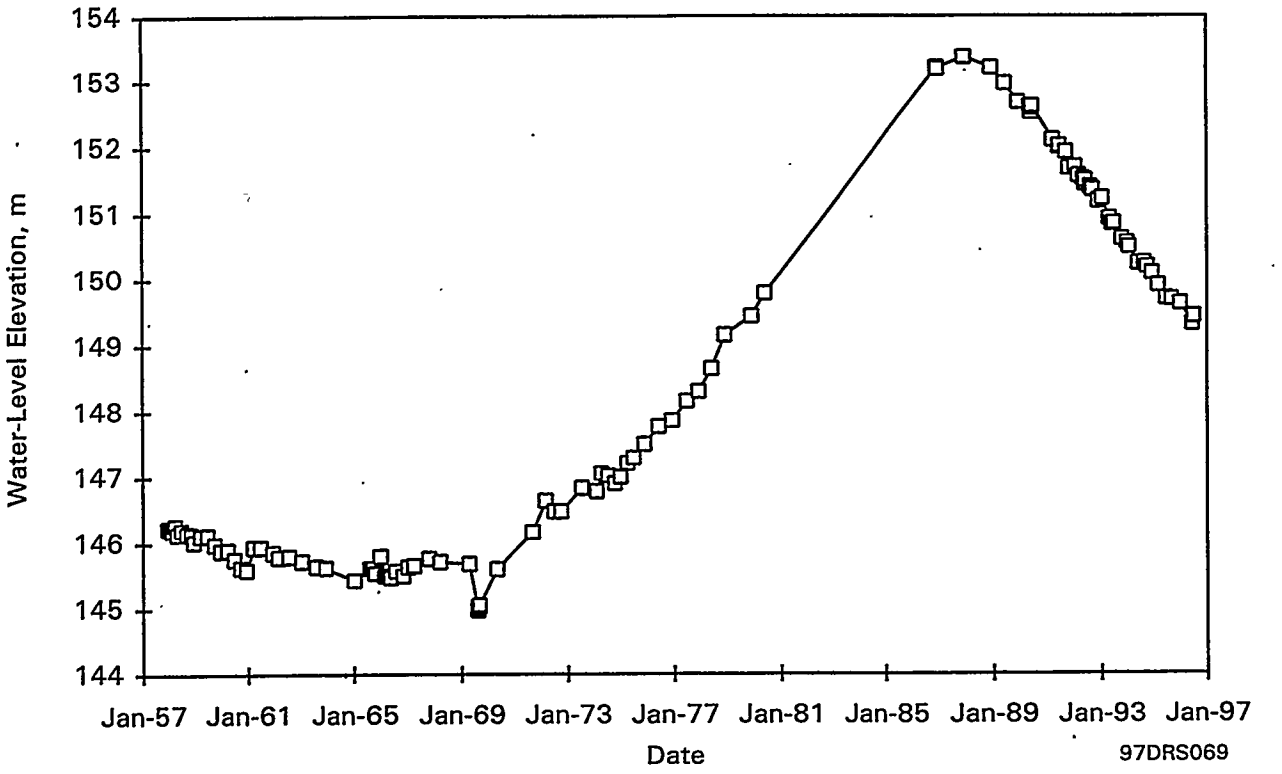


Figure 5.4-1. Water-Table Elevations in Well 699-43-104

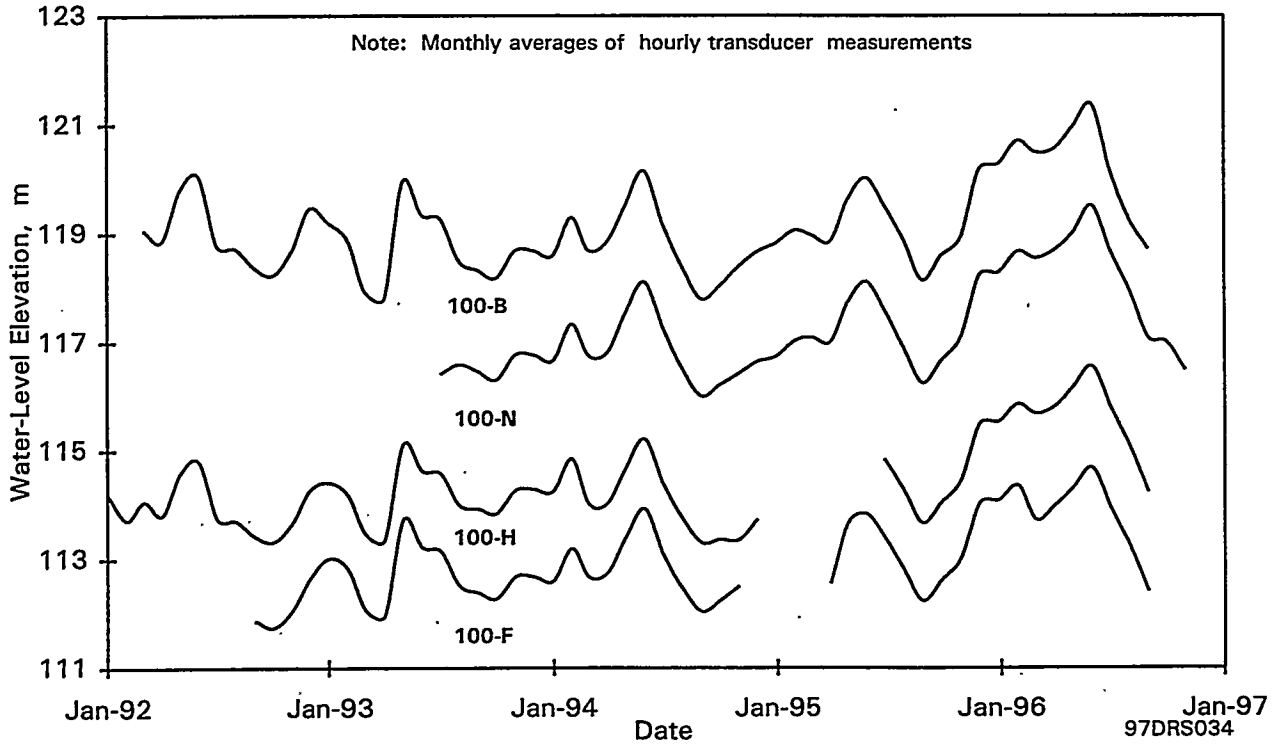


Figure 5.4-2. Columbia River Stage at 100-B,C, 100-N, 100-H, and 100-F Areas

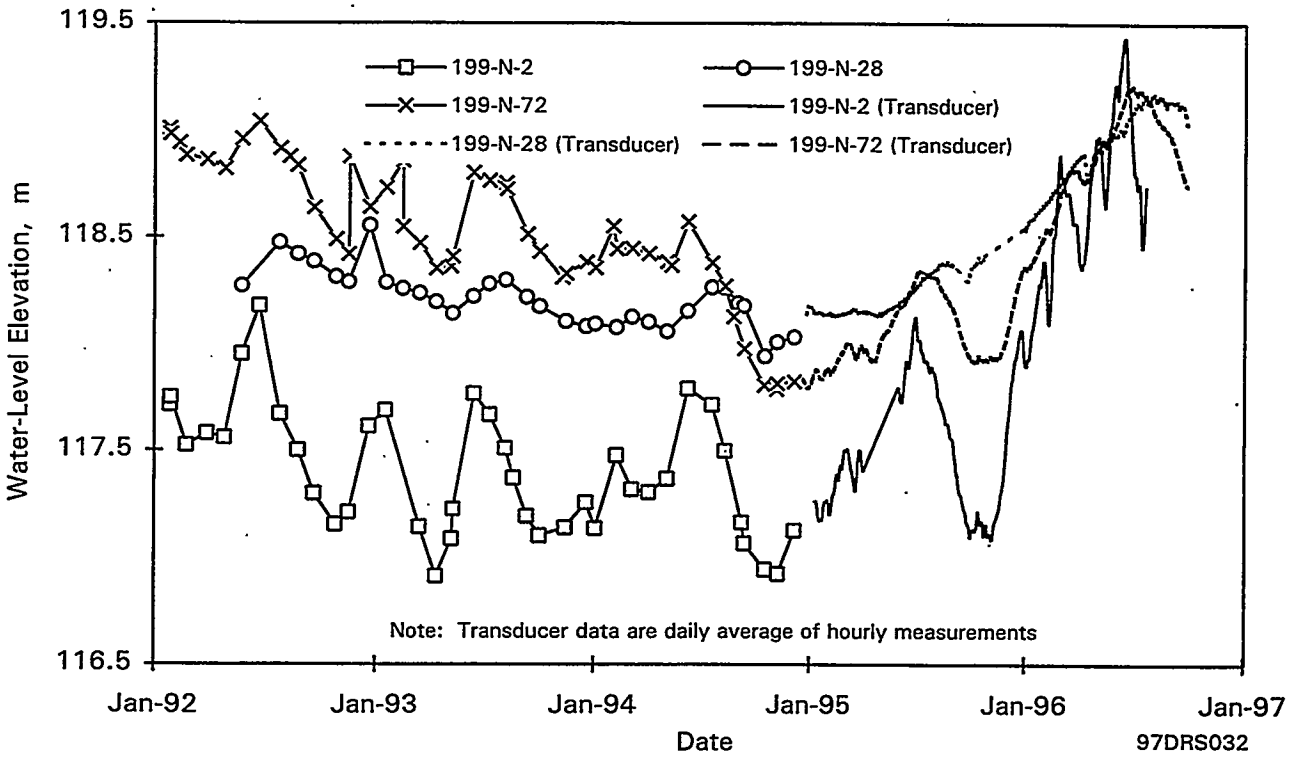


Figure 5.4-3. Water-Table Elevations in 100-N Area Monitoring Wells

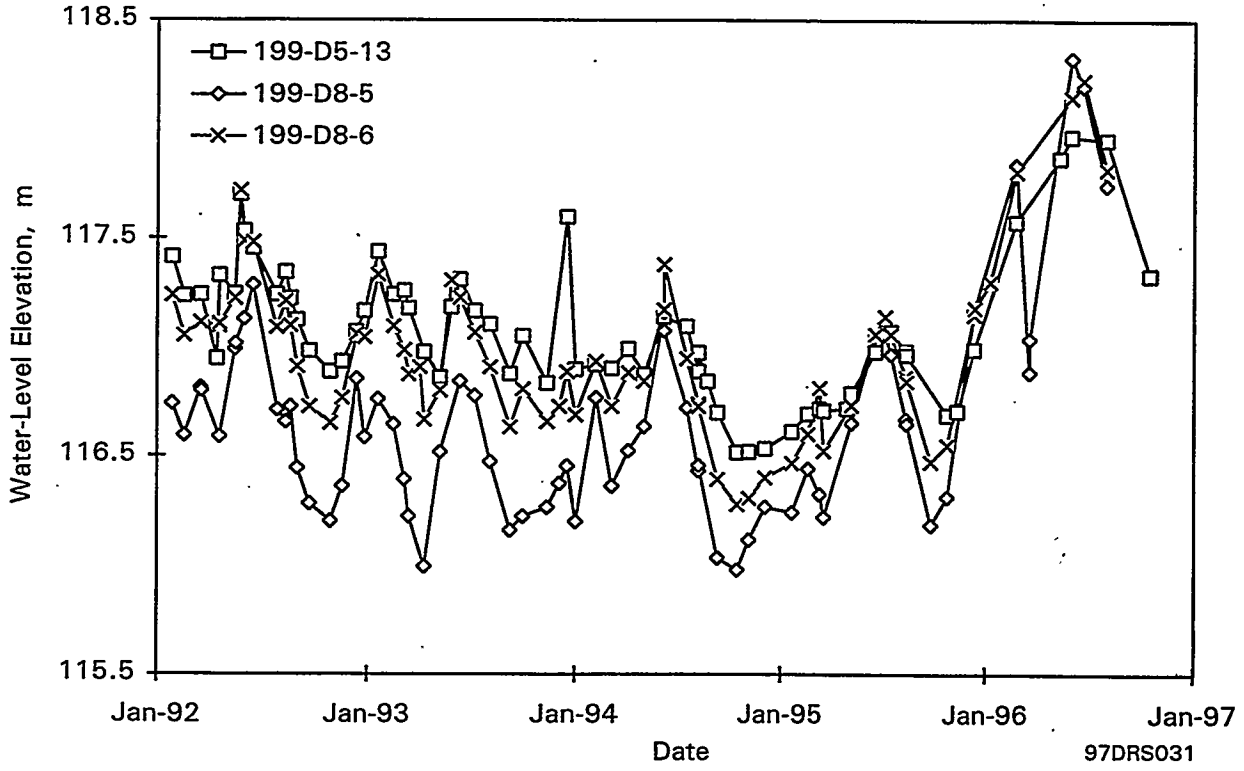


Figure 5.4-4. Water-Table Elevations in 120-D-1 Ponds Monitoring Wells

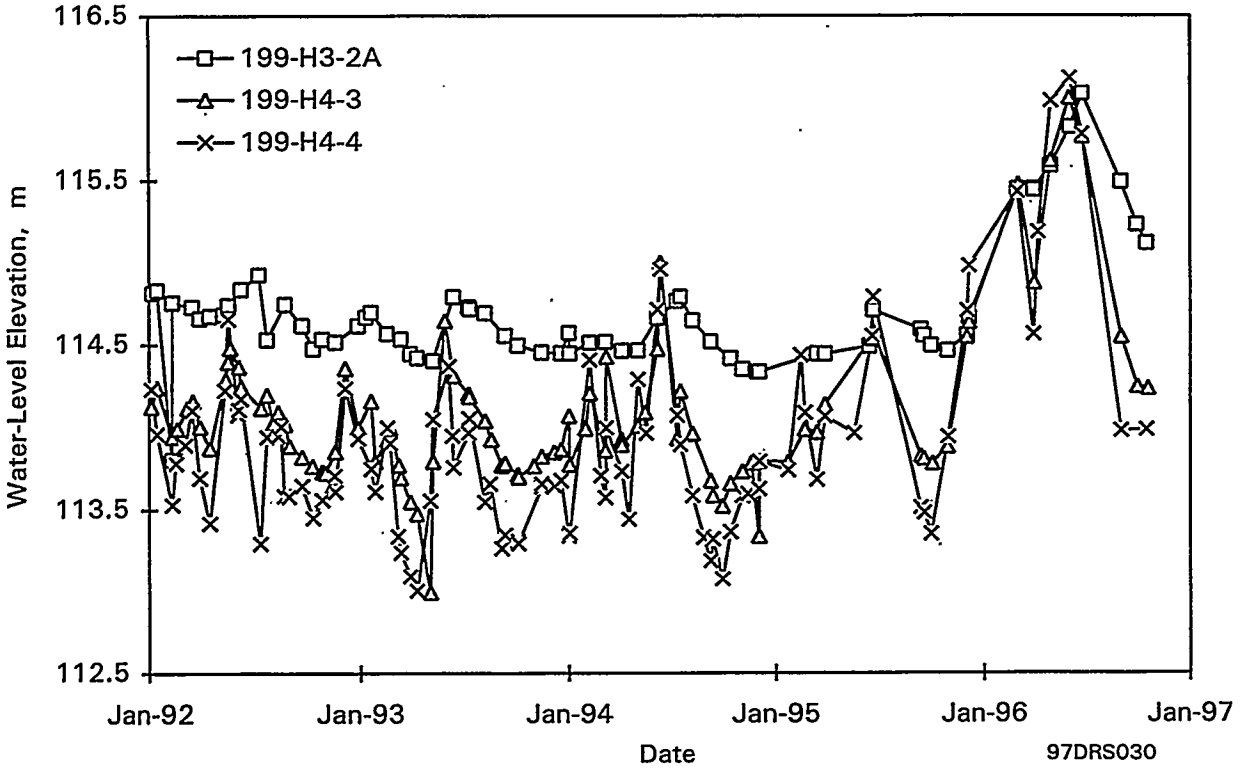


Figure 5.4-5. Water-Table Elevations in 183-H Solar Evaporation Basins Monitoring Wells

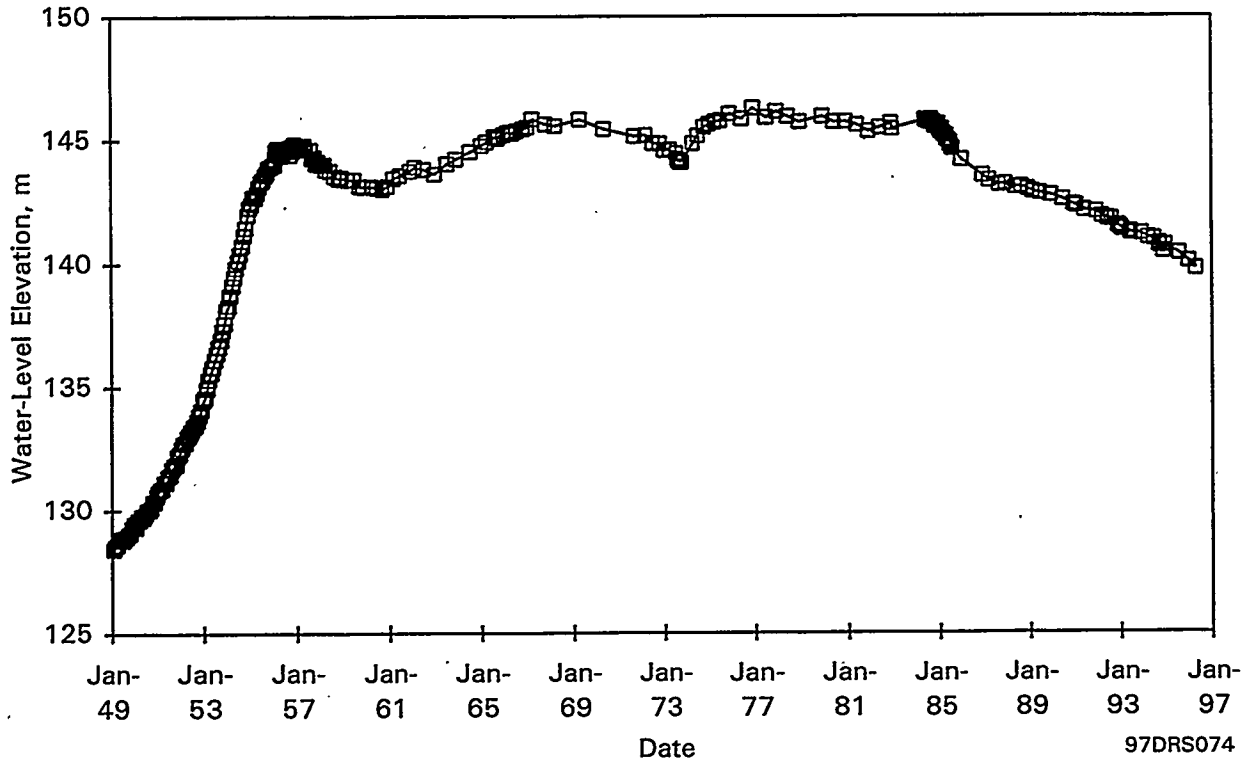


Figure 5.4-6. Water-Table Elevations in Well 699-39-79 Near Decommissioned U Pond

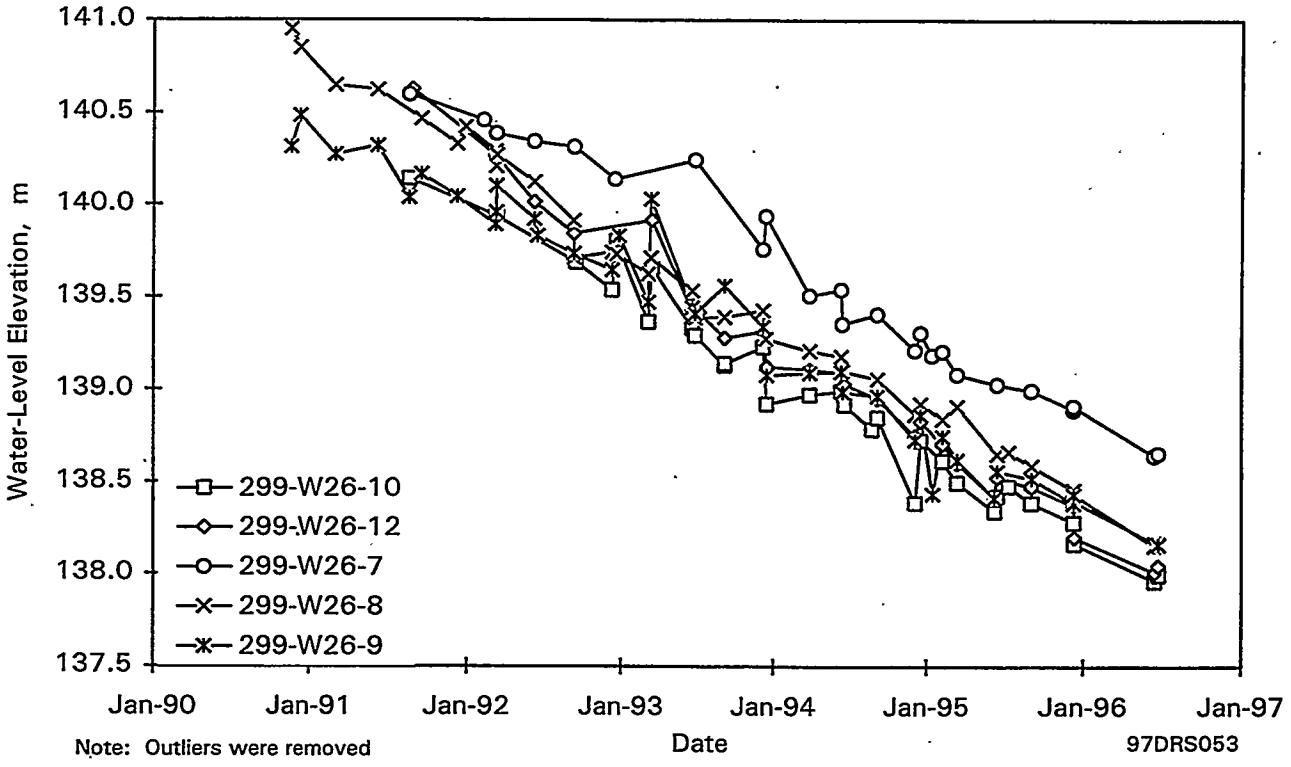


Figure 5.4-7. Water-Table Elevations in 216-S-10 Pond and Ditch Monitoring Wells

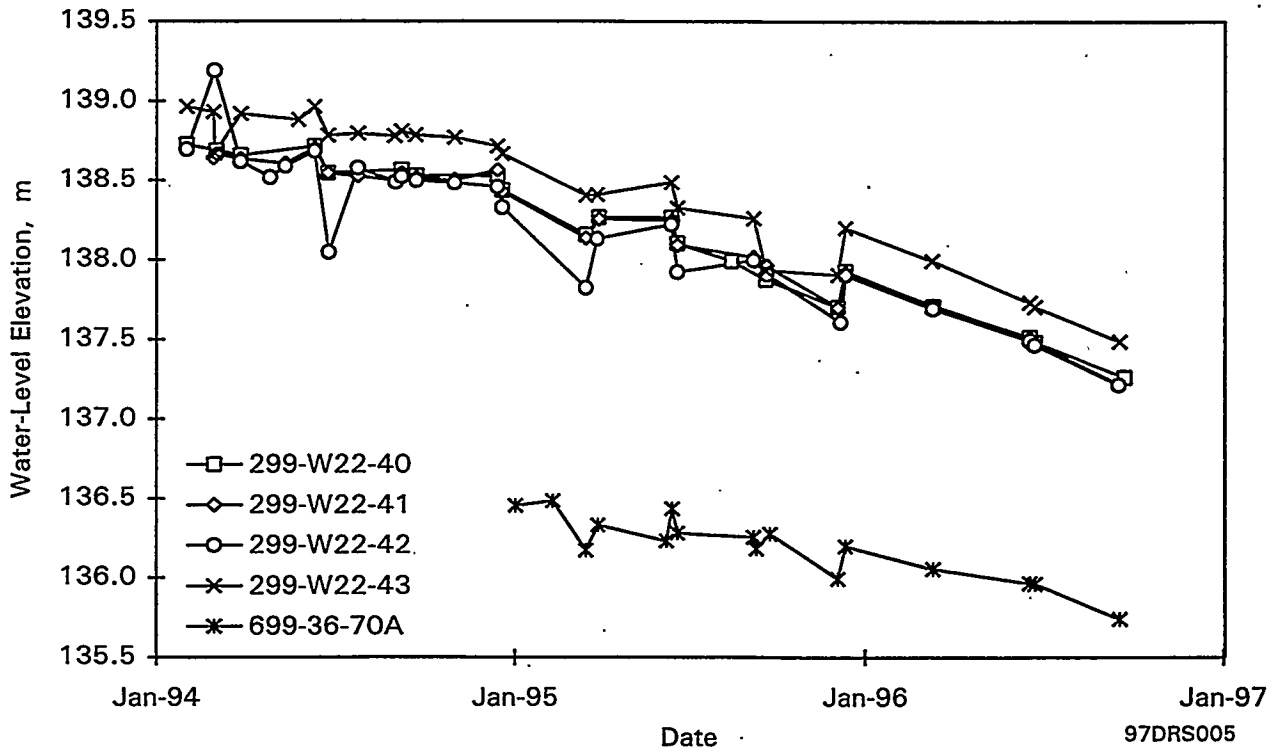


Figure 5.4-8. Water-Table Elevations in 216-U-12 Crib Monitoring Wells

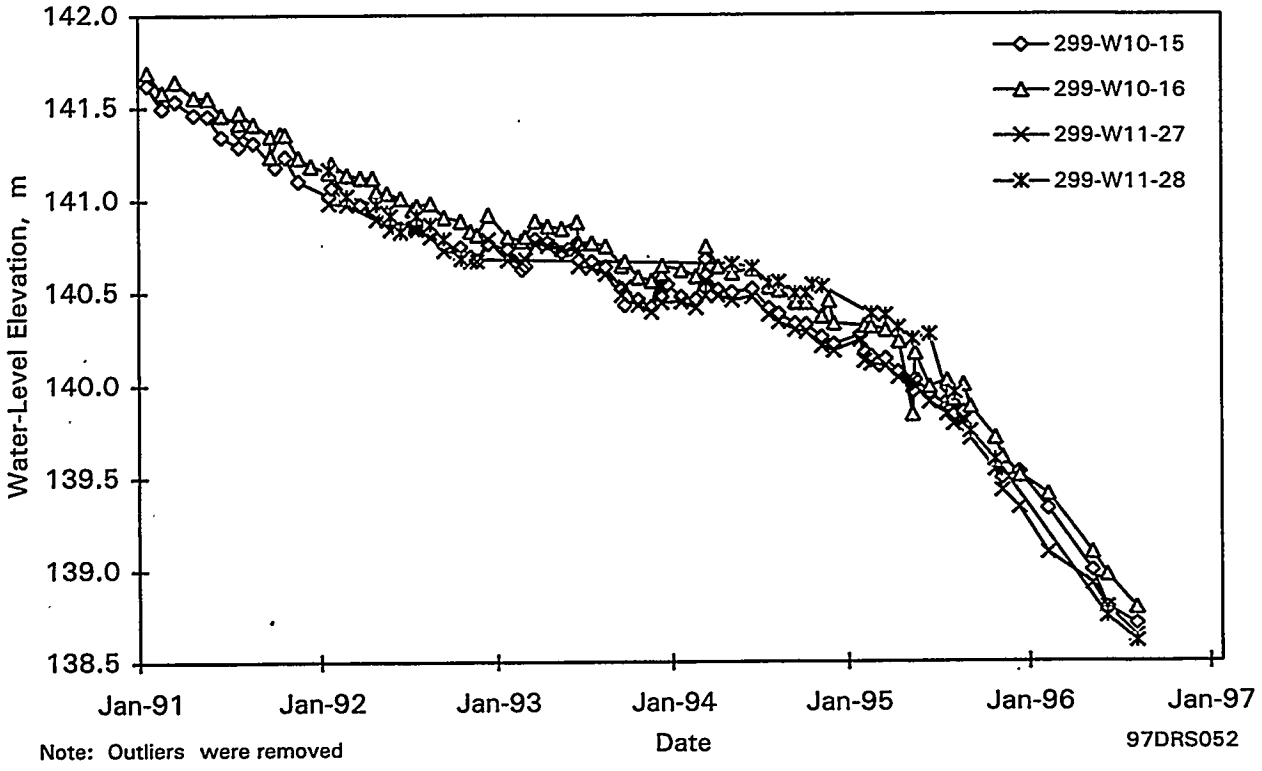


Figure 5.4-9. Water-Table Elevations in Wells Monitoring WMA-T Single-Shell Tank Farm

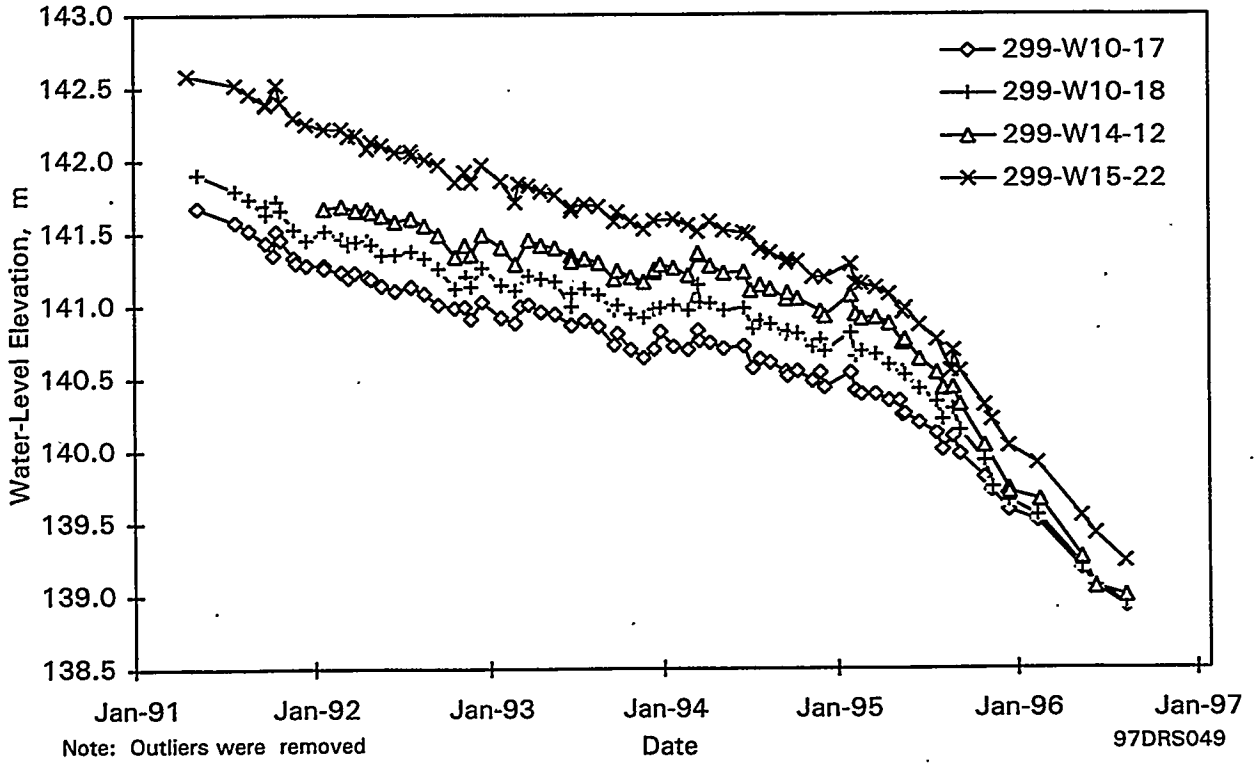


Figure 5.4-10. Water-Table Elevations in Wells Monitoring WMA-TX-TY Single-Shell Tank Farms

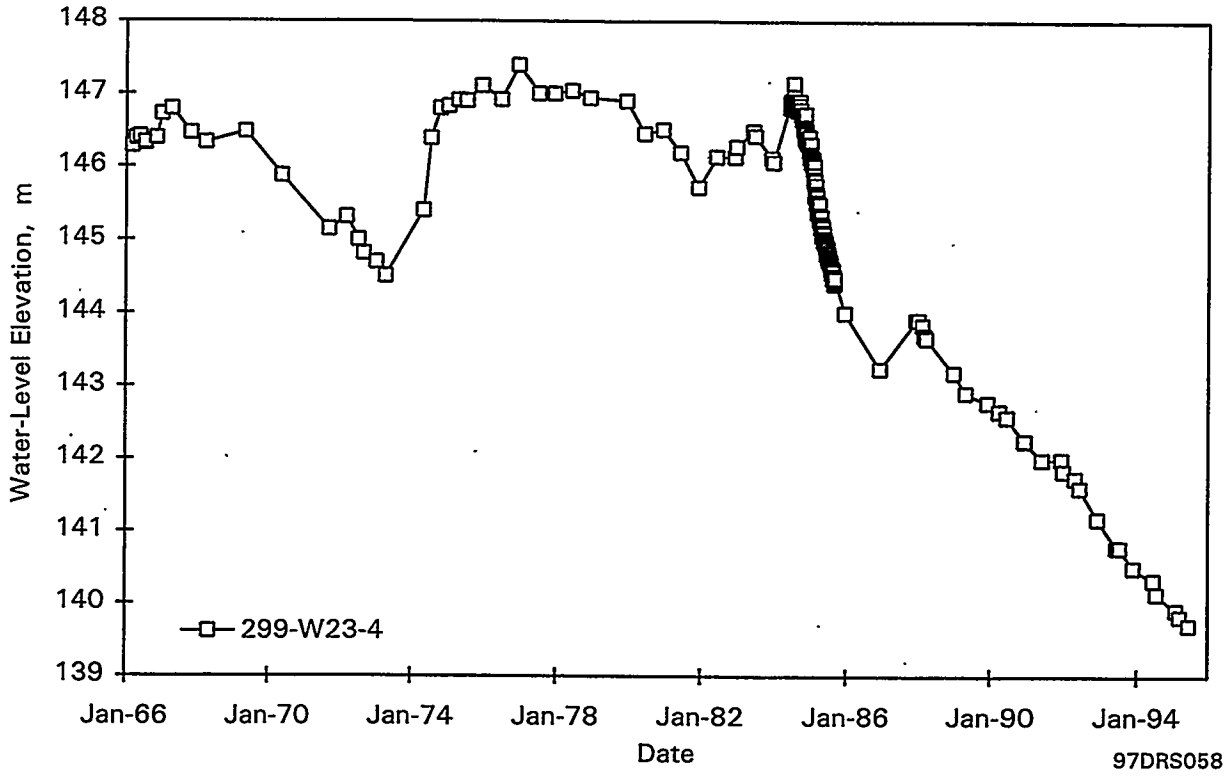


Figure 5.4-11. Water-Table Elevations in Well 299-W-23-4

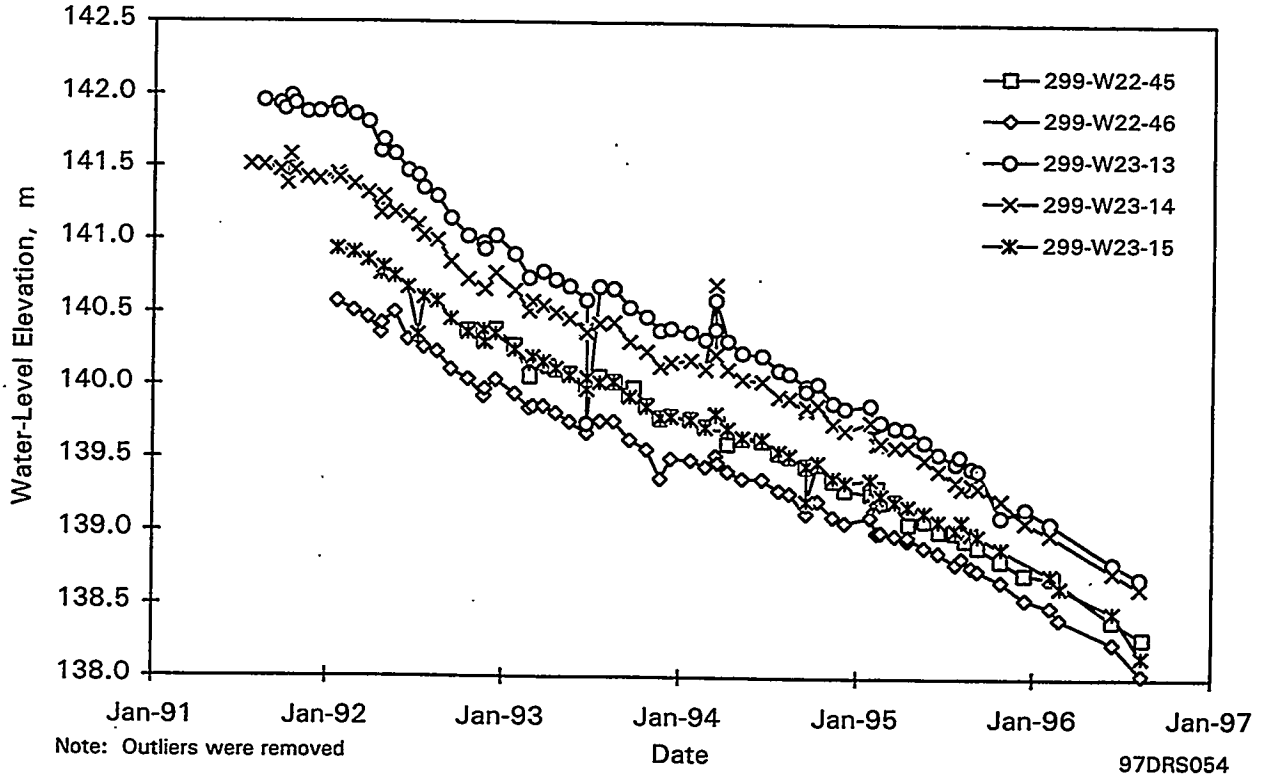


Figure 5.4-12. Water-Table Elevations in Wells Monitoring WMA-S-SX Single-Shell Tank Farms

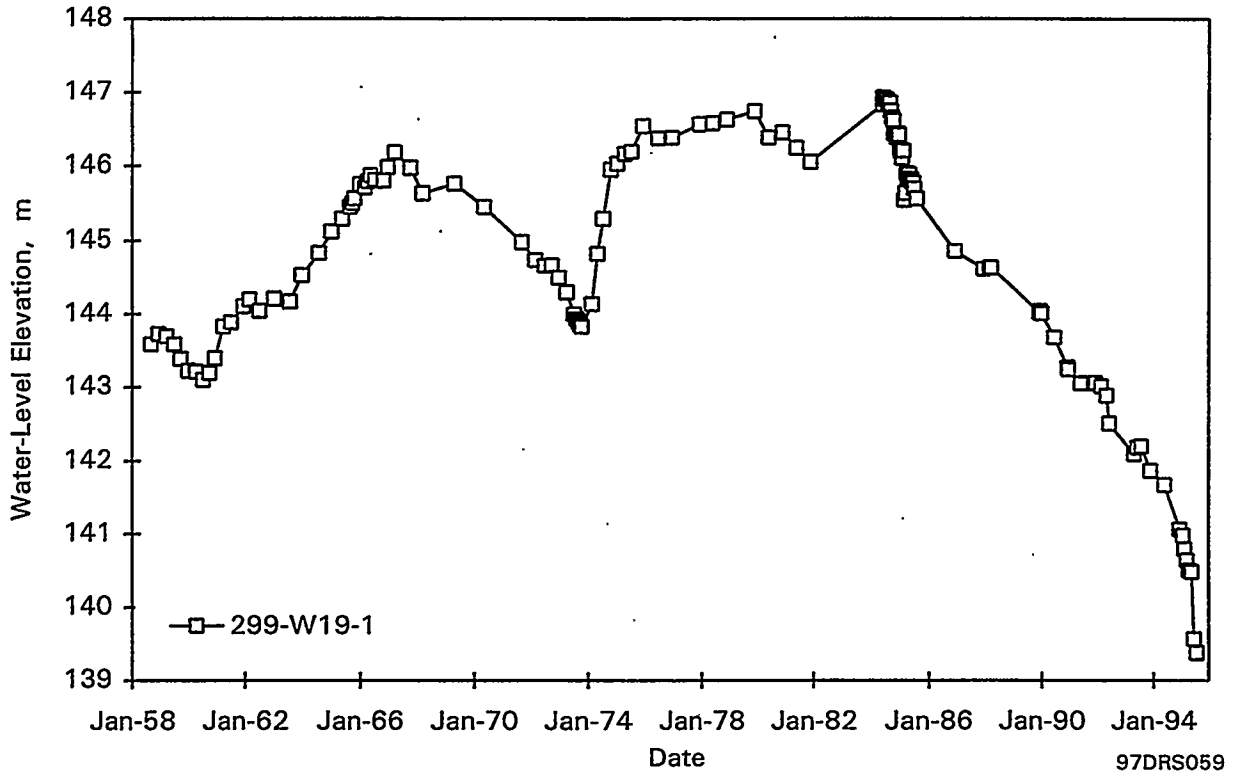


Figure 5.4-13. Water-Table Elevations in Well 299-W19-1

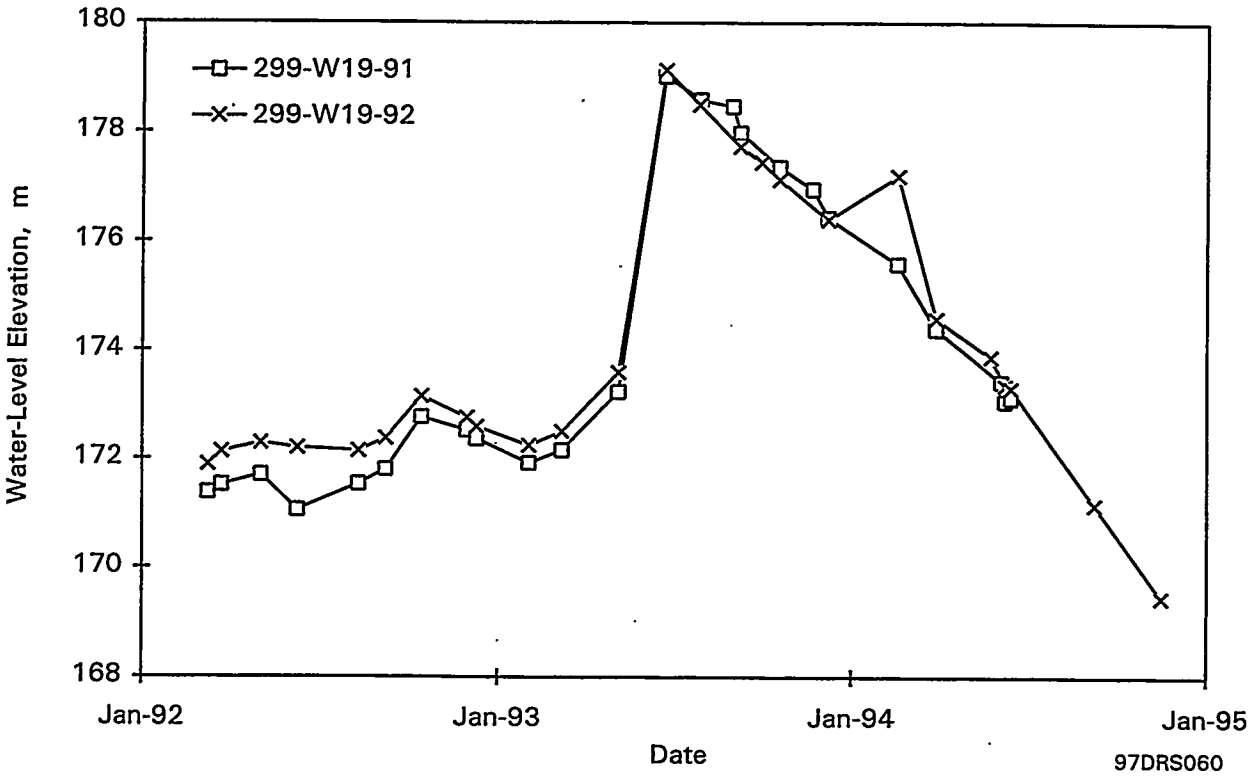


Figure 5.4-14. Water-Table Elevations in Perched Aquifer Wells 299-W19-91 and 299-W19-92

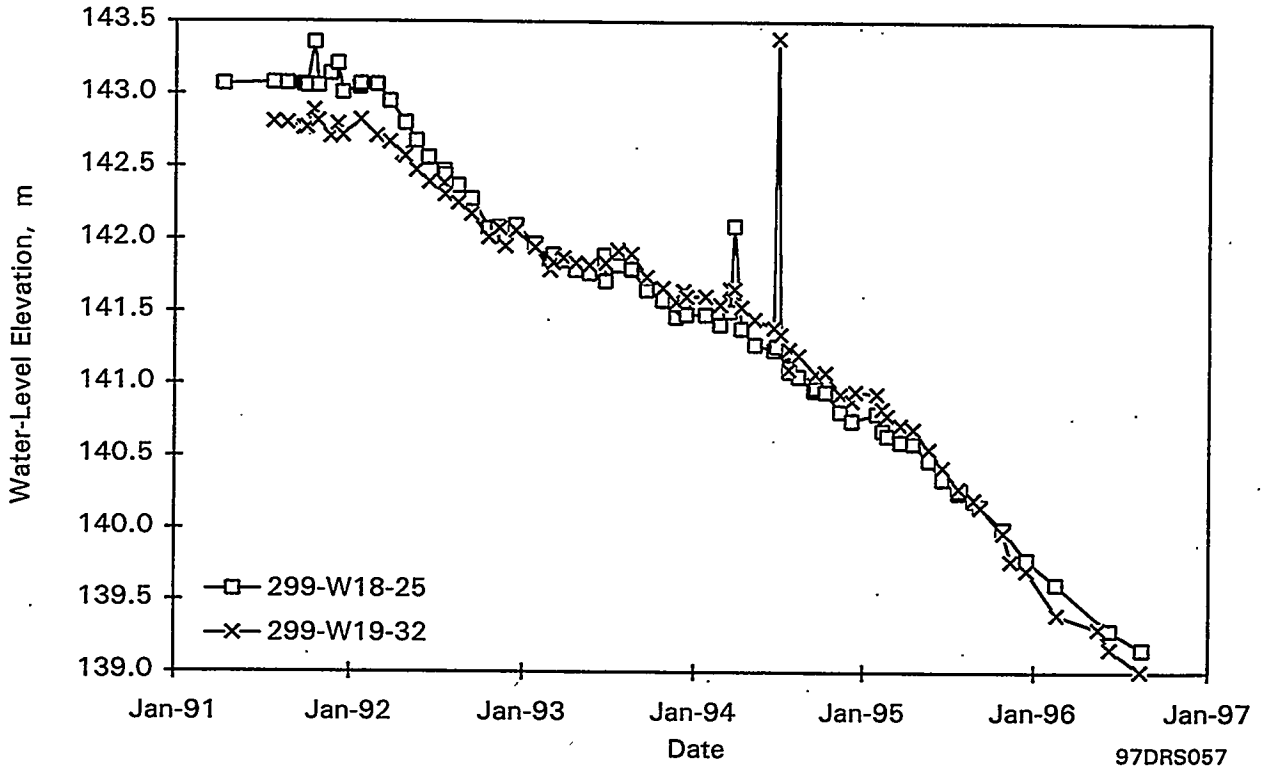


Figure 5.4-15. Water-Table Elevations in Wells 299-W18-25 and 299-W19-32

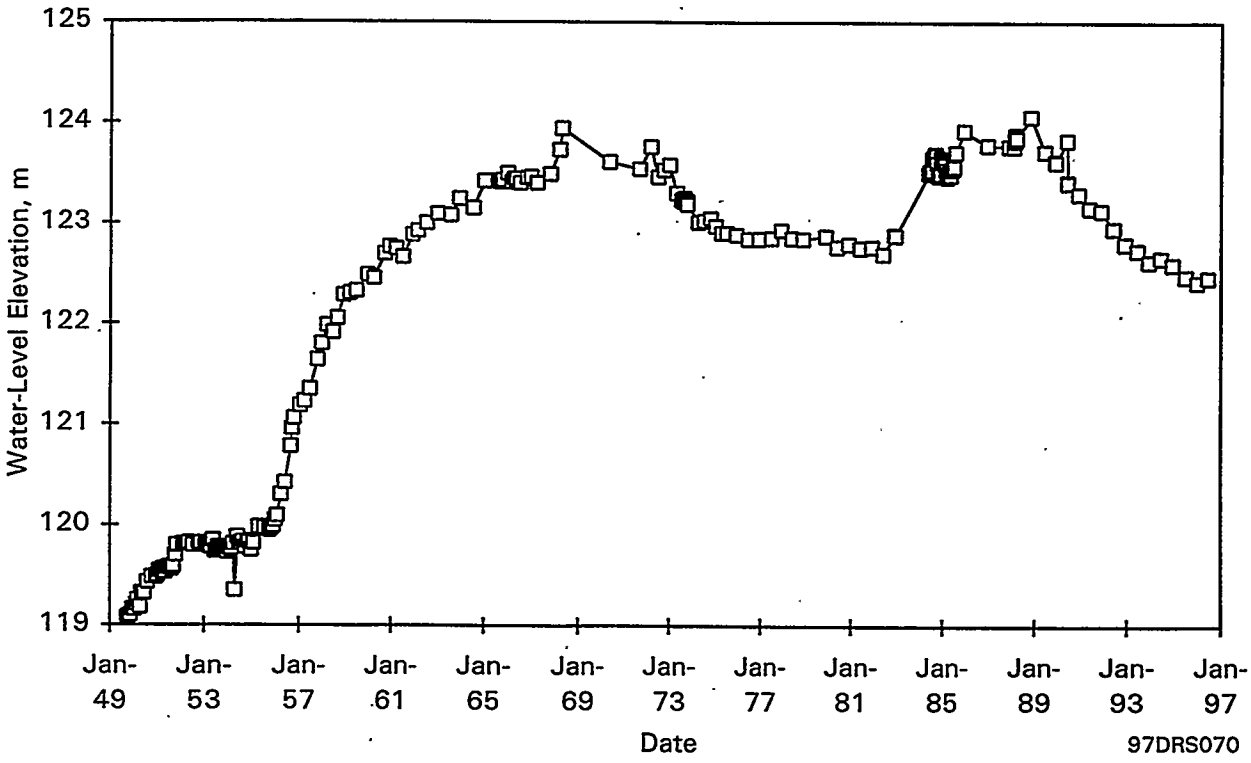


Figure 5.4-16. Water-Table Elevations in Well 299-E26-1

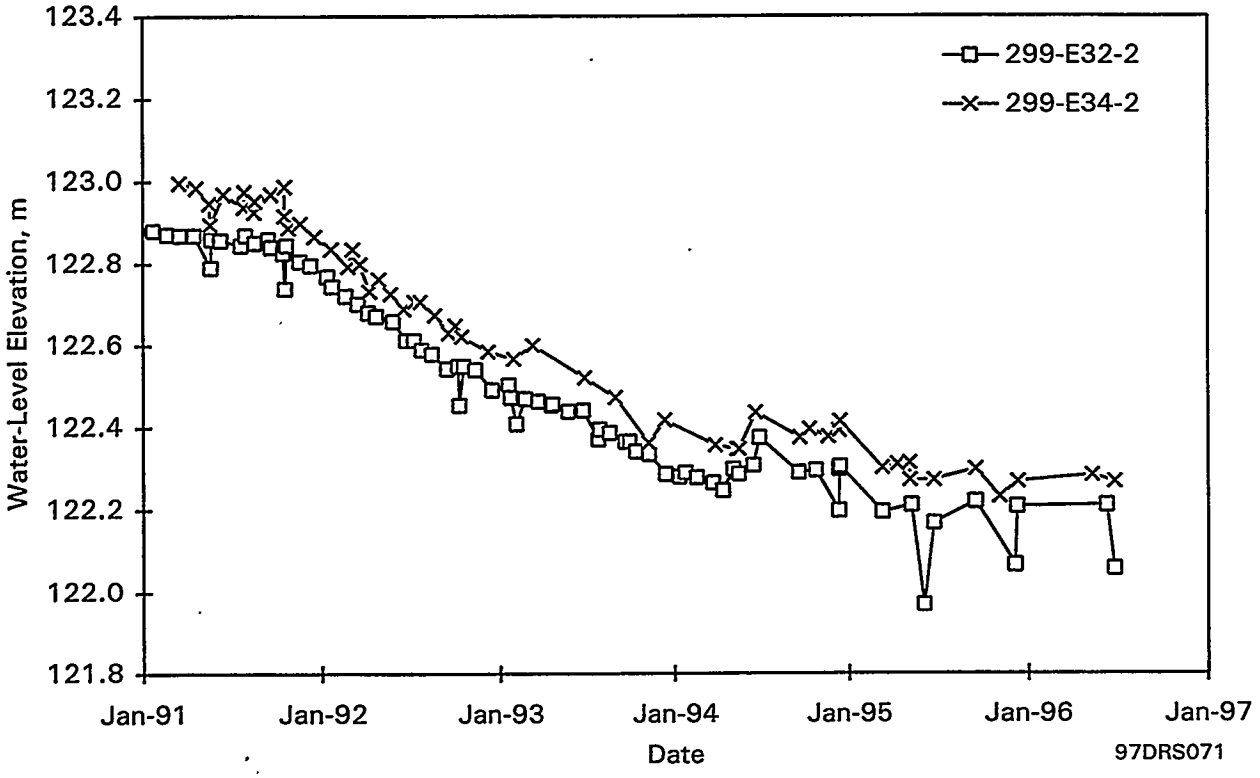


Figure 5.4-17. Water-Table Elevations in Wells 299-E32-2 and 299-E34-2

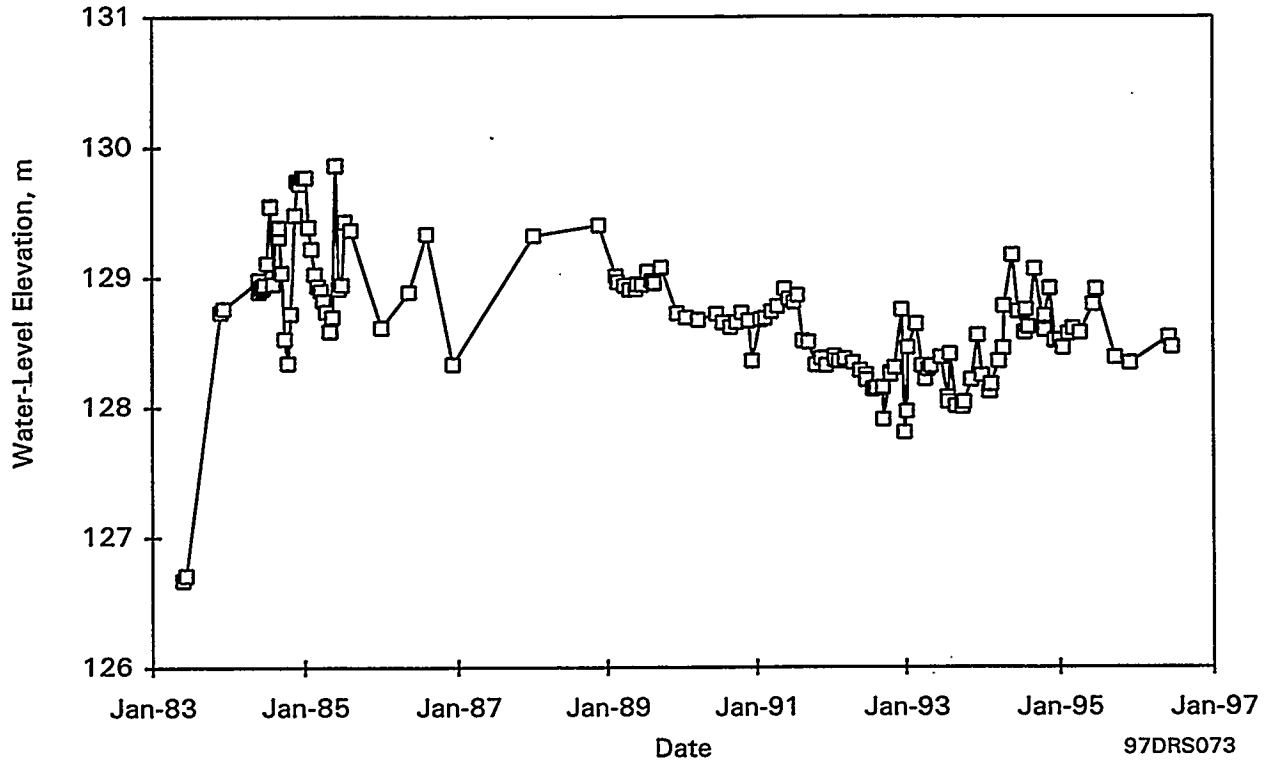


Figure 5.4-18. Water-Table Elevations in Well 699-42-40A

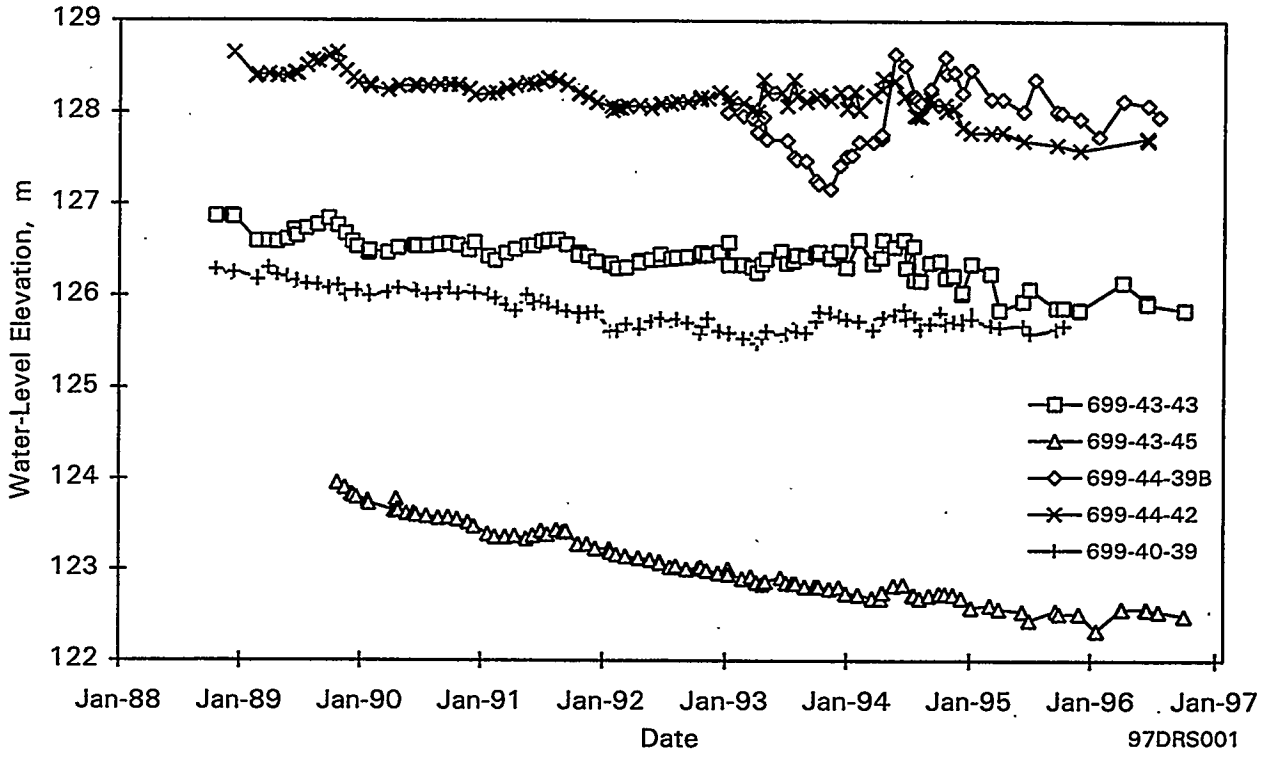


Figure 5.4-19. Water-Table Elevations in Wells Monitoring 216-B-3 Pond

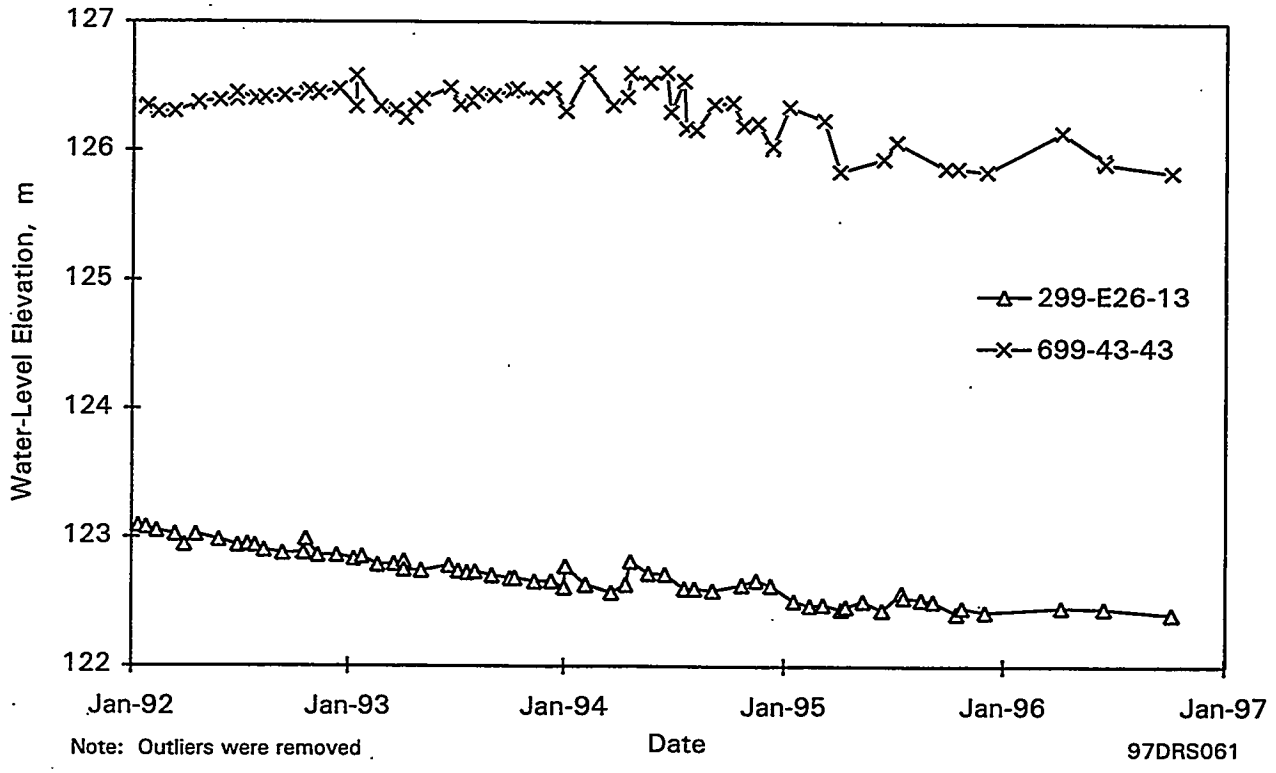


Figure 5.4-20. Water-Table Elevations in Wells Monitoring 216-A-29 Ditch

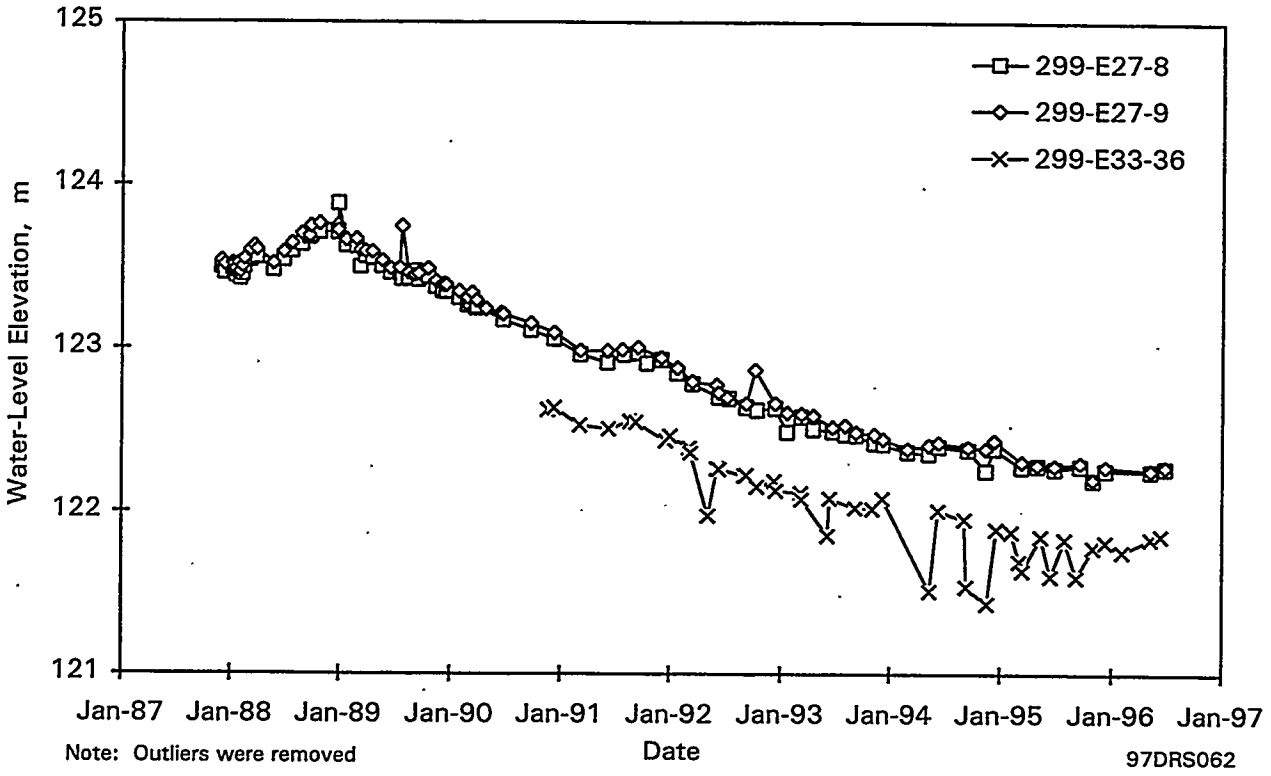


Figure 5.4-21. Water-Table Elevations in Wells Monitoring 216-B-63 Trench

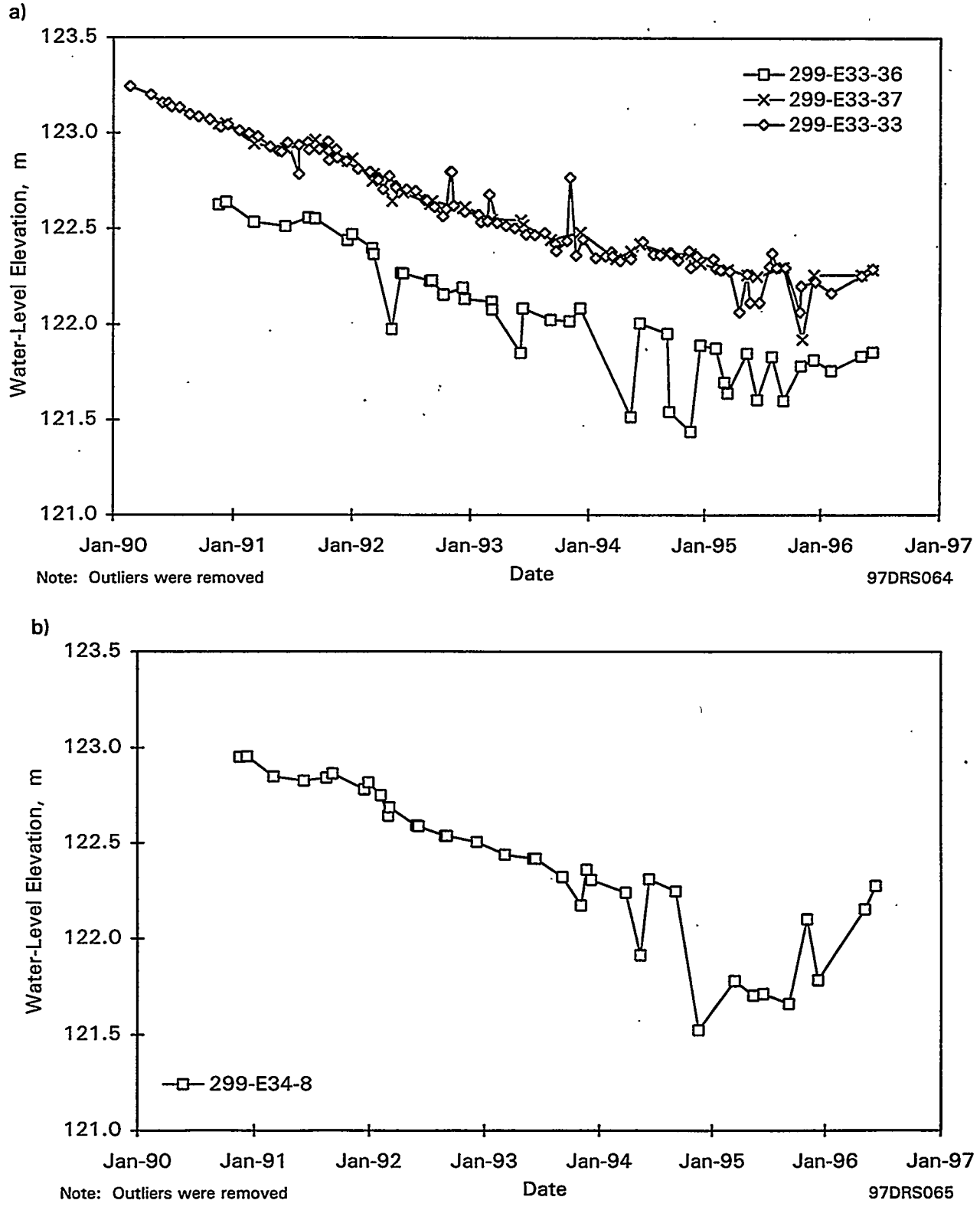


Figure 5.4-22. Water-Table Elevations in Monitoring Wells 299-E33-36, 299-E33-37, 299-E33-33, and 299-E34-8

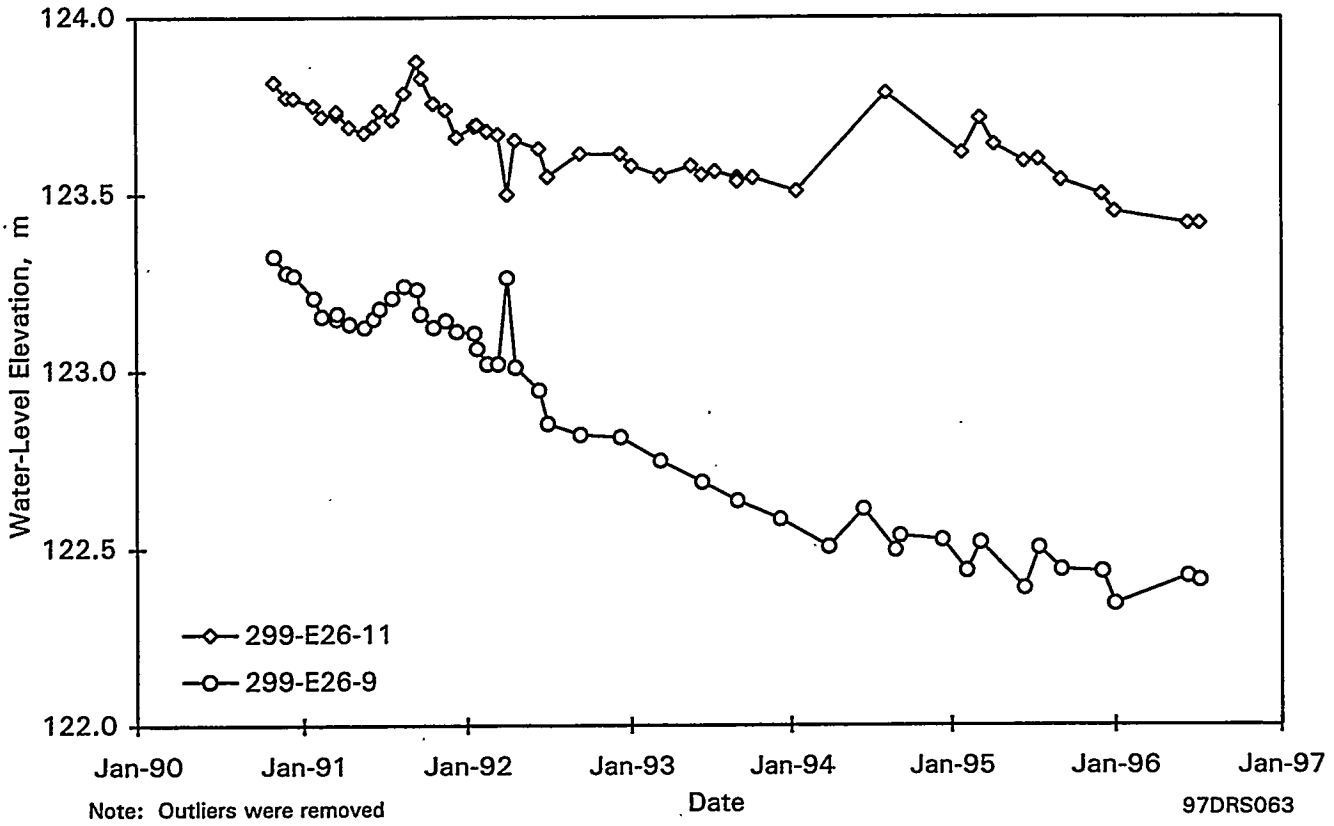


Figure 5.4-23. Water-Table Elevations in Wells Monitoring 200 Areas Liquid Effluent Retention Facility

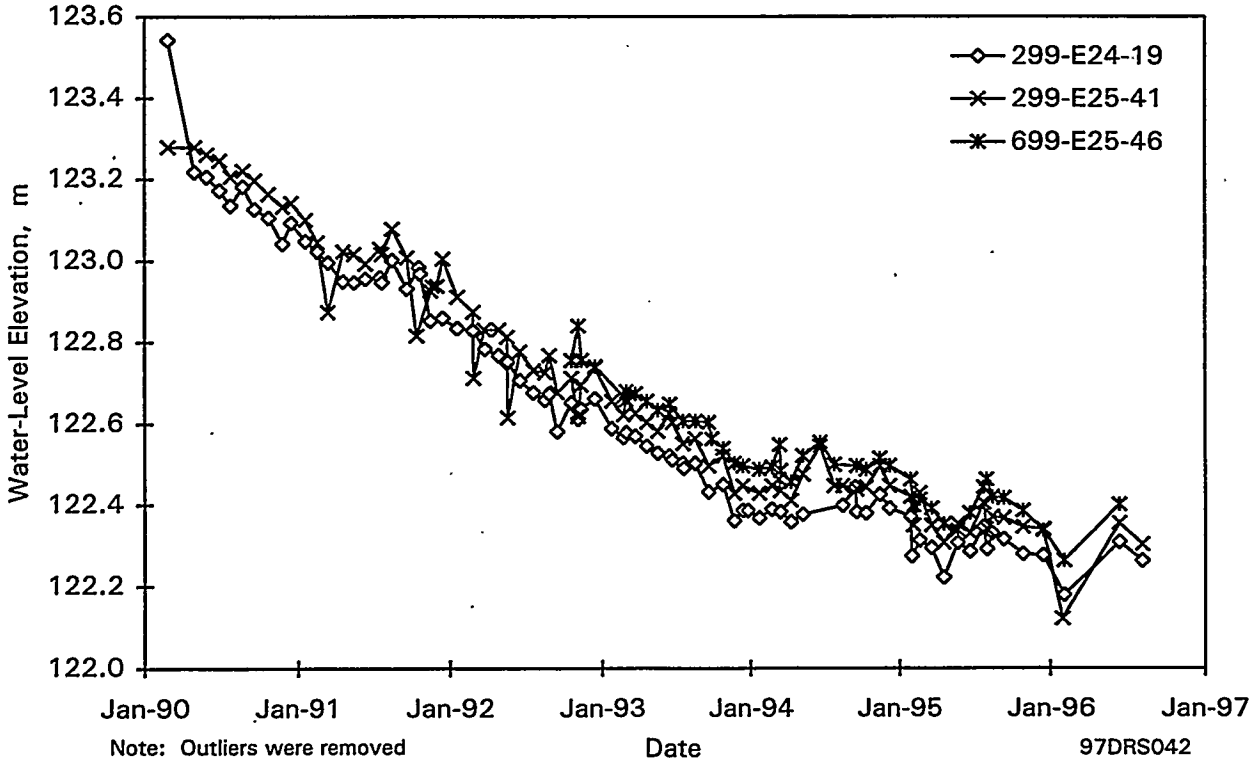


Figure 5.4-24. Water-Table Elevations in Wells Monitoring WMA-A-AX Single-Shell Tank Farms

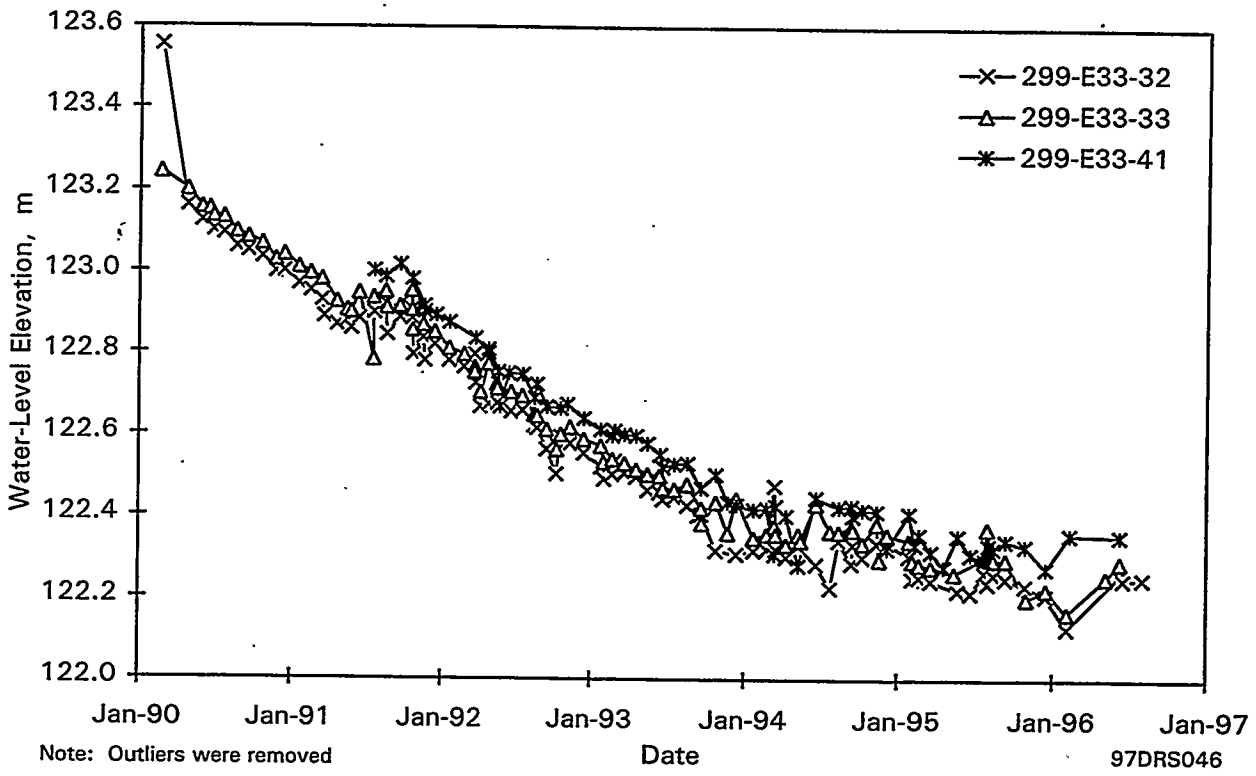


Figure 5.4-25. Water-Table Elevations in Wells Monitoring WMA-B-BX-BY Single-Shell Tank Farms

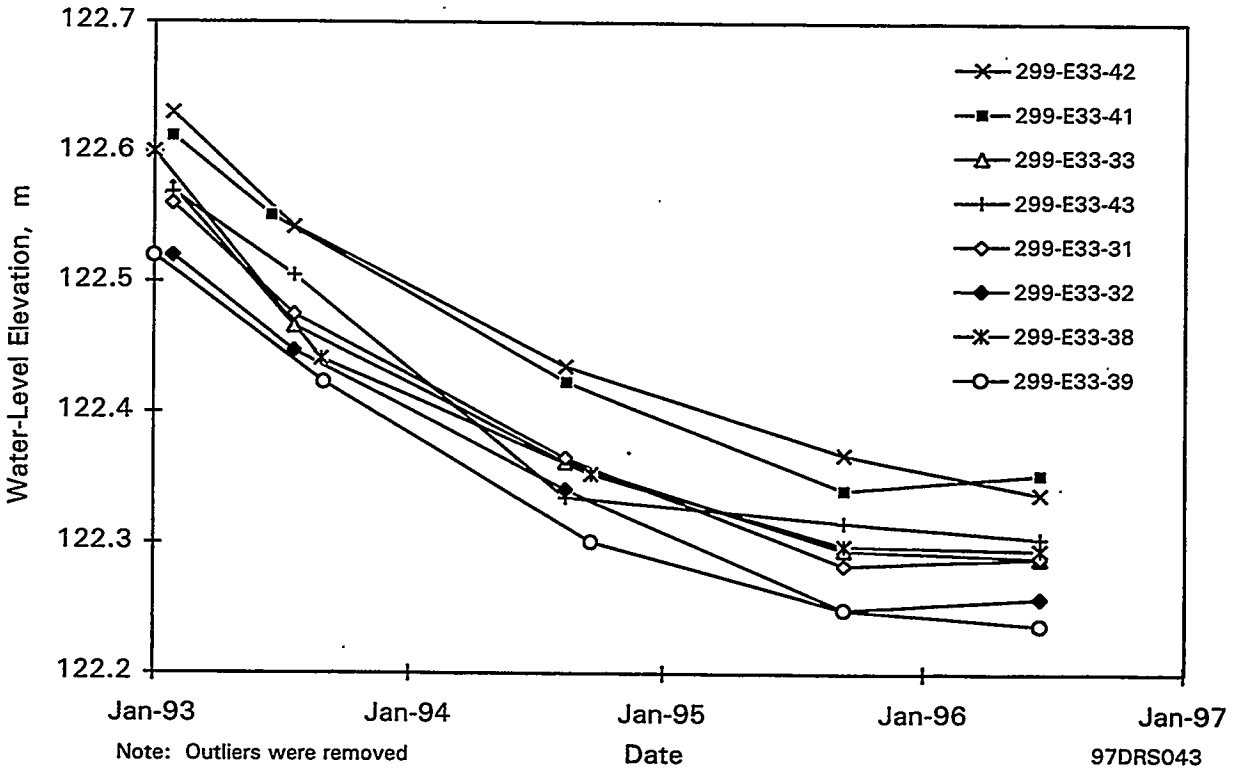


Figure 5.4-26. Water-Table Elevations in Wells Monitoring WMA-C Single-Shell Tank Farm

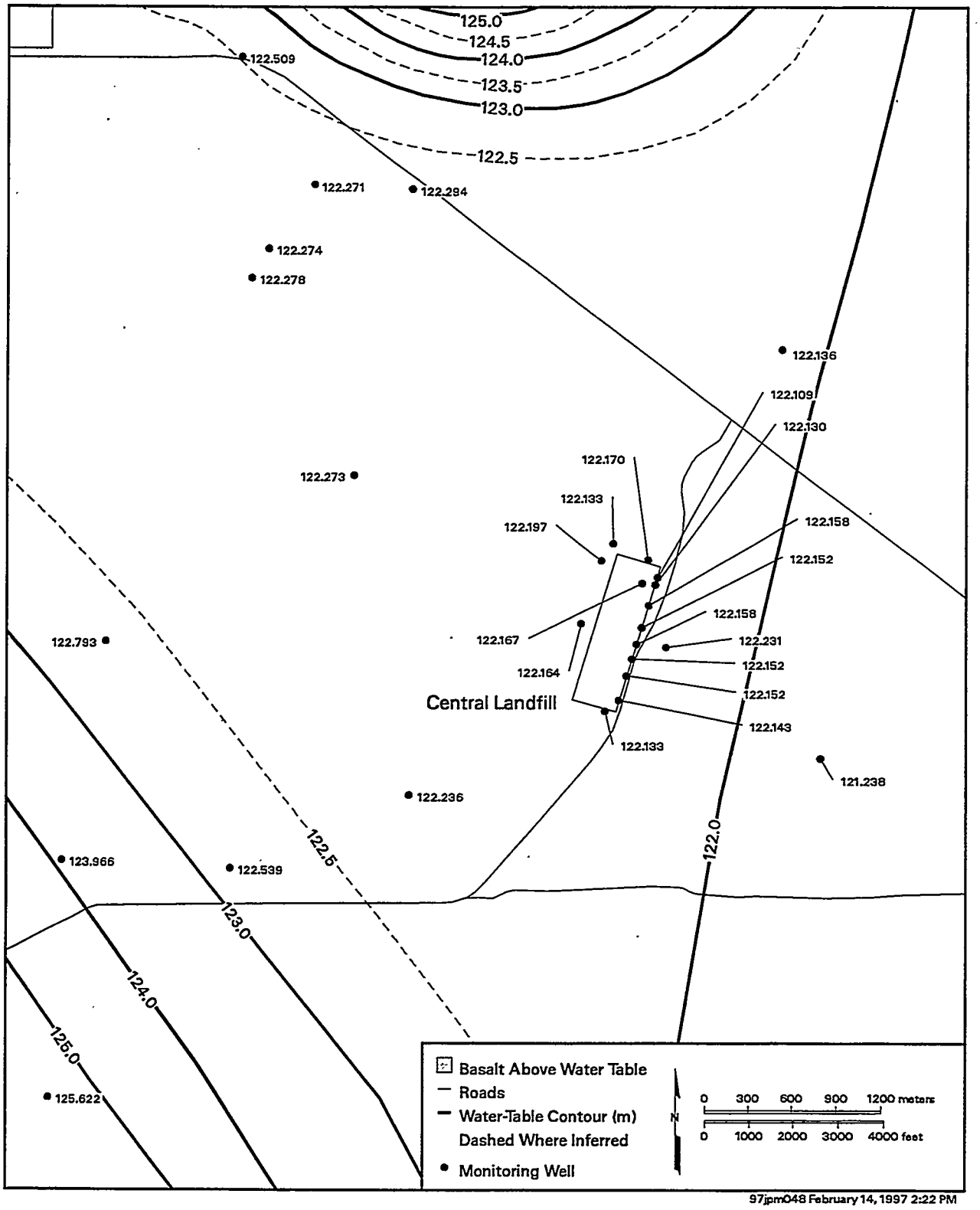


Figure 5.4-27. Water-Table Map for Solid Waste Landfill/Nonradioactive Dangerous Waste Landfill, June 1966

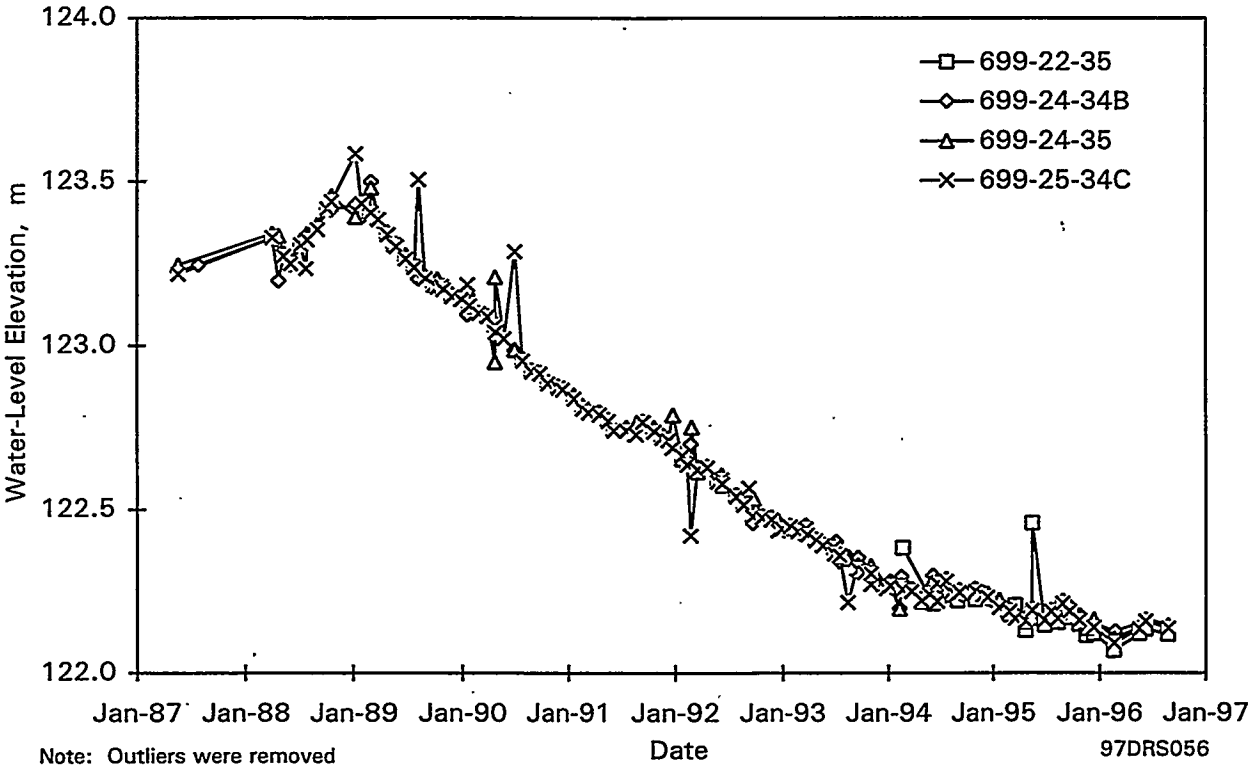


Figure 5.4-28. Water-Table Elevations in Wells Monitoring the Solid Waste Landfill

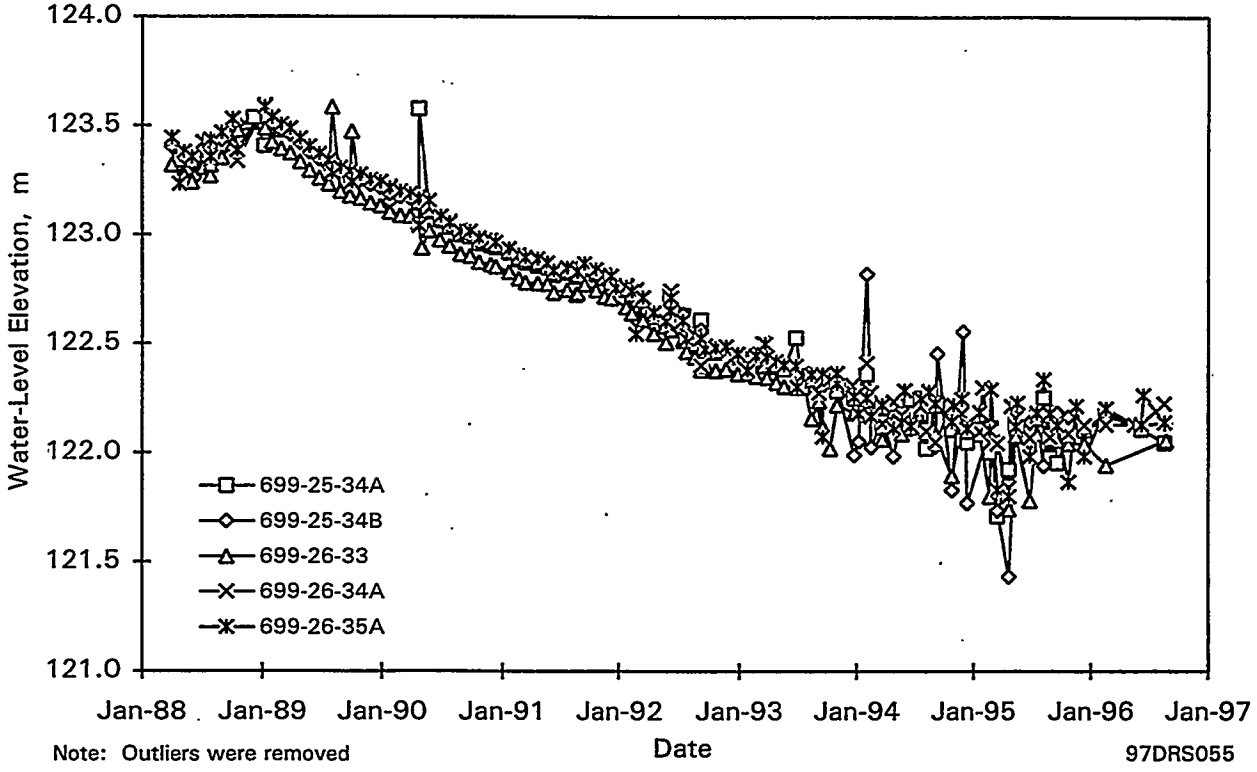


Figure 5.4-29. Water-Table Elevations in Wells Monitoring the Nonradioactive Dangerous Waste Landfill

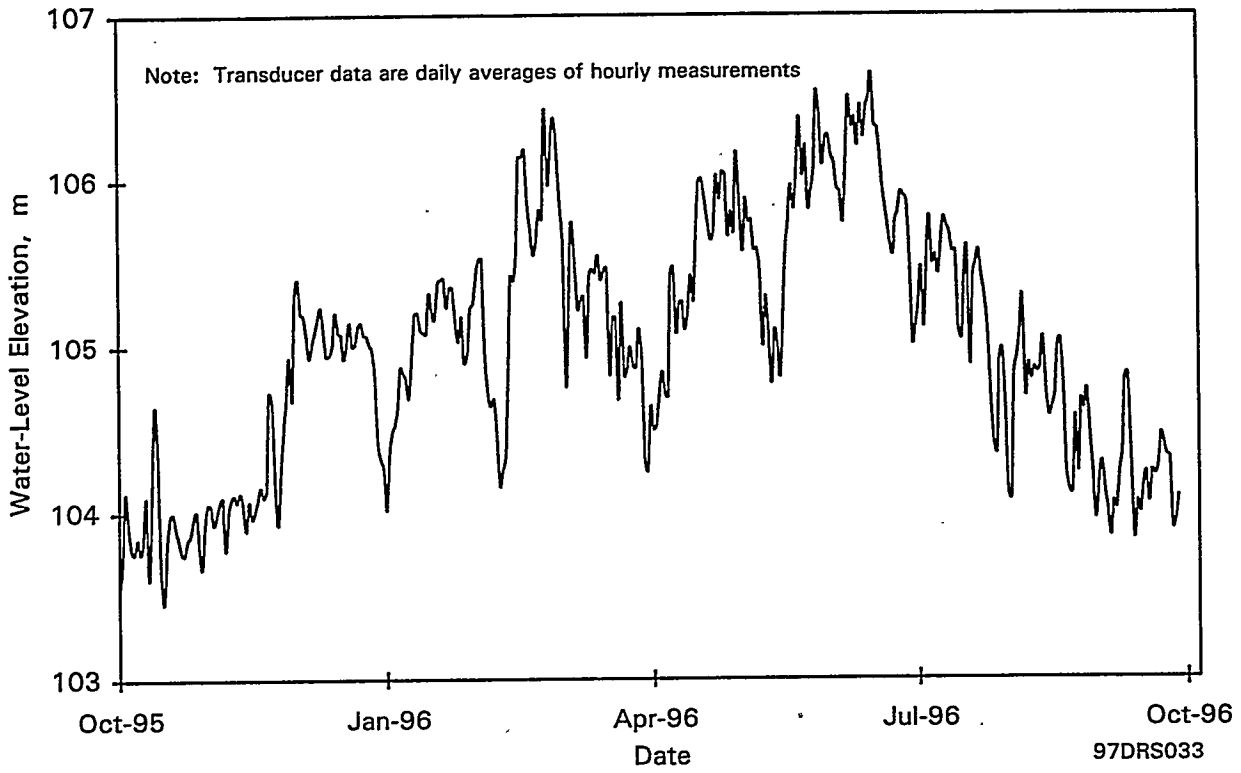
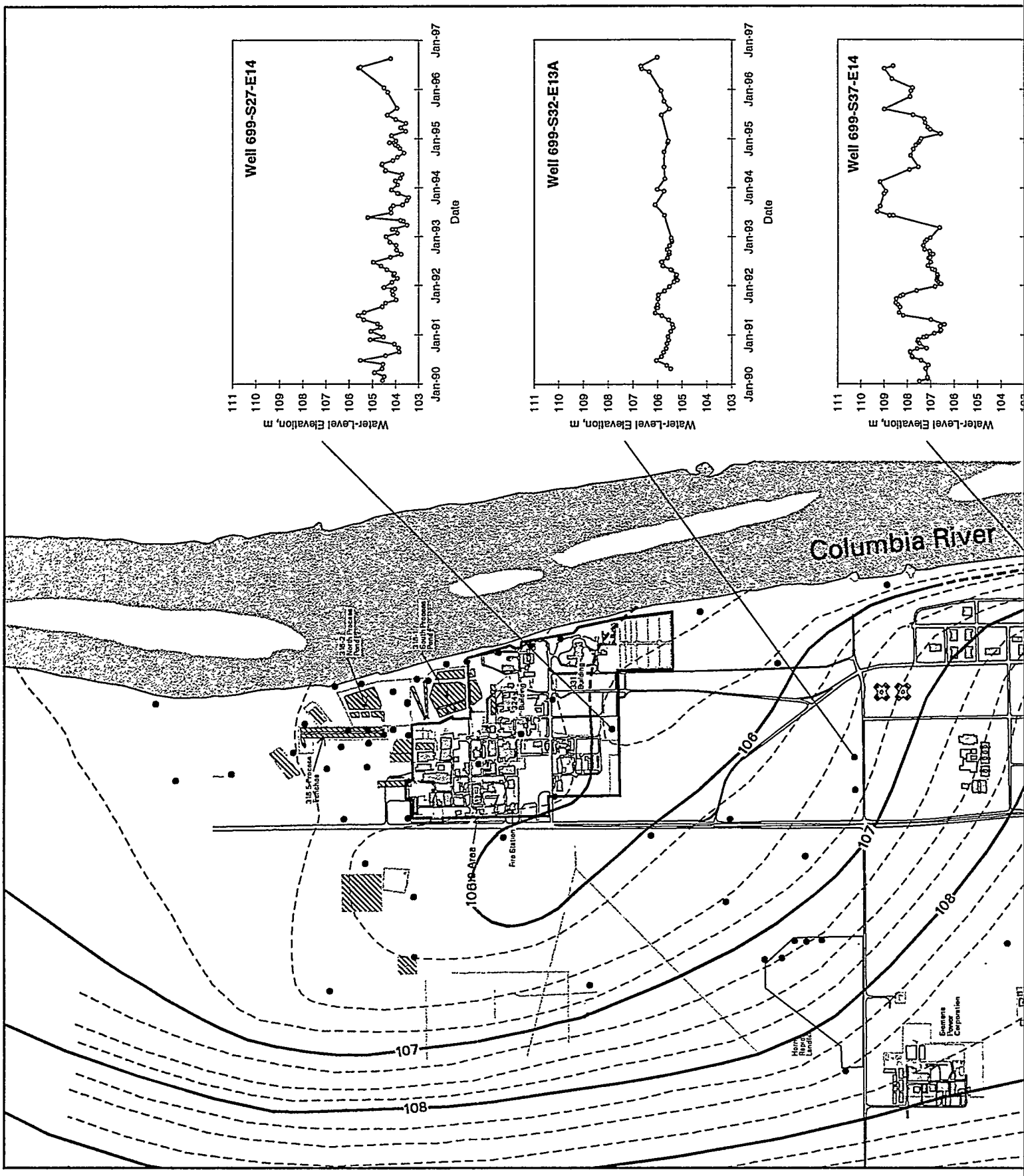


Figure 5.4-30. River-Stage Elevations Measured at the 300 Area


Well 699-S27-E14
Well 699-S32-E13A
Well 699-S37-E14
Water-Level Elevation, m
Date
Jan-90
Jan-91
Jan-92
Jan-93
Jan-94
Jan-95
Jan-96
Jan-97
111
110
109
108
107
106
105
104
103
Columbia River
106
107
108
1081 Area
Fire Station
Montana Power Corporation

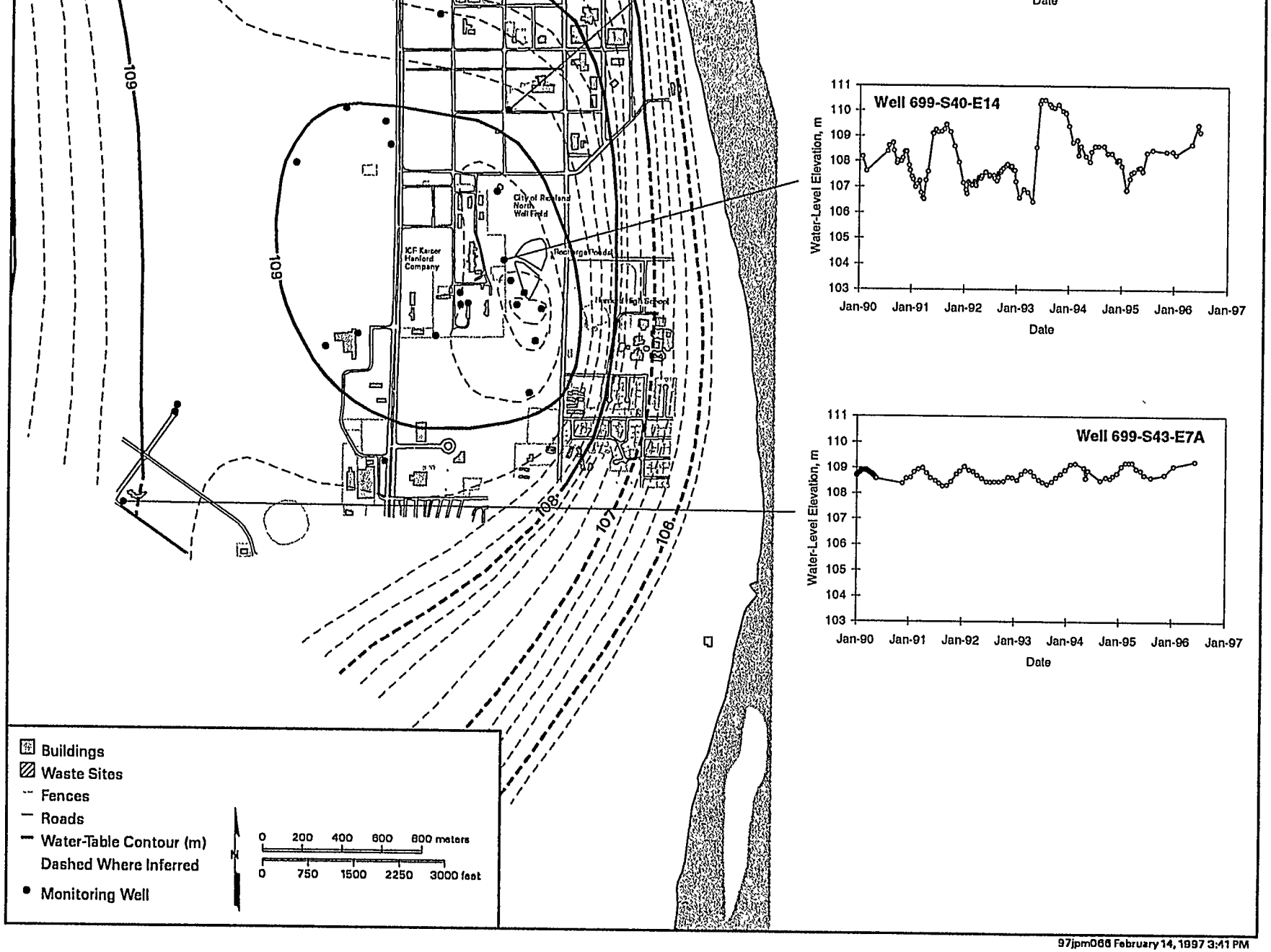


Figure 5.4-31. Water-Table Elevation-Contour Map of 300 and Richland North Areas, June 1996, and Hydrographs of Selected Wells

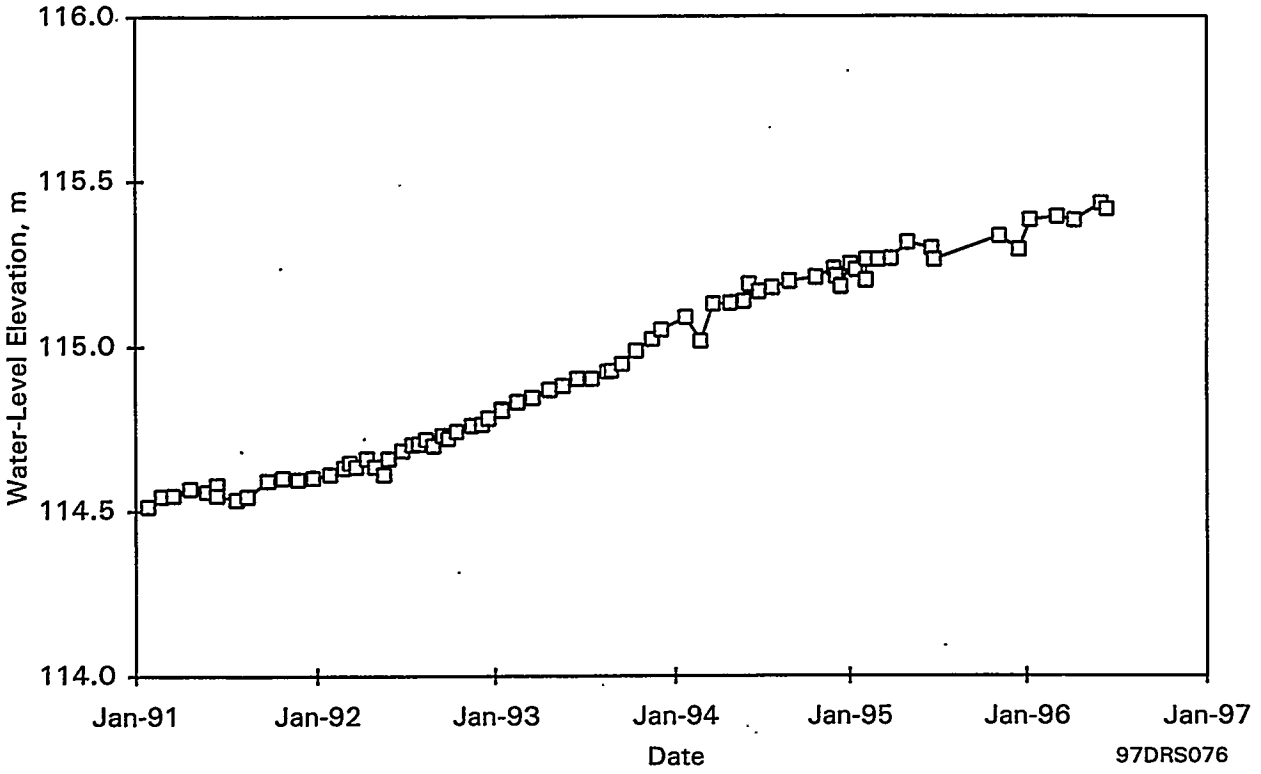


Figure 5.4-32. Water-Table Elevations Measured in Well 699-S31-1

6.0 Contaminant Evaluation and Compliance

Groundwater contamination at the Hanford Site is associated with a number of sources within its past and present operational areas. This chapter groups sources and potential sources of groundwater contamination by operational area in geographic (west to east) order. The results of the monitoring program and the evaluation of present contamination are discussed, as much as possible, in relation to source areas. In some cases, several potential sources such as cribs, trenches, or other disposal facilities may contribute to a particular groundwater plume, and their contributions cannot be readily distinguished. Therefore, they are discussed together. Monitoring of specific storage and disposal facilities, such as *Resource Conservation and Recovery Act of 1976* (RCRA) treatment, storage, and disposal units, is reported within the sections on the operational areas. Additional discussions are included for the potential receptors in the Richland North and 400 Areas and for the uppermost basalt-confined aquifer system.

6.1 Description of the Monitoring Program

P. E. Dresel, M. J. Hartman, and B. M. Gillespie

Groundwater monitoring at the Hanford Site during fiscal year (FY) 1996 was conducted under several programs with goals to track changes in the extent of existing contamination, to identify any new impacts of contamination on groundwater, to provide data needed to support groundwater remediation, and to evaluate the effectiveness of remedial activities. The selections of wells, constituents, and sampling frequencies are based on knowledge of waste-disposal practices and inventories (Stenner et al. 1988), regulatory requirements (RCRA/*Comprehensive Environmental Response, Compensation, and Liability Act of 1980* [CERCLA]), proximity to disposal areas, contaminant mobility, and site hydrogeology.

6.1.1 Monitoring Network

During FY 1996, ~800 wells were sampled for radiological and chemical constituents as part of the various Hanford Site groundwater investigations. Of the wells sampled, ~270 were sampled once, ~280 were sampled twice, ~100 were sampled three times, ~90 were sampled four times, and ~60 were sampled more frequently. Well locations for the Hanford Site are shown in Plate 1. A number of wells are sampled to meet RCRA- or CERCLA-specific requirements. More detailed maps of well locations are included in this chapter where necessary. Specific wells and constituents are identified in Bisping (1996), though some modifications to the monitoring networks were made after the Bisping report was issued.

A groundwater-monitoring plan for each RCRA unit describes the well networks, constituents, sampling and analytical methods, and sampling frequency. Well networks and constituents analyzed for each RCRA unit and for the Solid Waste Landfill are listed in Tables 6.1-1 through 6.1-28. These tables include the reference to the specific monitoring plan. Where applicable, the groundwater quality assessment plan is also referenced.

Most of the monitoring wells on the Hanford Site are completed near the top of the unconfined aquifer system. Most of the wells monitored in the operational areas are constructed to meet the Washington Administrative Code (WAC 173-160) (e.g., stainless steel casing and screen, sand pack, and full annular seal). Many of the wells in other areas were constructed before the adoption of WAC requirements. These older wells were usually constructed of carbon steel casing, often with perforated casing rather than well screens, and may have no annular seal.

6.1.2 Methods

Methods for chemical analysis of groundwater samples conform to the U.S. Environmental Protection Agency's (EPA's) *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods* (EPA 1986b); *Methods for Chemical Analysis of Water and Wastes* (EPA 1982) or other EPA methods; *Annual Book of ASTM Standards* (ASTM 1986); and *Standard Methods for the Examination of Water and Wastewater, 17th Edition* (American Public Health Association 1989). The methods used for analysis of radiochemical constituents were developed by the analyzing laboratory and are recognized as acceptable within the technical radiochemical industry. During FY 1996, samples were analyzed for chemical constituents by three main laboratories and for radiochemical analytes by two main laboratories. Analytical methods are described in Appendix E.

Groundwater was sampled by staff from Westinghouse Hanford Company (WHC), Pacific Northwest National Laboratory, and Bechtel Hanford, Inc. (BHI) during FY 1996. Samplers followed their company's documented procedures for sampling, recordkeeping, field measurements, and shipping samples. The procedures were equivalent in most aspects.

6.1.3 Data Quality

The chemical composition of groundwater at any location fluctuates with time because of differences in the contaminant source, recharge, and/or flow field. The range of this fluctuation can be estimated by taking many samples but there is a practical limit to the number that can be taken. Comparison of results through time and location helps in interpreting the natural variability.

Sampling techniques are designed to provide a sample that is reasonably representative of the aquifer concentration when the sample is taken. However, there are limitations to the ability to collect representative samples or even to define precisely the volume of aquifer that is represented in the sample. Proper well construction, well purging, sample preservation, and, in some instances, filtering are used to help ensure that samples are consistent and representative. Careful sample-labeling protocols, chain-of-custody control and documentation, and bottle preparation prevent many gross errors in sample results. Duplicate samples and field blanks help in assessing the sampling procedure. The majority of the analytical results have been found to be suitable for the intended purposes. See Appendix F for more specific discussions on quality assurance/quality control.

Uncertainties are also inherent in laboratory analysis of samples. Gross errors can be introduced in the laboratory as well as during sampling, including transcription errors, calculation errors, mislabeling of results, and other errors that result from failing to follow established procedures. Often, these gross

errors can be recognized because unreasonably high or unreasonably low values result. Data-review procedures are used to identify and correct gross errors.

Random errors are unavoidably introduced in the analytical procedures. Usually, there are too few replicate analyses to assess the overall random error. Instruments for analyzing radioactive constituents count the amount of ionizing radiation at a detector, and background counts are subtracted. The nature of radioactive decay and the instrument design result in a random counting error, which is reported with the analytical result. Generally, sample results that are less than the counting error are an indication that the constituent was not detected. The counting methods may also result in the reporting of results that are less than zero. Although they are physically impossible, the negative values may be of use for some statistical analyses.

Systematic errors may result from inaccurate instrument calibration, improper standard or sample preparation, chemical interferences in analytical techniques, or faulty sampling methodology and sample handling. Sample and laboratory protocols, therefore, were designed to minimize systematic errors. The laboratories participate in interlaboratory comparisons, including analysis of blind samples prepared by the EPA. The contracted laboratories compared favorably with other laboratories, indicating that the level of systematic error from many sources is small enough to be acceptable.

The RCRA groundwater data undergo a validation/verification process according to a documented procedure. In addition to the quality assurance/quality control checks mentioned above, data are screened by scientists familiar with the hydrogeology of the unit, compared to historical trends or spatial patterns, and flagged if they are not representative.

6.1.4 Data Management

Results of groundwater sampling and analysis are made accessible in the Hanford Environmental Information System (HEIS) database. This database currently resides on a Sun Sparc 20 UNIX-based multiprocessor computer. The database software is ORACLE® (Oracle Corporation, Redwood Shores, California), and the user-interface software is Uniface® (Compuware Corporation, Farmington Hills, Michigan). Analytical results from all groundwater-monitoring programs are stored in this common database, with the exception of some data collected for limited special projects that may not be directly comparable to standard data. The data are made available to federal and state regulators for retrieval.

The HEIS programmers and HEIS data owners, including the groundwater projects, ensure database integrity and data consistency through membership in the onsite HEIS configuration control board and other ad hoc groups. The majority of data are loaded into the database from electronic files provided by the analytical laboratories. This minimizes data-entry errors and reduces the cost of data management.

6.1.5 Interpretive Techniques

Overall sample uncertainty may be factored into data evaluation by considering the concentration trend in a given well over time. This often helps identify gross errors, and long-term trends can be

distinguished from short-term variability. The interpretation of concentration trends depends on an understanding of chemical properties as well as site hydrogeology. The trend analysis, in turn, aids in refining the conceptual model of the chemical transport.

Trend plots in this report generally include all the available data, including those points flagged as suspect; unless the suspect points are beyond the scale of the plot. For plots of specific conductance and pH, only field measurements are plotted. Replicate values are averaged by sample date, with outliers removed.

The plume maps presented in this report are diagrams of the interpretation of the groundwater chemistry at the Hanford Site based on data from all sampling programs. Although analytical data are available only for specific points where wells were sampled, contours are drawn to join the approximate locations of equal chemical concentration or radionuclide activity. The contour maps are, necessarily, simplified representations of plume geometry given the map scale, lack of detailed information, variations in well completion, and the fact that plume depth and vertical extent cannot be fully represented on a two-dimensional map. Thus, the contours shown do not honor all data values at individual wells. The contours show the extent of contamination at levels of regulatory concern, such as maximum contaminant levels (MCLs), interim drinking water standards (DWSs), or derived concentration guides (DCGs). Additional contours are shown at levels that illustrate additional features of the contaminant distribution, such as zones of high concentration or areas impacted at levels less than the interim DWSs or MCLs. Figures meeting these requirements are best prepared by using irregular contour intervals. In addition, groundwater contaminants are often found at values ranging over several orders of magnitude—often over short distances. In these cases, logarithmically increasing contour intervals or irregular intervals must be used to preserve the information about the distribution at both low and high concentrations.

Plume maps in this report were prepared using averages of FY 1996 samples from each well. Average values for radionuclides were calculated using reported values, including the negative values that may be reported when the sample measurement is less than the instrument background correction. Values for chemical constituents below detection limits were considered to be zero in calculating averages. In a few instances, data believed to represent gross errors in sample collection or analysis were removed from the data set before averaging. In addition, results that were reported as less than detection but at higher than normal detection levels were removed from the data set. This occurred when samples were diluted to bring another constituent into range and when certain samples were analyzed to meet specific needs of individual programs that did not require the same reporting levels. The average values are posted on the contour plots, allowing comparison of the contour interpretation to the input data set. As discussed above, not all posted values are in agreement with the contours presented. In some locations, contours are shown around areas with no supporting sample data from FY 1996. These contours are based on data from past monitoring. The wells may have been dropped from sampling as a result of changing sampling programs and budgets, sampling problems, or scheduling oversights.

Compliance monitoring at sites regulated under RCRA interim status regulations requires a comparison between upgradient and downgradient levels of selected indicator parameters to determine if the

facility impacted groundwater quality. Initial background monitoring was completed at all RCRA facilities having groundwater-monitoring requirements. The statistical methods applied in RCRA interim status monitoring are discussed in Appendix B. The results of the statistical analyses are presented in Appendix B but conclusions with regard to specific facilities are summarized in this chapter.

One facility on the Hanford Site was monitored under RCRA final status requirements in FY 1996—the 183-H solar evaporation basins. The statistical methods used for the final status monitoring are also discussed in Appendix B and the conclusions from the statistical interpretation are included in this chapter.

One CERCLA Operable Unit, 1100-EM-1, was subject to groundwater monitoring under a final record of decision (ROD 1993) during FY 1996. This record of decision, requires monitoring of trichloroethylene at point-of-compliance wells. The comparison to standards at the point of compliance is discussed in Section 6.14.4.

6.1.6 Regulatory Standards

Contaminant concentrations in this report are compared to various regulatory standards that may apply under different programs. These standards include the following:

- MCLs are federally or state-enforceable standards for drinking water supplies. Although MCLs only apply at the point of consumption of the water, they provide a useful indicator of the potential impact of groundwater contamination if water usage were to change. In addition to primary MCLs, secondary MCLs are set on aesthetic criteria such as taste rather than on health criteria and are generally not federally enforceable, though the State of Washington claims the right to require corrective actions in some instances where water supplies exceed secondary standards. Selected MCLs are shown in Table 6.1-29.

- interim DWS - Specific MCLs have not been set for most radionuclides; however, the MCL for gross alpha measurements, excluding uranium and radium, is 15 pCi/L. For beta particles and photon activity, the MCL is set at a 4-mrem/yr effective dose. The method of calculating the 4-mrem/yr effective dose equivalent for individual radionuclides that is used in the interim DWSs generally results in lower activities producing higher doses than result from calculations used in the proposed final standards. The interim DWS will serve the purpose of providing a measure of potential impacts from groundwater contamination until the final rule is promulgated. Interim DWSs for selected radionuclides are shown in Table 6.1-29.

- DCGs are standards set for protection of the public from radionuclides resulting from U.S. Department of Energy (DOE) activities. The DCG is based on a 100-mrem/yr exposure standard and is the amount of an individual radionuclide that would lead to that dose through ingestion under specified intake scenarios. Because the effective dose equivalent calculations for the DCG use more current methodology, the results are not completely consistent with the interim DWSs. Selected DCGs and the 4-mrem/yr effective dose equivalent are shown in Table 6.1-30.

The Solid Waste Landfill is not a RCRA facility but is regulated under WAC 173-304. Under WAC 173-304, the proper groundwater standards are those of WAC 173-200 and not the EPA groundwater standards used for interim status RCRA sites.

Also, concentration limits may be set in a facility's operating permit or record of decision. These limits are listed in the remainder of this chapter where they are applicable.

6.2 Overview of Hanford Site Groundwater Contamination

P. E. Dresel

Tritium, nitrate, and iodine-129 are the most widespread contaminants associated with past Hanford Site operations. Their concentrations in wells and plume contours for the upper part of the unconfined aquifer system are shown in Plates 3, 4, and 5, respectively. Available data indicate that the vast majority of the onsite contamination remains near the water table. The distributions of tritium, nitrate, and iodine-129 are generalized in Figures 6.2-1, 6.2-2, and 6.2-3. Figures for other constituent distributions are presented for specific areas as needed. Chromium contamination is widespread in several of the 100 Areas and extends into the surrounding 600 Area, as discussed below. Other extensive contaminant plumes include chromium contamination in the 600 Area south of the 200 Areas, technetium-99 and uranium extending eastward from the 200-West Area, and technetium-99 with minor amounts of cyanide and cobalt-60 northeast of the 200-East Area. Several other constituents are detected outside the boundaries of the operational areas but the contamination is clearly linked to operations in the specific areas and will be discussed with the source areas. A few smaller sources within the 600 Area are discussed in Section 6.12. Contamination in the confined aquifer is discussed in Section 6.15. All analytical results for FY 1996 are provided in Appendix H included on a computer disk at the back of this report.

A number of onsite facilities have specific RCRA monitoring requirements. The results of monitoring at these facilities are integrated into the discussion below, and specific RCRA-reporting requirements for the facilities monitored such as indicator parameter evaluations are included as needed. Appendix G summarizes analytical results for wells monitoring RCRA and state-permitted facilities that exceeded MCLs or interim DWSs. Statistical evaluations for RCRA monitoring requirements are discussed in Appendix B.

6.3 100-B,C Area

M. J. Hartman

The 100-B,C Area is the farthest upstream reactor area along the Columbia River. B Reactor was the world's first production nuclear reactor, placed into service in 1944 and operated until 1968. C Reactor operated from 1952 to 1969. The B and C Reactors used a single-pass system for cooling water (i.e., cooling water passed through the reactor and was discharged to the Columbia River).

6.3.1 Operable Units

For environmental restoration activities under CERCLA, the 100-B,C Area is divided into two source operable units that contain hazardous waste sites at or near the surface (100-BC-1 and 100-BC-2). A single groundwater operable unit (100-BC-5) addresses contamination at and below the water table and extends from beneath the source operable units laterally to adjacent areas where contamination may pose a risk to human and ecological receptors. For the 100 Areas, the lateral boundary is generally considered to be where Hanford Site groundwater meets Columbia River water. This interface occurs along the riverbanks and within the riverbed substrate.

High-priority waste sites in the 100-BC-1 Operable Unit include reactor coolant-retention basins, liquid waste-disposal trenches, and associated effluent pipelines. High-priority sites in the 100-BC-2 Operable Unit include liquid waste-disposal sites near the reactor buildings and solid waste-burial grounds. Descriptions of high-priority waste sites are presented in the proposed plans for source remediation activities in each of these operable units (DOE 1995h, 1995i).

The 100-BC-5 Operable Unit encompasses the groundwater underlying the 100-B,C Area. The groundwater was contaminated by liquid effluent disposal associated with past reactor operations. Most of the waste site sources for this contamination ceased operating by the late 1960s. A significant amount of contamination carried by the groundwater discharged into the Columbia River. A conceptual site model for groundwater contamination at the 100-BC-5 Operable Unit is included in Peterson et al. (1996).

6.3.2 Facilities

There are no active facilities or waste-disposal sites in the 100-B,C Area. The facilities noted below that are associated with former reactor operations that involved hazardous materials are to be decommissioned and remediated under CERCLA (see Plate 1).

- The 116-B-11 and 116-C-5 retention basins are located in the northern part of the 100-B,C Area. They received enormous volumes of reactor coolant effluent that contained radionuclides and metals. They held the effluent for a short time to allow thermal cooling and radionuclide decay before the effluent was discharged to the Columbia River. The basins developed significant leaks, creating a mound on the underlying water table that enhanced the spread of contamination.

- The 116-B-1 and 116-C-1 liquid waste-disposal trenches received highly radioactive coolant effluent that resulted when a reactor fuel element failed. The effluent was held briefly in the retention basins and was then diverted to the nearby liquid waste-disposal trenches instead of to the river. The trenches were unlined and intended as soil-column disposal sites because the natural soils were known to retain several radionuclides of concern.

- Relatively small soil-column-disposal facilities such as cribs, trenches, and french drains were located near the reactor buildings. Contaminated water and sludges from fuel-storage basins at each reactor were disposed to trenches.

- Solid wastes from reactors, including piping and equipment, were disposed in unlined trenches, buried metal culverts, or buried concrete pipes.

6.3.3 Extent of Contamination

The most notable contaminants in the 100-B,C Area are tritium and strontium-90. Groundwater is also contaminated locally with chromium at levels above drinking water MCLs. Although technetium-99 was detected, levels are far below the interim DWS. These contaminants were introduced from leaking retention basins, cribs, and trenches in the 100-B,C Area and, in some cases, from sources upgradient of the area.

Tritium was produced in B and C Reactors (DOE 1992b; Gerber 1993). Separation of tritium produced between 1949 and 1952 in the 100-B,C and other reactor areas was performed in the 108-B building. Liquid wastes from the tritium-recovery process were discharged to the 116-B-5 crib. Also, high-level liquid tritium wastes were disposed to the 118-B-6 burial ground (DOE 1992b).

Most of the wells monitored for tritium in this area during the past year showed tritium activity between 1,000 and 4,000 pCi/L (see Plate 3). One well (199-B5-2, downgradient of the 116-B-5 crib) contained 27,000 pCi/L of tritium, which is greater than the interim DWS of 20,000 pCi/L. Tritium activity appears to be increasing with time in this well (Figure 6.3-1). Tritium is also relatively high (14,000 pCi/L) in well 199-B2-13, located in the northwestern part of the area near the Columbia River. No potential tritium sources were identified upgradient of this well but samples consistently contained tritium at levels between 12,000 and 15,000 pCi/L since the first recorded sample in 1992. Past groundwater mounding from discharges may have caused contaminants to be transported toward this well from the 100-B,C Area.

Tritium levels in well 699-65-72, located ~2 km southeast of the 100-B,C Area, were also elevated but declined in recent years (Figure 6.3-2). Other wells farther to the east and southeast also show elevated tritium levels (see Plate 3). It is believed that this contamination is moving from the 200 Areas through the gap between Gable Mountain and Gable Butte and merges with tritium plumes in the 100-B,C and 100-K Areas. Another possible explanation for the elevated tritium is groundwater mounding from past disposal practices in the 100-B,C Area.

Groundwater with strontium-90 activity greater than the 8-pCi/L interim DWS extends from the B Reactor building downgradient to the retention basins, liquid waste-disposal trenches, and the Columbia River (Figure 6.3-3). Most of the data for the past year are for strontium-89 and -90. All of the strontium detected by this method may be assumed to be strontium-90 because strontium-89 has a shorter half-life (50.5 days, compared to 29 years for strontium-90). The highest activities of strontium-90 in the 100-B,C Area are in wells near the 116-B-1 and 116-C-1 liquid waste-disposal

trenches. The 116-B-11 and 116-C-5 retention basins and liquid waste-disposal sites near the B Reactor building also appear to have contributed strontium to groundwater.

Chromium was introduced to the soil column and groundwater from cooling water that leaked from retention basins and pipes or was disposed in trenches and cribs. Chromium is elevated in two very small areas. The first is near the river, downgradient of the retention basins, where well 199-B3-47 contained 35 μg/L chromium during FY 1996. Chromium increased to this level from ~12 μg/L when data collection began in this well in 1992. The second area of elevated chromium is downgradient of former water-treatment facilities, where sodium dichromate may have leaked from storage tanks and transfer facilities. The single monitoring well in this area (199-B5-1) had an average concentration of 75 μg/L in October 1995. Chromium concentrations fluctuate widely in this well, commonly varying between 12 and 70 μg/L in a single year. The fluctuations may be seasonal. The low values were observed in the winter or spring of the year; the high values in the fall. However, well 199-B3-47, which is much closer to the river than 199-B5-1, does not exhibit similar fluctuations.

Nitrate data are very limited for the past year in the 100-B,C Area because past monitoring showed that levels are low in this area. Nitrate data are plotted in Plate 4.. Concentrations in the 100-B,C Area are below the 45,000-μg/L MCL. Limited data from the past year show a maximum nitrate concentration of 26,000 μg/L in well 199-B3-46.

6.3.4 Compliance Issues

As discussed above, strontium-90 is the contaminant in the 100-B,C Area most extensively detected at levels above the DWSs. Tritium and chromium were each detected at levels above the DWSs in single wells. No radiological contaminants were detected at levels above the DCGs.

6.4 100-K Area

V. G. Johnson, R. E. Peterson, and P. E. Dresel

The 100-K Area is located along the Columbia River in the northern portion of the Hanford Site (see Plate 1). A comprehensive discussion of operations, along with detailed descriptions of facilities, waste sites, and hazardous waste-spill locations, is presented in Deford and Einan (1995). A brief summary of the operating history is provided here as background for the subsequent discussion of groundwater quality in this area and its associated riparian zone.

The 100-K Area consists of the inactive K-West (KW) and K-East (KE) Reactors and associated support facilities. The reactors were the largest production reactors and, thus, generated the greatest volume of liquid waste during their operation from 1955 until January 1971. Since 1975, the fuel-storage basins located in the reactor buildings have been used to store irradiated nuclear fuel from N Reactor. The fuel will be transferred to a new storage facility in the 200 Areas, which is planned for completion by the year 2000. In addition since 1994, the 183-KE filter plant water basins have been used as fish-rearing facilities operated by the Yakama Indian Nation with cooperation of the DOE.

During operation of the KE and KW Reactors, water was taken from the Columbia River, treated to remove particulates, and then conditioned with sodium dichromate, a corrosion inhibitor. The treated water passed once through the reactor core and was then detained in large retention basins to allow decay of short-lived radionuclides. The coolant was then discharged back into the river. Wastewater arising from the fuel-storage basins, chemical makeup operations, cell drainage, fuel-cladding failures, and laboratories was discharged into various soil-column-disposal structures. As indicated in Chapter 4.0, residual contaminants in the soil beneath the waste-disposal and leakage sites are potential sources of continuing groundwater contamination.

6.4.1 Operable Units

The 100-K Area includes two source operable units (100-KR-1 and 100-KR-2) and one groundwater operable unit (100-KR-4). The groundwater operable unit encompasses the groundwater underlying the 100-K Area and also includes adjacent areas outside the perimeter fence where contaminated groundwater from the 100-K Area may come in contact with human and ecological receptors. Examples of adjacent areas are the riverbed, where groundwater may upwell into sediments that form aquatic habitat, and locations where water seeps from the riverbank during low-river stages.

At this time, all soil-column and related remediation of the source operable units is deferred in accordance with the *Hanford Federal Facility Agreement and Consent Order* (also known as the Tri-Party Agreement) (Ecology et al. 1989). Remedial investigation activities consisted primarily of groundwater sampling and analysis in accordance with the CERCLA 100 Areas sampling and analysis plan (Peterson and Raidl 1996). Water levels were also obtained, which included continuous (hourly) measurements in wells 199-K-30, 199-K-32A, and 199-K-32B. Recent groundwater investigations are summarized in Peterson et al. (1996).

As part of source operable unit investigations, summaries were prepared that list known waste sites, describe their characteristics, and indicate the contaminants of concern. These summaries were originally presented in the proposed plans for the 100-KR-1 and 100-KR-2 Operable Units (DOE 1995j, 1995k). Key facilities and waste sites include the 116-K-2 liquid waste-disposal trench (also known as the mile-long trench); coolant water-retention basins; french drains and tile fields adjacent to each reactor building; and chemical-storage/transfer facilities located near the 183-KE and 183-KW water-treatment basins. Information on reactor operations and waste sites is described in Carpenter and Coté (1994), and the following summaries draw heavily on that source.

6.4.2 Facilities

6.4.2.1 Fuel-Storage Basins

The spent nuclear fuel-storage basins located in the KW and KE Reactor buildings and associated support structures are the only operational facilities in this area. The 183-KE filter plant water basins located south of the reactor building have been in use since 1994 for the fish-rearing experiment, and leakage from the basins may be impacting groundwater flow and contaminant transport. Utilities to support both the fuel-storage and fish-rearing basins include water, electrical, and sewage systems.

Water lines provide both potable water and raw water for fire hydrants and makeup water for the basins. Because of the proximity of the utility lines to waste-disposal and spill sites and the age of many of the water lines, leaks are potential causes for transport of contaminants in the soil column to groundwater (see Chapter 4.0). In addition, large paved areas around the reactor buildings, and the buildings themselves, create collection areas for surfacewater runoff that is a potential cause for downward transport of soil-column contaminants (Johnson and Evelo 1995).

The KW and KE basins both acquired radionuclides released from the irradiated fuel. The KE basin contains much higher concentrations than the KW basin because fuel elements stored in the basin are unencapsulated, allowing greater corrosion and release of radionuclides. Concentrations of major contaminants for the KE basins are shown in Table 6.4-1. The mobile constituents (i.e., most likely to appear in groundwater from a leak) are tritium and traces of antimony-125. Potential leakage of the KE basin was reported in 1993, though evidence suggests that earlier periods of leakage from the basins occurred. The use of tritium and other cocontaminants as indicators of leakage of fuel-storage basin water is complicated by the presence of other sources. In the discussion below on the extent of contamination, the potential sources for each contaminant will be considered as a single entity.

Operational groundwater monitoring during the year was limited to the guard wells located immediately downgradient of the fuel-storage basins in the reactor buildings (see Plate 1). Quarterly sampling was conducted in accordance with the sampling and analysis plan (Johnson et al. 1995). Monthly sampling for tritium was conducted in four key wells and the samples were analyzed in the 183-K health physics laboratory for quick-turnaround results to track changes resulting from potential leakage from the basins and/or changes resulting from leaking water lines near past-practices contaminated soil sites. Constituents of interest for leak detection and contamination from past leaks and soil-column disposal are strontium-90, cesium-137, tritium, antimony-125, gross beta, and gross alpha (transuranics indicator). Other chemical constituents were analyzed for background information on general water quality.

6.4.2.2 Other Facilities

The principal surface facilities associated with past liquid waste disposal to the soil column are shown in Plate 1. A detailed description of these waste-generating facilities is contained in Carpenter and Coté (1994). A description of how the plutonium-production reactors operated is presented in General Electric (1963). Both references provide comprehensive background material for interpreting the origin of groundwater contamination. The source information in the following summary is derived from those references unless otherwise cited.

116-K-2 Liquid Waste-Disposal Trench. This facility (see Plate 1) is the primary source for the chromium plume being targeted by the interim remedial measure discussed below. This trench is located to the northeast of the KE Reactor facilities and, in its original configuration, was 1,200 m long by 13.7 m wide by 4.6 m deep. The trench was designed as a soil-column liquid effluent-disposal facility and operated between 1955 and 1971. It is the largest radioactive liquid waste trench in the 100 Areas and received significant quantities of chemical wastes and occasional solid waste such as contaminated storage tanks and equipment. Solutions containing chromium that were discharged to the

trench were primarily decontamination solutions and leakage of routine coolant water from the 107-K retention basin and floor drains in the KW and KE Reactor buildings. Solutions contributing the greatest amount of radionuclides were decontamination solutions, shielding water from the fuel-storage basins, and coolant water containing debris from fuel-element failures.

Leakage via faulty valves on transfer lines from the retention basins to this trench was estimated to be ~38,000 to 76,000 L/min, which was sufficient to create a mound on the underlying water table. The mound was on the order of 6 m higher than the natural water table and caused an increase in the rate of groundwater flow to the river, to perhaps 3 m/d (Brown 1963). The source for these retention basins was greatly reduced after 1963, when coolant water was rerouted directly to the river, thus bypassing the faulty valving. The mound also would have caused flow away from the river to an unknown extent. Thus, contaminants from various sources may have been transported to the south-southeast of the reactor areas as well as to the south-southeast of the trench.

After 1963, the mound around the trench dissipated, and it is probable that chromium remained with the residual moisture in the normally unsaturated part of the soil column. This residual chromium may continue to migrate slowly downward for many years, contributing a small but continual supply to groundwater.

116-KW-3 and 116-KE-4 Water-Retention Basins. Coolant for the KW and KE Reactors was piped from the reactors to the retention basins, which were steel tanks located near the Columbia River. Thermal cooling and decay of short-lived radionuclides occurred in these tanks. The coolant was then discharged into the river via large-diameter outfall pipes. Significant leakage of coolant water occurred from the retention basins to the ground, as well as to the 116-K-2 liquid waste-disposal trench via faulty valves and associated piping.

Chemical Receiving Area. The area immediately south of the 183-KE filter plant was the receiving facility for makeup chemicals. Tank-car loads of sodium dichromate and other chemicals were transferred to other locations from this point. During transfers, spillage of highly concentrated solutions occurred and drained into the soil. Thus, a soil-column source of residual sodium dichromate may exist in this location and may explain the occurrence of very high chromium levels (up to 2,700 μg/L) that were observed in nearby monitoring well 199-K-36. A possible source is water leakage from the basin that was filled in 1994 for the fish-rearing project. If so, this could be a localized source at the present time that may be indirectly related to current use of the basin. It should also be noted that brine (sodium chloride) pits were located near well 199-K-36. Very high concentrations of residual material may be retained in the soil column beneath the unlined pits used to store the salt. Thus, this may be another source of chloride that appears in 100-K Area groundwater. A similar chemical-receiving area, monitored by well 199-K-35, existed behind the 183-KW filter plant.

116-KW-1 and 116-KE-1 French Drains. Approximately 200 Ci of tritium and 200 Ci of carbon-14 were discharged to the 116-KW-1 and 116-KE-1 french drains during reactor operations. These facilities are located near the KW and KE Reactors, respectively, and received condensate from the use of different inert gases in the reactors. Tritium and carbon-14 could be produced by irradiation of helium and nitrogen.

6.4.3 Extent of Contamination

The constituents that currently exceed regulatory standards in numerous wells include carbon-14, chromium, iron, nitrate, and tritium. Aluminum, gross beta, manganese, nickel, selenium, strontium-90, and trichloroethylene also exceed standards in isolated occurrences. Of the latter group, strontium-90 is a relatively new addition to the list of contaminants of concern that are relevant to interim cleanup decisions.

6.4.3.1 Chromium

Chromium is elevated in three regions of the 100-K Area (Figure 6.4-1). The first and most widespread occurrence is near the 116-K-2 liquid waste-disposal trench. This plume is being addressed by an interim remedial measure that includes a well-extraction/reinjection network and water-treatment system (DOE 1996c). The southeastern extent of the plume is uncertain because there is no monitoring well coverage in this area.

The second region of elevated chromium appears to originate in the vicinity of well 199-K-36, which is located at the southern end of the 183-KE filter plant and water-treatment basins (see Figure 6.4-1). The most recent results (2,700 μg/L) from well 199-K-36 are the highest observed values in the 100 Areas for analyses of filtered chromium samples. A widespread chromium plume is not indicated by samples from monitoring wells downgradient of this hot spot, suggesting it is of recent origin.

The third region of elevated chromium is centered near the KW Reactor building (see Figure 6.4-1). There, two wells (199-K-107A and 199-K-108A) show significantly elevated concentrations. The suspected source for this chromium is decontamination solution disposal to miscellaneous facilities near the reactor building.

Detectable chromium (40 μg/L) in a single well (699-78-62), located ~1,600 m west of the 100-K Area, may be a remnant from the operational period when chromate-bearing coolant, leaking from the retention basins, created a significant groundwater mound. The perturbation in the normal water-table elevations may have caused a widespread flow reversal. Water-level data from well 699-78-62 from 1958 onward shows the mound influenced water levels as far inland as this well. Thus, chromium could have been transported to the south-southeast during this period, leaving a remnant plume in an area that is inconsistent with the present-day hydraulic regime. Because of the paucity of wells in the area surrounding well 699-78-62, the extent of the hypothetical remnant plume is unknown. Field-screening results for chromium in 4 new injection wells drilled to the south of the 116-K-2 trench in FY 1996 for the pump-and-treat operation (discussed in Section 6.4.4) indicate concentrations of as high as 150 μg/L.

6.4.3.2 Tritium

The 100-K Area groundwater contains some of the highest tritium concentrations detected on site, though the extent of contamination is relatively limited. The highest concentrations are found in the

vicinity of the KE Reactor building. The major sources of contamination appear to be the french drains that received condensate from the gas wing and leaks in the fuel-storage basins that are located in the reactor buildings.

The tritium distribution in the 100-K Area is shown in Plate 3. Two high-concentration areas appear to originate near the reactor buildings. Multiple sources of tritium are suggested by Figure 6.4-2, which shows tritium in relation to suspected sources and expected flow direction of contaminant plumes from known source areas. Both tritium and relatively high carbon-14 levels are associated with the gas wing french drains or condensate cribs (see Figure 6.4-2) that received condensate from the inert gas loop of KW and KE Reactors. The continuing occurrence of both tritium and carbon-14 in the two downgradient wells from these sources (wells 199-K-106A and 199-K-30, respectively) suggest that long-term drainage must be occurring. This process could be maintained or accelerated because of enhanced infiltration of surfacewater that was observed to form shallow ponds over these sites during runoff events (see Chapter 4.0). The occurrence of elevated concentrations of chloride, which may be attributed to road salt used for ice control, in these and other wells suggests that a pathway exists for transport of near-surface contaminants to groundwater in this area (Johnson and Evelo 1995).

The concentration-history plots shown for wells 199-K-109A, 199-K-27, and 199-K-30 (see Figure 6.4-2) also suggest different sources and/or points of release. Tritium in well 199-K-109A exhibited an erratic initial concentration and then declined. This well also contained traces of antimony-125, a basin water cocontaminant. This well is located downgradient of distribution piping associated with the subbasin drainage-collection system (i.e., an asphalt layer and a sump that lies beneath the basin proper). Seepage from the basin is routed to a sump that was formerly connected to a soil-column-disposal system, consisting of a drain field and an injection well that discharged directly into the aquifer (location labeled French Drain near source area 3 in Figure 6.4-2). The combination drain field and injection well was decommissioned in ~1979. Since then, the water collects in a sump (known as D Sump) and is routed back into the basin. Any leakage from the piping, however, could serve as a continuing source (Johnson et al. 1995).

Well 199-K-27 (see Figure 6.4-2) exhibited a consistent pattern of declining tritium concentrations since leak rates were decreased as a result of both operational changes and attempts to isolate the construction joint from contaminated basin water. This well also contained a trace of antimony-125, suggesting a basin water source. The well is located near the centerline of a construction joint that lies between the basin proper and a fuel-discharge chute. The asphalt membrane subbasin collection system does not extend beneath the discharge chute and construction joint. Thus, any leakage from the joint drains directly into the underlying soil column.

The tritium-versus-time plot (Figure 6.4-3) for well 199-K-30 exhibited both increasing and decreasing trends that are not yet correlated, though infiltration of snow melt and mobilization of soil-column contaminants beneath the gas wing crib are suspected.

A comparison of the relative change in tritium concentration versus time for the two wells downgradient from the suspected french drain sources at the KW and KE nuclear fuel-storage basins is shown in Figure 6.4-3. This figure also illustrates that basin water is not a contributor to the tritium

levels observed in well 199-K-106A because the maximum tritium in this well is 10 times the tritium content of KW basin water (~50,000 pCi/L). Also, significant concentrations of carbon-14 are found only in wells 199-K-30 and 199-K-106A. The cause of the quite different response patterns for the two sites is unknown. Although speculative, a leaking fire hydrant was discovered and repaired near the 116-KW-1 french drain in 1995 and may account for the second tritium maximum that occurred in well 199-K-106A in FY 1996. Perhaps natural infiltration events account for the February-March 1995 peaks that occurred in both wells 199-K-30 and 199-K-106A.

6.4.3.3 Correlation of Basin Leak Rate and Tritium in Groundwater

As discussed above and illustrated in Figure 6.4-2, leakage of KE basin water is the assumed source of tritium in well 199-K-27. The construction joint was suspected of leaking and was the subject of several investigations that led to attempts to repair the leak. Declines in leak rate are attributed to a combination of operational changes (e.g., basin water temperature), repairs (e.g., sealants), and isolation of the construction joint from the basin proper. A comparison of calculated basin leak rates and tritium concentration in downgradient well 199-K-27 is shown in Figure 6.4-4.

Following the operational changes (shaded vertical bar in Figure 6.4-4[a]) and repairs, both the leak rate and tritium concentrations declined significantly. The tritium concentrations in the downgradient well appear to decline exponentially. This may be consistent with the manner in which water from a saturated soil column declines following termination of the source of water (i.e., an exponential decline). If so, the decline should be linear when plotted as the log of tritium concentration versus time. Figure 6.4-4(b) displays a linear regression of natural log concentration on time from March 1993 through June 1996. A reasonably good fit was obtained by excluding the data points after June 1996. The regression equation in Figure 6.4-4(b) predicts that tritium concentration would have declined to ~20,000 pCi/L by the end of FY 1996. This trend may be continued when the small perturbation in leak rate subsides. Nevertheless, the correlation illustrated in Figure 6.4-4 indicates that leakage from the basin is significantly reduced and seems to be declining in a predictable manner.

6.4.3.4 Carbon-14

Carbon-14 is elevated above the 2,000-pCi/L interim DWS in the 100-K Area (Figure 6.4-5). The highest concentrations are associated with the 116-KW-1 and 116-KE-1 french drains discussed above for tritium. The groundwater plume from these facilities appears more extensive near the KW Reactor than the KE Reactor.

Carbon-14 concentrations in individual wells are essentially independent of tritium fluctuations, as discussed by Dresel et al. (1996). Carbon-14 is apparently precipitated in carbonate minerals in the aquifer or sorbed to the sediments. This results in a continued source in the sediments and a slower migration rate.

An increasing trend in concentration with time is present in well 199-K-33, which is located farther downgradient from the suspected source than other wells. Well 199-K-34, located nearer the source, shows a decreasing trend. This pattern is consistent with a plume of groundwater containing carbon-14

that migrated downgradient toward the river, and that the highest concentrations of that water mass migrated away from the french drains. However, the trend in a relatively new well located immediately downgradient of the crib (well 199-K-106A) is erratic and indicates much higher contamination levels than the wells farther downgradient. As discussed above, infiltration of snow melt and surface runoff may be the source to sustain a continual input of contaminants to groundwater from this past-practices site.

Near the KE Reactor, carbon-14 is elevated in well 199-K-30, which is an analog to well 199-K-106A near the KW Reactor. Wells downgradient of 199-K-30 do not show evidence of a plume comparable to that at the KW Reactor. Carbon-14 levels are also elevated in wells 199-K-27 and 199-K-109A but to a lesser extent in a number of wells throughout the 100-K Area.

6.4.3.5 Strontium-90

Strontium-90 is found in relatively small plumes near both the KW and KE Reactor buildings and also downgradient from the 116-K-2 liquid waste-disposal trench (Figure 6.4-6). The highest strontium-90 concentrations are found in the vicinity of the KE Reactor building but the concentrations are highly variable.

The most significant change in groundwater quality in the 100-K Area during FY 1996 is the increasing trend in strontium-90 concentrations in well 199-K-109A near the northwest corner of the KE Reactor building. Concentrations increased to a maximum of ~6,000 pCi/L during the month of April 1996, declined following repair of a leaking hydrant, and then increased to a maximum of 8,000 to 9,000 pCi/L in September 1996. These levels are among the highest strontium-90 concentrations observed in Hanford Site groundwater and greatly exceed both the 1,000-pCi/L DCG and the 8-pCi/L DWS. The well in which these exceedances occur (199-K-109A) is located adjacent to a past-practices disposal site that received storage basin overflow containing relatively high concentrations of long-lived fission products. Significant soil-column contamination was identified when the monitoring well was drilled, as indicated by the gamma log (Figure 6.4-7). The occurrence of high gamma activity (cesium-137) shown in the borehole log at 11 m below ground surface is consistent with the depth of the drain tiles associated with the past-practices disposal site.

A leaking water-supply line was located within 5 m of well 199-K-109A. One possibility is that water from the line carried strontium-90 down the outside of the casing to groundwater. Evidence for a surfacewater source is suggested by the decline in specific conductance (dilution of ambient groundwater, with an average specific conductance of ~360 μS/cm, by raw water, with a specific conductance of 140 μS/cm) as illustrated in Figure 6.4-8(b). Gross beta, which was shown to be caused by strontium-90 (Johnson and Chou 1995), declined following repair of a fire hydrant in April 1996 (Figure 6.4-8[a]). This decline coincides with the increase in specific conductance (diminishing dilution of ambient groundwater). However, the second increase in gross beta after July 1996 is not correlated with this single event, suggesting there may be a not-yet-identified cause.

Relation to Changes in Water-Table Elevation. Increasing strontium-90 concentrations in 100-N Area wells were attributed to increasing water levels caused by the unusually high river stage

during 1996. As the water table rises, contaminants stored in the vadose zone soil column above can become mobilized as the rising water table saturates the contaminated sediments. This possibility was evaluated at the KE basin using the continuous water-level data collected at well 199-K-30 located ~75 m northeast of well 199-K-109A. A comparison of river-stage and water-level elevations from 1993 to the present is shown in Figure 6.4-9. The maximum water level in 1996 occurred between mid July and early August and is 1 m higher than the maximum for the previous year. However, the dramatic rise in strontium-90 in well 199-K-109A occurred during the time when the water level was declining. The changes in gross beta concentrations, resulting almost entirely from strontium/yttrium-90, are also more abrupt (see Figure 6.4-8) than would be expected from the more gradual change in water-level elevation. Thus, it does not seem likely that the unusually high water-level elevations during FY 1996 can account for the strontium-90 anomaly in well 199-K-109A.

The possible role of enhanced surfacewater infiltration and/or leakage of subsurface utility lines was identified and discussed in the 100-K Area monitoring plan and subsequent groundwater-monitoring reports (Johnson and Chou 1995; Johnson and Evelo 1995; Johnson et al. 1995). The observed ponding of surfacewater over other past-practices disposal sites and the occurrence of other water-line leaks add to the concern that remobilization of soil-column contaminants can occur, as indicated in the vadose-zone-monitoring discussion of soil-column contamination in Chapter 4.0.

The plume map for strontium-90 (see Figure 6.4-6) suggests this radionuclide is not very widespread from the suspected source locations. This is consistent with the slow migration rate of strontium through the aquifer. For example, previous estimates suggest a travel time of only a few meters per year in the 100-K Area (Johnson et al. 1995). Considering a maximum time period of 30 to 40 years, the dispersal from a point of origin would be restricted to a distance of 100 to 200 m. This expectation is consistent with the more localized or hot-spot nature of the plume distribution pattern for strontium-90 as compared to the more-mobile constituents (tritium, carbon-14, and nitrate). The source for the slightly elevated strontium-90 near the river is due to the 116-K-2 liquid waste-disposal trench that received fission products and other radionuclides during fuel-cladding failures.

The two strontium-90 hot spots both appear to be associated with the area around the french drains that received basin water leakage and other related wastewater. One involves two wells (199-K-34 and 199-K-107A) located adjacent to the KW Reactor and a second involves well 199-K-109A, which is located near the KE Reactor. The previous discussion of well 199-K-109A suggests that past-practices disposal sites received radiologically contaminated fuel-storage basin water and are the most likely sources of the two hot spots shown in Figure 6.4-6. Both KW and KE basins disposed of wastewater in the identical way and in the same relative locations. As previously noted, however, KW basin water was not as contaminated as the water in KE basin that received numerous fuel slugs with defective cladding. In later years, the irradiated fuel stored in KW basin was encapsulated. The fuel stored in the KE basin will be encapsulated as part of the stabilization and dry storage-transfer operation.

The soil column in the vicinity of the wells that monitor the KW and KE basins is very likely to contain radionuclides from past operations because of lateral spreading from the associated drain fields. When moisture in amounts greater than normal is added to the soil column, stored radionuclides such as strontium-90 may be remobilized downward, especially if the contaminants are near the well casing.

Mechanisms to increase moisture in the soil column include unusually high precipitation events, ponding of runoff from roads and buildings, and leakage of underground water lines—all of which may be implicated in accelerating the downward movement of radionuclides to groundwater (Johnson and Evelo 1995).

The soil column directly beneath the KE basin construction joint is also a potentially significant source. Previous estimates (Johnson et al. 1995) suggest that the inventory of strontium-90 beneath the basin could be several hundred curies, some of which could theoretically have reached the groundwater. However, the absence of strontium-90 in well 199-K-27, located immediately downgradient of the construction joint leak location, suggests that either breakthrough to the groundwater from this source has not yet occurred or that it has not yet arrived at this well location (the unknown status of soil-column contamination beneath the basin as well as other considerations led to the decision to decommission this facility).

6.4.3.6 Gross Alpha and Gross Beta Indicators

In accordance with the monitoring plan for the fuel-storage basins (Johnson et al. 1995), gross alpha and gross beta are sampled quarterly in the upgradient and downgradient wells. The data quality objective-based plan specifies that if statistically significant increases in gross beta or gross alpha occur, followup isotopic analyses will be performed. Use of gross count data to track changes resulted in an analytical cost savings by reducing the number of more-expensive isotopic analyses. With the exception of tritium, the gross alpha and gross beta measurements can detect the principal constituents of concern (see Table 6.4-1). Gross alpha concentrations in downgradient wells are similar to the upgradient wells for both fuel-storage basins (Table 6.4-2). Thus, as of October 1996, there is no indication that plutonium and americium migrated through the soil column beneath either the basin or past-practices disposal site.

In contrast to gross alpha, gross beta concentrations in downgradient well 199-K-109A greatly exceed the upgradient background well (199-K-110A) at the KE basin. Gross beta concentrations in downgradient wells at the KW basin also exceed the upgradient background concentrations. In both cases, these exceedances are due to strontium-90 (Johnson and Chou 1995) and are attributed to the past-practices drain field/injection well disposal system that received basin water overflow and subbasin seepage. The slightly elevated gross beta in well 199-K-27 was previously shown to be antimony-125 (a beta-gamma emitter) that has been consistently declining since 1983 (Johnson 1993b; Johnson and Chou 1995). The statistical test (see Table 6.4-2) shows the gross beta background 95/95 upper tolerance limit was slightly exceeded but was less than the DWSs and is attributed to residual antimony-125. Downgradient monitoring wells at the KW basin also show exceedance of the background (upgradient) 95/95 upper tolerance limit for gross beta (see Table 6.4-2) and, as previously indicated, is attributed to strontium-90 from past-practices disposal sites.

6.4.3.7 Nitrate

The distribution of nitrate in 100-K Area groundwater is shown in Plate 4. Two areas contain nitrate in concentrations that exceed the 45,000-μg/L MCL. The first appears to extend from the

vicinity of the KW Reactor building toward the river. The second area is more difficult to define by existing well coverage but appears to be associated with waste sites near the KE Reactor building and, possibly, the 116-K-2 liquid waste-disposal trench. Well-defined sources for nitrate plumes are not readily apparent.

6.4.3.8 Trichloroethylene

During FY 1996, trichloroethylene was detected at concentrations above the 5-μg/L MCL in two out of the six wells sampled for trichloroethylene in the 100-K Area (Figure 6.4-10). These two wells are located near the KW Reactor building and the 116-KW-3 water-retention basins. The maximum trichloroethylene concentration detected in FY 1996 was 27 μg/L in well 199-K-106A, located near the northeast corner of the KW Reactor building. Near the water-retention basins, a concentration of 12 μg/L was detected in well 199-K-33. These concentrations are less than those from each respective well in 1995. Of the four remaining wells sampled yielding concentrations below the MCL, two of the samples analyzed were nondetections.

6.4.4 Groundwater Remediation Activities

As a result of the CERCLA limited field investigation activities for the 100-KR-4 Operable Unit (DOE 1994c), hexavalent chromium was identified as presenting a relatively high risk to ecological receptors such as the early life stages of fall chinook salmon. An interim remedial measure was initiated that is intended to intercept the chromium plume near the Columbia River (DOE 1996c). The target plume is associated with past liquid waste disposal to the 116-K-2 liquid waste-disposal trench.

A description of activities associated with the interim remedial measure is presented in a remedial design/remedial action work plan (DOE 1996c). Groundwater containing chromium will be pumped from extraction wells located between the trench and the river shoreline. The groundwater will pass through an ion-exchange treatment system that removes chromium. The treated effluent will be injected back into the aquifer at locations upgradient of the extraction well network.

The extraction well network consists of six wells expected to produce 95 L/min each, with an average chromium concentration estimated at 114 μg/L. The ion-exchange treatment system is being designed as two modular units, each of which is capable of processing 379 L/min. The treated effluent injection well network consists of four wells located upgradient and to the south of the trench. The extraction and injection wells are shown in Plate 1. The pump-and-treat system is scheduled to begin operating in October 1997.

6.4.5 Compliance Status

The FY 1996 groundwater-monitoring results for the 100-K Area suggest that some improvement in groundwater quality is occurring as a result of corrective actions associated with the fuel-storage basin operations. Decommissioning of the basins and removal of water from the basins by the year 2000 should eliminate this source of groundwater contamination. However, in the area near the north-west corner of the KE Reactor building, erratic but increasing strontium-90 concentrations occur that

are over 1,000 times the DWS. The occurrence appears to be very localized, but the lack of additional wells in the downgradient area preclude a determination of the lateral extent. The possible cause is under investigation, and guard wells are being sampled monthly to track or follow changing conditions. Strontium-90 is the only constituent in the 100-K Area detected at levels above the DCG in FY 1996.

While tritium, nitrate, strontium-90, carbon-14, and chromium in the 100-K Area groundwater exceed the DWS, only chromium was identified as an immediate concern to potential ecological receptors in the river or riparian zone (shoreline springs and discharge zones of groundwater to the streambed). The sources of the other constituents that exceed the DWS will be addressed in connection with environmental restoration at the 100-KR-1 and 100-KR-2 Operable Units. Near-term actions by the Project Hanford Management Contractor include an evaluation of surfacewater controls and the integrity of water lines, especially in areas that could cause infiltration over past-practices waste sites.

The record of decision (ROD 1996a) for addressing chromium in the 100-KR-4 Operable Unit indicates that the interim remedial measure is intended to be protective of aquatic receptors that use the riverbed substrate (e.g., fall chinook salmon). The EPA's ambient water quality criteria for protection of freshwater aquatic organisms is 11 μg/L of hexavalent chromium (EPA 1986c). Because of the logistical difficulty in monitoring chromium concentrations at the point of exposure for aquatic organisms, the EPA indicated that onshore monitoring may be an acceptable substitute (ROD 1996a).

For samples collected from the aquifer near the river's high-water line, a dilution factor of 1:1 is being assumed as reasonable for estimating receptor-location concentrations. Therefore, the record of decision (ROD 1996a) indicates that concentrations of <22 μg/L hexavalent chromium observed at near-river compliance-monitoring locations would be protective of aquatic organisms in the riverbed substrate. It is expected that a period of time will pass after startup of the extraction system before concentration changes appear in the downgradient compliance-monitoring wells.

Water samples from wells are being obtained prior to startup of the system to establish a baseline against which data from the operating period can be compared (Borghese et al. 1996a). Data will be interpreted to evaluate the performance of the extraction system in controlling the movement of groundwater and in removing chromium from the aquifer. Data from monitoring wells specifically designed to demonstrate compliance with regulatory requirements will also be obtained prior to and during operations. These data will be compared to the 22-μg/L preliminary value that is proposed as protective of aquatic organisms. During the course of the interim remedial measure, data from system monitoring and concurrent characterization in the operable unit will become available to define compliance requirements that are reasonable for a final remedy record of decision.

6.5 100-N Area

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The 100-N Area, situated in the northern part of the Hanford Site adjacent to the Columbia River, is ~ 4 km^2 in size. The 100-N Area includes the N Reactor, the Hanford Generating Plant, a

Bonneville Power Administration Substation, and various support facilities such as water-treatment buildings, administrative office buildings, laboratories, maintenance buildings, waste-treatment facilities, and waste-disposal facilities.

6.5.1 Operable Units

The 100-N Area is divided into two operable units. The 100-NR-1 Operable Unit, a source operable unit, includes the liquid- and sludge-disposal sites generally associated with operation of N Reactor and includes the RCRA 1301-N, 1324-N, 1324-NA, and 1325-N liquid waste-disposal facilities. 100-NR-2 is a groundwater operable unit and includes the groundwater beneath the 100-NR-1 source operable unit, plus the adjacent groundwater, surfacewater, and sediments affected by 100-N Area operations.

6.5.2 Facilities

The N Reactor, the newest of the Hanford Site production reactors, is a graphite-moderated, light-water-cooled reactor. Constructed in 1963, the reactor was designed for plutonium production with steam production as a byproduct. The byproduct steam was used to produce 860 MW of electrical energy in the adjacent Hanford Generating Plant.

Periodically, the primary cooling systems of the reactor were cleaned and decontaminated. Decontamination solution and rinsate from these activities were transferred to a storage tank. As the tank neared full capacity, the decontamination solution and some of the rinsate were transferred to railcars and shipped to the tank farms in the 200 Areas. The remaining rinsate was diverted to the 1301-N or 1325-N liquid waste-disposal facilities.

Diesel fuel was stored in aboveground tanks at a few locations within the 100-N Area. Two storage areas that have been associated with leaks and spills are the 166-N diesel tank farm and the 184-N day tank storage area. The diesel tank farm was constructed in a large excavated area with an earthen-bermed containment pit. The day tank storage area was surrounded by a concrete wall for containment of spills. Spills and pipeline leaks released petroleum products to the soil in the area.

Also included in the 100-N Area is a Bonneville Power Administration electrical substation and a former military site. Unplanned releases of polychlorinated biphenyl-contaminated oils have been reported in operations documents for the substation. The military site included several facilities that housed military personnel and equipment (e.g., radar). This site includes sewage and solid waste-disposal areas.

Four RCRA units are located in the 100-N Area: 1) 1301-N liquid waste-disposal facility, 2) 1324-N surface impoundment, 3) 1324-NA percolation pond, and 4) 1325-N liquid waste-disposal facility (see Plate 1).

The 1301-N facility was the primary liquid waste-disposal facility for N Reactor from 1963 until 1985. Discharges to this facility were primarily radioactive fission and activation products. Minor

amounts of dangerous waste also were discharged, including hydrazine, ammonium hydroxide, diethylthiourea, sodium dichromate, morpholine, phosphoric acid, lead, and cadmium. The 1301-N facility consists of a concrete basin with an unlined, zig-zagging extension trench, covered with concrete panels.

The 1325-N facility was constructed in 1983, and N Reactor effluent was discharged to it and to the 1301-N facility. In 1985, discharge to 1301-N ceased, and all effluent was sent to 1325-N. All discharge to 1325-N ceased in late 1991. The facility consists of a concrete basin with an unlined extension trench, covered with concrete panels.

The 1324-N impoundment was a treatment facility that was in service from May 1986 to November 1988. This facility is a double-lined pond that was used to neutralize high- and low-pH waste from a demineralization plant. The 1324-NA pond is an unlined pond that was used to treat waste from August 1977 to May 1986 and to dispose treated waste from May 1986 to August 1990. The effluent to both facilities contained sulfuric acid and sodium hydroxide, whose pH was occasionally high or low enough to be classified as a dangerous waste.

6.5.3 Extent of Contamination

The most notable groundwater contaminants in the 100-N Area are strontium-90 and tritium from liquid waste-disposal facilities. Nondangerous, nonradioactive contaminants such as sulfate and sodium are also present from a separate disposal facility. Nitrate is elevated in several wells scattered across the area.

6.5.3.1 1301-N and 1325-N Liquid Waste-Disposal Facilities

The maximum strontium-90 value of 19,100 pCi/L for the year was observed in well 199-N-99A in May 1996. The highest concentration downgradient of the 1325-N facility but upgradient of the 1301-N facility was 662 pCi/L, observed in well 199-N-81 in March 1996. The maximum average annual strontium-90 concentration found in the 100-N Area in FY 1996 was 12,000 pCi/L in well 199-N-67 (Figure 6.5-1). The strontium-90 plume, as depicted by the 8-pCi/L isopleth in Figure 6.5-1, extends areally ~600 m along the Columbia River shoreline and ~1,000 m inland and covers ~0.7 km^2. The plume configuration indicates that strontium-90 in groundwater is flowing toward the river at concentrations above the 8-pCi/L interim DWS. Strontium-90 contamination at levels above the 1,000-pCi/L DCG is found in wells downgradient of the 1301-N facility.

High-river stage in the winter, spring, and summer of FY 1996 raised the water table at the 100-N Area. This water-level rise in the unconfined aquifer saturated areas that have strontium-90 adsorbed to the sediments. Because strontium-90 on the sediments comes into equilibrium with the surrounding groundwater relatively quickly (2 to 10 days) (Serne and LeGore 1996), the concentration in the groundwater increased at certain locations. Concentrations in some wells increased by an order of magnitude. The trend plot for well 199-N-67 shows an example of the increase and the decline in strontium-90 concentration (Figure 6.5-2). Strontium-90 concentrations in well 199-N-14 located near the northeastern edge of the plume remained below the DCG in FY 1996, as it did in 1995 (Figure 6.5-3).

The concentrations in this well dropped after the well was cleaned and the casing replaced.. The high-river stage in FY 1996 influenced the concentrations of strontium-90 detected in the monitoring wells and the average values shown on the contour map are not representative of what would be expected in a year of more normal river stage.

Tritium. The tritium plume at the 100-N Area is shown in Plate 3. The maximum average concentration detected in FY 1996 was 57,000 pCi/L in well 199-N-32, downgradient of the 1325-N trench. The principal sources of tritium contamination were the 1301-N and 1325-N facilities.

The tritium isopleth of 20,000 pCi/L extends ~600 m along the Columbia River shoreline and at least ~1,500 m inland (see Plate 3). The areal extent of the plume is similar to that of strontium-90. Tritium contamination forms part of the water molecule; thus, it moves at the same rate as the groundwater. The configuration of the tritium plume changed significantly over the past few years. The center of the plume moved from a location near the 1325-N facility to between the 1301-N and 1325-N facilities. Tritium contamination at levels greater than the 20,000-pCi/L interim DWS found in well 699-87-55 located east of the 100-N Area and south of the 100-D Area potentially is related to past disposal in the 100-N Area. Tritium at levels less than the interim DWS is detectable throughout the area between the 100-N and 100-H Areas (see Plate 3).

Cobalt-60. Cobalt-60 was detected at levels above the interim DWS in one well (199-N-33) in the 100-N Area in FY 1996. The concentration in an unfiltered sample from this well was 648 pCi/L. However, the concentration in a filtered sample collected at the same time was only 5.54 pCi/L, which indicates that most of the cobalt-60 is sorbed to particulate matter and, thus, is not representative of groundwater quality. The turbidity in this well when the sample was collected was high (183 nephelometric units), indicating excessive particulate matter in the unfiltered sample.

RCRA Indicator Parameters. The RCRA indicator parameters at the 1301-N and 1325-N facilities are specific conductance, pH, total organic carbon (TOC), and total organic halogen (TOX) (40 CFR 265.92[b][3]). Specific conductance of ambient groundwater near the 1301-N facility is relatively low (200 to 300 μS/cm) compared to typical site groundwater because of the lower conductivity of the demineralized water discharged from reactor operations. Upgradient well 199-N-57 and downgradient well 199-N-3 show elevated specific conductance (700 to 900 μS/cm; Figure 6.5-4). The position of these wells and the chemical composition of the water indicate that the source of the elevated specific conductance is the 1324-N/NA facilities (Hartman 1992b).

Specific conductance near the 1325-N facility was ~300 to 400 μS/cm during the past year (Figure 6.5-5). When the 1325-N facility was in use, specific conductance of groundwater was lower because of artificial recharge with low-conductivity water. After discharge to the facility ceased, specific conductance of groundwater gradually increased. Specific conductance in the upgradient well (199-N-74) was elevated in the past, possibly because of the upgradient influence of the 1324-NA percolation pond.

Groundwater pH beneath the 1301-N and 1325-N facilities averaged between 7.5 and 8.5 in the past year. There are no clear upward or downward trends and no significant differences between

upgradient and downgradient wells. TOX was not detected in most monitoring wells. Detections up to 12 μg/L were observed in wells 199-N-3, 199-N-74, and 199-N-27 but these were single sampling events.

Groundwater at 1301-N and 1325-N is also analyzed for other constituents that were discharged to these facilities during their use (see Section 6.5.2). These analytes include nitrate, chromium, phosphate, lead, and cadmium. Phosphate, lead, and cadmium (in filtered samples) were not detected in 1301-N or 1325-N groundwater in significant concentrations. Nitrate is sporadically detected, as discussed in Section 6.5.3.3, but the sources are uncertain.

Chromium. Well 199-N-33, downgradient of 1325-N, had unusually high chromium concentrations in September 1996 (430 μg/L filtered; 550 μg/L unfiltered). These were the first chromium data in several years for this well. From 1988 to 1992, filtered chromium concentrations in well 199-N-33 were between 10 and 20 μg/L. The high values this year are considered anomalies. Well 199-N-80, completed deeper in the unconfined aquifer system in a sand layer within the Ringold Upper Mud unit, typically shows levels of chromium greater than the MCL. In the filtered sample from FY 1996, the chromium concentration was 178 μg/L, similar to levels reported in 1995.

6.5.3.2 1324-N/NA Liquid Waste-Disposal Facilities

Groundwater beneath 1324-N/NA is characterized by high specific conductance (>1,000 μS/cm), primarily because of high levels of nondangerous constituents such as sulfate and sodium (Figure 6.5-6). The distribution of sulfate is illustrated in Figure 6.5-7. The sulfate concentrations exceed the secondary DWS (250 mg/L) in a plume that extends from the 1324-N/NA site toward the north to the Columbia River.

The RCRA indicator parameters at 1324-N/NA are specific conductance, pH, TOC, and TOX (40 CFR 265.92[b][3]). The pH in 1324-N/NA wells generally was between 8.0 and 8.3 during the past year. TOC concentrations were <500 μg/L, except for a single value of 1,070 μg/L in well 199-N-59 in March 1996.

TOX was slightly elevated in some of the 1324-N/NA downgradient wells in 1992 and 1993 but subsequently decreased. There was no significant difference between TOX in upgradient and downgradient wells during FY 1996 (Figure 6.5-8). A final RCRA assessment report concluded that chloroform caused the elevated TOX (Hartman 1996b). A french drain used to dispose nondangerous chlorinated water is located near the 1324-NA pond and is believed to be the cause of the chloroform (i.e., chlorine interacting with organic material).

6.5.3.3 Other Groundwater Contamination

Nitrate continues to be elevated in scattered monitoring wells throughout the 100-N Area (see Plate 4). Some of the nitrate concentrations exceed the 45,000-μg/L DWS (Figure 6.5-9). Well 199-N-26 is located near the N Reactor building, well 199-N-3 monitors the 1301-N facility, and well 199-N-32 monitors the 1325-N facility. The sources of nitrate are unknown. Elevated nitrate concentrations

were noted in several wells located near the Columbia River, approximately downgradient of the 1324-N/NA facilities. The maximum concentration was found in well 199-N-19, which contained 220 mg/L of nitrate in the FY 1996 sample; however, this may represent an analytical error.

Total petroleum hydrocarbons were identified as a floating product in wells 199-N-17 and 199-N-18, located downgradient of a tank farm, and in high concentrations in well 199-N-16 located near the diesel day tanks. The amount of product floating in wells varies with water level.

6.5.4 N Springs Pump-and-Treat Facility

The State of Washington Department of Ecology (Ecology) and the EPA issued an action memorandum in September 1994 (Ecology and EPA 1994), directing DOE to install a pump-and-treat system combined with a removable vertical barrier. Subsequently, in December 1996, the action memorandum and the directives given to DOE were revised. In particular, the capacity of the pump-and-treat system was increased and the removable barrier wall was eliminated.

The pump-and-treat system was installed and, in the fall of 1996 was being upgraded to meet the requirements of the revised action memorandum (Ecology and EPA 1994). The upgraded pump-and-treat system consists of four groundwater extraction wells, a 227-L/min treatment system, and three injection wells (wells are shown on Plate 1).

The performance goals for the pump-and-treat system are to reduce strontium-90 contamination flux from the groundwater to the Columbia River and to provide data necessary to set demonstrable strontium-90 groundwater-cleanup standards.

The Tri-Party Agreement required DOE to submit a report to Ecology and EPA that evaluated the pump-and-treat facility for effectiveness and efficiency and to provide recommendations for continued operations. DOE (1996d) provides the necessary information to meet the requirement. The report concluded that the pump-and-treat system met the performance requirements and successfully reduced the strontium-90 flux to the Columbia River. Recommendations made in the report are reflected in the directions provided in the revised action memorandum. The reduction in flux to the river was determined with a real-time water-level-monitoring network and modeled flow conditions. An estimated flux reduction by $>70\%$ was achieved. The pump-and-treat system ion-exchange efficiency was very high. During September 1995 to September 1996, the efficiency was $>98\%$. The report also discussed the difficulty in removing strontium-90 from the aquifer sediments. It is estimated that 0.1 Ci of strontium-90 will be removed on an annual basis with the existing system. Calculations indicate that the majority of the remaining strontium-90 inventory is fixed in the vadose zone rather than in the aquifer (1,800 Ci versus 75.5 to 88 Ci). Of the strontium-90 in the aquifer, only ~ 0.5 Ci is dissolved in the groundwater, with the rest sorbed on the sediments (DOE 1995a).

General operating requirements are defined in the revised action memorandum and in Frain and Jackson (1994). Continuous operation of the pump-and-treat system began in September 1995; an operational lifetime of up to 10 years is expected. The upgraded system operates as follows.

- Four extraction wells are available to supply contaminated groundwater to the treatment system. The standard operating configuration uses three wells with the fourth in standby to provide backup for maintaining the 227-L/min operating capacity.

- Four in-series ion-exchange columns make up the treatment system. Contaminated groundwater is processed through the system at a nominal rate of 227 L/min and is discharged to the injection wells.

- Two upgradient wells are available for injecting processed water back into the aquifer. A third injection well is also available upgradient and provides backup.

- Maintenance of the pump-and-treat system involves periodic removal and replacement of the ion-exchange media, component repair and replacement, and general upkeep of the site.

6.5.5 Compliance Issues

6.5.5.1 RCRA Requirements

Statistical evaluations are required by RCRA to determine whether the 1301-N, 1325-N, or 1324-N/NA facilities adversely affected groundwater quality. Indicator parameter data from upgradient wells were statistically evaluated as required by 40 CFR 265.93(b) and WAC 173-303-400. Indicator parameters from downgradient wells were compared to values established from the upgradient well (see Appendix B). Specific conductance, pH, TOC, and TOX in downgradient wells remained below the comparison values at 1301-N and 1325-N.

The 1324-N/NA facilities reverted to indicator evaluation monitoring in May 1996, and statistical comparisons were performed on data from the September 1996 sampling event. TOC, TOX, and pH were below comparison values. Specific conductance in downgradient wells was above the comparison value. This was expected because the 1324-NA percolation pond introduced nondangerous constituents (e.g., sulfate, sodium) to groundwater. Concentrations of these constituents and specific conductance are continuing previous trends, so no additional groundwater assessment is warranted.

The RCRA indicator evaluation monitoring networks and constituent lists for 1301-N and 1325-N were modified during the past year in coordination with CERCLA, sitewide surveillance, and other monitoring projects (Borghese et al. 1996b). Because of the effects of groundwater extraction, treatment, and injection near these facilities, it may not be possible to meet the RCRA objectives fully (i.e., immediate detection of the units' impacts on groundwater) (Hartman 1996c). However, the new networks meet RCRA requirements for upgradient and downgradient wells and were approved by Ecology (DOE and Ecology 1992). There are no plans to change the networks in the coming year.

The RCRA monitoring program for 1324-N/NA was modified when it reverted to an indicator evaluation program in FY 1996. The new program is adequate to detect the impact of the facility on groundwater and was approved by Ecology (DOE and Ecology 1996). There are no plans to change the network in the coming year.

Closure plans are being prepared for the 1324-N/NA and 1301/1325-N facilities. 1324-N/NA are scheduled to be incorporated in the Hanford Site RCRA Permit in 1998. 1301-N and 1325-N are scheduled to be incorporated into the Hanford Site RCRA Permit in 1999.

6.5.5.2 CERCLA Compliance

The CERCLA groundwater-monitoring activities are controlled by Tri-Party Agreement (Ecology et al. 1989) change-control procedures. Prior to September 1996, 100-NR-2 Operable Unit monitoring was conducted under a change control dated September 23, 1992. A reduction of this monitoring program based on the consolidation of groundwater programs in the 100-N Area was agreed to in a change control dated October 9, 1996.

6.5.5.3 Drinking Water Standards and Derived Concentration Guides

As discussed above, strontium-90, tritium, nitrate, and chromium were detected at levels above their DWSs. Sulfate was detected at levels above the secondary MCL. Strontium-90 continues to be the only constituent in the 100-N Area detected at levels above the DCG.

6.6 100-D/DR Area

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The 100-D/DR Area is located along the Columbia River in the northern portion of the Hanford Site and contains D Reactor, which operated from 1944 to 1967, and DR Reactor, which operated from 1950 to 1964. A comprehensive summary of operations and detailed descriptions of facilities and wastes sites are presented in Carpenter (1993), from which the following facility/waste site descriptions are taken, unless otherwise cited.

The deactivated reactor buildings remain standing, along with miscellaneous other facilities that are in various stages of decontamination and decommissioning under the Environmental Restoration Program. Some components of the original coolant water makeup facilities are currently in use as a backup for other Hanford Site water supplies.. A pilot-scale test of a pump-and-treatment system to remove chromium from groundwater was conducted between August 1994 and August 1996 (DOE 1995l). An interim remedial measure to address chromium in groundwater near the river by pump-and-treatment technology is scheduled to start operations in July 1997 (DOE 1996c).

6.6.1 Operable Units

For CERCLA environmental restoration activities, the 100-D/DR Area is divided into two source operable units: 100-DR-1 and 100-DR-2; both contain hazardous waste sites at or near the surface. A groundwater operable unit, 100-HR-3, encompasses the 100-D/DR and 100-H Areas and the intervening 600 Area. For the 100 Areas, the lateral boundary of groundwater operable units is generally considered to be where Hanford Site groundwater meets Columbia River water. This interface occurs along the riverbanks and within the riverbed substrate.

High-priority waste sites in the 100-DR-1 Operable Unit include reactor coolant-retention basins, liquid waste-disposal trenches, and associated effluent pipelines. High-priority sites in the 100-DR-2 Operable Unit include liquid waste-disposal sites near the reactor buildings, various spill/leakage sites, and solid waste-burial grounds. Descriptions of high-priority waste sites are presented in the proposed plans for source remediation activities in each of these operable units (DOE 1995m, 1995n).

6.6.2 Facilities

This section describes facilities within the 100-D/DR Area. One section describes a treatment, storage, disposal facility regulated by RCRA; a second describes facilities associated with former reactor operations that involved liquid effluents and spills/leakage of hazardous materials being remediated under CERCLA.

6.6.2.1 120-D-1 Ponds

These ponds were constructed in 1977 for disposal of nonradioactive effluent derived from 100-D/DR operating facilities. The ponds are located in the former 188-D ash-disposal basin and include a settling pond and a percolation pond separated by a dike (Figure 6.6-1).

Effluent to the ponds originated from two sources: the 183-D filter plant and the 189-D building engineering testing laboratories. Some past discharges contained hydrochloric acid, sulfuric acid, and sodium hydroxide. Before 1986, the effluent may have had a >12.5 or <2.0 pH and, thus, may have been dangerous waste. There was also a potential for up to 2.3 kg of mercury to have been discharged to the ponds (DOE 1993b). Effluent discharge ceased in 1994. Between 1986 and 1994, the effluent included chlorine and flocculating agents such as aluminum sulfate.

In August 1996, sediment was removed from the bottom of the settling pond. The sediment was contaminated with several metals, polychlorinated biphenyls, and very low levels of radioactivity. Contaminant levels were below dangerous waste levels, so the sediment was not designated as dangerous or mixed waste. After the sediment was removed, the bottoms of both ponds were sampled to verify that all contamination had been removed. Initial results indicated that no contamination was present.

6.6.2.2 Other Facilities

The following summaries describe principal past-practices waste sites that may have contributed to groundwater contamination. They draw heavily on information presented in Carpenter (1993) and on summaries of contaminant sources that are described in conceptual site models for groundwater (Peterson et al. 1996). Additional details on reactor operations and waste-disposal facilities are provided in those reports.

- The 116-D-7 and 116-DR-9 retention basins are located in the northern part of the 100-D/DR Area. They received enormous volumes of reactor-coolant effluent that contained radionuclides and chromium. They held the effluent for a short time to allow thermal cooling

and radionuclide decay prior to discharging the effluent to the Columbia River via outfall pipes. The basins developed significant leaks, creating a mound on the underlying water table. Mounding enhanced the spread of contamination over a broad area that potentially exceeded the reactor area boundaries.

- The 116-D-1 and 116-DR-2 liquid waste-disposal trenches received highly radioactive coolant effluent that resulted when a reactor fuel element failed. The effluent would be held briefly in the retention basins and then diverted to the nearby trenches instead of the normal discharge via river-outfall pipes. The trenches were unlined and intended as soil-column-disposal sites.

- Relatively small soil-column-disposal facilities such as cribs and french drains were located near the reactor buildings. Contaminated water and sludges from fuel-storage basins at each reactor were disposed to trenches and percolation ponds. Decontamination solutions, consisting of various acid solutions that picked up radionuclides and metals were also disposed to the ground near the reactors. Condensate from the inert gas system that was part of the reactor contributed tritium and carbon-14 to the soil column, and possibly groundwater, via french drains.

- Sodium dichromate, which was added to coolant water as a corrosion inhibitor, was typically transferred from railcars to storage tanks and then piped to the facilities where it was added to coolant water. Leakage and spillage of stock solution occurred at storage tanks located on the north side of the D Reactor building and from piping that transferred the materials to the 190-D building located immediately west of the reactor. During the later period of operations, a sodium dichromate transfer station was established ~300 m west of D and DR Reactors. Significant spillage of sodium dichromate solution and washdown waste is assumed to have occurred at this location.

6.6.3 Extent of Contamination

Contamination of groundwater occurred as the result of liquid effluent disposal associated with past reactor operations. Most of the waste-site sources for this contamination ceased operating by the late 1960s. A significant proportion of contamination carried by groundwater was either discharged into the Columbia River or dispersed over the broad region between the 100-D/DR and 100-H Areas that is referred to as the horn of the Columbia River. Peterson et al. (1996) described a conceptual model of the groundwater contamination in the 100-D/DR Area.

The predominant contaminants in 100-D/DR Area groundwater are chromium, nitrate, tritium, and strontium-90. The distribution of contamination was influenced by numerous factors, including the time period since liquid waste-disposal operations ceased, locations of waste sites, stratigraphy of the contaminated aquifer, and changes in the configuration of the water table. The 120-D-1 ponds are monitored under specific requirements for RCRA indicator monitoring. The results of that monitoring are discussed at the end of this section.

6.6.3.1 Chromium

Chromium is the predominant contaminant of concern tracked as part of the remedial investigation of 100-D/DR Area groundwater. Chromium is widely distributed because of multiple source facilities and spill locations and also because it was in the reactor-coolant effluent that formed large mounds on the water table. These mounds directed groundwater flow in all directions, including against the natural groundwater-flow direction. Some of the contaminated groundwater moved inland to the north and east, ultimately reaching the 100-H Area and region to the north of 100-H Area (Brown 1963).

Figure 6.6-2 shows average chromium concentrations in filtered groundwater samples during FY 1996. The concentration data are representative of conditions near the water table (i.e., the uppermost hydrogeologic unit). Process knowledge, high solubilities, and past characterization activities show that these results represent hexavalent chromium, which is readily transported by groundwater flow, and is toxic to aquatic organisms.

Potential sources of chromium contamination are located near the D Reactor building and coolant water makeup facility (demolished in early FY 1996). The dashed 1,000-μg/L contour shown in Figure 6.6-2 is based on past data from wells not sampled in FY 1996. The plume formed when sodium dichromate stock solution leaked during transfer and/or storage operations during the reactor-operating period. This contaminated the soil column and underlying groundwater. The plume moved north-northeast and currently intersects the river channel. The dramatic decrease in concentrations in near-river wells during the winter of 1995/1996 may be the result of unusually high river stage. Trend plots for chromium in two wells located near the major suspected source of the plume are shown in Figure 6.6-3 and for two wells located near the river in Figure 6.6-4.

Chromium contamination along the western boundary of the 100-D Area is less well-defined because of limited coverage by monitoring wells. Contamination in this area was hinted at by data from well 199-D2-6 and its presence was firmly established by samples from riverbed sediment pore water and from aquifer-sampling tubes at the river shoreline (Hope and Peterson 1996). The potential sources for this chromium contamination are believed to be the same as for the plume described above. Numerical simulation of flow patterns using the water-table configuration that existed during various reactor-operating and postoperating times is the basis for this hypothesis (Peterson et al. 1996). A new monitoring well (199-D4-1) was installed in October 1996 to provide additional information on this plume (Johnson et al. 1996).

Chromium concentration data were collected from riverbed sediment pore water at ~100 sites along the 100-D/DR Area shoreline during October/November 1995 (Hope and Peterson 1996). Pore water was obtained from sampling tubes driven into the sediment to a depth of ~45 cm. The purpose for the sampling project was to obtain field measurements of chromium concentrations in spawning habitat, where salmon eggs and developing juvenile fish are potentially exposed. The pore-water results are shown in Figure 6.6-5. In general, the appearance of chromium in pore-water samples correlates with the locations of plumes revealed by data from monitoring wells.

A second aspect of the pore-water-sampling project involved driving a temporary steel casing into the aquifer at sites along the river shoreline where pore-water results revealed the presence of chromium. The purpose of the sampling tubes was to measure chromium concentrations at various depths in the aquifer near the river channel. Plastic sampling tubes, which have 15-cm screened openings at their end, were inserted into the casing. The casing was backpulled, allowing the sediments to collapse around the tubing. Multiple tubes were installed within each casing, with the screened opening at various depths. The results from the sampling tubes are shown in Figure 6.6-6. Note that the uppermost sample ports typically show lower chromium concentrations than deeper ports, suggesting that the shallow port is influenced by riverwater mixing in bank storage.

6.6.3.2 Strontium-90

This radionuclide is a common constituent of liquid waste effluent from reactor operations in the 100 Areas. A principal source is the fuel-storage basin located within each reactor building. The basin water often became contaminated with radionuclides from damaged fuel rods, and radioactive sludge accumulated on the basin floor. Contaminated basin water and sludge were disposed to the soil column via tile fields and trenches located near the reactor buildings. A second source for strontium-90 is the 116-DR-1 and 116-DR-2 liquid waste-disposal trenches that received reactor effluent following the failure of a fuel element.

Although the soil column at various locations in the 100-D/DR Area undoubtedly contains strontium-90 from past activities, groundwater does not show extensive contamination. A single well (199-D5-12) located near the fuel-storage basin trench near D Reactor shows a relatively constant concentration of ~40 pCi/L for the past 4 years. Strontium-90 is also detected at concentrations below the 8-pCi/L DWS in several wells located immediately downgradient of the retention basins and nearby trenches.

6.6.3.3 Tritium and Nitrate

These two waste constituents are common in all reactor areas. Tritium sources include past disposal of fuel-storage basin water and gas condensate from reactor atmosphere gases to facilities near the reactor buildings. A predominant source for nitrate is past disposal of nitric acid decontamination solutions to soil-column facilities located near the reactor buildings.

The distributions of tritium and nitrate in the 100-D/DR Area are shown in Plates 3 and 5. The DWS for nitrate (45,000 μg/L) is exceeded near the reactor buildings and downgradient from the 116-DR-9 retention basin. Tritium contamination at levels greater than the interim DWS is localized around the reactor buildings.

6.6.3.4 120-D-1 Ponds RCRA Monitoring

Effluent discharge to these ponds appears to have diluted the ambient groundwater. Groundwater chemistry in the vicinity is characterized by low concentrations of metals, anions, and no detectable radionuclides.

The RCRA indicator parameters for the ponds are pH, specific conductance, TOC, and TOX (40 CFR 265.92[b][3]). During the past year, TOC was below the contractually required quantitation limit in all wells except upgradient well 199-D5-13 (1,063 μg/L in May 1996). Also, TOX was below the quantitation limit in the downgradient wells, and ranged from less than detection to 16.4 μg/L in upgradient well 199-D5-13. Specific conductance is low in wells 199-D8-4 and 199-D8-6, which are nearest the ponds (Figure 6.6-7). This is probably due to dilution by artificial recharge from the ponds.

The dilution effect appears to have influenced groundwater chemistry even in upgradient well 199-D5-13. After discharges to the pond ceased in 1994, higher-conductivity groundwater from upgradient sources flowed past the well and specific conductance increased. The rate of increase slowed in 1995 and FY 1996 (see Figure 6.6-7). Other constituents (e.g., nitrate) also increased in well 199-D5-13 (Figure 6.6-8).

Groundwater pH is higher in the wells immediately adjacent to the ponds than in the other wells (Figure 6.6-9). This effect was investigated by Alexander (1993). A RCRA assessment report updated the investigation (Hartman 1996d). Results are summarized below.

Effluent discharges to these ponds in the past tended to be slightly acidic (low pH). Sediments underlying the Hanford Site would tend to buffer the solution and make it slightly alkaline. More significantly, the presence of coal ash beneath the ponds would raise pH. Water reacts with periclase and lime in the ash, increasing pH (Figure 6.6-10).

Groundwater pH in wells 199-D8-4 and 199-D8-6 increased since 1994 (see Figure 6.6-9). This increase in pH followed the cessation of discharge to the ponds. When the ponds were in use, the residence time of infiltrating water in the vadose zone and aquifer beneath the ponds was short. After discharge ceased, the residence time of water in contact with hydroxide minerals in the vadose zone and in the aquifer increased. Chemical reactions have more time to approach equilibrium, which, in turn, increases the pH of pore fluid in contact with the hydroxide mineral phases. During the longer residence time, higher concentrations of hydroxide accumulate in residual soil moisture and drainage, and/or in aquifer pore fluid (Alexander 1993; Hartman 1996d).

Mercury is a dangerous waste constituent analyzed under RCRA because it was potentially discharged to these ponds (DOE 1993b). No mercury was detected in downgradient wells monitoring the ponds.

6.6.4 Groundwater Remediation Activities

Two groundwater remediation projects were implemented in the 100-D/DR Area under the Environmental Restoration Program. The first was a pilot-scale test of a pump-and-treat system to test methods to remove hexavalent chromium from groundwater, and the second was an interim remedial measure to intercept hexavalent chromium moving with groundwater into the Columbia River.

6.6.4.1 Pilot-Scale Treatability Test

The pilot-scale treatability test was conducted in the 100-D/DR Area to determine the effectiveness of using the pump-and-treat technology for removing hexavalent chromium from groundwater. The project was conducted under Tri-Party Agreement Milestone M-15-06E (Ecology et al. 1989). Operations began in August 1994 and continued through August 1996. Results for the project through December 1995 are presented in DOE (1995l), from which the following summary is taken.

An extraction well network was set up immediately downgradient of D Reactor building in an area of groundwater contamination believed to be caused by leakage/spillage of sodium dichromate solution. The wells included in the network exhibited the highest concentrations of chromium within the 100-HR-3 Operable Unit (trend charts for two of the extraction wells were shown in Figure 6.6-3). The extracted groundwater was treated using an ion-exchange column, and the treated effluent was reinjected into the aquifer at a location upgradient of the extraction network.

Although the primary objectives of the project were associated with system design and performance, a significant amount of chromium was removed from the aquifer. By November 1995, the system had removed 29.9 kg of hexavalent chromium, which amounts to between 9% and 14% of the total mass of chromium in the plume, as estimated by numerical simulation of the plume. Additional chromium was removed prior to shutting the system down in August 1996.

6.6.4.2 Interim Remedial Measure to Address Chromium Contamination

During the CERCLA limited field investigation phase, chromium was identified as a contaminant of potential concern (DOE 1994c). A subsequent focused feasibility study evaluated chromium as a contaminant of concern and recommended using pump-and-treat technology to intercept chromium plumes near the Columbia River (DOE 1995v). A decision was then made to proceed with an interim remedial measure to address chromium near the river, thereby reducing the potential threat to aquatic organisms from hexavalent chromium (ROD 1996a).

In the 100-D/DR Area, the interim remedial measure to being operation in FY 1997 includes a network of extraction wells located between the retention basins and the river (see Plate 1). The extracted groundwater will be piped to a treatment system being constructed in the 100-H Area. The effluent from the treatment system will then be returned to the aquifer via injection wells in the 100-H Area. Design characteristics of the extraction wells and treatment system, along with a description of performance monitoring that will be conducted to evaluate system effectiveness and efficiency, are described in DOE (1996c).

6.6.5 Compliance Issues

Compliance issues in the 100-D/DR Area involve RCRA regulations associated with the 120-D-1 ponds and CERCLA requirements contained within the record of decision (ROD 1995) for interim remedial measures.

6.6.5.1 RCRA Facility Compliance Issues

The RCRA regulations require statistical evaluations to determine whether the ponds adversely affected groundwater quality. Indicator parameter data from upgradient well 199-D5-13 were statistically evaluated as required by 40 CFR 265.93(b) and WAC 173-303-400. Indicator parameters from downgradient wells were compared to values established from the upgradient well (see Appendix B). Specific conductance, TOC, and TOX in downgradient wells remained below the comparison values.

Samples from wells 199-D8-4 and 199-D8-6 exceeded the comparison value for pH in February 1996. Verification sampling was conducted in March 1996 (40 CFR 265.93[c][2]). Results for well 199-D8-4 were below the comparison value but results for well 199-D8-6 were confirmed to be greater than the comparison value. Ecology was promptly notified of the exceedance as required by 40 CFR 265.93(d)(1).

A report describing the results of a groundwater quality assessment at the ponds was prepared and transmitted to Ecology in April 1996 (Hartman 1996d). The report concluded that the elevated pH originates from coal ash under the ponds and not from the ponds themselves (see Section 6.6.3.1). Therefore, the site remains in indicator evaluation monitoring.

Specific conductance increased significantly in upgradient well 199-D5-13 since comparison values were initially established. The well is sampled quarterly, and the data were evaluated to reestablish comparison values. Results are tabulated in Appendix B.

The monitoring network for the ponds is adequate to assess impacts on groundwater quality under RCRA interim status regulations. The pilot-scale pump-and-treat system does not appear to affect groundwater flow beneath the ponds. No changes are planned for the coming year. The adequacy of the network will be reevaluated after a new pump-and-treat system is activated in the summer of 1997.

The RCRA closure plan for the ponds is currently being revised, and the site is scheduled to be incorporated into the Hanford Site Permit in 1998.

6.6.5.2 CERCLA Record of Decision for Interim Remedial Measures

The record of decision (ROD 1996a) for addressing chromium in the 100-HR-3 and 100-KR-4 Operable Units indicates that the interim remedial measure is intended to be protective of aquatic receptors that use the riverbed substrate (e.g., fall chinook salmon). The EPA's ambient water quality criteria for protection of freshwater aquatic organisms is 11 μg/L of hexavalent chromium (EPA 1986c). Because of the logistical difficulty in monitoring chromium concentrations at the point of exposure for aquatic organisms, the EPA indicated that onshore monitoring is an acceptable substitute (ROD 1996a).

For samples collected from the aquifer near the river high-water line, a dilution factor of 1:1 is being assumed as reasonable for estimating receptor location concentrations. Therefore, the record of decision indicates that concentrations of <22 μg/L hexavalent chromium observed at near-river compliance-monitoring locations would be protective of aquatic organisms in the riverbed substrate. It

is expected that a period of time will pass after startup of the extraction system before concentration changes appear in the downgradient compliance-monitoring wells.

Water samples from wells are being obtained prior to startup of the system to establish a baseline against which data from the operating period can be compared (Borghese et al. 1996a). Data will be interpreted to evaluate the performance of the extraction system in controlling the movement of groundwater and in removing chromium from the aquifer. Data from monitoring wells specifically designed to demonstrate compliance with regulatory requirements will also be obtained prior to and during operations. These data will be compared to the 22-μg/L preliminary value that is proposed as protective of aquatic organisms. During the course of the interim remedial measure, data from monitoring the system and from concurrent characterization in the operable unit will become available to define compliance requirements that are reasonable for a final remedy record of decision.

6.6.5.3 Drinking Water Standards and Derived Concentration Guides

As discussed above, chromium, strontium-90, nitrate, and tritium were detected at levels greater than their DWSs in the 100-D/DR Area. No radiological contaminants were detected at levels above the DCGs.

6.7 100-H Area

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The 100-H Area is located along the Columbia River in the northern portion of the Hanford Site. This is the site of H Reactor that began operating in 1949 and was deactivated in 1965. A comprehensive summary of operations, along with detailed descriptions of facilities, waste sites, and hazardous waste-spill locations, is presented in Deford and Einan (1995). The following facility and waste-site descriptions are taken from that report, unless otherwise cited.

Most of the 100-H Area facilities were decommissioned and demolished. However, H Reactor remains standing, as do several small buildings, one of which is planned to house an ion-exchange treatment system for removing chromium from groundwater. Remnants of the coolant water-treatment plant and coolant water-retention basins are still present, as are the outfall pipes that lead to the center of the river channel. An interim remedial measure to address chromium contamination in groundwater using pump-and-treat technology is scheduled to begin in July 1997 (DOE 1996c).

6.7.1 Operable Units

For environmental restoration activities under CERCLA, the 100-H Area is divided into two source operable units (100-HR-1 and 100-HR-2) and one groundwater operable unit (100-HR-3), which encompasses the 100-D/DR and 100-H Areas and the intervening 600 Area.

High-priority waste sites in the 100-HR-1 Operable Unit include the 107-H retention basins and 107-H liquid waste-disposal trench; all located relatively near the river. Additional sites involve

process effluent pipelines and a small crib (known as the pluto crib) located near the reactor building. High-priority sites in the 100-HR-2 Operable Unit are primarily solid waste-burial grounds that are not believed to be primary contributors to groundwater contamination. Descriptions of high-priority waste sites are presented in the proposed plans for source remediation activities in each of these operable units (DOE 1995p, 1995q).

Contamination of groundwater occurred as the result of liquid effluent disposal associated with past reactor operations. Most of the waste-site sources for this contamination ceased operating by the late 1960s. A significant proportion of contamination carried by groundwater was either discharged into the Columbia River or dispersed over the broad region between 100-D/DR and 100-H Areas. Recent groundwater investigations are summarized in Peterson et al. (1996).

6.7.2 Facilities

This section describes the facilities within the 100-H Area. Described are the treatment, storage, and disposal units regulated by RCRA and facilities associated with former reactor operations being remediated under CERCLA.

6.7.2.1 RCRA Facilities

The 183-H solar evaporation basins are a RCRA facility. Now demolished, the facility was once four separate concrete basins surrounded by an earthen berm. Each basin measured ~16 by 39 m. Between 1973 and 1985, the basins were used to store liquid waste that resulted primarily from nuclear fuel-fabrication activities conducted in the 300 Area. Volume reduction occurred by solar evaporation. The waste was predominantly acid etch solution that had been neutralized with sodium hydroxide before being discharged into the basins (DOE 1991d, pp. I-8 through I-11). The acid solutions included nitric, sulfuric, hydrofluoric, and chromic acids. The waste solutions, described as supersaturated, contained various metallic and radioactive constituents (e.g., chromium, uranium, technetium).

By the end of 1990, essentially all of the waste had been removed from these basins. By FY 1996, all of the concrete basins had been demolished. Some of the concrete temporarily remains in clear wells adjacent to the former basins. After samples of the concrete are analyzed, the concrete will be permanently disposed of elsewhere on the Hanford Site.

6.7.2.2 Other Facilities

The following describes principal past-practices waste sites that may have contributed to groundwater contamination, drawing heavily on information presented in Deford and Einan (1995) and Peterson et al. (1996). Additional details on reactor operations and waste-disposal facilities are provided in those reports.

- The 107-H retention basin is located in the eastern part of the 100-H Area adjacent to the Columbia River. The basin received enormous volumes of reactor coolant effluent that contained radionuclides and chromium and held the effluent for a short time to allow thermal

cooling and radionuclide decay prior to discharging the effluent to the river via outfall pipes. The basin leaked at rates sufficient to create a mound on the underlying water table (Brown 1963). Mounding enhanced the spread of contamination over a broad area that potentially exceeded the reactor area boundaries.

- The 107-H liquid waste-disposal trench received highly radioactive coolant effluent that resulted when a reactor fuel element failed. The effluent would be held briefly in the retention basin and then diverted to the nearby liquid waste-disposal trench instead of the normal discharge via river-outfall pipes. The trench was unlined and intended as a soil-column-disposal site.

- Relatively small soil-column-disposal facilities such as cribs and french drains were located near the H Reactor building. Contaminated water and sludges from the fuel-storage basin located within the reactor building were typically disposed to nearby trenches, though the fate of the fuel-storage-basin effluents is not well documented. Fuel-storage-basin water typically contained high concentrations of tritium. Decontamination solutions, consisting of various acid solutions that picked up radionuclides and metals, were also disposed to the ground near the reactor. Decontamination solutions also contained large amounts of chromate.

6.7.3 Extent of Contamination

As in the 100-D/DR Area, chromium remains the predominant contaminant of concern in groundwater for environmental restoration considerations. Concentration data for other waste indicators, such as nitrate, tritium, strontium-90, technetium-99, and uranium are useful in helping to identify source areas and to reveal groundwater-flow patterns. With the exception of a plume created by leakage/spillage from the 183-H solar evaporation basins, groundwater plumes created during the operating years (1949 to 1965) have had considerable time to dissipate. An additional source for groundwater contamination is past disposal in the 100-D/DR Area that migrated across the horn of the Columbia River and is now passing through the 100-H Area.

6.7.3.1 183-H Solar Evaporation Basins

Groundwater chemistry in the vicinity of these basins is characterized by elevated levels of nitrate, chromium, sulfate, sodium, technetium-99, and uranium. All of these constituents were present in waste discharged to the basins when they were in use. The RCRA groundwater-monitoring plan for these basins (Hartman and Chou 1995) identifies four contaminants of concern (waste indicators) for statistical evaluations under WAC 173-303-645(10): chromium, nitrate, technetium-99, and uranium.

The concentrations of the waste indicators typically are highest in well 199-H4-3, located immediately downgradient of the basins. Although the concentrations decreased several orders of magnitude in this well since the basins ceased operation, they remained above DWSs for most of the past year, as discussed below.

6.7.3.2 Technetium-99 and Uranium

Technetium-99 and uranium are present in groundwater downgradient from the basins (Figures 6.7-1 and 6.7-2). Well 199-H4-3 contained the maximum average annual concentration of technetium-99 in the 100-H Area (2,200 pCi/L). Technetium-99 concentrations in this well continued to fluctuate widely, ranging from 1,000 to 5,140 pCi/L in FY 1996. This well also contained the maximum average uranium value of 170 μg/L.

6.7.3.3 Nitrate

These basins also contributed to a more widespread plume of nitrate (see Plate 5). Nitrate is only found at levels above the MCL immediately downgradient of the basins. An additional source for nitrate is past disposal of nitric acid decontamination solutions to soil-column facilities located near the reactor buildings. Figure 6.7-3 illustrates nitrate concentrations in wells 199-H4-3 and 199-H4-4 for the past 5 years. Chromium, technetium-99, and uranium followed similar trends in well 199-H4-3 during the past year. The trends for chromium are shown in Figure 6.7-4. In the past year, nitrate was lowest from September 1995 through June 1996, when the river stage was very high and groundwater in this well was probably diluted. The first fall measurement (September 1996) was much higher, probably because the water table had dropped again. However, changes in contaminant concentrations in previous years are not clearly related to water levels. For example, the low-contaminant levels in 1992 cannot be attributed to high-river stage, nor can the increase observed in 1993 be attributed to low-river stage. Wells closer to the river show even greater dilution effects from high-river stage that occurred during much of FY 1996.

6.7.3.4 Chromium

Chromium, which exceeds the MCL, is the predominant contaminant of concern being tracked as part of the remedial investigation of 100-H Area groundwater. Chromium is widely distributed because of multiple source facilities and spill locations and also because chromium was in the reactor coolant effluent that formed large mounds on the water table. These mounds directed groundwater flow in all directions, including against the natural groundwater-flow direction (Brown 1963).

Figure 6.7-5 shows average concentrations for chromium in filtered groundwater samples during FY 1996. The concentration data are representative of conditions near the water table (i.e., the uppermost hydrogeologic unit). Process knowledge, high solubilities, and past characterization activities show that these results represent hexavalent chromium that is readily transported by groundwater flow and is toxic to aquatic organisms.

Defining plume boundaries within the 100-H Area is highly subjective for several reasons. The sources that contributed chromium have long since ceased to operate and there has been ample time for dispersion of the plumes. Minor lithologic differences can be expected to affect the rate at which chromium contamination is flushed from the aquifer, leading to variability in the remaining concentrations between adjacent wells. Also, chromium-laden groundwater is moving into the 100-H Area

from the west and intermingling with plumes from 100-H Area sources. The distribution of chromium contamination across the horn of the Columbia River is not well defined, particularly along the stretch of the river north of the 100-H Area.

Groundwater flows through the 100-H Area at an average rate of perhaps 0.3 m/d (Hartman 1996a). Flow passing beneath the reactor building, which is located 610 m inland, should have reached the river in just under 6 years. Because the majority of liquid waste-disposal operations in the 100-H Area ceased in the mid-1960s, what is observed today represents residual amounts of more-concentrated plumes.

Chromium contamination is also detected deeper in the aquifer in the 100-H Area. As discussed in Dresel et al. (1996) and Peterson et al. (1996), the deeper chromium contamination is not associated with technetium-99. This suggests that the chromium deeper in the aquifer does not originate from the 183-H basins. It is more likely that the source is upgradient contamination from the 100-D Area, though past disposal in other parts of the 100-H Area may have contributed. Chromium concentrations in well 199-H3-2C were found at levels above the MCL in one sampling event in FY 1996. This is the first time that contamination was detected in that well, completed in a sand-silt zone of the upper Ringold Formation, and is considered suspect. The well will be resampled in FY 1997 to determine if the value is representative. Chromium concentrations detected in well 199-H4-12-C, also completed in the Ringold Formation, continued to remain above 200 μg/L in filtered samples. A 0.6-cm-dia. piezometer in nearby well 199-H4-15C(s), which monitors nearly the same horizon as 199-H4-12C, was sampled in 1995 and also showed elevated chromium, which supports an interpretation of chromium contamination at depth. The extent of chromium in the middle to lower parts of the unconfined aquifer system is poorly defined because nearly all wells are completed across the water table.

Several 100-H Area wells are located 150 m or less inland from the low-water line. Water quality measurements from these wells are influenced by seasonal river-stage fluctuations and, possibly for some wells, daily fluctuations. The maximum contaminant concentrations correlate with seasonal low-river stage, when the influence of bank storage is minimized. Nitrate and chromium trends for well 199-H4-4, which is located ~120 m inland, illustrate this effect (see Figures 6.7-3 and 6.7-4). The anomalously low concentrations correspond to periods of high-river stage.

Chromium concentration data were collected from riverbed sediment pore water at ~30 sites along the 100-H Area shoreline during March/April 1995 (Hope and Peterson 1996). Pore water was obtained from sampling tubes driven into the sediment to a depth of ~45 cm. The purpose for the sampling project was to obtain field measurements of chromium concentrations near spawning habitat, where salmon eggs and developing juvenile fish are potentially exposed. The pore-water results are shown in Figure 6.7-6.

6.7.3.5 Strontium-90

This radionuclide is a common constituent of liquid waste effluent from reactor operations in the 100 Areas and is currently present at concentrations above the 8-pCi/L DWS in wells downgradient of the 107-H retention basin and adjacent 107-H liquid waste-disposal trench. The maximum concentration

observed in FY 1996 was 20 pCi/L in well 199-H4-13, similar to 1995 levels (Figure 6.7-7). Although the soil column at various locations in the 100-H Area undoubtedly contains strontium-90 from past activities, groundwater does not show extensive contamination.

6.7.3.6 Tritium

Tritium in 100-H Area groundwater, while detectable, no longer exceeds the interim DWS (see Plate 3). The relatively low concentrations provide additional evidence that contamination from the operating years has now passed out of the 100-H Area. Tritium continues to be detectable in a broad band across the horn of the Columbia River between the 100-N and 100-H Areas.

6.7.4 Groundwater Remediation Activities

An interim remedial measure to address chromium contamination in 100-H Area groundwater is scheduled to begin in July 1997. During the CERCLA limited field investigation process, chromium was identified as a contaminant of potential concern (DOE 1994d). A subsequent focused feasibility study evaluated chromium as a contaminant of concern and recommended using pump-and-treat technology to intercept chromium plumes near the Columbia River (DOE 1995r). A decision was then made to proceed with an interim remedial measure at the 100-K, 100-D/DR, and 100-H Areas to address chromium near the river, thereby reducing the potential threat to aquatic organisms from hexavalent chromium (ROD 1996a).

In the 100-H Area, the interim remedial measure includes a network of extraction wells (see Plate 1). The capture zones created by pumping these wells are intended to intercept the chromium plume depicted in Figure 6.7-5. The extracted groundwater will be processed using an ion-exchange treatment system currently being constructed at the western edge of the 100-H Area. Effluent from the treatment system will be injected back into the aquifer via injection wells. Design characteristics of the extraction wells and treatment system, along with a description of performance monitoring that will be conducted to evaluate system effectiveness and efficiency, are described in DOE (1996c).

6.7.5 Compliance Issues

Compliance issues in the 100-H Area involve RCRA regulations associated with the 183-H solar evaporation basins and requirements contained in the ROD (1996a) for interim remedial measures under CERCLA regulations.

6.7.5.1 RCRA Facility Compliance Issues

Statistical evaluations of the waste indicators are required under RCRA final status regulations (WAC 173-303-645[10]). Downgradient concentrations are compared to concentration limits defined in the monitoring plan (Hartman and Chou 1995). Results of statistical evaluations for the past year are included in Appendix B.

Results of the September through December 1995 sampling event indicated that concentration limits for uranium, technetium-99, chromium, and nitrate were exceeded in one or more downgradient wells. Confirmation sampling was conducted in the spring of 1996. Some of the samples confirmed the presence of contamination at levels above regulatory limits. Ecology was notified of the exceedances, which normally triggers the initiation of a corrective action program. The 183-H solar evaporation basins are part of the 100-HR-1 and 100-HR-3 Operable Units, so corrective action was deferred to CERCLA. RCRA monitoring will continue under the current program.

The 183-H basins RCRA monitoring program is adequate under current flow conditions. However, a planned pump-and-treat system will extract groundwater from 5 wells around the basins, including two of the RCRA wells. The adequacy of the RCRA network and the appropriateness of doing RCRA monitoring will be evaluated in the coming year.

In 1986, Ecology issued a compliance order that placed the 183-H basins into RCRA interim status assessment monitoring (Ecology and EPA 1986). These basins were incorporated into the Hanford Site permit in September 1994 (Ecology 1994) and became subject to final status monitoring. A revised closure plan will be incorporated into the permit in the summer of 1997.

6.7.5.2 Record of Decision for Interim Remedial Measures Under CERCLA

The record of decision (ROD 1996a) for addressing chromium in the 100-HR-3 and 100-KR-4 Operable Units indicates that the interim remedial measure is intended to be protective of aquatic receptors that use the riverbed substrate (e.g., fall chinook salmon). The EPA's ambient water quality criteria for protection of freshwater aquatic organisms is 11 μg/L of hexavalent chromium (EPA 1986c). Because of the logistical difficulty in monitoring chromium concentrations at the point of exposure for aquatic organisms, the EPA indicated that onshore monitoring is an acceptable substitute (ROD 1996a).

For samples collected from the aquifer near the river high-water line, a dilution factor of 1:1 is being assumed as reasonable for estimating receptor location concentrations. Therefore, the record of decision (ROD 1996a) indicates that concentrations of <22 μg/L hexavalent chromium observed at near-river compliance-monitoring locations would be protective of aquatic organisms in the riverbed substrate. It is expected that a period of time will pass after startup of the extraction system before concentration changes appear in the downgradient compliance-monitoring wells.

Water samples from wells are being obtained prior to startup of the system to establish a baseline against which data from the operating period can be compared (Borghese et al. 1996a). Data will be interpreted to evaluate the performance of the extraction system in controlling the movement of groundwater and in removing chromium from the aquifer. Data from monitoring wells specifically designed to demonstrate compliance with regulatory requirements will also be obtained prior to and during operations. These data will be compared to the 22-μg/L preliminary value that is proposed as protective of aquatic organisms. During the course of the interim remedial measure, data from monitoring the system and from concurrent characterization in the operable unit will become available to define compliance requirements that are reasonable for a final remedy record of decision.

6.7.5.3 Drinking Water Standards and Derived Concentration Guides

As discussed above, technetium-99 is detected in groundwater in the 100-H Area at levels above the interim DWS in an area immediately downgradient of the 183-H solar evaporation basins. Uranium is found at levels above the proposed MCL in the same vicinity. Strontium-90 is found at levels above the interim DWS near the 107-H retention basin and 107-H liquid waste-disposal trench. Chromium is found at levels above the state and federal MCLs downgradient of the basins, but is also found at levels above the MCL in a broader plume emanating from upgradient sources. Chromium is also found at levels above the MCL in a well completed in the middle of the unconfined aquifer system, indicating that the contamination extends to some depth, though the extent of contamination in the deeper parts of the aquifer is not well defined. Nitrate contamination at levels above the MCL is also found downgradient of the 183-H basins. No contaminants were found at levels above the DCGs.

6.8 100-F Area

M. J. Hartman

The 100-F Area is located the farthest east and downstream of the other reactor areas. F Reactor operated from 1945 to 1965. Like all of the other Hanford Site reactors, except for N Reactor, it was cooled by a single-pass system (i.e., cooling water passed through the reactor and was discharged directly to the Columbia River).

6.8.1 Operable Units

For environmental restoration activities under CERCLA, the 100-F Area is divided into two source operable units (100-FR-1 and 100-FR-2), which contain hazardous waste sites at or near the surface. A single groundwater operable unit (100-FR-3) addresses contamination at and below the water table, which extends from beneath the source operable units laterally to adjacent areas where contamination may pose a risk to human and ecological receptors. For the 100 Areas, the lateral boundary is generally considered to be where Hanford Site groundwater meets Columbia River water. This interface occurs along the riverbanks and within the riverbed substrate.

High-priority waste sites in the 100-FR-1 Operable Unit include reactor coolant-retention basins, liquid waste-disposal trenches, associated effluent pipelines, and french drains near the F Reactor building. High-priority sites in the 100-FR-2 Operable Unit are primarily burial grounds that received radioactive and mixed wastes. Descriptions of high-priority waste sites are presented in the proposed plans for source remediation activities in each of these operable units (DOE 1995s, 1995t).

Contamination of groundwater occurred as the result of liquid effluent disposal associated with past reactor operations and from solid wastes disposed in burial grounds. A conceptual site model for groundwater contamination in this operable unit is included in Peterson et al. (1996).

6.8.2 Facilities

There are no active facilities or waste-disposal sites in the 100-F Area. Facilities associated with former reactor operations that may have affected groundwater, summarized below, are being decommissioned and remediated under CERCLA.

The greatest volumes of liquid wastes in the 100-F Area were associated with the 116-F-14 retention basin and pipelines that lead to the basin from the F Reactor building. The retention basin is located near the Columbia River in the eastern part of the 100-F Area. They received enormous volumes of reactor coolant effluent that contained radionuclides and sodium dichromate. The basin held the effluent for a short time to allow thermal cooling and radionuclide decay before the effluent was discharged to the Columbia River. The basin developed significant leaks, creating a mound on the underlying water table that enhanced the spread of contamination.

The 116-F-2 overflow trench, located near the retention basin, received highly radioactive effluent from the basin and F Reactor. A second trench (116-F-9) is also located near the retention basin and received liquid wastes from cleaning the experimental animal laboratories. The trenches were unlined and intended as soil-column-disposal sites because the natural soils were known to retain many radionuclides.

Other prominent liquid waste-disposal sites include cribs and french drains near the reactor building. The 116-F-6 and 116-F-3 trenches received cooling water and sludge from F Reactor. The 116-F-1 trench (also known as the Lewis canal) received liquid waste from F Reactor and associated buildings. Effluent discharged to these facilities contained radionuclides and metals.

Solid waste-burial grounds are located in the southwestern part of the 100-F Area. They were used to dispose contaminated equipment, animal wastes from the experimental animal laboratories, or coal ash and soil.

6.8.3 Extent of Contamination

Groundwater in the 100-F Area was sampled for CERCLA investigations and as part of the site-wide surveillance program. Most of the wells were sampled once between October 1995 and September 1996. Most of the monitoring wells are located generally along a line from the southwest to the northeast of the area. Thus, the downgradient extent of some plumes is poorly defined. Primary groundwater contaminants in the 100-F Area are tritium, nitrate, and strontium-90. Chromium, trichloroethylene, and uranium concentrations are also elevated locally. Contaminants are organized below by their general source areas.

6.8.3.1 118-F-1 and 118-F-6 Burial Grounds

Tritium continued to exceed the DWS in well 199-F8-3 near the 118-F-1 burial grounds (see Plate 3). The year's average was 110,000 pCi/L in this well. There are few monitoring wells downgradient of the burial grounds, so the areal extent of the plume is not well defined. The tritium plume

appears to extend toward the southeast, where it meets the Columbia River. It is very unusual to observe tritium levels in the 100,000-pCi/L range near solid waste-burial sites where there is no obvious liquid waste disposal nearby.

6.8.3.2 116-F-14 Retention Basin and 116-F-2 Trench

Strontium-90 exceeded the 8-pCi/L DWS in wells in the eastern part of the 100-F Area, near the 116-F-14 retention basin and the 116-F-2 liquid waste-disposal trench (Figure 6.8-1). Most of the data for the past year are for strontium-89 and -90. All of the strontium detected may be assumed to be strontium-90 because strontium-89 has a much shorter half-life (50.5 days, compared to 29 years for strontium-90). The highest activity of strontium-90 during the past year was 135 pCi/L in well 199-F5-3.

6.8.3.3 Vicinity of Reactor Building

Nitrate is elevated throughout most of the 100-F Area (see Plate 4). Nitrate exceeds the 45-mg/L DWS in most of the monitoring wells near the reactor building and solid waste-burial grounds, reaching the 100-mg/L level. Nitrate provides a good indication of contaminant movement through preferential pathways created by buried former river channels. Movement of nitrate is generally to the south and southeast from sources near the F Reactor building and the 116-F-1 trench.

Uranium data are available for some 100-F Area wells for FY 1996. The highest levels were in well 199-F8-1 that had 257 μg/L in October 1995 and 28 μg/L in September 1996. Both values are within the trend of limited historical data for this well. Well 199-F8-1 is located south of the reactor building near several solid and liquid waste-disposal facilities.

A small area of strontium-90 at the 8-pCi/L DWS was observed near the F Reactor building in wells 199-F5-48 and 199-F5-47 (see Figure 6.8-1).

6.8.3.4 Other Sources

Chromium exceeded the 100-μg/L federal and the 50-μg/L state MCLs in filtered samples in only one well (199-F5-46) during the past year. The average value for the year was 150 μg/L. The source of this elevated chromium is not clear. Chromium fluctuates widely in well 199-F5-46 (Figure 6.8-2). The variations may be associated with seasonal river-stage changes and complex groundwater movement caused by buried former river channels.

Trichloroethylene was detected in the southwest corner of the 100-F Area (well 199-F7-1) and in the adjacent 600 Area. The maximum concentration in the past year in well 199-F7-1 was 24 μg/L, which exceeds the 5-μg/L MCL. Trend plots for this well and a nearby well in the 600 Area (699-77-36) are illustrated in Figure 6.8-3. A field screening investigation of trichloroethylene in soil gas and groundwater was performed in 1995 (DOE 1996e). The extent of contamination was delineated but no specific sources were identified.

6.8.4 Compliance Issues

Only limited contamination at levels above the MCLs or DWSs was found in the 100-F Area. No contamination at levels above the DCG was detected; however, tritium and strontium-90 were found at levels above the interim DWS. Trichloroethylene, nitrate, and chromium were detected at levels above the MCL.

6.9 200-West Area

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The 200-West Area was used historically for chemical separation and purification of plutonium and associated waste management. For reasons of safety and security, the area was established with a significant spatial separation from the 200-East Area and with some redundancy of function. Differing hydrogeology between the two sites resulted in significant dissimilarities in the degree of the spread of contaminants. Four key source areas in the environs of the 200-West Area will be discussed: T Plant, Reduction-Oxidation (REDOX) Plant, U Plant, and Plutonium Finishing Plant (formerly known as Z Plant).

6.9.1 Operable Units

Numerous source area operable units exist in the 200-West Area; however, only two CERCLA groundwater operable units relate to 200-West Area contamination (200-UP-1 and 200-ZP-1). These operable units are defined mainly on the basis of the contaminant plumes, rather than on precisely defined geographic regions. The 200-UP-1 Operable Unit generally covers the groundwater in the southeastern part of the 200-West Area. Currently technetium-99 and uranium contamination in the vicinity of U Plant are being addressed by 200-UP-1 interim remedial measures. The 200-ZP-1 Operable Unit generally covers groundwater contamination in the northwestern part of the 200-West Area, though the remediation of contaminants, specifically carbon tetrachloride, that extend to other parts of the area are considered part of the operable unit.

6.9.2 Facilities

Numerous waste-disposal and storage facilities are located in the 200-West Area. Specific facilities that may have contributed to groundwater contamination will be discussed, as appropriate, in Section 6.9.3. However, because of the complexity of past waste-disposal operations in the 200 Areas, as well as the close spacing of the facilities, it is often impossible to determine the exact source of contamination.

6.9.2.1 T Plant

T Plant used the bismuth phosphate process from December 1944 through August 1956 to separate plutonium from irradiated fuel (Anderson 1990). More recently, T Plant has been used as an

equipment-decontamination facility. The waste facilities for T Plant are located generally southwest of the plant and include cribs and the waste management area (WMA) T and TX-TY single-shell tank farms. Waste-management techniques changed during the period of operations, reducing the volume of waste produced for a given amount of fuel processed. Waste-disposal practices were complex and changed, depending on available storage capacity and treatment technology. The 242-T evaporator was used to reduce the volume of first-decontamination-cycle wastes. Waste tanks in the WMA-T-TX tank farms were used in a cascading system for settling solids in the waste stream. First-decontamination-cycle and second-decontamination-cycle wastes were discharged to specific retention trenches in T Plant disposal facilities (Anderson 1990). In addition, Waite (1991) indicated that in 1954 evaporator bottoms (concentrated waste) from the 242-T evaporator were discharged to the 216-T-25 trench. Thus, some of the most radioactive liquid waste was discharged to the ground rather than being stored in tanks. The wastes discharged were closely related to tank wastes; the tanks, however, apparently retained much of the solid fraction in the waste streams. With current knowledge, it is not possible to definitively identify chemical signatures that distinguish leaks from waste-storage tanks from other contaminant sources in the T Plant area.

There are a number of significant waste-discharge sites in the T Plant area. Of particular interest is the 216-T-26 crib that received diverse chemical and radiological waste, including first-decontamination-cycle-scavenged waste via the 101-TY, 103-TY, and 104-TY tanks (Stenner et al. 1988). The adjacent 216-T-28 crib received large amounts of water, as well as some decontamination wastes. The large volumes of water discharged to the 216-T-28 crib may have enhanced migration of contaminants from nearby sources. The 216-T-19 crib and tile field are located south of the WMA-TX-TY tank farms and received a variety of waste streams, including condensate from the 242-T evaporator and second-decontamination-cycle supernatant waste. Cribs located to the west of WMA-T tank farm, including the 216-T-7 and 216-T-32 cribs, received waste via the WMA-T tank farm. A large amount of nitrate was present in the wastes discharged to these cribs (an estimated 2,300,000 kg of nitrate to the 216-T-7 crib, according to Stenner et al. 1988). As discussed above, the 216-T-25 trench, located west of the WMA-TX-TY tank farms, received evaporator bottom waste.

6.9.2.2 REDOX Plant

Operation of the REDOX Plant began in 1951 and continued through 1967, with its primary mission to separate plutonium from uranium and fission products using countercurrent solvent extraction, eventually replacing the bismuth phosphate process used in T and B Plants. The solvent-extraction process used an organic solvent (hexone) to separate plutonium from uranium fuel that had been dissolved in nitric acid. Chemical contaminants found in the groundwater near the REDOX Plant include nitrate and minor amounts of trichloroethylene. The carbon tetrachloride plume prevalent in most of the rest of the 200-West Area is largely absent near the REDOX Plant, apparently as a consequence of the low-permeability sediment in that area and the lack of any local discharges of carbon tetrachloride. The main radiological contaminants are tritium, iodine-129, technetium-99, and uranium.

Disposal facilities associated with the REDOX Plant are generally located to the west of the plant. A number of disposal facilities, including several ponds that received large amounts of water, are

located outside the 200-West Area perimeter fence. Waste from the REDOX process is stored in the WMA-S-SX single-shell tank farms and the WMA-SY double-shell tank farm. Of the 27 single-shell tanks, 11 are known or assumed to have leaked. A number of disposal facilities located around the WMA-S-SX tank farms received waste from REDOX operations, including condensate from the self-boiling waste tanks. The presence of these disposal facilities in proximity to the tank farms and the similarities between the waste streams discharged to the ground and the tank wastes complicate assessment of the impact of tank leaks to the groundwater. Leakage of piping and transfer boxes during tank farm operations may also have released contaminants in this area. Waite (1991) indicated that tank wastes were not discharged directly to ground via pumping or cascade overflow from the WMA-S-SX tank farms.

6.9.2.3 U Plant

U Plant was originally designed as a plutonium-separation facility but was never used for that purpose. The plant was converted in 1952 to recover uranium from waste generated by the bismuth phosphate process that had been stored in tanks up to that time. Subsurface contamination near the plant and in other areas resulted from processing wastes that were moved to tanks in the 200-East Area. Waste from U Plant operations was also disposed to the BC cribs south of the 200-East Area. Groundwater contaminants in the U Plant area include uranium, technetium-99, iodine-129, nitrate, and trichloroethylene. In contrast to many parts of the fuel-processing areas, tritium contamination near U Plant is only minor.

6.9.2.4 Plutonium Finishing Plant (Formerly Z Plant)

Constructed in 1949, Z Plant purified plutonium and reduced it to a metallic state. In the early 1980s, the plant was modernized and renamed the Plutonium Finishing Plant. The mission of the plant remained essentially unchanged but liquid discharges were significantly reduced. Primary wastes associated with the plant include transuranics (primarily plutonium and americium), nitrate, carbon tetrachloride, tributyl phosphate, dibutyl phosphate, dibutyl phosphonate, aluminum fluoride nitrate, and lard oil. Transuranic contaminants typically remain bound in the soil column at relatively shallow depths, though there are exceptions particularly where complexants for plutonium were present in the waste stream (see Section 4.4.3.2). Alkyl phosphates were not observed in the groundwater, and their fate is still relatively obscure. Lard oil is expected to remain at shallow depth in the soil because of its high viscosity. Nitrate; carbon tetrachloride, and trichloroethylene associated with the plant's cribs produced plumes in the groundwater. Some minor fluoride contamination near the T Plant area may have originated from the Plutonium Finishing Plant cribs.

6.9.2.5 RCRA Facilities

A number of facilities in the 200-West Area are being monitored under RCRA requirements. Additional detail on those facilities is warranted by the RCRA monitoring and reporting requirements.

Single-Shell Tank Farms. The single-shell tanks that are currently storing hazardous, radioactive wastes in the 200-West Area are located in WMA-S-SX, -T, -TX-TY, and -U tank farms (Figure 6.9-1). These WMAs, decommissioned in 1980, have been designated as RCRA facilities since 1989.

Currently, the single-shell tanks are used to store mixed waste received from various chemical-processing facilities. These tanks were constructed between 1943 and 1964 and, depending on dimensions, each held between 1,892,500 and 3,785,000 L. WMA-T and -U tank farms contain four smaller tanks (200-series tanks) that hold 208,175 L. The waste in the tanks was generated by chemical processing of spent fuel rods using the tributyl phosphate, bismuth phosphate, REDOX, or plutonium-uranium-extraction (PUREX) processes.

The single-shell tanks received mixtures of organic and inorganic liquids containing radionuclides, solvents, and metals that were originally discharged to the tanks as alkaline slurries. Waste-management operations mixed various waste streams from numerous processes generated in the processing of spent fuel rods. Thus, the original contents within each tank are difficult to determine. The situation is further complicated by subsequent chemical reactions, degradation, and decay of radionuclides. However, much recent work has been done to characterize the tank waste (e.g., Agnew 1995, Agnew et al. 1996). The radionuclide and chemical inventories of the single-shell tanks are summarized in Van Vleet (1993), while waste types and historical operations at the tank farms are summarized in Anderson (1990). Source determination for the single-shell tanks is further complicated because tank wastes were, in some instances, discharged to nearby cribs, unlined specific retention trenches, unlined ditches, french drains, and ponds.

Tank wastes exist in the form of salt cake and sludge, which is left after the liquids were removed. However there are small quantities of supernatant and interstitial liquids that could not be removed by pumping. The wastes consist predominantly of sodium hydroxide and sodium salts of nitrate, nitrite, carbonate, aluminate, and phosphate. Some hydrous oxides of iron and manganese also are present. Fission-product radionuclides such as cesium-137, strontium-90, and technetium-99 and actinide elements such as uranium, thorium, plutonium, and neptunium constitute the principal radioactive components. Some of the tanks also contain ferrocyanide or organic salts.

216-U-12 Crib. The 216-U-12 crib is located ~610 m south of U Plant (see Plate 1). This crib is an unlined, gravel-bottom, percolation crib that has bottom dimensions of 3.05 m wide, 30.5 m long, and 4.3 m deep. The crib has a plastic barrier cover and is backfilled with the original excavated soil. A vitrified clay distributor pipe buried in gravel dispersed the effluent across the bottom of the crib.

The crib received U Plant wastewater from April 1960 until February 1988, when the crib was permanently retired and replaced by the 216-U-17 crib. The wastewater disposed to the 216-U-12 crib contained dangerous waste and radioactive materials. Specifically, the waste was composed of effluent from U Plant and included 291-U-1 stack drainage and highly acidic process condensate from the 224-U Building. The 216-U-12 crib received this waste stream from April 1960 until 1972, when it was deactivated. The 216-U-12 crib was reactivated in November 1981 and received U Plant waste until it was permanently retired in February 1988. An average of over 133 million L/yr of effluent was disposed to this crib during its active life, and received low-level radioactive waste that is known

to have included chemicals such as nitric acid in addition to plutonium, strontium, ruthenium, and uranium. In 1985, physical controls and operating procedures were modified to avoid inadvertent discharge of hazardous chemicals to the wastewater stream.

216-S-10 Pond and Ditch. This facility is located south-southwest of the 200-West Area directly outside the perimeter fence (see Plate 1). Initially, the facility consisted of an open, unlined ditch ~1.82 m deep, 1.21 m wide, and 685.8 m long. An open, unlined percolation pond, constructed at the southwest end of the 216-S-10 ditch and ~2.0 ha in size, was also active during part of the time that the ditch was receiving waste.

The ditch began receiving waste from the REDOX Plant in August 1951. The pond was excavated and placed in service in February 1954. In October 1985, the pond and portions of the ditch were decommissioned and backfilled. The remaining portion of the ditch received nondangerous, nonregulated waste from the 202-S building chemical sewer. The waste stream included cooling water, steam condensate, water tower overflow, and drain effluent. From 1985 to October 1991, physical controls and operating procedures were modified to avoid inadvertent discharge of hazardous chemicals to the wastewater stream. The effluent stream to the 216-S-10 facility was permanently deactivated in October 1991. The facility will not receive additional dangerous substances, and will be closed in final status pursuant to WAC 173-303-610.

Releases of dangerous constituents to the 216-S-10 facility are poorly documented. Radioactive waste was reportedly disposed to the facility as a result of contaminated floor and sewer drains at the REDOX Plant. Hazardous chemical releases were documented in 1954 and 1983 and included aluminum nitrate, sodium nitrate, sodium phosphate, sodium hydroxide, sodium fluoride, sodium chloride, and potassium dichromate.

Low-Level Burial Grounds. The low-level (LL) WMAs in the 200-West Area are monitored under RCRA interim status requirements and include a number of burial grounds within each area.

LLWMA-3 is located in the north-central portion of the 200-West Area. Burial grounds 218-W-3A, 218-W-3AE, and 218-W-5 make up LLWMA-3, which is located in the north-central portion of the 200-West Area (Figure 6.9-2). These facilities cover 74.3 ha. Burial ground 218-W-3A began accepting waste in 1970 and received primarily ion-exchange resins and failed equipment (e.g., tanks, pumps, ovens, agitators, heaters, hoods, jumpers, vehicles, and accessories). Burial ground 218-W-3AE began operation in 1981 and contains low-level and mixed waste, including rags, paper, rubber gloves, broken tools, and industrial waste. Burial ground 218-W-5 first received waste in 1986, and contains low-level and low-level-mixed waste, including lead bricks and shielding.

LLWMA-4 covers 24.4 ha in the south-central portion of the 200-West Area. Burial grounds 218-W-4B and 218-W-4C make up LLWMA-4 (Figure 6.9-3). Burial ground 218-W-4B first received waste in 1968 and contains mixed and retrievable transuranic waste in trenches and 12 caissons. One caisson is believed to contain mixed waste. Waste was first deposited in burial ground 218-W-4C in 1978. Transuranic, mixed, and low-level waste was placed in burial ground 218-W-4C, including contaminated soil, decommissioned equipment, and remote-handled transuranic waste.

LLWMA-5, located in the north-central portion of the 200-West Area, has been eliminated from further groundwater monitoring because no waste has been disposed to this facility and there are no plans for its use (Figure 6.9-4).

6.9.2.6 Effluent Treatment Facility

Liquid condensate derived from 200-Areas double-shell tank wastes is treated in the 200 Areas Effluent Treatment Facility (also known as C-018H) and discharged to a soil-disposal site north of the 200-West Area (see Plate 1). Discharge to this facility began in November 1995. Various waste products were removed from the condensate at the facility but the resulting water still contains extremely high concentrations of tritium (~10,000,000 pCi/L). No cost-efficient technology exists to remove tritium from water.

6.9.3 Extent of Contamination

The groundwater contamination in the 200-West Area may generally be related to the four major production locations (T, REDOX, U, and Plutonium Finishing Plants). The discussion below divides the monitoring activities according to these four major areas.

6.9.3.1 T Plant

Groundwater plumes originating from the T Plant area include tritium, technetium-99, iodine-129, uranium, nitrate, and chromium. A fluoride plume is also present in the area. Carbon tetrachloride and trichloroethylene plumes, originating near the Plutonium Finishing Plant, appear to extend throughout the T Plant area. Aqueous discharges to the 216-T-19 crib may be responsible for part of the carbon tetrachloride and trichloroethylene plumes in that area (Rohay et al. 1994).

WMA-T and -TX-TY RCRA Assessment Parameters. In November 1992, the critical mean for field specific conductance was exceeded in downgradient wells 299-10-15 at WMA-T and 299-W10-17 and 299-W14-12 at WMA-TX-TY single-shell tank farms (see Figure 6.9-1 for well locations). Verification sampling triggered these two sites into groundwater quality assessment monitoring under interim status regulations. As can be seen in Figure 6.9-5, specific conductance in well 299-14-12 was traditionally higher than the other wells in the network. However, the contaminant concentrations in this well decreased substantially since early 1995. The value for third quarter sampling for FY 1996 yielded 741 μS/cm, which is closer to the critical mean of 667.4 μS/cm. For well 299-W10-17, the specific conductance value is also only slightly greater (at 751 μS/cm) than the critical mean.

Quarterly sampling along with historic trends and waste-management data identified nitrate and chloride charge balanced mainly by calcium and magnesium as the cause for the elevated specific conductance. For example, Figure 6.9-6 shows similar historical trends for specific conductance, nitrate, chloride, calcium, and magnesium and in downgradient well 299-W14-12. In addition, in upgradient well 299-W15-22, there are slight increases in specific conductance, calcium, fluoride, and

nitrate. It should be noted that elevated nitrate is areally widespread in the groundwater in the northern part of the 200-West Area (see Plate 4) because of the discharge of large volumes of these constituents to nearby trenches and cribs in the mid-1950s.

The current assessment study of WMA-T and -TX-TY is attempting to differentiate between contamination emanating from nearby trenches and cribs from that which may have leaked inside the tank farms.

A number of other constituents exceeded regulatory limits in the vicinity of these WMAs. These include nitrate, tritium, carbon tetrachloride, filtered iron, filtered chromium, nickel, fluoride, technetium-99, and iodine-129. Some of these contaminants historically follow the same analyte trend as nitrate, indicating a source more extensive than these WMAs. Examples of the historical trends are shown for downgradient well 299-W14-12 in Figure 6.9-7. Although this correlation is not as clear in wells 299-W10-17 and 299-W10-18, upgradient well 299-W15-22 has been increasing in these constituents since 1992 or 1993. A correlation in the trend of these constituents suggests a common source.

In WMA-T, concentrations in samples from well 299-W11-27 show large increases in several chemical species that diverge from trends in nearby wells in the monitoring network, including specific conductance, nitrate, technetium-99, and tritium. Results for this well are discussed in more detail in the following sections.

Tritium. A tritium plume that covers much of the northern half of the 200-West Area has its highest concentrations near the WMA-TX-TY single-shell tank farms and associated cribs (see Plate 3). The maximum average annual tritium detected in this plume in FY 1996 was 120,000 pCi/L in well 299-W15-4. Concentrations of tritium in well 299-W14-12, which had the maximum concentration in 1995 declined steadily through FY 1996; the August 1996 sample contained only 39,123 pCi/L of tritium. The plume extends northeast, beyond the 200-West Area boundary. An area north of the WMA-T single-shell tank farm consistently shows tritium at levels much lower than the surroundings. The reason for this is unclear but may be related to discharge of relatively clean water to the 216-T-4 ditch (Alexander et al. 1995). Concentrations of tritium and other contaminants, including nitrate and technetium-99, are increasing rapidly in well 299-W11-27 in the southern portion of this less-contaminated zone, indicating that the clean water is moving downgradient to the northeast as a pulse.

Technetium-99. A technetium-99 plume in the T Plant area has dimensions similar to the tritium plume (Figure 6.9-8). This contrasts with the U Plant technetium-99 plume, discussed below, which has lower tritium levels. The area of the technetium-99 plume above the interim DWS is restricted to the immediate vicinity of the WMA-TX-TY single-shell tank farms and associated disposal facilities, and the northeast corner of the WMA-T single-shell tank farm. The maximum average annual technetium-99 detected near the WMA-TX-TY tank farms in FY 1996 was 1,700 pCi/L in well 299-W14-12. The technetium-99 concentration in this well, like the tritium concentration discussed above, declined sharply in 1996 (see Figure 6.9-7); the August 1996 sample contained only 227 pCi/L of technetium-99. As discussed above, technetium-99 along with tritium and nitrate increased sharply in well 299-W11-27 to 17,900 pCi/L, giving an FY 1996 average annual concentration of 7,400 pCi/L.

Gross beta concentrations show a corresponding increase. There are no corresponding increases in nearby or upgradient wells for WMA-T. These data are under review for sampling or analysis problems.

Iodine-129. The extent of iodine-129 above the interim DWS in the T Plant area coincides with the tritium and technetium-99 plumes (see Plates 5 and 3 and Figure 6.9-8, respectively). The maximum concentration of iodine-129 detected in this vicinity in FY 1996 was 8.2 pCi/L in well 299-W14-12. The sharp decline in iodine-129 concentration is similar to that of tritium and technetium-99.

Uranium. Few analyses for uranium were performed in the vicinity of T Plant in FY 1996 because most wells showed insignificant levels in previous monitoring. Wells monitored near the single-shell tanks for RCRA compliance are sampled for gross alpha measurements, which would show an increase if uranium contamination appeared. Uranium was detected above the proposed MCL in only one well in the T Plant area; well 299-W11-14 contained 74 μg/L of uranium in the single FY 1996 sample. This well is located immediately northwest of T Plant, and the source of the uranium has not been determined (Figure 6.9-9).

Nitrate. Much of the northern part of the 200-West Area continued to contain nitrate at concentrations in excess of the 45-mg/L MCL (see Plate 4). The nitrate contamination is more widespread than the iodine-129/tritium/technetium-99 plumes discussed above. Maximum concentrations in this part of the 200-West Area in FY 1996 ranged up to 1,100 mg/L in well 299-W10-1, which is located west of the WMA-T single-shell tank farm near the 216-T-7 and 216-T-32 cribs. A large quantity of nitrate was discharged in this area. In spite of the large amount of nitrate discharged during T Plant operations, the major impact of nitrate in well 299-W10-1 was not seen until the 1980s, as shown in Figure 6.9-10. Nitrate was also found at elevated levels farther south near the WMA-TX-TY single-shell tank farms. The area of low nitrate north of the WMA-T tank farm corresponds to the area of low concentration of other constituents discussed above.

Chromium. Chromium contamination continues to be found above the 50-μg/L state MCL and the 100-μg/L federal MCL in the T Plant area (Figure 6.9-11). Chromium is above the MCL in filtered samples from the area north and west of the WMA-T single-shell tank farm, where the maximum average annual concentration detected in FY 1996 was 290 μg/L in well 299-W11-27. Chromium concentrations in this well rose in FY 1996 along with tritium, technetium-99, iodine-129, and nitrate. Chromium was also above the MCL in well 299-W14-12, located east of the WMA-TX-TY tank farms, though at lower levels than in 1995. The 216-T-28 crib, located to the north of well 299-W14-12, is reported to have received miscellaneous decontamination waste from T Plant. Because hexavalent chromium was frequently used in decontaminating systems containing uranium, that crib is a likely source. Chromium is also above the MCL in wells downgradient of those discussed above, northeast of T Plant, though a number of the wells were not sampled for chromium in FY 1996 because of budget constraints and the slow-moving nature of the plumes. Dashed contours shown in the area northeast of the 200-West Area in Figure 6.9-11 are based on past data.

Fluoride. Fluoride was detected above the primary 4-mg/L MCL and the secondary 2-mg/L MCL near the T Plant waste-disposal facilities. The fluoride contamination was found in a number of wells

in the vicinity of the WMA-T single-shell tank farm (Figure 6.9-12). Fluoride was also found above the MCL in well 299-W15-4, located near the 216-T-19 crib south of the WMA-TX-TY single-shell tank farms. The concentration detected in the single sample from that well in FY 1996 was 7.8 mg/L. The correlation of high fluoride with high nitrate in this vicinity suggests decontamination solutions from T Plant operations are a possible source.

Chlorinated Hydrocarbons. Although the bulk of the carbon tetrachloride plume in the 200-West Area is known to have originated from liquid waste-disposal facilities in the vicinity of the Plutonium Finishing Plant, a second source may exist in the vicinity of T Plant. According to Rohay et al. (1994), the source could be carbon tetrachloride that was dissolved in the 242-T evaporator overhead and discharged from 1973 to 1976 to the 216-T-19 crib. An increase in carbon tetrachloride concentrations west of T Plant may be related to that disposal. The carbon tetrachloride distribution in the 200-West Area is shown in Figure 6.9-13. Trichloroethylene is also found at levels above the MCL in the vicinity of T Plant (Figure 6.9-14). It is difficult to ascertain if sources in the T Plant vicinity are contributing to the trichloroethylene contamination or if the only source is upgradient near the Plutonium Finishing Plant.

6.9.3.2 REDOX Plant

Groundwater plumes originating in the vicinity of the REDOX Plant and its associated waste-storage and -disposal facilities include tritium, iodine-129, nitrate, chromium, and trichloroethylene. Although technetium-99 is detected, levels were below the interim DWS in FY 1996. The technetium-99 plume is mainly of interest to aid the evaluation of impacts on groundwater from the WMA-S-SX single-shell tank farms. Although in past years a few wells near REDOX disposal facilities contained strontium-90 at levels above the interim DWS, all levels reported in FY 1996 were below the interim DWS. Two facilities in this vicinity, the WMA-S-SX tank farms and the 216-S-10 facility, have RCRA monitoring requirements and are discussed separately. Other facilities, however, appear to have produced the major part of the groundwater contamination.

Tritium. The movement of tritium plumes in the 200-West Area was consistent with previous observations (see Plate 3). The plume, extending from near the REDOX Plant in the southern part of the 200-West Area, continued to expand slowly to the east and north. Tritium was found above the interim DWS upgradient of the REDOX Plant, as far as the 216-S-25 crib. The concentrations of tritium detected in well 299-W22-9, which contains the maximum tritium concentrations in the 200-West Area, decreased since 1977 to the FY 1996 average annual concentration of 1,100,000 pCi/L (Figure 6.9-15). Thus, tritium was not detected above the 2,000,000-pCi/L DCG in any part of the 200-West Area. Water levels are declining in this well and it is becoming increasingly difficult to sample. An attempt will be made to rehabilitate the well in FY 1997.

The tritium plume from the 200-West Area is approaching US Ecology's low-level radioactive waste-disposal facility. The maximum concentrations (3,780 to 4,044 pCi/L) of tritium detected in groundwater at that facility in FY 1996 were in well 699-35-59 (US Ecology well no. 13). This well is located on the western (upgradient) side of the facility. Well 699-35-57 (US Ecology well no. 3),

which is on the eastern side of the facility, contained concentrations of tritium nearly as high, with a maximum of 3,984 pCi/L in FY 1996. These data were provided by US Ecology and are not included in Appendix H or shown in Plate 3.

Movement of the REDOX Plant tritium plume is expected to be slow because of the low-permeability sediments in this area and the dissipation of the groundwater mound beneath the 200-West Area since the reduction of effluent discharge.

Iodine-129. The highest average annual iodine-129 concentration observed on the Hanford Site in FY 1996 was 66 pCi/L, found in well 299-W22-9. This is also the same well in which the maximum tritium concentration was found in the 200-West Area. The iodine-129 plume from the 200-West Area (see Plate 5) extends into the 600 Area to the east and coincides with the tritium plume originating near the REDOX Plant (see Plate 3). This iodine-129 plume and the iodine-129 contamination originating farther north near U Plant appear to coalesce downgradient and become indistinguishable at the current level of monitoring detail.

Uranium. Uranium was found above the proposed MCL to the west of the REDOX Plant (see Figure 6.9-9). The uranium contamination extends from areas upgradient of the technetium-99 plume toward the REDOX Plant. The highest uranium concentration detected in FY 1996 in the vicinity of the REDOX Plant was 86 μg/L in the single sample from well 299-W23-7. This value is considerably higher (5.0 μg/L) than the previous sample collected in 1994. The cause of the increase is unclear. As discussed in relation to the WMA-S-SX single-shell tank farms, the distribution of uranium does not generally correspond to the technetium-99 distribution; thus indicating different sources.

Nitrate. Nitrate was detected in 1995 above the MCL in only one well (299-W22-20) in the vicinity of the REDOX Plant (the FY 1996 average was 60 mg/L) (see Plate 4). Well 299-W22-20 is located near the 216-S-20 crib, which received laboratory waste from the 222-S building. The trend plot for nitrate in well 299-W22-20 indicates that contamination has been present for at least 35 years (Figure 6.9-16). In past years, nitrate was detected above the MCL in wells near the 216-S-25 crib and the WMA-S-SX single-shell tank farms.

WMA-S-SX RCRA Assessment Parameters. As discussed in Section 4.4, spectral gamma logging at the WMA-S-SX single-shell tank farms in FY 1996 indicated the presence of cesium-137 at depths ranging from 18 to 37 m. As a result of this logging and the high concentrations of technetium-99 in groundwater, Ecology reexamined the groundwater-monitoring program at the unit. This reexamination led to Ecology requiring DOE to initiate a groundwater-assessment-monitoring program according to WAC 173-303-400 and 40 CFR 265.91(a)(2) and (b). Ecology also required that a groundwater-monitoring-assessment plan be prepared and submitted to them. This latter requirement was met by Caggiano (1996a). A detailed account of vadose and groundwater contamination at these tank farms is presented in Chapter 4.0.

pH. Field pH measurements for all wells ranged from 7.9 to 8.1 for FY 1996, with the upgradient and downgradient wells exhibiting the same range. The comparison values of 6.68 and 9.18 were not exceeded.

Specific Conductance. Field measurements of specific conductance in downgradient wells ranged from 207 to 272 μS/cm for FY 1996, while values for upgradient wells ranged from 220 to 263 μS/cm. If values from the initial four quarters for upgradient wells 299-W23-13 and 299-W23-14 are used, the critical mean is 532.8 μS/cm. Using this value, there were no exceedances of the critical mean for specific conductance. However, in putting the site into assessment, Ecology computed a new critical mean using only southernmost upgradient well 299-W23-14, which had lower specific conductance values during the initial four quarters. When using this new 248.6-μS/cm critical mean, there were exceedances in well 299-W22-39 in February (256 μS/cm) and August (256 μS/cm); in well 299-W22-45 in February (272 μS/cm) and August (271 μS/cm); and in well 299-W23-15 in August (250 μS/cm). It should be noted that specific conductance in upgradient well 299-W23-14 has risen steadily since early 1995 and that if the critical mean were redetermined using current values, there would be no exceedances.

The origin of the elevated specific conductance, one of the major factors sending the site into assessment, is problematical; however, some light may be shed on this subject by the ongoing assessment study. The historically high specific conductance in downgradient wells 299-W22-39, 299-W22-46, and 299-W23-15 was not reflected in upgradient well 299-W23-14. However, specific conductance in wells 299-W22-39 and 299-W22-46 has decreased continuously since the start of monitoring in 1991-1992. Specific conductance in well 299-W23-15 peaked in 1993 and has declined since that time (Figure 6.9-17). On the other hand, specific conductance in downgradient well 299-W22-45 and upgradient well 299-W23-14 increased since 1994. This is not a straightforward relationship, however; with a southwest-flow direction, the appropriate upgradient well for 299-W22-45 would appear to be 299-W23-13, which did not reveal an increase in specific conductance during this period. These complex relationships can only be resolved when there is a better understanding of groundwater-flow directions and flow rates at the site.

TOC. Reported values for TOC ranged from 237 to <300 μg/L; none exceeding the comparison value of 535 μg/L.

TOX. Reported values for TOX ranged from <6.9 to 22.8 μg/L for FY 1996. The 22.8 μg/L for the August 1996 sampling of upgradient well 299-W23-14 and 22.1 μg/L for the August 1996 sampling of downgradient well 299-W23-15 exceed the 16.2-μg/L comparison value.

The higher TOX concentrations reported for the August 1996 samplings are almost surely a result of the southward and eastward migration of the carbon tetrachloride plume resulting from historical discharge activities at the Plutonium Finishing Plant. The location of this plume and its relationship to the WMA-S-SX single-shell tank farms was shown in Figure 6.9-13.

Technetium-99 and Gross Beta. As late as 1994, technetium-99 was found above the interim DWS in a plume extending southeasterly from the vicinity of the WMA-S-SX single-shell tank farms; however, since that time, levels have declined. FY 1996 levels were less than the interim DWS for all samples from this plume (see Figure 6.9-8). The distribution of technetium-99 is different from tritium, iodine-129, and uranium, discussed below. The highest technetium-99 concentrations are found near the eastern half of the WMA-S-SX tank farms and near the 216-S-1 and 216-S-2 cribs. The

technetium-99 contamination extends to the southeast, and can be detected beyond the 200-West Area boundary, though at levels far below the interim DWS. It is possible, however, that other sources such as the 216-S-13 crib contributed to the downgradient parts of the plume. Technetium-99 was generally not measured in groundwater samples before approximately 1986 in this vicinity; nevertheless, data from gross beta measurements can help in the interpretation because the trends for gross beta and technetium-99 generally correlate where the measurements overlap. The technetium-99 measurements are typically a factor of ~3 to 6 times higher than gross beta measurements for the same sample, though some scatter occurs. The technetium-99 and gross beta trend plots for selected wells near the WMA-S-SX tank farms are shown in Figures 6.9.18 and 6.9-19. The gross beta trends show a sharp spike in values in the second half of the 1980s. This spike appears to occur slightly earlier in the northernmost wells and is distinctly later in well 299-W23-15, located south and west of the tank farms, where the peak is found in early 1993. The gross beta measurements appear to be mainly attributable to the presence of technetium-99.

The origin and distribution of technetium-99 and tritium beneath the WMA-S-SX tank farms are discussed in Chapter 4.0. The determination of whether groundwater contamination detected near these single-shell tanks is from the tanks, or from very similar waste disposed to nearby cribs, has been a long-term problem. In these tank farms, the answer may be found in the fractionation of uranium, technetium-99, and tritium within the waste.

Technetium and uranium have similar transport properties; therefore, differences in the ratio are probably indicative of different sources. Available data indicate that the ratios are high (>300) in tank waste and on average <0.1 for waste disposed to the adjacent cribs. The reason for the higher ratios in the tank waste is the partition of uranium into the solid phases, both as hydroxides and phosphates. Tritium, on the other hand, is removed from the tanks by evaporation of water, and the condensate from this evaporation is disposed in the adjacent cribs, thus depleting the tanks and enriching the discharge to the cribs with tritium.

A large area under the eastern portion of the WMA-S-SX tank farms is underlain by groundwater with technetium-99-to-uranium ratios >50 (see Figure 4.4-1). In addition, the areas with high ratios tend to have high technetium-99 and low tritium activities. Thus, there is a strong possibility that the elevated technetium-99 at these tank farms is a result of groundwater contamination from leaking tanks, and the elevated tritium is a result of contamination by the adjacent cribs.

Cesium-137. One sample collected in 1994 from well 299-W23-7, located in the WMA-SX single-shell tank farm, contained 21.8 pCi/L of cesium-137. This well was sampled in FY 1996 to confirm the presence of cesium-137 in groundwater at this location. In March 1996, 18 pCi/L of cesium-137 were detected in this well. Little or no cesium-137 was found in filtered samples collected at the same time, indicating that the contamination is dominantly sorbed to particulate matter and, thus, has a low mobility in groundwater. The significance of this low concentration of cesium-137 is that it suggests a small impact to groundwater from unintentional releases in the tank farm. It is unknown, however, if the impact results from downward transport in the well bore, downward transport in the annulus around the well, or more pervasive downward migration within the vadose zone. Well 299-W23-7 is

the only well in this area with a definitive detection of cesium-137 in FY 1996. Information on cesium-137 in the vadose zone beneath the WMA-S-SX tank farms is discussed in Chapter 4.0.

216-S-10 Pond and Ditch RCRA Parameters. Groundwater quality, drinking water, or site-specific parameters did not exceed the DWSs during FY 1996, except for chromium and pH. The chromium exceedance was in upgradient well 299-W26-7, which suggests that the elevated chromium concentration may be from upgradient sources, not the 216-S-10 facility.

Statistical evaluations of 216-S-10 facility data for the past year consisted of the required comparisons of indicator parameters between upgradient and downgradient wells for any indication of underlying contamination. Statistical methods and results are described in Appendix B. The contamination indicator parameters for this facility include specific conductance, field pH, TOC, and TOX.

The pH in the June 1996 sample from well 299-W26-8 was higher than the secondary MCL. The mean result was 8.8. The result was still within the critical range for indicator parameter evaluations (see Appendix B).

In the past, well 299-W26-8 showed levels of gross alpha slightly elevated over other 216-S-10 monitoring wells (Figure 6.9-20) but gross alpha levels appear to be declining. Well 299-W26-8 is an upgradient well, which suggests the 216-S-10 facility is probably not the source of the elevated alpha levels. The source may be the 216-U-10 pond (also known as U Pond [now decommissioned]), which is upgradient of the 216-S-10 facility and known to have received radioactive wastewater.

There were several exceedances of the indicator parameters. In both the December 1995 and June 1996 sampling events, the critical mean for specific conductance was exceeded in well 299-W27-2, the well that monitors the base of the unconfined aquifer system. Because this well is screened at the base of the aquifer and there are no corresponding upgradient wells, the critical mean does not apply to this well.

In the June 1996 sampling event, the critical mean for specific conductance was exceeded at well 299-W26-12, with a result of 308 μS/cm. Verification sampling was conducted in October 1996. Two sets of field readings with different instruments were obtained, and duplicate samples were collected for laboratory analysis. Results of this verification sampling indicated that the specific conductance exceedance in June was caused by errors in field measurement.

The limit of quantitation was used as the critical mean for TOX at the 216-S-10 facility. TOX was detected in upgradient well 299-W26-8 in June; it was determined that it is no longer appropriate to use the limit of quantitation as the critical mean for this site. The two upgradient wells will be sampled quarterly for one year to determine a critical mean.

6.9.3.3 U Plant

As discussed below, groundwater pump-and-treat remediation is taking place in the vicinity of U Plant. Because of the effects of the remediation and injection of treated water into the aquifer, the

plume maps in this report are somewhat generalized in the area of system influence. The discussion below includes contamination from the facilities in the vicinity of U Plant, including contamination currently being remediated under CERCLA, and also includes the specific reporting requirements for RCRA monitoring at the 216-U-12 crib and WMA-U single-shell tank farm.

Waste Indicators for WMA-U Single-Shell Tank Farm. The WMA-U single-shell tank farm is currently under a detection-level monitoring program. There were several critical mean exceedances for contamination indicator parameters pH and TOX during the fiscal year; however, given the flux in groundwater-flow directions and resultant uncertainty in upgradient-downgradient distinctions, the meaning of the exceedances is somewhat uncertain. The critical means are discussed in Appendix B.

Field pH measurements for all wells ranged from 7.3 to 8.8 for FY 1996. The upper comparison value of 8.59 was exceeded in well 299-W19-31 in February 1996 (pH = 8.7) and May 1996 (pH = 8.8). The lower comparison value was exceeded in well 299-W19-32 in November 1995 (pH = 7.3). A small peak in pH values apparently passed through wells 299-W19-31 and 299-W19-32 during FY 1996, with samples from 299-W19-32 reaching a pH of 8.2 in February 1996. The pH exceedances were apparently the result of some changing groundwater-flow directions. They were of short duration and do not appear to be significant.

Reported TOX values ranged from 25 to 416 μg/L for FY 1996. The 416-μg/L value reported for the August 1996 sampling of well 299-W18-30 exceeded the comparison 241.3-μg/L value. There was a general increase in TOX values across the site; with northernmost well 299-W18-30 having the highest values. The increasing TOX values are, in all probability, a result of carbon tetrachloride. The pattern of TOX concentrations is consistent with increased encroachment by the Plutonium Finishing Plant's carbon tetrachloride plume and the return of groundwater-flow directions to an east-southeasterly direction.

Technetium-99 and gross beta both showed significant increases in downgradient well 299-W19-31, with gross beta reaching 147 pCi/L and technetium-99 reaching 782 pCi/L in the August 1996 sampling (Figure 6.9-21).

The increase in technetium-99 and gross beta in well 299-W19-31 corresponds closely to the change in groundwater-flow direction back to an easterly direction and probably is related to that change. Historically, the highest technetium-99 activities occurred in well 299-W19-12. Since the start of RCRA monitoring, the highest activities occurred in downgradient well 299-W19-32 in 1993, coincident with the last major discharge to the 216-U-14 ditch and the reversal of groundwater-flow direction. However, activity in well 299-W19-32 declined rapidly in 1994-1995 and remained low.

The relationship between the 1993 increase in technetium-99 and discharge to the 216-U-14 ditch is problematical. If the two are related, there are at least two possibilities. First, the technetium-99 may have been introduced into the groundwater by the effluent discharge or, second, perched water may have moved laterally from the ditch and mobilized vadose-zone contaminants from earlier tank leaks. Singleton and Lindsay (1994) reported that technetium-99 activities in the perched water were quite low, indicating that the ditch effluent is probably not the source. Singleton and Lindsay (1994) also

observed that the perched water beneath the ditch is shallow enough that it could potentially mobilize tank-leak material at the WMA-T single-shell tank farm if it reached that far. A problem with the second possibility is the question of why the much larger 1991 discharge to the ditch did not cause technetium-99 increases at the tank farm. Another possibility is that the coincidence of ditch discharge and technetium-99 increase is accidental, and the technetium-99 increase is due to mobilization by leaking water pipes within the tank farm or some other cause. Whatever the source, contamination at well 299-W19-32 would have been pushed to the northwest, beneath the tank farm, when the groundwater-flow direction reversed and may well be showing up in well 299-W19-31 now that groundwater resumed its normal flow direction.

Waste Indicators for 216-U-12 Crib RCRA Monitoring. The groundwater below the 216-U-12 crib has been monitored and analyzed as part of the RCRA program since September 1991. The site-specific waste indicators currently selected for the crib's assessment monitoring include nitrate, tritium, gross alpha, gross beta, technetium-99, and iodine-129. Nitrate, technetium-99, iodine-129, and tritium are detected repeatedly and are being investigated to determine whether the crib is the source. Initial data evaluation indicates that the crib may be a source of this contamination. A final assessment report will be published in early 1997.

Waste indicator parameters (specific conductance, TOX, TOC, and pH) are monitored at the 216-U-12 crib as part of RCRA assessment monitoring. Of these, specific conductance exceeded the 457.8-μS/cm critical mean in downgradient wells 299-W22-41, 299-W22-42, and 699-36-70A since groundwater monitoring began (Figure 6.9-22). Nitrate is the only constituent with significantly consistent and elevated concentrations in the downgradient wells (Figure 6.9-23) and, as such, is the most significant contributor to the elevated specific conductance. Documented releases of nitric acid waste to the crib during its operation substantiate this interpretation (Jensen et al. 1990).

Uranium. The highest uranium levels in groundwater occurred near U Plant in 1995 in wells downgradient from the 216-U-1 and 216-U-2 cribs and adjacent to the 216-U-17 crib (see Figure 6.9-9). Uranium concentrations in wells near the 216-U-1 and 216-U-2 cribs have been decreasing over the past 7 to 8 years. A trend plot of uranium concentrations in samples from well 299-W19-3, immediately downgradient from the cribs, is shown in Figure 6.9-24. The uranium levels in this well decreased considerably since the maximum measured in 1986 but remained relatively stable at levels greater than the proposed MCL since 1990. The maximum average annual concentration detected near U Plant in FY 1996 was 2,800 μg/L in a sample from well 299-W19-37 (see Figure 6.9-9). This is a new well, installed to monitor the remediation. The uranium concentrations for several wells in the U Plant vicinity represent dose values greater than the DCG. Assuming natural isotopic abundance, a uranium concentration of 790 μg/L represents the 100-mrem/yr dose equivalent for ingestion of drinking water. The uranium plume extends into the 600 Area to the east.

Technetium-99. Technetium-99 typically followed uranium throughout much of the fuel cycle. Thus, a sizable technetium-99 plume is associated with the 216-U-1, 216-U-2, and 216-U-17 cribs in essentially the same location as the uranium plume (see Figures 6.9-8 and 6.9-9). The extent of the plume is greater because of the somewhat higher mobility of technetium-99 in the aquifer. The maximum average annual technetium-99 concentration associated with this plume in FY 1996 was

21,000 pCi/L, found in well 299-W19-30 (see Figure 6.9-8). This is similar to levels detected in previous years. Technetium-99 in the vicinity of the 216-U-12 crib exhibits a distribution similar to nitrate. Time/concentration plots reflect a consistent, low-volume source emanating from below the crib.

Iodine-129. Iodine-129 was found above the interim DWS in the immediate vicinity of the 216-U-1 and 216-U-2 cribs (see Plate 5). The maximum average annual concentration of iodine-129 detected in this vicinity was 3.7 pCi/L in the single sample from well 299-W19-3. In FY 1996, 3.2 pCi/L of iodine-129 were detected in a sample from well 299-W19-2, which is located adjacent to the 216-U-8 crib that received process condensate and stack drainage from U Plant operations. Downgradient, the iodine-129 plumes from U Plant operations become indistinguishable from the REDOX Plant plume (as discussed in Section 6.9.3.2).

Nitrate. Some of the highest onsite nitrate concentrations in FY 1996 continued to be found in wells east of U Plant near the 216-U-17 crib (see Plate 4). The maximum average annual concentration detected was 830 mg/L in well 299-W19-26. Nitrate was observed in wells near this crib before February 1988 when the crib went into operation. The main source of the nitrate is believed to be wastes disposed to the 216-U-1 and 216-U-2 cribs. These cribs received >1,000,000 kg of nitrate during their operation from 1951 to 1967 (Stenner et al. 1988). Nitrate concentrations in wells located near the 216-U-1 and 216-U-2 cribs west of U Plant continued to decrease, with concentrations in several wells dropping below the MCL. For example, the nitrate concentration in well 299-W19-3 near U Plant decreased to less than the MCL, as shown in Figure 6.9-25. The distribution of the highest concentrations in the nitrate plume is similar to the technetium-99 plume, which would indicate a common source. Elevated nitrate concentrations are also observed farther south near the 216-U-8 and 216-U-12 cribs. The nitrate distribution near the 216-U-17 crib is being affected by the pump-and-treat remediation discussed in Section 6.9.4.1.

Nitrate concentrations downgradient of the 216-U-12 crib continued to exceed the 45-mg/L MCL and are greater than 10 times the average background value established in the upgradient well. The elevated concentration trends (see Figure 6.9-23) in the three downgradient wells remained above the MCL since the monitoring began. Vadose zone modeling and studies (see Chapter 4.0) show that liquid travel times to the aquifer could take many years. Given these considerations, the effluent disposed during the last years of crib operation is still seeping into the aquifer but at a slower rate then when a driving head was available. It is believed that these slugs and seeps of residual effluent are still moving downward and contaminating the aquifer, even though effluent disposal ceased in 1988. The fluctuations in the concentration are a result of this noncontinuous effluent migration and heterogeneities within the aquifer. Concentration trends are expected to decline as the vadose zone drains.

Monitoring at downgradient well 299-W22-40 did not detect any nitrate contamination; it is most likely outside the flow path of the 216-U-12 crib nitrate plume. This is supported by mapping flow lines on the water-table map. The spatial relationship of the monitoring network, with respect to the detected contamination, indicates that the current source is already restricted and of relatively low volume and high concentration. This is expected because effluent disposal ceased over 5 years ago.

Two years of data are now available for the new RCRA assessment well (699-36-70A). This well was installed to determine the extent of contaminants migrating downgradient and presumed to have leaked into the aquifer from the 216-U-12 crib. Nitrate also was consistently elevated above the MCL. These data substantiate preliminary travel-time estimates for a plume emanating from this crib. These estimates will be presented in detail in the assessment report (to be published in FY 1997). What is important to note is that this new well provides data that will change the current nitrate plume interpretation. These new data significantly enlarge the 100-mg/L contour to a much greater area then previously mapped (see Plate 4). It is possible that the crib contributed a significant portion of nitrate to the groundwater (Jensen et al. 1990) and is indistinguishable from the regionally extensive nitrate plume.

Tritium. The long-term concentration trend for tritium in well 299-W22-42 could be inferred to be a contaminant released from the 216-U-12 crib, but tritium results collected in remediated well 299-W22-23 (located upgradient) suggest that there more likely is an upgradient source from REDOX Plant operations (Figure 6.9-26). Well 699-36-70A shows 300,000+ pCi/L tritium values, well over background and the interim DWS, and appear to be attributable to REDOX Plant sources. Tritium will be evaluated as part of the 216-U-12 crib assessment. Tritium is a documented component of the effluent disposed to that crib.

Trichloroethylene. A relatively low-level trichloroethylene plume can be seen in groundwater near U Plant (see Figure 6.9-14). The maximum average annual concentration of trichloroethylene found in FY 1996 in this plume was 9.9 μg/L in well 299-W19-35, located generally downgradient of the U Plant cribs. This plume extends to the east, beyond the 200-West Area boundary.

6.9.3.4 Plutonium Finishing Plant

Contamination from volatile organic compounds, predominantly carbon tetrachloride, forms the major plumes discussed in this section. Migration of plutonium contamination from the vadose zone is of concern because of the large quantities disposed in the area and the presence of complexing agents that could enhance the mobility. Nitrate contamination is also present. The only facilities near the Plutonium Finishing Plant with RCRA groundwater-monitoring requirements are the burial grounds in LLWMA-4. These are not believed to contribute to groundwater contamination and are discussed with the other LLWMAs below. Remediation of volatile organic compounds in groundwater and the vadose zone is being undertaken in this area.

Plutonium and Americium. Plutonium-239, -240 and americium-241 were detected at low levels (up to 8.3 and 5.9 pCi/L, respectively) in 1990 and 1991 in well 299-W15-8, which monitors the 216-Z-9 trench. This trench received a large burden of transuranic wastes from Plutonium Finishing Plant liquid effluent streams. That well has not been monitored for transuranic wastes since 1991 because the water level dropped below the well screen. The origin of the transuranic contaminants in the well is unclear but may be associated with poor-quality well completion and, thus, may be very localized (Rohay et al. 1994). Other wells in the area showed no detectable plutonium contamination in FY 1996.

Rohay et al. (1994) discuss the potential mobilization of plutonium and americium isotopes in the organic liquid phase discharged to ground in the vicinity of the Plutonium Finishing Plant. A liquid phase, containing carbon tetrachloride and tributylphosphate, was used in the purification process to complex and remove plutonium from the aqueous phase. The distribution of transuranic contaminants in the vadose zone suggests an increased mobility because of their transport in the nonaqueous-phase liquid. Vadose transport of transuranics near the Plutonium Finishing Plant is discussed in Section 4.4.3.2.

Nitrate. The 216-Z-9 trench received an estimated 1,300,000 kg of nitrate-containing chemicals over the course of its operation from 1955 to 1962. Other liquid waste-disposal facilities associated with the Plutonium Finishing Plant received smaller but significant amounts of nitrate. There is, thus, a nitrate plume originating in this area, with levels in FY 1996 ranging up to a maximum average annual concentration of 220 mg/L in well 299-W18-1 (see Plate 4). This nitrate plume extends toward T Plant and contributes to the T Plant contamination discussed above.

Chlorinated Hydrocarbons. Carbon tetrachloride contamination was found in the unconfined aquifer system beneath much of the 200-West Area (see Figure 6.9-13). The contamination is believed to be from pre-1973 waste operations associated with the Plutonium Finishing Plant. The maximum average annual carbon tetrachloride concentration detected in the 200-West Area in FY 1996 was 4,300 μg/L in well 299-W15-30. The MCL for carbon tetrachloride is 5 μg/L.

The carbon tetrachloride distribution in the 200-West Area groundwater changed slowly since the presence of the contaminant plume was first noted. Figure 6.9-27 shows the trends over time in carbon tetrachloride concentrations for wells located around the plume. Well 699-39-79, to the west of the disposal areas, shows a major increase during 1987 and 1988, indicating arrival of the bulk of the plume at that time. Since 1988, concentrations in well 699-39-79 declined slowly. Well 299-W7-4, to the north, shows an increase in concentration in recent years, though the trend in well 299-W6-2, also to the north, is fairly level. Concentrations in well 299-W18-21, south of the disposal areas, exhibit a considerable increase since approximately 1992. Concentrations in well 699-38-70, on the eastern edge of the plume, remained relatively stable in 1995. Carbon tetrachloride concentrations in the central part of the plume declined in recent years. The trend plot in Figure 6.9-28 for well 299-W15-16 illustrates this decline from concentrations >8,000 μg/L in the late 1980s to values ranging from 3,400 to 5,170 μg/L in FY 1996.

The extent of carbon tetrachloride contamination is poorly constrained in several directions. The greatest uncertainty lies in the extent of contamination to the southwest and east. The apparent division into two lobes on the eastern side of the 200-West Area may be related to discharge of water from the laundry facilities and steam plant but the data available for this area are insufficient to determine if this is the case or if in fact two separate lobes actually exist. In addition, there is considerable uncertainty regarding the extent of contamination in deeper parts of the aquifer.

Ford (1995) provides some information on the vertical distribution of carbon tetrachloride in the vicinity of U Plant, showing the presence of carbon tetrachloride at greater than the MCL in a zone over 60 m below the water table in one well (299-W19-34A). This contamination was found in an

interval below the lower mud unit of the Ringold Formation (see Figure 3.2, Unit 8). The maximum depth of contamination was not determined at other locations.

The spreading of the 200-West Area carbon tetrachloride plume to the west, and now apparently to the south as well, is thus somewhat unexplained because it is counter to the apparent groundwater-flow direction. Changes in groundwater flow since the decommissioning of the 216-U-10 Pond (also known as U Pond) and the shift in wastewater disposal to newer facilities may influence the plume location and configuration. Another potential influence is the continued spreading of the carbon tetrachloride above the water table, in either the liquid or the vapor phase. Free-phase liquid carbon tetrachloride above and, possibly, below the water table could provide a continuing source of contamination. Subsurface investigations performed in association with the ongoing expedited response action and the Volatile Organic Compounds-Arid Integrated Demonstration or the CERCLA 200-ZP-1 Operable Unit investigation so far failed to conclusively demonstrate the presence of free-phase liquid, though the extremely high soil-gas concentrations (tens of thousands of micrograms per liter) found at several locations suggest the presence of free-phase liquid. Because of the difficulties and high costs associated with subsurface access, the investigation was relatively limited in scope, and any conclusions concerning the presence of free-phase liquid will, of necessity, be based on indirect evidence. The contaminant concentrations and distribution suggest that nonaqueous-phase liquid is probably present above and below the water table.

In addition to carbon tetrachloride, lesser concentrations of trichloroethylene and chloroform were found in the same area. Trichloroethylene is slightly above the MCL near the Plutonium Finishing Plant. The source is presumably disposal in the plant area, but the downgradient end of the plume could also be impacted by disposal near T Plant. The highest annual average concentration of trichloroethylene found near the Plutonium Finishing Plant in FY 1996 was 6.8 μg/L in well 299-W18-1 (see Figure 6.9-14).

The highest annual average chloroform level in FY 1996 was 250 μg/L in well 299-W15-39. The chloroform plume is associated with the carbon tetrachloride plume. The origin of the chloroform is unknown but it is strongly suspected to be a degradation product of carbon tetrachloride. In the past, septic drainage fields operated in the area close to where the chloroform maximum was measured, so anaerobic bacterial degradation processes are strongly indicated. The MCL for chloroform is 100 μg/L (total trihalomethanes), which is 20 times higher than that for carbon tetrachloride.

6.9.3.5 Low-Level Waste Management Areas

Several low-level burial grounds are monitored in the 200-West Area to meet RCRA requirements. The burial grounds are grouped into LLWMAs for RCRA monitoring purposes. Because of their extent across the area and the evidence that they are not contributing to groundwater contamination, the LLWMAs are discussed separately from the source area previously described.

LLWMA-3 Groundwater Chemistry. Carbon tetrachloride and nitrate are consistently above the MCLs at LLWMA-3. The elevated values can be attributed to contaminant plumes originating to the south of LLWMA-3 (see Figure 6.9-13 and Plate 4). Trichloroethylene exceeded the 5-μg/L MCL in

upgradient wells 299-W10-19, 299-W10-20, and 299-W10-21. There appears to be no groundwater contamination directly attributable to LLWMA-3, and there were no exceedances of the critical mean values for indicator parameters. See Appendix B for a discussion of the statistical analysis and critical means for LLWMA-3.

LLWMA-4 Groundwater Chemistry. There appears to be no groundwater contamination directly attributed to LLWMA-4. The samples from the downgradient wells did not exceed the critical means established for the contamination indicator parameters (see Appendix B). Concentrations of carbon tetrachloride above the DWSs were found in most wells in FY 1996. As discussed above, the source of carbon tetrachloride is past disposal of waste to liquid waste facilities near the Plutonium Finishing Plant. The TOX levels in the groundwater are historically high beneath LLWMA-4, and these levels are related to the carbon tetrachloride plume. The upgradient wells are generally higher than the downgradient wells. Significant changes in groundwater chemistry are expected when the full impact of the 200-ZP-1 Operable Unit pump-and-treat program becomes apparent.

Nitrate also exceeded the MCL in wells 299-W15-15, 299-W15-16, 299-W15-18, 299-W15-19, 299-W15-24, 299-W18-21, and 299-W18-24. This is most likely related to the nitrate plume emanating from the vicinity of the Plutonium Finishing Plant (see Plate 4). Well 299-W18-21 had been showing an increase in nitrate and carbon tetrachloride (Figure 6.9-29), and the values are considerably above those from nearby wells. The values for both constituents declined in FY 1996; however, a confirmed trend cannot be established.

6.9.3.6 200 Areas Effluent Treatment Facility

Predictive modeling of the discharge from this facility (also known as C-018H) indicated that tritium would first reach groundwater ~1 year from the beginning of discharge and would first appear in a hypothetical well 100 m downgradient from the facility in ~9 years (Lu et al. 1993). A groundwater-monitoring network was established and a monitoring plan was developed in 1995 to track tritium-bearing effluent in groundwater (Davis et al. 1996).

Operation of this disposal site began in November 1995, and elevated tritium activities were first observed in groundwater samples from monitoring well 699-48-77A in July 1996. By October 1996, tritium activity in this well had increased to 450,000 pCi/L. Concomitantly, concentrations of sulfate and calcium rose in this well because the clean water apparently leached natural components from the sediments beneath the facility. Groundwater monitoring at this disposal site is currently focusing on the tracking of tritium and in coincident changes in other constituents.

6.9.4 Summary of Remediation Effects

6.9.4.1 200-UP-1 Operable Unit

The pump-and-treat system for this operable unit is located on the north side of the 216-U-17 crib. The system was constructed to contain and treat elevated concentrations of uranium and technetium-99 in groundwater of this operable unit. Phase I pump-and-treat operations commenced September 25,

1995, using one extraction and one injection well, pumping at a rate of 190 L/min. Previous operations consisted of an ~57-L/min treatability test conducted from March 1994 to September 1995. For more detailed information about operations over the last year, refer to Myers et al. (1996). Figure 6.9-30 is a plan view of the site, showing facilities and well locations. It should be noted that pump-and-treat remediation was also performed in 1985 near the 216-U-1 and 216-U-2 cribs (Baker et al. 1988). Treated water from this remediation system was discharged to the 216-S-25 crib.

Contaminant Removal and Overall Effectiveness. The treatment system uses an ion-exchange medium composed of Dowex 21K™ (Dow Chemical Company, Midland, Michigan) to remove uranium and technetium-99 from the groundwater. Following ion-exchange treatment, in-line liquid-phase granular activated carbon is used to remove carbon tetrachloride. An overall contaminant-removal efficiency of >99% was achieved for both uranium and technetium-99. Removal efficiency is not reported for carbon tetrachloride because it is not a system performance criterion. Since initiation of pump-and-treat operations in March 1994 (treatability test), >108 million L of water have been treated, resulting in removal of 3.4 kg of technetium-99, 39.2 kg of uranium, and 7.6 kg of carbon tetrachloride (Table 6.9-1).

During FY 1996, technetium-99 concentrations increased significantly at the extraction well, from the 1,750-pCi/L level reported when Phase I activities were initiated to a high of 6,140 pCi/L. Following this concentration peak, a gradual downward trend of influent technetium-99 concentrations was observed (Figure 6.9-31). The volume of groundwater treated and the mass of contaminants removed for technetium-99, uranium, and carbon tetrachloride are summarized in Table 6.9-1.

Uranium concentrations varied throughout the year, ranging from 385 to 158 mg/L, trending downward until recently, as shown in Figure 6.9-32. Carbon tetrachloride levels also varied over the year, trending upward (based on field-screening data) from a low of 30 to 200 μg/L, as shown in Figure 6.9-33. During the first quarter of FY 1996, carbon tetrachloride concentrations were 29 to 47 μg/L, while values of 74 to 200 μg/L were reported for the fourth quarter.

Water-Level Impact and Capture-Zone Analysis. Water levels in the area of the pump-and-treat operations are affected by extraction and injection activity, as well as a regional water-level decline, resulting from decay of the residual 216-U-10 pond mound. The mound in this area appears to be declining at ~0.8 m/yr (Myers et al. 1996). Modeling indicates that most of the targeted plume is captured under the current well configuration (Figure 6.9-34), though a small portion may not fall within the capture zone. It is estimated that ~50% of one pore volume was extracted from the high-concentration portion of the plume during FY 1996 (Myers 1996).

Contaminant concentrations at monitoring well 299-W19-29, near injection well 299-W19-36, are decreasing (Figure 6.9-35), as expected because of the injection of treated water. At well 299-W19-40, located ~83 m downgradient from extraction well 299-W19-39, technetium-99 and uranium concentrations are also decreasing.

The midportion of the plume was influenced by both extraction and injection operations. For example, at well 299-W19-37, technetium-99 concentrations decreased from near 18,000 to near 4,000 pCi/L, carbon tetrachloride from ~150 to ~30 μg/L, and uranium from ~4,000 to 2,000 μg/L by the end of September 1996 (Figure 6.9-36).

6.9.4.2 200-ZP-1 Operable Unit

The pump-and-treat system located north of the Plutonium Finishing Plant was implemented as an interim remedial measure to prevent further movement of carbon tetrachloride, chloroform, and trichloroethylene from the high-concentration portion of the carbon tetrachloride plume (2,000- to 3,000-μg/L contour) and to reduce contaminant mass (Freeman-Pollard et al. 1996). The pump-and-treat operations and system are being implemented in a three-phased approach. Phase I operations, which have been terminated, consisted of a pilot-scale treatability test from August 29, 1994 to July 19, 1996. During this operation, contaminated groundwater was removed from one extraction well at a rate of ~150 L/min, treated, and then injected into one injection well. For more detailed information about operations during the treatability test, refer to DOE (1995u).

Phase II operations commenced August 5, 1996 in accordance with Tri-Party Agreement (Ecology et al. 1989) Milestone M-16-04A, pumping at a rate of 568 L/min from three extraction wells and then injecting into one well after treatment. Phase III operations are scheduled for startup August 31, 1997 (Tri-Party Agreement Milestone M-16-04B). Extraction rates at the 6 pumping centers will total 568 to 1,892 L/min, and be injected into a series of 3 to 5 wells. Figure 6.9-37 shows facilities and Phase III well locations.

The following information is summarized from Freeman-Pollard et al. (1996), the first quarterly report released since Phase II operations commenced.

Contaminant Removal and Overall Effectiveness. During the pilot-scale treatability test, ~5.3 million L of groundwater were treated using a liquid granular activated carbon system, removing ~12.15 kg of carbon tetrachloride. Average influent concentrations observed during the test were 1,992 μg/L for carbon tetrachloride (ranging from 1,100 to 3,000 μg/L), 34.4 μg/L for chloroform (ranging from 7.8 to 75 μg/L), and 2.9 μg/L for trichloroethylene (ranging from 0.7 to 4.5 μg/L). The pilot-scale treatability test's removal efficiency was calculated at 99.96% for all contaminants.

The Phase II treatment system uses conventional air stripping and vapor-phase granular activated carbon adsorption technology to remove the volatile organic compounds from the contaminated groundwater. Since initiation of the Phase II interim remedial measure activities on August 5, 1996, ~21 million L of groundwater have been treated, removing 63.7 kg of carbon tetrachloride. Influent concentrations at the westernmost pumping well, 299-W15-33, increased from 2,500 to 4,860 μg/L of carbon tetrachloride. Chloroform and trichloroethylene ranged from 21 to 58 and 1.2 to 8.8 μg/L, respectively.

Water-Level Impact and Capture-Zone Analysis. The baseline water-table map (see Figure 6.9-37) shows hydraulic and contaminant conditions prior to the start of Phase II interim remedial

measure activities. The baseline groundwater-monitoring data indicate that groundwater flow in the vicinity of the Phase II extraction wells is mainly to the northeast. A broad and relatively flat mound characterizes the water table in this area. This mound is a residual groundwater feature from previous surfacewater discharges to U Pond. Water levels appear to be declining in some areas of the mound at a rate up to 0.8 m/yr (Freeman-Pollard et al. 1996).

Since operations began, a groundwater sink started to form around the extraction wells (Figure 6.9-38). The radial distance of the sink is significant, extending beyond well 299-W15-31A. This well is located 124 m south-southwest of well 299-W15-33 and exhibited a water-level change of over 0.3 m (Figure 6.9-39).

A small groundwater mound developed at and near injection well 299-W15-29. Water-level buildup near this well is relatively minor, with increases of ~0.15 m measured in the two monitoring wells 88 m to the south, 699-39-79 and 299-W18-36 (Figure 6.9-40). This estimation does not take into account the regional water-level decline in this area. No obvious water-level change from injection operations was observed at the nearest low-level burial ground well, 299-W18-26.

6.9.5 Compliance Issues

6.9.5.1 WMA-T and -TX-TY Single-Shell Tank Farms

In November 1992, the critical means for field specific conductance were exceeded at these tank farms, triggering them into quality assessment monitoring under interim status regulations. In groundwater, it may not be possible to discriminate between wastes from these tanks versus wastes from the nearby cribs. This may lead to a consolidation of this groundwater quality assessment, in that the two WMAs would be expanded to one unit to determine the concentration and extent of contaminants causing the elevated specific conductance (nitrate and chloride charge balanced by sodium calcium and/or magnesium).

These WMAs comply with the RCRA requirement to have at least one upgradient and three downgradient monitoring wells. Additional wells are used for measurement of water levels as needed. Most of these wells are older carbon steel wells but some are RCRA standard wells constructed for other projects.

As noted in Section 5.4.3.3, the rate of decline in the water table under these WMAs more than doubled since liquid effluent discharges to the ground ceased in June 1995. This implies that recent discharges (i.e., prior to 1995) were still influencing groundwater elevations and, possibly, groundwater chemistry. During this next year, water elevations for each network will be evaluated closely to determine if wells require remediation or replacement to maintain the network's RCRA compliance.

6.9.5.2 WMA-S-SX Single-Shell Tank Farms

Given the current flow direction toward the southeast (see Section 5.4.3.3), the monitoring network completed in 1992 at these tank farms is adequate. However, there is a lack of upgradient wells along

the northern margin of the site. Given the potential for large changes in groundwater-flow directions over the next several years, this should be addressed only if it becomes a problem.

6.9.5.3 WMA-U Single-Shell Tank Farms

The monitoring network completed in 1993 was designed on the basis of a west-to-east groundwater-flow direction. The flow reversal between mid-1993 and late 1995 resulted in flow toward the northwest (see Section 5.4.3), which rendered both upgradient and downgradient coverage inadequate. However, by the time this reversal was recognized, groundwater flow had returned toward the southeast. Under current flow conditions, some downgradient wells may be impacted by the carbon tetrachloride prior to its being detected in the upgradient wells.

6.9.5.4 216-U-12 Crib

Because the groundwater-flow direction is unchanged, the wells are appropriately located for RCRA assessment monitoring to monitor releases and assess contaminant discharges from this crib. The original monitoring network was designed based on Wilson et al. (1992) to provide leak-detection monitoring efficiency for an estimated 90% of the crib.

Water levels are measured regularly and the adequacy of the existing monitoring network is evaluated according to the ability of the downgradient wells to detect contamination at the point of compliance. Declining water levels at this crib are not expected to jeopardize the ability to sample the network wells FY 1996.

6.9.5.5 216-S-10 Pond and Ditch

Based on the Wilson et al. (1992) model and the hydrogeology of the site, the existing network should provide a monitoring efficiency of ~85% for this facility. The network is judged to be adequate for the indicator evaluation program.

The water table in the vicinity of this facility is dropping at an average rate of 0.43 m/yr. Assuming this rate continues, well 299-W26-8 will be completely dry within 4 years, wells 299-W26-9 and 299-W26-10 will be completely dry within 5 years, well 299-W26-7 will be completely dry within 8 years, and well 299-W26-12 will be completely dry within 6 years. Within 3 years, well 299-W26-8 will not contain enough water to sample with the installed Hydrostar™ (Instrumentation Northwest, Inc., Redmond, Washington) pump. The minimum depth of water needed in a well with a Hydrostar™ pump is ~0.6 m, assuming there is no drawdown. With increasingly greater amounts of drawdown, a larger column of water is needed, which means the well will need to be replaced sooner.

Two of the downgradient wells, 299-W26-10 and 299-W26-12, produced increasingly turbid samples. Several measures were undertaken to try to collect less-turbid samples. In May 1995, the Hydrostar™ screens were removed and the pumps were lowered in both wells. In August, both wells underwent comprehensive maintenance and development. At that time, the well-maintenance crew noted that purgewater coming from the wells seemed to contain bentonite, though the presence of

bentonite was not confirmed. After maintenance and development in well 299-W26-10, the lowest turbidity the maintenance crew was able to achieve was 181 nephelometric units. The lowest turbidity the crew was able to achieve in well 299-W26-12 was 13.7 nephelometric units. Lowering the pump rate helped to reduce the turbidity in both cases. The next step under consideration for lowering the turbidity is replacing the Hydrostar™ pumps with pumps that will allow lower flow rates during purging/sampling, such as a bladder pump.

6.9.5.6 LLWMA-3 and -4

The monitoring well network for LLWMA-3 is complete and adequately monitors the burial ground. No additional wells are planned at this time.

The groundwater monitoring network at LLWMA-4 continues to satisfy the requirement for upgradient and downgradient wells. No additional monitoring wells are planned at this time for this network. Considerable changes in groundwater-flow direction caused by the pump-and-treat activities will necessitate the review of the upgradient/downgradient status of many wells in this monitoring network and may result in some wells going dry.

6.9.5.7 Drinking Water Standards and Derived Concentration Guides

No radiological contaminants were found at levels above the DCGs in the 200-West Area, except for total uranium analyses of samples from wells near U Plant that indicate the DCGs for uranium-234 and -238 are exceeded. Tritium, iodine-129, and technetium-99 are found at levels above the interim DWSs in the 200-West Area. Uranium is found at levels above its proposed MCL. Carbon tetrachloride, trichloroethylene, chloroform, nitrate, fluoride, and chromium were detected at levels above the MCLs.

6.10 200-East Area

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The 200-East Area was used historically for chemical separation and purification of plutonium with associated waste management. For reasons of safety and security, the area was established with a significant spatial separation from the 200-West Area and with some redundancy of function. Differing hydrogeology between the two sites resulted in significant dissimilarities in the spread of contaminants. In the 200-East Area, specific waste-disposal sources include the PUREX Plant, B Plant, BY cribs, and 216-B-5 injection well. Waste-disposal facilities associated with operations include cribs, trenches, tile fields, surface impoundments, injection wells, tank farms, and landfills. Because of the complexity of past waste-disposal operations in the 200 Areas, as well as the close spacing of the facilities, it is generally impossible to determine the exact source of contamination. For example, though it is well-known that numerous tank leaks occurred in the 200-East Area, there is no conclusive evidence for groundwater impacts from tank leaks. In most cases, the tanks are located close to cribs or other waste-disposal facilities that received similar wastes in the same periods. In some instances, tank

supernatant or other waste from tank farm operations was discharged to the ground in nearby cribs, so the groundwater impacts resulted from the overall tank farm operations but specific impacts of tank leaks are potentially masked by the discharges to the nearby cribs.

6.10.1 Operable Units

Numerous source area and two groundwater operable units exist in the 200-East Area. The groundwater operable unit boundaries for 200-BP-5 and 200-PO-1 were defined in Connelly et al. (1992a) by an east-west-trending groundwater divide across the 200-East Area. The 200-BP-5 Operable Unit lies to the north of this divide, whereas the 200-PO-1 Operable Unit is south of the divide. The divide itself is caused by hydraulic interference between wastewater mounding at the 216-B-3 pond (also known as B Pond) with groundwater flowing from the 200-West Area. The geographic boundary between the two operable units extends from B Pond southwest through the PUREX tank farms and then in an east-to-west direction just south of the Semiworks and B Plant facilities. A number of RCRA and CERCLA source and vadose units are encompassed in the operable units.

6.10.1.1 200-BP-5 Operable Unit

This operable unit contains all plumes located north of the groundwater divide. Important plumes within the unit originated from B Plant's bismuth phosphate liquid disposal and include the strontium-90/cesium-137/plutonium-239/-240 plume centered around the 216-B-5 injection well. The 200-BP-5 cobalt-60/technetium-99/cyanide/nitrate plume is centered in the area of well 699-50-53A. This latter plume was derived from liquid waste disposal to the 216-BY cribs.

Both plumes were the target of pump-and-treat programs in 1995, which successfully removed quantities of radionuclides and cyanide. Following these treatability tests, it was determined that no further action at either plume was required. The plume at the 216-B-5 injection well has a low-migration potential. Even though the plume is more mobile, it poses a small health risk and, therefore, continued treatment was not deemed necessary. Instead, an annual groundwater-monitoring program was implemented in FY 1996 to track migration of these plumes.

6.10.1.2 200-PO-1 Operable Unit

This operable unit is being addressed as a RCRA past-practices unit and encompasses the area south of the 200-East Area groundwater divide. The operable unit consists generally of plumes derived from PUREX operations. Plumes of concern extend mostly to the south and east from the PUREX Plant. This operable unit was the subject of a RCRA facility investigation/corrective measure study because remediation is being carried out under RCRA requirements. The study examined existing groundwater monitoring data for the last 10 years.

The RCRA facility investigation report (DOE 1995o) identified three low-to-medium-concentration, widespread plumes. These plumes of tritium, iodine-129, and nitrate cover broad areas

within and southeast of the 200-East Area. A number of small plumes or sporadic detections were identified for arsenic, manganese, chromium, strontium-90, and vanadium, occurring either as one-time hits or within a very limited area.

The RCRA corrective measures study (DOE 1996f), which included numerical modeling and a risk assessment, identified only the tritium and iodine-129 plumes for further evaluation. The corrective actions evaluation considered only the no-action and institutional control alternatives because of the widespread nature of the plumes, the low concentrations over much of the plume area, and the lack of a suitable treatment technology. Also, because of its 12.3-year half-life, tritium is expected to decay to acceptable concentrations in the next 50 years. A groundwater-monitoring plan is being developed to address all plumes of concern in this operable unit. No other actions are expected at this time.

6.10.2 Facilities

6.10.2.1 B Plant

Waste-disposal facilities and single-shell tanks associated with B Plant operations are generally located in the northwestern part of the 200-East Area. The waste-disposal history associated with B Plant is similar to that of T Plant (in the 200-West Area); both plants operated over a similar time period (1944 through 1956) and used the bismuth phosphate process. High-level waste tanks in the B Plant area were used in a cascading system to settle solids. Fractions of the waste were discharged to the ground in nearby cribs and trenches (Waite 1991). First-decontamination-cycle wastes from B Plant operations were discharged via the single-shell tanks to trenches west of the tank farm. Second-decontamination-cycle wastes were discharged to the 216-B-7A, 216-B-7B, and 216-B-8 cribs. According to Anderson (1990), first-decontamination-cycle waste contained $\sim 10\%$ of the original fission activity and 1% of the plutonium. Second-decontamination-cycle waste was lower in overall activity, containing $< 0.1\%$ of the overall fission activity and 1% of the plutonium. Evaporator bottoms from the 242-B evaporator were discharged to the 216-B-37 trench. These evaporator bottoms were concentrated wastes that were highly radioactive. All these facilities are closely located, and the precise waste sources are difficult to distinguish.

The 216-B-5 injection well was operated from April 1945 to September 1946 and received radioactive wastes from B Plant activities, including some hot-cell drainage and supernatant overflow from settling tanks. The waste was injected below the water table, resulting in radiological contamination that is still apparent 50 years later. Radiological contaminants associated with the facility include strontium-90, cesium-137, and plutonium. These three contaminants are restricted to the immediate vicinity of the 216-B-5 injection well by their low mobility in groundwater and the extremely low hydraulic gradient in this area.

In 1954 and 1955, scavenged uranium-recovery waste supernatant, containing large amounts of ferrocyanide and other chemical and radiological components from U Plant operations, was discharged to the BY cribs and to a trench in the northern part of the 200-East Area (Waite 1991). This practice was soon discontinued because of the appearance of unacceptably high levels of cobalt-60 in the groundwater.

6.10.2.2 PUREX Plant

The PUREX Plant started operation in 1956, eventually replacing the REDOX Plant as the plutonium-separations facility. The first PUREX operational campaign extended from 1956 to 1972. Following an 11-year shutdown, the PUREX Plant began operations again in 1983, which ended in December 1988 when the weapons-production mission ended. A short run was started in December 1989 to stabilize material in the system. Waste from the PUREX Plant was discharged to a number of nearby cribs, ditches and ponds. A number of these facilities have RCRA monitoring requirements.

6.10.2.3 RCRA Facilities

A number of facilities in the 200-East Area are being monitored under RCRA requirements, and additional detail is warranted.

216-A-36B Crib. This crib, now retired from use, was a liquid waste-disposal facility for the PUREX Plant. The crib is located ~360 m south of the PUREX Plant. It is ~110 m east of the 216-A-10 crib. The 216-A-36B crib is the south end (150 m) of the crib, originally known as the 216-A-36 Crib (Figure 6.10-1).

The original crib dimensions were 180 m long, 4 m wide, and 4 m deep. A 0.15-m-dia. perforated distributor pipe was placed at the bottom of the crib on a 0.3-m bed of gravel, covered with another 0.3 m of gravel, and backfilled to grade. Ammonia scrubber distillate waste from the PUREX Plant was discharged through the distribution pipe to the crib and allowed to percolate through the soil column.

The original 216-A-36 crib received liquid effluent from September 1965 to March 1966. A substantial inventory of radionuclides was disposed to the crib and was assumed to have infiltrated sediments near the inlet to the crib. To prevent radionuclides from reaching the water table, the head end of the crib was used as a specific retention facility. This practice limited the amount of water discharged to the crib (Smith and Kasper 1983). To continue effluent discharges to the crib, it was divided into two sections: 216-A-36A and 216-A-36B. Grout was injected into the gravel layer to form a curtain separating the two sections. The liquid effluent discharge point was moved to the 216-A-36B section and the -36A section was no longer used. Discharge to the 216-A-36B crib resumed in March 1966 and continued until 1972, when the crib was temporarily removed from service. The crib was placed back in service in November 1982 and continued to operate until it was taken out of service again in October 1987.

Ammonia scrubber distillate discharged to the crib consisted of condensate from nuclear fuel-decladding operations, in which zirconium cladding was removed from irradiated fuel by boiling in a solution of ammonium fluoride and ammonium nitrate. Other waste stream constituents included tritium, strontium-90, cesium-137, iodine-129, ruthenium-106, cobalt-60, and uranium (Buelt et al. 1988).

216-A-10 Crib. This crib, also retired from use, was a liquid waste-disposal facility for the PUREX Plant. This crib is located ~122 m south of the PUREX Plant and is ~110 m east of the 216-A-36B Crib (see Figure 6.10-1).

This crib is 84 m long, has a V-shaped cross section, and is 14 m deep. Several waste streams, collectively described as process distillate discharge, were disposed to this crib and were allowed to percolate through the soil column. The crib first received liquid waste over a 4-month period during PUREX startup in 1956. In 1961, the crib replaced the 216-A-5 crib and received PUREX effluent continuously until 1973. Periodic discharges were received in 1977, 1978, and 1981. From 1982 to 1987, effluent discharges resumed on a continuous basis. Discharge between 1981 and 1987 averaged 100 million L/yr. In 1987, the crib was taken out of service and replaced by the 216-A-45 crib.

The process distillate waste stream to the 216-A-10 crib was characteristically acidic and contained concentrated salts. Other waste-stream constituents included aliphatic hydrocarbon compounds; organic complexants; and plutonium, uranium, strontium-90, cobalt-60, cesium-134 and -137, ruthenium-103 and -106, and tritium (Aldrich 1987).

216-A-29 Ditch. This is an earthen ditch ~2 m wide and 2,000 m long. The depth of the ditch varies from 1 m at the head end (southwestern end) to 5 m at the point of discharge. The ditch conveyed PUREX chemical sewerage to the 216-B-3 pond from 1955 to 1986. In 1984, administrative and physical controls were implemented to avoid inadvertent discharges of hazardous waste to the ditch. All effluent sources were rerouted in July 1991 and use of this ditch for disposal was discontinued. The ditch was backfilled and revegetated for interim stabilization later that year.

The ditch was part of a complex effluent-discharge system used during nuclear materials production, was deactivated in 1991, and discharges ceased. Prior to deactivation, the ditch received an average of 950 to 2,000 L/min of effluent from the PUREX Plant chemical sewer line. The lower range of effluent discharges continued after production was halted in 1986 because cleanout runs were performed prior to PUREX decommissioning.

The ditch received effluents that contained hazardous and radiological waste. Stratigraphic control of migrating effluents is limited to sporadic perching horizons composed of silt and other fine-grained sediments. Of primary concern for RCRA regulations were discharges of sodium hydroxide and sulfuric acid, which occurred on a daily basis from 1955 until February 1986. These wastes were produced as a result of ion-exchange regeneration at PUREX.

Because this ditch is inactive and reuse is not expected, it will be closed under RCRA regulations. A closure plan is scheduled to be delivered to Ecology by March 2000.

216-B-3 Pond. This pond is a regulated wastewater-disposal facility for effluents generated by past operations in the 200-East Area. The pond is located east of the 200-East Area and consists of a main pond and three expansion ponds constructed for wastewater disposal (Figure 6.10-2). The main pond, which began receiving effluent in 1945, was located in a natural topographic depression and diked on the eastern margin. The pond covered ~14.2 ha and had a maximum depth of ~6.1 m. Three

expansion ponds (216-B-3A, 216-B-3B, and 216-B-3C) were placed in service in 1983, 1984, and 1985, respectively. The A and B expansions are ~4.5 ha; the C expansion is ~16.6 ha. Water discharged to these ponds infiltrated into the ground and artificially recharged the underlying aquifer. Only the 216-B-3C pond remains in operation. Details of the operation of these ponds are presented in DOE (1994e).

In 1994, the main pond and the 216-B-3 ditch were filled with clean soil and all vegetation was removed from the perimeter as part of interim stabilization activities. Three ditches (no longer in use) leading to the ponds are included in the system for groundwater-monitoring purposes. Discharges to the main pond ceased, and all effluents were rerouted to 216-B-3C via a bypass pipeline in April 1994.

Currently, the 216-B-3C pond receives nondangerous, nonradioactive effluent primarily from the PUREX and B Plants. Specifically, these streams consist of B Plant cooling water, 242-A evaporator cooling water and steam condensate, 241-A-702 vessel ventilation system cooling water, 283-E water treatment facility filter backwash, and 284-E powerhouse liquid effluent. These streams will continue to discharge to the pond until October 1997, at which time they will be rerouted to the 200 Areas Treated Effluent Disposal Facility.

In the past, B Plant steam condensate and chemical sewerage and PUREX Plant chemical sewerage were also discharged to the B Pond system (primarily the main pond). Potential contaminants contained within past waste streams, which may have entered the groundwater, are discussed in DOE (1994e). During January through October 1996, the volume of effluent discharged to the B Pond system averaged ~9,460 L/min or 13,626,000 L/d. The total effluent discharged during this period was 4.2 billion L.

200 Areas Treated Effluent Disposal Facility. As mandated by Tri-Party Agreement Milestone M-17-08 (Ecology et al. 1989), this facility (a non-RCRA waste-disposal site) was built to provide an infiltration site for treated liquid effluent from the generating facilities in the 200 Areas. The facility is located ~600 m east of the 216-B-3C pond (see Figure 6.10-2). In operation since June 1995, the facility allows infiltration of steam condensate and other clean water to the soil column. Some of the streams formerly discharged to the 216-B-3C pond were rerouted to this facility and effluent received in FY 1996 totaled 761 million L.

216-B-63 Trench. This trench, in service from March 1970 to February 1992, received liquid effluent (378,540 to 1,514,160 L/d) from the B Plant chemical sewer. The liquid effluent was a 70/30 mixture of steam condensate and raw water, which was disposed to the west end of the open, unlined earthen trench. Past releases to the trench included radioactive and dangerous waste. Documented hazardous discharges occurred from 1970 to October 1985 and consisted of aqueous sulfuric acid and sodium hydroxide solutions that exceeded 2.0 and 12.5 pH, respectively. Radioactive soils were dredged from the trench in August 1970 but no records exist of radioactive waste disposal to the trench. Starting in 1985, physical controls, radiation monitoring, and operating procedures were modified to avoid inadvertent discharge of chemicals or radioactive substances to the wastewater stream. Liquid effluent discharge to this trench ceased in February 1992.

Single-Shell Tank Farms. The single-shell tanks that are currently storing hazardous, radioactive wastes in the 200-East Area are located in WMA-A-AX, B-BX-BY, and C tank farms. These WMAs, decommissioned in 1980, have been designated as RCRA facilities since 1989.

General information on facilities overview and tank history can be found in Section 6.9.2.5. Although B, BX, BY, and C tank farms each contain 12 tanks, AX contains only 4 tanks, while A contains 6 tanks (Figure 6.10-3). One of the largest known leaks occurred in 1971 at tank 241-BX-102; estimated at 264,950 L.

Low-Level Burial Grounds. LLWMA-1 is located in the northwest corner of the 200-East Area, is currently following interim status detection-level monitoring regulations, and includes all of the 218-E-10 burial ground (Figure 6.10-4). This WMA is divided by an east-west access road. The southern portion of the burial ground is currently active, while the portion north of the road is for future expansion. The active area measures 22.9 ha, and the area for future expansion measures 15.3 ha, for a total area of 38.2 ha. Disposal activities began in 1960 and continue to the present. Materials placed in this facility are primarily dragoff waste, failed equipment, and mixed industrial waste from the PUREX Plant, B Plant, and N Reactor.

LLWMA-2 is currently in indicator parameter evaluation status. This WMA is also located in the northeast corner of the 200-East Area and includes all of burial ground 218-E-12B (Figure 6.10-5). This burial ground has a total area of 70.1 ha and has been in use since 1968. The majority of the waste disposed is in the eastern half of the burial ground and consists primarily of miscellaneous dry waste and submarine reactor compartments. Parts of two trenches contain transuranic waste.

200 Areas Liquid Effluent Retention Facility. This facility consists of three 24.6 million-L surface impoundments (basins), located on a 15.8-ha site northeast of the 200-East Area (Figure 6.10-6). The three basins were constructed of two composite liners, a leachate-collection system between the liners, and a floating cover. The fourth basin is excavated but is not completed and will not be used.

This facility serves as temporary storage for evaporator process condensate. The 242-A evaporator is used to substantially reduce the quantity of waste stored in the double-shell tanks and the effluent was discharged to cribs in the 200-East Area. The evaporator was shut down when listed waste was found in the effluent stream but was restarted on April 14, 1994.

Primary constituents detected in the effluent stream from the 242-A evaporator were ammonium, acetone, aluminum, 1-butanol, 2-butanone, tritium, strontium-90, ruthenium-106, and cesium-137. Further information of the effect on groundwater from release of this waste stream is documented in WHC (1990b).

The 242-A evaporator process condensate effluent is regulated as a dangerous waste under WAC 173-303 because of the toxicity of the ammonium and the presence of listed waste constituents. An interim status groundwater-monitoring system is in place to detect any impact on groundwater quality. The facility is monitored under an indicator evaluation program.

6.10.3 Extent of Contamination

During site operations considerable waste was produced in the 200-East Area and disposed to numerous facilities. The exact source of the contamination detected in the groundwater cannot always be defined with a high degree of certainty. The discussion below divides the extent of contamination into that found generally in the vicinity of B Plant and that found in the vicinity of and downgradient of the PUREX Plant. Additional detail is provided for facilities with specific RCRA monitoring requirements.

6.10.3.1 B Plant Area

With the decommissioning of Gable Mountain Pond in recent years, groundwater near B Plant began flowing northward and a number of groundwater-contaminant plumes reappeared north of the 200-East Area boundary. Several facilities in the vicinity of B Plant are notable with regard to groundwater contamination. Radiological contaminants, including substantial levels of technetium-99 as well as some cobalt-60, are found near the BY cribs. Chemical contaminants include nitrate and cyanide (as ferrocyanide). Minor uranium contamination is also detected. Injection of waste below the water table at the 216-B-5 injection well produced localized groundwater contamination. The waste stream apparently contained a large amount of suspended solids and some of the waste was most likely emplaced as particulate matter. The constituents detected in groundwater (plutonium, cesium-137, and strontium-90) typically have low mobilities because of their sorption to aquifer sediments. Characterization activities in the vicinity of the 216-B-5 injection well were reported by Smith (1980). Tritium and iodine-129 contamination is widespread in the 200-East Area and the source is difficult to ascertain.

Tritium. Tritium contamination is widespread throughout the northwestern part of the 200-East Area and extends northward through the gap between Gable Mountain and Gable Butte (see Plate 3). The maximum average annual tritium concentration detected in this part of the 200-East Area in FY 1996 was 96,000 pCi/L in well 299-E28-6, located immediately east of B Plant. Another pulse of tritium at levels above the interim DWS can be seen between Gable Mountain and Gable Butte, where the maximum average annual concentration for FY 1996 was 71,000 pCi/L in well 699-61-62. The exact sources of the tritium were not determined.

Iodine-129. Iodine-129 forms another widespread contaminant plume in the 200-East Area and the contamination also extends northward through the gap between Gable Mountain and Gable Butte (see Plate 5). The maximum average annual iodine-129 concentration detected in this part of the 200-East Area in FY 1996 was 7.9 pCi/L in well 299-E33-36. The exact sources for the iodine-129 contamination, like tritium, were not determined; however, the concentrations of iodine-129 in this vicinity do not correlate well with tritium concentrations. The highest concentrations of iodine-129 are located generally eastward of the highest parts of the tritium plume.

Uranium. Uranium is detected at levels above the 20-μg/L proposed DWS in a few wells in the vicinity of B Plant. The distribution of uranium contamination suggests the plumes are of limited extent and the source of this uranium is not understood. The maximum average annual uranium

concentration in the 200-East Area was 130 μg/L in well 299-E33-13, located to the east of the BY cribs, west of the 216-B-8 crib, and northeast of the WMA-B-BX-BY single-shell tank farms. Concentrations in this well have been rising since 1991 and increased dramatically in the last year (Figure 6.10-7).

Cobalt-60. Wells located north of the 200 Areas, in an area affected by waste disposed to the BY cribs, consistently show the presence of detectable cobalt-60. In FY 1996, the maximum average annual cobalt-60 detected in this vicinity was 41 pCi/L in well 699-52-54, below the 100-pCi/L interim DWS. Much of that discharged cobalt-60 has now decayed away because of its relatively short (5.3-year) half-life. Cobalt-60 in this area appears to be highly mobile, probably because of the presence of a soluble cobalt-cyanide (or ferrocyanide) complex associated with the plume originating in the BY cribs. The presence of complexed cobalt-60 in ferrocyanide-scavenged wastes from the bismuth phosphate process was known by 1957 to result in little retention by sediments (Haney 1957).

Technetium-99. Elevated technetium-99 levels apparently associated with the BY cribs' plume continued to be observed in FY 1996 (Figure 6.10-8). Well 699-50-53A was used in 1995 for an extraction well in treatability testing and contained up to 9,910 pCi/L of technetium-99 in 1995. This well was not sampled after the completion of the test. The maximum average annual technetium-99 detected in this vicinity in FY 1996 was 2,800 pCi/L in well 699-52-54. Concentrations of technetium-99 had increased in well 699-52-54 (Figure 6.10-9) until 1995, but concentrations measured in FY 1996 were lower. Concentrations of technetium-99 less than the interim DWS detected north of Gable Mountain indicate that this plume is moving into and through the gap between Gable Mountain and Gable Butte.

Nitrate. The plume originating from the BY cribs contains some of the highest groundwater nitrate levels on the site (see Plate 4). The maximum average annual concentration detected in FY 1996 in the 600 Area to the northwest of the BY cribs was 120 mg/L in well 699-52-54, though the maximum concentration detected in a single sample was 320 mg/L in well 699-53-48A.

Cyanide. Cyanide was detected in samples collected from wells in and directly north of the BY cribs and the source is believed to be wastes containing ferrocyanide disposed to the cribs. The MCL for cyanide is 200 μg/L. There is some evidence that contamination in this area migrated to some depth in the flow system, including detection of cyanide and cobalt-60 in the upper basalt-confined aquifer, discussed in Section 6.15. However, characterization of the deeper parts of the unconfined and confined aquifers in the vicinity of the BY cribs is considerably less complete than the characterization of the top of the unconfined aquifer system. Migration through the unconsolidated sediments may have been increased by the higher hydraulic head caused by past disposal activities and by the high density of some of the waste streams (Smith 1980; Graham et al. 1984; Kasza 1993). The maximum average annual concentration of cyanide detected in FY 1996 was 140 μg/L in well 699-52-54. Wells containing elevated cyanide often contain elevated concentrations of several radionuclides, including cobalt-60. Although cobalt-60 is normally immobile in the subsurface, it appears to be chemically complexed and mobilized by cyanide or ferrocyanide.

Strontium-90. Concentrations of strontium-90 in FY 1996 ranged up to 3,100 pCi/L (above the 1,000-pCi/L DCG) in well 299-E28-23 near the 216-B-5 injection well (Figure 6.10-10). The value detected was slightly lower than found in 1995 and was over a factor of two lower than the 1994 maximum of 9,110 pCi/L. The difference probably results from the use of this well as an extraction well during the treatability test. Strontium-90 was also found at 82 pCi/L in well 299-E28-2, which is ~150 m from the 216-B-5 injection well. This injection well received an estimated 27.9 Ci of strontium-90 (decayed through April 1, 1986) during 1945 to 1946 when it was used for waste disposal (Stenner et al. 1988).

Cesium-137. Concentrations of cesium-137 in FY 1996 reached 114 pCi/L in well 299-E28-25, located near the 216-B-5 injection well. The cesium-137 concentration reached a maximum of 1,470 pCi/L in well 299-E28-23 in 1995 but that well was not sampled in FY 1996 because of the transition from calendar year to fiscal year sampling schedules. The interim DWS for cesium-137 is 200 pCi/L and the DCG is 3,000 pCi/L.

Plutonium. The maximum concentration of plutonium-239, -240 detected near the 216-B-5 injection well in FY 1996 was 81.7 pCi/L in the single sample from well 299-E28-25. Plutonium continues to be detected (0.11 pCi/L) in well 299-E28-2, ~150 m northwest of the 216-B-5 injection well. It is unusual to see plutonium that far from Hanford Site sources. Plutonium is generally considered to bind strongly to sediments and, thus, has limited mobility in the aquifer. The DCG for plutonium-239 is 30 pCi/L. There is no explicit interim DWS for plutonium-239; however, the gross alpha MCL of 15 pCi/L would be applicable, at a minimum. Alternatively, if the DCG (which is based on a 100-mrem dose standard) is converted to the 4-mrem dose equivalent used for the interim DWS, 1.2 pCi/L would be the relevant guideline.

WMA-B-BX-BY Single-Shell Tank Farms RCRA Parameters. This is the largest of the three single-shell tank WMAs in the 200-East Area. The RCRA groundwater-monitoring network consists of two upgradient wells with five downgradient wells (see Figure 6.10-3).

There were no exceedances of critical means for the pH, TOC, or TOX indicator parameters. However, the specific conductance value has been rising in downgradient wells since monitoring began in 1990. In upgradient well 299-E33-33, specific conductance values remained constant. In June 1996, DOE was informed that WMA-B-BX-BY may be affecting groundwater quality based on results from the February 1996 sampling and subsequent verification sampling. The specific conductance contamination indicator parameter in downgradient well 299-E33-32 was elevated (369 μS/cm) above the critical mean value (366 μS/cm) (Figure 6.10-11).

Work began on investigating this WMA and the nearby crib source chemistry. However, to understand migration of contaminants in the groundwater, a better understanding of the local hydrology is required. The groundwater elevations indicate an extremely flat gradient in most of the 200-East Area; particularly under the WMA with differences in elevation of only a few tenths of a meter. However, this does not necessarily mean groundwater velocities are slow because the permeability of the Hanford formation is generally high. Further discussion of this problem can be found in Section 5.4.4.

The rise in specific conductance appears to be related to an increase in nitrate and chloride, as can be seen in Figure 6.10-12. Several other downgradient wells display trends of increasing nitrate and chloride with corresponding increases in specific conductance since 1992.

As with much of the 200-East Area, there are iodine-129 levels in the groundwater above the DWSs. Although erratic, most wells surrounding this WMA display no distinct trend in this contaminant. However, downgradient well 299-E33-33 has shown an increase since the 1 pCi/L in 1992 to the August 1996 4.5 pCi/L. For comparison, downgradient well 299-E33-32 had 5.8 pCi/L in 1992 and 5.6 pCi/L in August 1996.

In the past, the concentration of technetium-99 in downgradient well 299-E33-41 was above the 900-pCi/L DWS, rising to a maximum of 1,630 pCi/L in August 1995 (Figure 6.10-13). The value for August 1996 is 600 pCi/L. Although other wells in the network show elevated values of technetium-99, none display the upward trend and large fluctuations seen in this well. These observations imply a local source for the greater technetium-99 value in this well. The well is located on the eastern edge of the 241-BX tank farm (between this farm and the 241-B tank farm) (see Figure 6.10-3).

Antimony in filtered samples also exceeded the MCLs in wells 299-E33-31, 299-E33-32, 299-E33-36, 299-E33-39, and 299-E33-43 with values ranging from ~76 to 38 μg/L. The concentrations detected in these samples are less than the laboratory's quantitation limit and, thus, are only approximate. The DWS is 6 μg/L. Data for the other wells were less than the 24- or 43-μg/L MDL.

216-B-63 Trench RCRA Parameters. Groundwater monitoring continues to provide no evidence that dangerous nonradioactive constituents from the site entered the groundwater from this trench. The RCRA indicator parameters are specific conductance, pH, TOC, and TOX (40 CFR 265.92[b][3]). Included in the 216-B-63 trench analysis list are a gamma scan, alkalinity, gross beta, and turbidity. There were no significant detections that could be attributed to this trench. The statistical analyses presented in Appendix B revealed no exceedances in pH, specific conductance, TOC, or TOX.

6.10.3.2 PUREX Plant Area

Numerous waste facilities received waste from PUREX operations. In particular, numerous cribs located to the south and east of the PUREX building impacted groundwater quality over a large area of the site. Two cribs (216-A-10 and 216-A-36B) were monitored under RCRA requirements in FY 1996, but it is clear that the impacts to groundwater also result from other facilities, located generally northeast and east of the plant, that are being addressed under the CERCLA process. The 216-A29 ditch and the 216-B-3 pond are monitored under RCRA requirements. In addition, high-level waste tanks in the WMA-A-AX and -C RCRA units will be discussed in this section. This section also discusses the large plumes from the vicinity of PUREX that migrated through the 600 Area as far as the Columbia River and the 300 Area.

Tritium. The highest tritium concentrations in the 200-East Area continued to be found in wells near cribs that received effluent from the PUREX Plant (see Plate 3). Concentrations greater than the 2,000,000-pCi/L DCG were detected only in well 299-E17-9, located next to the 216-A-36B crib. The

maximum concentration detected in this well in FY 1996 was 3,606,000 pCi/L, which was also the maximum tritium concentration detected onsite in FY 1996 (the average was 3,205,000 pCi/L). Tritium concentrations exceeding the interim 20,000-pCi/L DWS continued to be found in many wells affected by cribs near the PUREX Plant.

The movement of the widespread tritium plume (see Plate 3), extending from the southeastern portion of the 200-East Area to the Columbia River, was consistent with patterns noted in Dresel et al. (1996). Separate tritium pulses associated with the two PUREX operational periods can be distinguished in the plume. The first pulse, which resulted from discharges during the PUREX operation from 1956 to 1972, can be detected near the Columbia River (e.g., well 699-40-1, Figure 6.10-14). The highest concentrations of tritium associated with the first pulse for FY 1996 declined to <200,000 pCi/L as a result of continued radioactive decay and dispersion. Elevated tritium concentrations measured immediately downgradient from the 200-East Area represent the second pulse of tritium moving away from PUREX waste-disposal facilities. The area immediately downgradient of the cribs, where concentrations are >200,000 pCi/L, is naturally attenuating as a result of radioactive decay and dispersion combined with the decreasing source that resulted from the termination of operations. Figure 6.10-15 clearly shows the arrival of the plume at well 699-24-33, located near the Central Landfill, in early 1987, well after the passage of the plume from the earlier operation. The tritium concentrations in this well during passage of the first pulse were at least three times the maximum concentrations in the pulse from the second period. Thus, the second pulse is expected to have a significantly lower impact than the first pulse downgradient toward the Columbia River. The overall decline in concentrations throughout this plume indicate that the greatest impacts expected at the Columbia River have already occurred.

The zone of lower tritium concentrations near the 400 Area may be related to an area where Ringold Formation sediments are present at the water table (see Chapter 3.0 in Dresel et al. 1996). This suggests that a zone of lower hydraulic conductivity sediments is present in this area that may be diverting the bulk of the contaminant transport to the north and south.

Nitrate. The highest nitrate concentrations in the 200-East Area continued to be found near liquid waste-disposal facilities that received effluent from PUREX Plant operations. The maximum nitrate concentration detected near the PUREX Plant in FY 1996 was 130 mg/L in well 299-E17-9, which is adjacent to the 216-A-36B crib. Nitrate concentrations in wells near the 216-A-36B and 216-A-10 cribs generally tended to decrease in the past few years but remain above the MCL, even though the facilities were removed from service in 1987. The extent of the nitrate plume emanating from the 200-East Area (see Plate 4) is nearly identical to that of the tritium plume. However, the area with nitrate greater than the 45-mg/L MCL is considerably more restricted than the area with tritium above the interim DWS.

Iodine-129. The highest iodine-129 concentrations observed in the 200-East Area in FY 1996 were near the PUREX Plant cribs (see Plate 5). The maximum detected iodine-129 concentrations in FY 1996 were 13.59 pCi/L in well 299-E17-14 and 13.18 pCi/L in well 299-E24-17, which monitor the 216-A-36B and 216-A-10 cribs. Concentrations of iodine-129 in groundwater near these cribs are

declining slowly or are stable, as shown for well 299-E17-9 (Figure 6.10-16). The iodine-129 plume extends southeast into the 600 Area and appears to coincide with the tritium and nitrate plumes (see Plates 3, 4, and 5).

Strontium-90. A single groundwater sample from one well near cribs located south of the PUREX Plant was above the DWS for strontium-90 in FY 1996 (see Figure 6.10-10). The maximum strontium-90 concentration detected in FY 1996 was 15.67 pCi/L; the single analysis from well 299-E17-14, located next to the 216-A-36B crib. The impact is very localized because of the lower mobility of strontium-90 as compared to tritium, iodine-129, and nitrate.

Technetium-99. Technetium-99 was found at levels below the interim DWS near the PUREX Plant and downgradient, but was not monitored for in this area in 1995 or FY 1996 because of its generally low levels in previous years. Gross beta measurements confirm that technetium-99 (a beta emitter) remained far below the interim DWS near the PUREX Plant. The presence of technetium-99 in this area inhibits the effectiveness of using gross beta measurements to infer strontium-90 concentrations.

Cobalt-60. A review of FY 1996 and past data for groundwater near the Old Hanford Townsite showed the presence of extremely low but detectable concentrations of cobalt-60. Data from the 1970s and 1980s indicate that cobalt-60 was detected in wells within the area of the current tritium plume and the source is probably in the 200-East Area. This detection suggests that, at least at low levels, cobalt-60 may be more mobile than indicated in recent reports; further detail is given in Dresel et al. (1996). Monitoring reports from the 1970s (Myers et al. 1977; Myers 1978) indicate that cobalt-60 detected in large-volume resin-bed samples was predominantly retained on the anion resin, indicating transport as an anionic complex, though the data indicate some of the cobalt-60 passed through the entire system, suggesting another highly mobile species is present.

216-A-36B and 216-A-10 Cribs RCRA Parameters. These cribs are monitored under RCRA requirements and are located in a region where several groundwater plumes contain constituents that exceed the DWSs. Examples of these exceedances include nitrate, tritium, iodine-129, and strontium-90. The similarities in effluent constituents disposed to these cribs, as well as to the 216-A-45 crib, make determining the contribution of the 216-A-36B and 216-A-10 cribs very difficult. The data from RCRA monitoring of these facilities are integrated into the assessment of the overall extent of contamination for these constituents.

During FY 1996, groundwater quality beneath the cribs was subject to the RCRA-required continuing evaluation for sites under indicator parameter evaluation status. Tables 6.1-15 and 6.1-16 list the wells of the monitoring networks and constituents analyzed. Figure 6.10-1 shows the location of the monitoring wells. Appendix B explains the statistical method used to evaluate the groundwater analytical results. The critical mean values were not exceeded for the four indicator parameters (specific conductance, pH, TOC, and TOX) in the monitoring networks during FY 1996, except for one constituent at one 216-A-36B crib monitoring well. Critical means for each RCRA facility are found in Appendix B. Specific conductance exceeded the 613.1-μS/cm critical mean at well 299-E17-9 with an average value of 634 μS/cm for the four replicate samples collected May 6, 1996. However, this well

does not meet RCRA construction standards and is not used for statistical purposes. The elevated specific conductance is related to elevated nitrate concentrations discussed above.

WMA-A-AX Single-Shell Tank Farms RCRA Parameters. Critical mean values of the indicator parameters (specific conductance, pH, TOC, and TOX) were not exceeded during FY 1996 (see Appendix B). For iodine-129, all wells show concentration values above the 1.00-pCi/L DWS because the plume extends through this region (see Plate 5). An area of iodine-129 concentrations >5 pCi/L north of the PUREX Plant is centered in the general vicinity of these tank farms. Tritium levels are historically greater in one upgradient well versus downgradient wells at this WMA because it is downgradient from the 216-A-8 and 216-A-24 cribs, which received substantial tritium from PUREX. Although tritium activity continues to decline in this upgradient well, the values are significantly above the DWS.

Another exceedance for this WMA is found in well 299-E24-19 for chromium and nickel, both with a 100-μg/L MCL. The historical trends for the samples are shown in Figure 6.10-17. In general, the concentration for each element is decreasing with a recent value of 140 μg/L for chromium and 160 μg/L for nickel as of February 1996. Other wells in the network show concentrations below 15 μg/L for chromium and below 19 μg/L for nickel, suggesting a local source for these elements. An increase in manganese was also noted in conjunction with the chromium and nickel (see Figure 6.10-17). This well is closest to the tank farm perimeter fence, and further work will be done in FY 1997 to explain these exceedances.

Technetium-99 concentrations in well 299-E24-19, which is located adjacent to these tank farms, were increasing in 1995 but decreased through FY 1996 and remain below the DWS (Figure 6.9-18). There was also a corresponding rise in gross beta measurements, but there is no evident plume of technetium-99 upgradient from this location.

WMA-C Single-Shell Tank Farm RCRA Parameters. Critical mean values of the indicator parameters (specific conductance, pH, TOC, and TOX) were not exceeded during FY 1996. For iodine-129, all wells show concentrations above the 1.00-pCi/L interim DWS because the plume extends through this region. Otherwise, there were no exceedances for this WMA.

Technetium-99 concentrations remained relatively steady in FY 1996 in wells 299-E27-13 and 299-E27-14, located near this tank farm (with the exception of an anomalously low value in one sample from well 299-E27-13). Concentrations in both wells were far below the interim DWS but were above the concentrations in surrounding wells. There is no evidence of an extensive plume farther upgradient.

216-A-29 Ditch RCRA Parameters. As noted in Votava (1995), the levels of sulfate in the groundwater under this ditch have been declining steadily since the facility stopped receiving sulfate-bearing effluent. This trend continued in FY 1996 (Figure 6.10-19). Sample results confirm a general decline in specific conductance in both upgradient and downgradient wells (Figure 6.10-20). Assessment monitoring performed between 1990 and 1995 confirmed that the elevated specific conductance was related to calcium, sodium, and sulfate, which are nonregulated substances.

The groundwater in the vicinity of this ditch contains iodine-129 at levels above the interim DWS (see Plate 5). In contrast to the area of the 216-A-36B and 216-A-10 cribs, this contamination is not associated with high levels of tritium (see Plate 3).

216-B-3 Pond RCRA Parameters. The 216-B-3 Pond (also known as B Pond) received very large amounts of water from site operations and had a major impact on groundwater flow as discussed in Chapter 5.0. Information from the 200 Areas treated effluent-disposal facility, because of its proximity to the B Pond system, also enhances knowledge of B Pond hydrogeology and groundwater chemistry. The 200 Areas treated effluent-disposal facility and its three monitoring wells are within the area of influence of the groundwater mound from the B Pond system (see Plate 2). A groundwater-monitoring plan, required to fulfill requirements of the 200 Areas treated effluent-disposal facility's state waste-discharge permit (WAC 173-216) is described by Barnett et al. (1995b).

Chemistry data for the groundwater contamination indicator parameters (specific conductance, pH, TOC, and TOX) from the two upgradient wells for B Pond were used to establish background concentration limits not to be exceeded in the downgradient wells. Groundwater monitoring at the B Pond system was changed to assessment level in 1990 because of elevated TOX concentrations in downgradient well 699-43-41E. During 1990, well 699-43-41F also produced high concentrations of TOX and TOC (Harris 1991).

Four quarters of sampling were completed at B Pond during FY 1996. Because of the elevated TOX and TOC detected in several wells from 1990 to 1993 (699-42-40A, 699-43-41E, 699-43-41F, and 699-43-42J), semivolatile organic compounds were sampled for in all the downgradient wells during FY 1996. These analyses were chosen to identify the particular chemical species that may be causing the elevated TOX results and to evaluate overall groundwater chemistry of the site.

Following the change to assessment level in 1990, TOX concentrations in wells 699-43-41E and 699-43-41F continued to be above established background limits during 1991 but have generally declined since. During FY 1996, all 12 downgradient wells were sampled quarterly for TOX and compared with corresponding analytical results for semivolatile organic compounds. Only one replicate average (well 699-44-39B in April) exceeded the limit of quantitation for TOX during FY 1996, and two of the four replicate results were at or below detection.

Analyses for semivolatile organic compounds revealed low-level detections of tris-2-chloroethyl phosphate in five wells since April 1993. Comparison of occurrence trends of this compound with corresponding results for TOX suggests a correlation in some wells. The correlation appears to be imperfect, however, because relatively high TOX concentrations occurred in some analyses without a corresponding elevation in tris-2-chloroethyl phosphate, and vice versa. The extremely low levels of TOX and tris-2-chloroethyl phosphate have been trending generally lower still, such that it is difficult to justify further research into this connection.

No results for FY 1996 exceeded critical mean values for pH, specific conductance, or TOC (see Appendix B). Four wells exceeded the upper pH limit for DWSs at least once during FY 1996. The highest replicate average during FY 1996 was 8.66 in well 699-42-39B for the October 1995 sampling

event. Downward trends in specific conductance are suggested for wells 699-41-40 and 699-43-42J and for upgradient well 299-E18-1 located in the southeastern part of the 200-East Area. Possible downward trends in TOC are seen for wells 699-40-40A, 699-41-42, and 699-43-40. Other wells in the network reveal no definitive trend.

Groundwater beneath the B Pond system contains elevated levels of tritium from past wastewater disposal to the facility (see Plate 3). Monitoring wells show a consistent decline in tritium activities since the late 1980s. The observed decline is likely a result of the dilution of older, more-contaminated water by recent tritium-free effluent and decay (tritium half-life is 12.3 years). The highest result for tritium in FY 1996 near B Pond (111,120 pCi/L) was recorded in April from well 699-41-40, historically the well with the highest tritium activities. This result is down from 135,000 pCi/L in January 1995.

Well 699-42-40C monitors the Rattlesnake Ridge interbed beneath the B Pond system. Analytical results for tritium since 1986 indicate a rise until early 1993 to a maximum value of 8,000 pCi/L, then a downward trend until late 1994 when results began rising again. The most recent result (June 1996) is once again in the range of the maximum value of 8,000 pCi/L. This is discussed further in Section 6.15.

Quarterly sampling for nitrate was conducted for all wells in the network during FY 1996. All downgradient wells produced nitrate above 2,000 mg/L; the highest was well 699-41-40 (16,000 mg/L in July). All wells showed a downward trend in nitrate concentration, except 699-43-40 and 699-43-41G that showed little or no trend. Upgradient well 299-E32-4 yielded the highest nitrate value in the network for FY 1996 (29,000 mg/L in July) and has had an upward trend for nitrate since 1992.

Although the turbidity DWS applies only to surfacewater analyses (40 CFR 265), this property is monitored quarterly during sampling of groundwater at B Pond to provide insight to occurrences of other constituents and to ensure that representative samples are collected. High-turbidity levels are most obviously correlated to elevated concentrations of certain metals in unfiltered samples. During 1995, purging and sampling rates were reduced in six wells to decrease turbidity: 699-40-39, 699-40-40B, 699-41-40, 699-42-40A, 699-43-40, and 699-43-41E. As predicted, reduction in purging and sampling rates in these wells significantly lowered turbidity levels and resulted in lower levels of metals in unfiltered samples, particularly iron and manganese. During FY 1996, turbidity was generally below 5 nephelometric units, with only one exception in well 699-42-41 wherein one high value of 52 nephelometric units was found. Thus, no effects on hydrochemistry could be attributed to turbid samples.

6.10.3.3 Low-Level Burial Grounds

LLWMA-1 and LLWMA-2 are two areas within the 200-East Area that have RCRA requirements for groundwater monitoring. The facilities cover large parts of the northern 200-East Area and are not directly related to operations at either the B or PUREX Plants. Evidence indicates that these LLWMAs are not contributing to the groundwater contamination, so it is appropriate to discuss them separately from the facilities discussed above.

Critical means for the contamination indicator parameters established for LLWMA-1 were not exceeded in any groundwater-monitoring well for the average of the required quadruplicate samples in FY 1996. However, there were two wells where the pH critical mean was exceeded in some samples (299-E32-7 and 299-E32-8). These were considered to be anomalous, and the averages were below the critical mean even when the values were included. See Appendix B for a discussion of the statistical analysis and critical means.

Although there is no evidence of any contaminant contribution from LLWMA-1, contaminant plumes from other sources are affecting the groundwater quality beneath it. Tritium and nitrate plumes are evident and appear to be the major contaminants (see Plates 3 and 4). Tritium values indicate the presence of a plume beneath LLWMA-1 with a source to the southeast. The data suggest that the maximum concentrations have already passed beneath LLWMA-1 and the values continue to decline.

The November 7, 1995 average of analyses for TOC from LLWMA-2 in downgradient well 299-E34-7 exceeded the critical mean. This well was resampled and the values were below the critical mean. The results were flagged in the database as suspect. No other exceedances occurred in FY 1996. See Appendix B for a discussion of the statistical analysis and critical means.

Values for iodine-129 were slightly above the DWS in several of the wells along the southern boundary of LLWMA-2. These are related to the widespread iodine-129 plume beneath the 200-East Area, and there is no evidence of contamination from LLWMA-2.

6.10.3.4 200 Areas Liquid Effluent Retention Facility

Groundwater monitoring at this facility continues to provide evidence that no dangerous nonradioactive constituents entered the groundwater from this facility. The RCRA indicator parameters are specific conductance, pH, TOC, and TOX (40 CFR 265.92[b][3]). Included in the analysis list are a gamma scan, alkalinity, gross beta, and turbidity. There were no significant detections in these analyses that could be attributed to this facility. Statistical analyses results are presented in Appendix B, and there were no exceedances in specific conductance, pH, TOC, or TOX.

6.10.4 Compliance Issues

6.10.4.1 216-B-63 Trench

Based on the Wilson et al. (1992) groundwater-modeling program, the existing network should provide a monitoring efficiency of 66% to 85% for this trench. The 66% monitoring efficiency results from a flow-direction azimuth of 270 (toward the west), while the 85% monitoring efficiency is associated with a 225 azimuth flow direction (toward the southwest).

The current network is composed of six wells drilled specifically to monitor this trench. The network also includes five upgradient wells drilled to monitor the low-level burial grounds located just

north of this trench and one upgradient well drilled to monitor the single-shell tanks. The network is considered adequate but will be continuously evaluated as water levels and groundwater gradients change with time.

6.10.4.2 216-A-36B and 216-A-10 Cribs

Interim status RCRA groundwater-monitoring networks have been in place for these cribs since 1988 (Kasza 1994). Groundwater-monitoring programs at both cribs are in indicator parameter evaluation status. RCRA closure/postclosure plans for the cribs are scheduled to be submitted to Ecology and the EPA in June 1998 and will satisfy Tri-Party Agreement (Ecology et al. 1989) Milestone M-20-33.

A plan is being written to incorporate the 216-A-36B, 216-A-10, and 216-A-37-1 cribs into one groundwater-monitoring program. Previously, the 216-A-37-1 crib was monitored by the Operational Monitoring Program. A groundwater quality assessment program is proposed for this combination of cribs because of known groundwater contamination and the high probability that a new indicator parameters program for the cribs would show that critical means are exceeded.

Water levels are measured regularly, and the adequacy of the existing monitoring networks for the 216-A-36B and 216-A-10 cribs is evaluated accordingly. Although water levels were decreasing prior to FY 1996, they appear to have stabilized. Therefore, there is no near-term need to replace any of the existing groundwater-monitoring wells. Furthermore, because these cribs are surrounded by 13 groundwater-monitoring wells, the downgradient well network is currently adequate to monitor the quality of the groundwater beneath these cribs.

Evaluation of the upgradient monitoring wells is more difficult because of the very low water-table gradient and previously declining water levels. Very small relative changes in water levels between wells may constitute gradient reversals. In FY 1996 and previous years, well 299-E17-17 was used as an upgradient well in the 216-A-36B crib well network. However, at times, other downgradient wells in this network have had higher water levels, indicating that well 299-E17-17 may be inappropriate for an upgradient well. Although well 299-E17-17 was used as an upgradient well along with wells 299-E24-18 and 299-E25-36 in FY 1996, starting in FY 1997 it will be dropped from use as an upgradient well in this crib's monitoring well network. Therefore, in the future, both cribs and the 216-A-37-1 crib will use the same upgradient wells (i.e., 299-E24-18 and 299-E25-36).

6.10.4.3 216-A-29 Ditch

Background sampling for indicator parameter evaluation was completed in August 1989. The ditch's monitoring network was sampled semiannually for indicator parameters and annually for groundwater quality and drinking water parameters. In January 1990, specific conductance increased beyond the critical mean and an assessment monitoring program was initiated. The assessment program was resolved in October 1995 by confirming that the ditch was the likely source of the elevated

specific conductance. However, the source constituents were determined to be sulfate, calcium, and sodium, which are nonregulated substances (Votava 1995). The program subsequently reverted to indicator evaluation monitoring.

Water levels in each well of the 216-A-29 ditch-monitoring network were compared to the depth of the screen interval and the pump-intake elevation to ensure that sufficient volumes of water exist for sampling purposes. There is no short-term need to replace any of the existing groundwater-monitoring wells.

6.10.4.4 216-B-3 Pond

Detection-level RCRA groundwater monitoring began in 1988 and was changed to an assessment program in 1990 because of elevated TOX levels in two downgradient wells. The B Pond system continued in a groundwater quality assessment monitoring program during FY 1996 but will likely be returned to detection-level monitoring in FY 1997 as a result of research that concluded in 1996 (see discussion of B Pond RCRA parameters above). The constituent responsible for the elevated TOX (tris-2-chloroethyl phosphate) is present at extremely low concentrations, has diminished over time, and will not be the subject of a corrective action. A groundwater quality assessment plan was submitted to Ecology as part of the original groundwater-monitoring plan (Harris 1990). The assessment plan augments the interim status plan (Sweeney 1995) and the closure/postclosure plan (DOE 1994e).

The monitoring well network is adequate to detect contamination originating from the B Pond site. Eight wells were eliminated from the regular sampling list during 1995 because of duplication of effort. Because of the radial flow from the apex of the groundwater mound, a constituent introduced at this apex should be theoretically detectable at any selected point within the mound, barring heterogeneities in the geologic structure of the aquifer. Obviously, heterogeneities do exist at this site, as known from drilling, but they are not predictable to a level of detail that would allow justification of siting wells at specific locations. Hydraulic head measurements indicate, however, that groundwater flows predominantly in an east-to-southeasterly direction. In the future, that area will be focused on to ensure adequate coverage and well integrity.

During 1993, an evaluation was made to determine if any wells in the network were going dry, thus rendering the wells incapable of producing a sample. The evaluation determined that four wells (699-42-41, 699-43-45, 699-44-42, and 699-44-43B) may be going dry. Comparison of the 1993 water levels with the October 1996 levels showed that water had fallen $\sim$1 m in well 699-44-43B and that the rate of decline is $\sim$0.3 m/yr. Calculations indicate that $>$1.2 m of water still remain above the pump intake in this well. Water levels in wells 699-42-41 and 699-43-45 have not fallen appreciably since 1993. The only well in which the water level approached the pump intake level and was in immediate danger of going dry is well 699-44-42 and was eliminated from the sampling schedule in 1995.

The redirection of discharges from the 216-B-3 (main) pond to the 216-B-3C pond that began in early 1994 is possibly introducing wastewater into the parts of the Hanford formation (i.e., above the lower mud sequence) that were formerly unsaturated. During FY 1997, discharges to 216-B-3C are scheduled to be rerouted to the 200 Areas treated effluent-disposal facility. This change may accelerate

the rate at which the original mound at the B pond system is diminishing. Wells near the main pond must be monitored to determine fitness for use. Coverage would remain adequate even if additional wells were eliminated because of falling water levels.

6.10.4.5 Single-Shell Tank Farms RCRA Parameters

There were no exceedances in WMA-B-BX-BY for the pH, TOC, and TOX indicator parameters. The specific conductance value has been rising in downgradient wells since monitoring began in 1990. In June 1996, DOE was informed that this WMA may be affecting groundwater quality based on results from the February 1996 sampling and subsequent verification sampling in one downgradient well. As required, an assessment monitoring plan was developed and submitted, and the facility was placed on quarterly monitoring (Caggiano 1996c). The well network was increased with construction of two nearby RCRA standard wells.

When viewed regionally, the groundwater-monitoring network appears to be adequate to detect contamination from WMA-B-BX-BY. However, hydraulic gradients are almost flat in most of the 200-East Area and the gradient is particularly flat under this WMA with differences in elevation of only a few tenths of a meter. This does not mean, however, that groundwater velocities are slow because the permeability of the Hanford formation is generally high. As part of the assessment evaluation, a more-detailed study of the groundwater-flow directions under this WMA is being conducted to determine the extent, if any, that this facility is out of RCRA compliance.

Groundwater samples from wells monitoring WMA-A-AX and -C were analyzed for constituents that exceeded the DWS, indicator parameters, and water quality parameters during FY 1996. These samples were analyzed semiannually for indicator parameters and annually for selected groundwater quality parameters. Concentration values of the indicator parameters (specific conductance, TOC, pH, and TOX) were not exceeded during FY 1996.

The groundwater-monitoring networks appear to comply with respect to placement of the wells. However, continued observation is required as the B Pond mound dissipates. With the expected change in flow direction, these networks may require further evaluation with time. The previously rapid water-level decline has slowed in the last 2 years and appears to be nearly stable.

6.10.4.6 LLWMA-1 and -2

The groundwater-monitoring network for LLWMA-1 continues to meet requirements. There are no plans for additional groundwater monitoring wells at this time.

The monitoring network for LLWMA-2 continues to satisfy the requirements for upgradient and downgradient monitoring wells and is adequate to monitor the burial ground. No additional wells are planned at this time.

6.10.4.7 Liquid Effluent Retention Facility

The current groundwater-monitoring network is composed of four wells, one of which is upgradient. The network is considered adequate but will be continuously evaluated as water levels and groundwater gradients change with time. The Wilson et al. (1992) groundwater program calculated monitoring efficiency at 95.5%. No additional wells are under consideration at this time.

6.10.4.8 Drinking Water Standards and Derived Concentration Guides

Strontium-90 and plutonium exceeded the DCG in the immediate vicinity of the 216-B-5 injection well. Tritium exceeded the DCG near the 216-A-36B crib. Strontium-90, plutonium, tritium, iodine-129, technetium-99, and cesium-137 exceeded the interim DWS, while uranium exceeded the proposed DWS. Nonradioactive chemical constituents that exceeded MCLs in the 200-East Area were nitrate, chromium, and antimony.

6.11 400 Area

E. C. Thornton

The 400 Area on the Hanford Site is the location of the Fast Flux Test Facility, a liquid sodium-cooled reactor. The reactor is on standby pending a restart decision for the production of medical isotopes and tritium. Assessment efforts associated with the CERCLA 300-FF-2 Operable Unit will extend to include groundwater contamination in the 400 Area.

6.11.1 Facilities

6.11.1.1 400 Area Process Ponds

The 400 Area process ponds (4608 B/C facility), located north of the 400 Area perimeter fence, are unlined infiltration ponds that receive wastewater from the 400 Area facilities. The waste stream consists primarily of cooling water and intermittent small contributors (e.g., sinks and drains). The facility is designated as a WAC-173-216 discharge permit site and the permit was issued on August 1, 1996. One permit condition identified was the addition of another downgradient well to the monitoring network, which is yet to be installed.

6.11.1.2 Water-Supply Wells

The water supply for the 400 Area, including the drinking water, is provided by wells completed in the unconfined aquifer system. The original water-supply wells (499-S0-7 and 499-S0-8) were completed near the top of the aquifer. When tritium contamination was detected in the water supply, an additional well (499-S1-8J) was drilled in the lower unconfined aquifer in 1985 to reduce the tritium concentration below the 4-mrem/yr effective dose equivalent standard. Well 499-S1-8J is now the primary water-supply well, and well 499-S0-7 is used as a backup supply well. Well 499-S0-8 is maintained for emergency use.

6.11.2 Extent of Contamination

Nitrate is the only significant contaminant attributable to 400 Area operations detected in the single downgradient well (699-2-7) to the process ponds. Elevated nitrate concentrations of up to 95 mg/L (45-mg/L DWS) found in well 669-2-7 were attributed to the sanitary sewage lagoon located immediately west and upgradient of the process ponds (Figures 6.11-1 and 6.11-2). A recently constructed treatment system for sanitary sewage should eliminate this source of groundwater contamination.

Elevated levels of tritium (Figure 6.11-3) associated with the groundwater plume from the vicinity of the PUREX Plant in the 200-East Area were identified in 400 Area wells. This source of groundwater contamination is relevant to the water-supply wells. The tritium activities in wells 499-S0-7, 499-S0-8, and 499-S1-8J are compared in Figure 6.11-4 to that of the 400 Area drinking water supply. Tritium was found at levels above the interim DWS in most samples from well 499-S0-7, where the average annual concentration was 22,000 pCi/L in FY 1996.

Tritium remained below the 20,000-pCi/L interim DWS and the 4-mrem/yr dose equivalent in the drinking water supply (sampled at a tap) for all sampling events in FY 1996 (see Figure 6.11-3). Nitrate remained below the MCL in FY 1996 for the water-supply wells, indicating they are not affected by the 400 Area process ponds. A review of FY 1996 and past data from 400 Area and surrounding wells indicates that no other constituents are present at levels above their MCLs or interim DWSs.

6.11.3 Compliance Issues

As discussed above, tritium was detected at levels above the interim DWS in the 400 Area and nitrate was detected at levels above the MCL just north of the perimeter fence near the process ponds. Tritium was consistently detected at levels above the interim DWS in the backup water-supply well for this area. However, the interim DWS is set at a level that ensures that any one radionuclide would not exceed a 4-mrem/yr dose if ingested at the average annual rate of consumption. Because the backup well is seldom used, the monthly water-supply sampling indicates that the concentration in the drinking water is maintained at a level below 4 mrem/yr even if the dose-conversion factor used in setting the 20,000-pCi/L interim DWS is used. As discussed in Section 6.1.6, the dose-conversion factor used in setting the interim DWS is more conservative than that used in more current methodology.

6.12 600 Area

F. N. Hodges, P. E. Dresel, and S. S. Teel

The 600 Area consists of all parts of the Hanford Site not specifically included in other operational areas. Most groundwater contamination found in the 600 Area is related to sources in the operational areas discussed previously. However, several other sources or potential sources of contamination exist, including the Central Landfill and Gable Mountain Pond. Chromium was detected in wells in the

Central Plateau in the past; its source, however, is uncertain. Also, uranium was detected in a well near the 618-10 burial grounds. Nitrate found in the western part of the 600 Area appears to have an offsite source.

6.12.1 Facilities

6.12.1.1 Solid Waste Landfill

The Solid Waste Landfill (SWL) is a 27-ha non-RCRA-regulated facility located ~5.6 km southeast of the 200-East Area (Figure 6.12-1 and see Plate 1). The SWL, along with the adjacent Nonradioactive Dangerous Waste Landfill (NRDWL), are parts of the former Central Landfill; however, the two facilities are now considered separately and under differing regulations. The SWL groundwater is monitored according to WAC 173-304. The SWL began operation in 1972 and received principally solid waste, including paper, construction debris, asbestos, and lunchroom waste. In addition to the solid waste, ~3.8 to 5.7 million L of sewage were disposed in trenches along the east and west sides of the SWL between 1975 and 1987, and ~380,000 L of Hanford Site bus/garage washwater were disposed in three short trenches along the west side of the site between 1985 and 1987.

6.12.1.2 Nonradioactive Dangerous Waste Landfill

The NRDWL is a 4-ha inactive landfill located ~5.5 km southeast of the 200-East Area (see Figure 6.12-1 and Plate 1). The NRDWL received waste from 1975 to 1985 that included asbestos, miscellaneous laboratory wastes, solvents, paints; sewerage, sulfamic and other acids, batteries and battery acid, and mercury. The NRDWL continued to receive asbestos waste until 1988 (DOE 1990b). The groundwater is monitored under RCRA requirements.

6.12.1.3 Other Facilities

Gable Mountain Pond. This pond was a liquid waste-disposal area located south of Gable Mountain (see Plate 1), and received 200-East Area liquid wastes from 1957 until it was decommissioned in 1987. The surface area of the pond reached at least 28 ha during its operational period (Strait and Moore 1982). The pond is currently dry and covered with fill. Discharge to the pond included cooling water and condensate from a variety of sources in the 200-East Area. In addition, an unplanned release from a cooling coil in the PUREX Plant contributed ~100,000 Ci of fission products to Gable Mountain Pond and the 216-B-3 Pond (Strait and Moore 1982). The primary radiological constituents discharged to the pond were ruthenium-106, strontium-90, and cesium-137.

618-10 Burial Ground and 316-4 Crib. The burial ground and adjacent crib are located southeast of the 400 Area, adjacent to Route 4S. The burial ground operated from 1954 to 1963 and received a variety of low- to high-activity radioactive waste, mostly composed of fission products with some plutonium-contaminated material (DOE 1996g). These wastes were disposed in pipe storage units (caissons) and trenches and may have included liquid and solid waste forms. The crib began receiving uranium-bearing waste solutions in 1948 and continued to periodically receive nitrate, hexone, and

organic wastes through at least 1962 (DOE 1996g). This site was investigated as part of a CERCLA limited field investigation report for the 300-FF-2 Operable Unit (DOE 1996g).

6.12.2 Extent of Contamination

6.12.2.1 SWL Parameters

Analytical results for groundwater-sampling events are presented in Appendix H. Results of statistical evaluations are presented in Appendix B (Table B.4). This section discusses the constituents required by WAC 173-304, chlorinated hydrocarbons, which are site-specific constituents, and tritium, which is monitored to provide information on groundwater-flow direction and rate.

Downgradient wells show higher specific conductance, alkalinity, total carbon, and cation concentrations than upgradient wells. As indicated in Hodges (1994a), it is believed that this is a result of high vadose-zone concentrations of carbon dioxide, resulting from the degradation of sewage material beneath the SWL. High concentrations of carbon dioxide are indicated by the vadose-zone gas surveys of Evans et al. (1989) and Jacques and Kerkow (1993). Solution of carbon dioxide in groundwater produces carbonic acid, which lowers groundwater pH, making it more reactive with aquifer materials. Reaction with aquifer materials, principally hydrolysis of silicates, results in the dissolution of cations with a resultant increase in groundwater pH. The aquifer materials, in effect, act as a pH buffer. The dissolution of carbon dioxide is indicated by concentrations of inorganic carbon (total carbon minus TOC) that are 30% to 40% higher in downgradient wells than in upgradient wells. At ambient groundwater pH, almost all of this inorganic carbon will exist in the form of the bicarbonate ion.

Indicator Parameters. Average values for replicate temperature determinations measured during sampling ranged from 16.5 to 25°C. All measurements were below the tolerance interval of 21°C, except for one 25°C value from upgradient well 699-24-35. There is a tendency for the higher temperatures to occur at the north end of the site, near the axis of the tritium and nitrate plumes (see Plates 3 and 4).

Average values for replicate specific conductance measurements in downgradient wells ranged from 454 to 775 μS/cm. Replicate averages for monitoring wells 699-22-35 and 699-23-34B exceeded the 700 μS/cm (WAC 246-290-310). The 550-μS/cm tolerance interval value was exceeded for all samples from downgradient wells, with the exception of the March 1995 sampling of well 699-25-34C, which equalled the tolerance interval value.

Average values for replicate pH measurements in downgradient wells ranged from 6.6 to 7.4. None of the pH measurements exceeded the tolerance interval range of 6.2 to 8.5. As in the past, the lower values occurred in the southernmost downgradient monitoring wells.

Average (of replicates) TOC concentrations in downgradient wells ranged from 88 to 350 μg/L for FY 1996 samples. All results for the August 1996 samples were <532 μg/L. The reported values did not exceed the 1,250-μg/L tolerance interval value.

Reported TOX values in downgradient wells ranged from <2.65 to 36 μg/L (Table 6.12-1). The values increased from north to south along the line of compliance-point wells, consistent with the pattern for the chlorinated hydrocarbons.

Anions. Chloride concentrations in downgradient wells ranged from 5,910 to 7,620 μg/L. The 9,045-μg/L tolerance interval value was not exceeded. There is a tendency for the higher values to occur in the northernmost wells.

Nitrate concentrations in the downgradient monitoring wells ranged from 11,000 to 23,700 μg/L. The 33,800-μg/L tolerance interval value and the 45,000-μg/L standard (WAC 173-200) were not exceeded. The highest nitrate concentrations occur in the northernmost wells.

All nitrite analytical results were nondetections, reported as either <2, <11, or <140 μg/L.

Most results for ammonium were nondetections, reported as <16 or <27 μg/L. However, isolated values, ranging from 36 to 39 μg/L, were reported for both upgradient and downgradient wells.

Reported sulfate concentrations in downgradient wells ranged from 39,500 to 56,800 μg/L. Two samples from well 699-22-35 and one sample from well 699-23-34B exceeded the 51,500-μg/L tolerance interval value. None of the samples exceeded the 250,000-μg/L standard (WAC 173-200). There is a strong tendency for the highest sulfate concentrations to occur in the southernmost wells.

Dissolved Metals. Reported values for filtered iron showed a high degree of variability, ranging from 14 to 80 μg/L in downgradient wells. Reported filtered iron concentrations exceeded the 78-μg/L tolerance interval value for only one sampling of downgradient well 699-25-34C.

Reported values for filtered manganese concentrations in downgradient wells ranged from <0.29 to 5.3 μg/L. None of the manganese concentrations exceeded the 11-μg/L tolerance interval value or the 50-μg/L standard (WAC 173-200).

Reported values for filtered zinc concentrations in downgradient wells ranged from <3.7 to 24.7 μg/L and did not exceed the 34-μg/L tolerance interval value or the 5,000-μg/L standard (WAC 173-200).

Chemical Oxygen Demand. Reported values for chemical oxygen demand in downgradient wells, with one exception, were all reported as <2,800, <2,900, or <3,000 μg/L. The reported value for well 699-24-34C for the August 1996 sampling was 5,000 μg/L and exceeded the 3,000-μg/L tolerance interval value.

Total Coliform. All reported values for total coliform were nondetections (i.e., <1 col/100 mL).

Chlorinated Hydrocarbons. A number of chlorinated hydrocarbons were detected at low concentrations (see Table 6.12-1). These included 1,1,1-trichloroethane, trichloroethylene, tetrachloroethylene,

and 1,1-dichloroethane. Several of these constituents occurred in low concentrations in the upgradient wells. The highest concentrations consistently occurred in the downgradient wells, particularly toward the south end of the SWL, and the trend of southward-increasing concentrations continued, as evidenced by data gathered from the two new downgradient wells at the south end of the SWL. However, concentrations of tetrachloroethylene are lower in the two new wells.

Carbon tetrachloride was detected in both downgradient and upgradient wells (<0.04 to 3.2 μg/L); however, the most consistent detection and the highest concentrations occurred in southernmost downgradient well (699-22-35). Low concentrations of chloroform (0.03 to 2.9 μg/L) were detected in all downgradient wells. In addition, trans-1,2-dichloroethylene was detected in downgradient well 699-24-34B.

There was a decline in the concentration of chlorinated hydrocarbons; however, several remained above the groundwater quality criteria set forth in WAC 173-200. The range of reported concentrations of chlorinated hydrocarbons was given in Table 6.12-1. Only tetrachloroethylene, 1,1-dichloroethane, and carbon tetrachloride exceeded their respective criteria.

Chlorinated hydrocarbons occurred in all monitoring wells; however, the southernmost monitoring wells had the highest concentrations since the initiation of sampling in 1988. The concentrations generally increased from north to south along the line of downgradient wells, indicating that the highest concentration is south of the area sampled by the southernmost downgradient well. This southward-increasing trend is demonstrated by data from the two new downgradient wells, especially for 1,1,1-trichloroethane, trichloroethylene, and 1,1-dichloroethane. This demonstrates that the principal sources probably migrated south of the SWL boundary; however, the principal source of tetrachloroethylene is probably still within the boundaries. The concentrations of 1,1,1-trichloroethane, tetrachloroethylene, trichloroethylene, and 1,1-dichloroethane, as a function of distance from the south end of the SWL downgradient monitoring network, are shown in Figures 6.12-2 through 6.12-5.

The most likely cause of the widespread chlorinated hydrocarbon contamination at the SWL, including upgradient wells and the adjacent NRDWL, is the dissolution of vadose-zone vapors into groundwater. However, the source of the vadose-zone vapors is uncertain. Total inorganic carbon (total carbon minus TOC) increases southward along with the chlorinated hydrocarbons. This correspondence suggests a link between the chlorinated hydrocarbon contaminants and the sewage waste, which is the most probable source of the elevated inorganic carbon in groundwater. Thus, the source(s) may be chlorinated hydrocarbons dissolved in sewage liquids that are migrating southward (downdip) along silt layers in the vadose zone.

Tritium. Tritium, which has a source in the 200-East Area (see Section 2.10), was added to the constituent list in 1989 as an aid in determining groundwater-flow directions and rates. Tritium concentrations in groundwater-monitoring wells ranged from <85 to 129,000 pCi/L and are decreasing. The tritium concentrations in 7 monitoring wells were above the primary 20,000-pCi/L DWS.

6.12.2.2 Nonradioactive Dangerous Waste Landfill RCRA Parameters

Monitoring of the NRDWL concentrates on the RCRA indicator parameters (specific conductance, pH, TOC, and TOX). Chlorinated hydrocarbons are monitored because they may represent groundwater contamination originating from the NRDWL. Tritium and nitrate are also included in NRDWL monitoring but have a source in the 200-East Area (see Section 6.10).

Field pH values in shallow downgradient and upgradient wells ranged from 7.4 to 7.8. pH values in the two deeper wells were slightly higher, ranging from 7.9 to 8.2, and did not exceed the critical means of pH (5.16 and 9.87).

Field specific conductance values for the shallow downgradient and upgradient wells ranged from 442 to 542 and 444 to 538 μS/cm, respectively. Values for the deep upgradient and downgradient wells ranged from 393 to 412 and 315 to 323 μS/cm, respectively, which did not exceed the critical mean of 821.9 μS/cm).

The TOC concentrations reported in the February 1996 samples ranged from 181 to 219 μg/L in the shallow downgradient wells and from 189 to 206 μg/L in the shallow upgradient wells, while concentrations in the two deep wells ranged from 179 to 189 μg/L, which did not exceed the critical mean of 971.2 μg/L. Concentrations for the August 1996 samples were all $<$532 μg/L because of a change to a laboratory with a higher MDL.

Reported TOX values for the February 1996 samples ranged from $<$6.9 to 9.1 μg/L in the shallow downgradient wells and from $<$6.9 to 11.4 μg/L in the shallow upgradient wells. The reported values for the deep wells were $<$6.9 μg/L. Reported values for the August 1996 samples ranged from $<$2.65 to 4.1 μg/L for the shallow downgradient wells and from $<$2.65 to 2.3 μg/L for the shallow upgradient wells. Reported concentrations for the deep wells were all $<$2.54 μg/L. The values did not exceed the critical mean of 16.3 μg/L.

Six chlorinated hydrocarbons were detected; however, none exceeded their MCLs. 1,1,1-trichloroethane and trichloroethylene are believed to be present in groundwater at the NRDWL principally as a result of vadose-zone vapor transport from the adjacent SWL. Tetrachloroethylene is present in vadose-zone gas beneath the SWL and is the principal vadose-zone gas contaminant around the chemical disposal trenches at the NRDWL; thus, there may be contributions from both sources. Carbon tetrachloride and chloroform may be a result of vadose-zone contamination at the NRDWL. Distributions of chlorinated hydrocarbon concentrations along the compliance point boundaries of the NRDWL and SWL are presented in Section 6.12.2.2.

6.12.2.3 Gable Mountain Pond

Concentrations of strontium-90 above the MCL were detected in several wells near Gable Mountain Pond (see Figure 6.10-10). Strontium-90 in that area apparently resulted from the discharge of waste to that pond during its early use. The maximum annual average concentration of strontium-90 detected in the Gable Mountain Pond area in FY 1996 was 1,500 pCi/L in well 699-53-48B (see

Figure 6.10-10). This is the first time in recent years when the concentration of strontium-90 in the vicinity of Gable Mountain Pond was above the DCG. Strontium-90 was also detected in basalt just below the contact with the sediments in well 699-53-48A, where the annual average concentration was 230 pCi/L. The depth to basalt in this well is 13 m. Wells completed above the basalt in the vicinity of Gable Mountain Pond are becoming difficult to sample because of declining water levels.

6.12.2.4 618-10 Burial Ground and 316-4 Crib

This burial ground and adjacent crib are located southeast of the 400 Area, adjacent to Route 4S. This site was investigated as part of a CERCLA limited field investigation for the 300-FF-2 Operable Unit (DOE 1996g). In 1995, high levels of uranium (768 mg/L, unfiltered) and the presence of hydrocarbon contamination (total petroleum hydrocarbon 104 mg/L; alkane and assorted decanes at estimated values ranging from 770 to 1,800 mg/L; unknown volatile organics estimated at 3,200 mg/L) were detected in well 699-S6-E4A, which is adjacent to both the burial ground and crib.

The CERCLA activities in FY 1996 included renovating well 699-S6-E4A as a sampling well and collecting samples from this well and two cone penetrometer borings. Analyses of samples from well 699-S6-E4A after renovation showed a lower uranium concentration (108 mg/L unfiltered; 72.9 mg/L filtered), a lower total petroleum hydrocarbon concentration (3.38 mg/L), and lower alkane and assorted decanes (estimated from 10 to 43 mg/L). Also, tributyl phosphate, which may have been derived from the 316-4 crib, was detected in well 699-S6-E4A at 65 mg/L. Results from the cone penetrometer borings (B2763 and B2764) showed values for unfiltered uranium (5.3 and 10.1 mg/L, respectively) and filtered uranium (4.79 and 9.74 mg/L, respectively). No total petroleum hydrocarbons or volatile or semivolatile organics were found in the cone penetrometer borings. The conclusions in DOE (1996g) were that uranium and hydrocarbon groundwater contamination are probably localized in the area of well 699-S6-E4A and the source of such contamination is primarily the 316-4 crib, with possibly some contribution from the 618-10 burial ground.

During FY 1996, well 699-S6-E4C was reconfigured to provide two deep, depth-discrete monitoring intervals within the unconfined aquifer system that, in conjunction with shallow monitoring wells 699-S6-E4B and 699-S6-E4D, provided information on the vertical distribution of contaminants at this location. (Chapter 8.0 gives more information on well reconfiguration.)

Tritium concentrations from samples collected in January 1996 ranged from 24,387 to 31,741 pCi/L in wells 699-S6-E4B, 699-S6-E4CT, and 699-S6-E4D and were significantly lower (2,520 pCi/L) in piezometer 699-S6-E4CS. The lower value for tritium in the piezometer can be expected because it monitors deep in the unconfined aquifer system. The tritium level in piezometer 699-S6-E4CT (27,800 pCi/L) is within the range of concentrations shown by the wells that monitor the top of the unconfined aquifer system (i.e., wells 699-S6-E4B and 699-S6-E4D). These results may indicate a greater vertical extent of tritium contamination than was previously thought for this site. This result is consistent with data obtained from monitoring well 699-18-21, located ~10 km northwest (upgradient) of 699-S6-E4CS and 699-S6-E4CT. Well 699-18-21 is screened from 50.9 to 63 m; groundwater data from this well indicate comparable tritium concentrations to those observed at the water table. It should be noted, however, that elevated tritium concentrations in 699-S6-E4CT may be associated with

historical intercommunication between the water table and deeper portions of the unconfined aquifer system via well 699-S6-E4C prior to reconfiguration. Future sample results should provide sufficient data to determine whether the elevated tritium levels at depth were caused by intercommunication or are representative of the vertical extent of tritium contamination at this location.

6.12.2.5 Central Plateau

Chromium was detected in 1995 at levels above the 50-μg/L state MCL in three widely spaced wells south of the 200-East Area (Dresel et al. 1996). Although one of the wells is located near the BC cribs, the other two wells are upgradient, suggesting that the cribs are not the source of chromium. The maximum concentration detected in filtered samples in this vicinity in 1995 was 220 μg/L in the single sample from well 699-32-62. This chromium contamination was only recently recognized but its source and extent are uncertain. The extent of chromium contamination to the south is particularly poorly defined. No investigation of this contamination was performed in FY 1996 but is planned for FY 1997.

6.12.2.6 Western 600 Area

Nitrate was detected at levels above the MCL in wells in the western part of the site (see Plate 4). Nitrate upgradient of the 200-West Area appears to have an offsite source, possibly related to agricultural activity. An extension of Yakima Ridge, south of the 200-West Area, forms a hydraulic barrier for the unconfined aquifer system. For this reason, nitrate south of the ridge is not believed to result from Hanford Site activities. Upgradient agricultural activities may also explain this zone of elevated nitrate.

6.12.3 Compliance Issues

6.12.3.1 Solid Waste Landfill

Activities at the SWL are regulated by WAC 173-304 and are detailed in Hodges (1993b). The SWL is part of the 200-IU-3 Operable Unit. A permit application for operation of the site was submitted to the Benton-Franklin District Health Department in 1991 (DOE 1991a) and was rejected. Responsibility for the site was assumed by Ecology and a revised permit application was submitted in 1993 (DOE 1993a). As part of the permit review, Ecology requested that a corrective action program be established for the site, and a corrective action plan (Hodges 1994c) was submitted. In 1995, because of groundwater contamination at the site, Ecology informed DOE that all future trenches must be lined. DOE decided to close the site and operations ceased in March 1996. The final closure plan for the site is pending.

Two downgradient wells were installed in December 1993, completing the shallow compliance-point monitoring network. The presence of the two downgradient wells raises the Wilson et al. (1992) monitoring efficiency from 68% to 94%. Additional wells will be needed only if it is shown that significant quantities of contaminants have migrated south of the site boundary (Hodges 1994c).

6.12.3.2 Nonradioactive Dangerous Waste Landfill

As part of the Tri-Party Agreement (Ecology et al. 1989), it was agreed to close the NRDWL under RCRA (WAC 173-303). A closure/postclosure plan was submitted to Ecology in 1990 (DOE 1990b).

The uncertainty in groundwater-flow directions beneath the NRDWL (see Section 5.4.5.2) makes the evaluation of the monitoring network more difficult. If the groundwater flows toward the southeast, as indicated by the tritium and nitrate plumes (shown in Plates 3 and 4), the boundary between the NRDWL and SWL should be part of the compliance point. If the groundwater flows in an east-northeast direction, as indicated by the water-level data, the north boundary of the NRDWL should be part of the compliance point. The two monitoring wells along the north and south boundaries of the NRDWL, completed in 1992, solve this problem and provide the Wilson et al. (1992) monitoring efficiency between 96% and 99%, depending on groundwater-flow directions. The current shallow monitoring network is adequate; however, deep characterization and monitoring are called for in the NRDWL groundwater-monitoring plan (Hodges 1992b).

6.12.3.3 Drinking Water Standards and Derived Concentration Guides

Strontium-90 was detected at levels above the DCG near the decommissioned Gable Mountain Pond in FY 1996. This is the first time in recent years that the DCG was exceeded in this vicinity. No other radionuclides exceeded the DCG in the 600 Area. Contamination from other operational areas impacted the 600 Area at levels that exceeded the interim DWS or MCL as discussed in the sections above. Additional contamination at levels greater than the interim DWS or MCL in the 600 Area includes strontium-90 near Gable Mountain Pond, uranium in the vicinity of the 618-10 burial ground and 316-4 crib, and chromium in the southern Central Plateau and south of the 200-East Area. Nitrate concentrations that exceeded the MCL were found upgradient of the operational areas and probably result from offsite agriculture.

6.13 300 Area

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Activities in the 300 Area have been historically related to various research activities and the processing of uranium into fuel elements for the reactors. In addition to the fuel-fabrication processes, many technical-support, service-support, and research-and-development activities related to fuel fabrication were carried out. Fuel-fabrication activities ended in 1987. During fuel fabrication, uranium was disposed to the process ponds and trenches in dissolved and particulate forms. Facilities known to have received uranium include the 316-1 south process pond, the 316-2 north process pond, and the 316-5 process trenches (see Plate 1). The process ponds were removed from service in the mid-1970s. Discharge to the 316-5 process trenches ceased in December 1994.

6.13.1 Operable Units

The largest volume of waste generated in the 300 Area is from the fuel-fabrication operations associated with three source operable units. The 300-FF-1 Operable Unit contains the south and north process ponds, the sanitary leaching trenches, and the process trenches. The 300-FF-2 Operable Unit consists primarily of waste-management units that received solid waste and contaminated equipment in the north and northwestern parts of the area. The 300-FF-3 Operable Unit includes a variety of miscellaneous waste-management units, including solid and liquid wastes in the southern portion of the area.

The 300-FF-5 Operable Unit is the groundwater beneath the three source operable units and is defined by the observed and assumed extent of uranium contamination in the groundwater. The extent of the 300-FF-5 Operable Unit includes all contamination emanating from the source operable units detected in groundwater and sediments below the water table that exceeds ARARS (applicable or relevant and appropriate federal and state environmental requirements).

Groundwater beneath the 300 Area is potentially affected by inflowing groundwater from several source areas in addition to the 300 Area source operable units. The other sources are:

- the 300-IU-1 Operable Unit, located 3.8 km northwest (upgradient) of the 300 Area, consists of various waste management units that received waste from fuel-fabrication operations and miscellaneous construction debris
- the 300-FF-4 Operable Unit, located at the 400 Area (the Fast Flux Test Facility), which is also approximately upgradient
- the southeastern portion of the tritium plume emanating from the 200 Areas (200-PO-2 Operable Unit)
- the 1100-EM-1 Operable Unit associated with the Horn Rapids Landfill, which contains a plume of trichloroethylene that is migrating in the direction of the 300 Area.

6.13.2 Facilities

The facilities in the 300 Area that affected the groundwater include the 316-5 process trenches, operating until December 1994, which have RCRA requirements for monitoring and many of the other past-practices waste sites. Three of the most significant of these are the 316-1 south and 316-2 north process ponds and the 300 Area Fire Station.

6.13.2.1 316-5 Process Trenches

The groundwater near these process trenches has been monitored by a RCRA interim status groundwater quality assessment well network since June 1985. The trenches are located in the northern portion of the 300 Area (see Plate 1). The two unlined trenches were constructed in 1975. From 1975 until shutdown of fuel-fabrication activities in 1987 and other operations in 1988, the

trenches were used for the disposal of most liquid wastes generated in the 300 Area. The liquid waste was known or suspected of including the following (Schalla et al. 1988a):

uranium, or other alpha emitters	sodium	potassium
at least one beta emitter	iron	chloroform
chloride	sulfate	methyl chloride
nitrate	copper	trichloroethylene
tetrachloroethylene	ammonium	cis-1,2-dichloroethylene
barium	vanadium	

The discharge rate reached a maximum of ~7,600 L/min. After 1988, the wastewater consisted of cooling water with small quantities of nonhazardous maintenance and process waste. In July 1991, the trenches were modified as part of an expedited response action. The modification of the trenches involved removing bottom sediment from the inflow end of the trench and placing it at the opposite end of the trench behind a berm. The trenches were used on an alternating, as-needed basis. The west trench was rendered inoperable on November 20, 1992. Subsequently, the east trench received all discharges. The average discharge to the east trench was ~850 L/min in the latter years of operation. In December 1994, all discharges to the trenches were terminated.

6.13.2.2 316-1 and 316-2 Process Ponds

These process ponds were the main facility for the disposal of uranium-contaminated wastewater until 1975 when the 316-5 process trenches were constructed and put into use. These retired process ponds are within the 300-FF-1 Operable Unit and 300-FF-5 groundwater Operable Unit.

6.13.2.3 300 Area Fire Station and 382 Pumphouse

In April 1992, an unknown quantity of contaminated soil was found under the fuel-dispensing island at the 3709-A building (300 Area Fire Station). This fueling facility consisted of two 1,893-L (500-gal) underground storage tanks and approximately 10 m of piping leading to the fuel-dispensing island. One tank contained unleaded gasoline and the other contained diesel fuel. Releases to the soil column occurred reportedly as a result of failure of corroded flex piping located directly beneath the dispensing island and also possibly from loose fittings. The underground storage tanks, piping, and dispensing island have since been removed.

Also, an unknown amount of petroleum product was released from the 382-1 underground storage tank, located at the 382 pumphouse building. The tank system was physically removed, along with an unknown quantity of petroleum-contaminated soil, for disposal on September 29, 1992.

6.13.3 Extent of Contamination

Uranium (an alpha-emitting radionuclide) is the major contaminant of concern in the 300 Area. Tritium contamination from the 200-East Area impacted the 300 Area at levels less than the interim DWS. The tritium contamination is discussed in Sections 6.10 and 6.14. Additional constituents

detected include strontium-90, nitrate, trichloroethylene, cis-1,2-dichloroethylene, iron, and manganese. Petroleum hydrocarbons are being monitored near the 300 Area Fire Station.

6.13.3.1 Uranium and Gross Alpha

The uranium distribution in the 300 Area is shown in Figure 6.13-1. The highest uranium concentrations are located in the northern part of the 300 Area, downgradient from the 316-5 process trenches and near the 316-1 and 316-2 process ponds. Because the process ponds are downgradient of the process trenches, it is difficult to determine the relative contribution of each facility to the contamination. The maximum uranium concentration detected in the 300 Area was 300 μg/L in well 399-1-17A on March 4, 1996. This well monitors the area near the inflow of the trenches. The average for well 399-1-17A for FY 1996 was 230 μg/L. Farther downgradient, the average for well 399-2-2 for FY 1996 was 260 μg/L. Figure 6.13-2 shows the historical trend for uranium in well 399-1-17A. Uranium concentrations dropped dramatically in 1991 as a result of the expedited response action but then began to rise sharply again as process trench discharges ceased in January 1995. In FY 1996, the rise continued.

Presumably, the contribution of uranium to the unconfined aquifer system by the soil column at the process trenches was diluted by the large quantities of process wastewater prior to January 1995. Because wastewater is no longer discharged to the trenches, the increase in concentration since January 1995 indicates that uranium continues to be contributed to the groundwater by the soil column at the trenches. The contribution is either 1) the waning stages of percolation from (what is now the unsaturated zone) above the water table or 2) as uranium already in the saturated zone that continues to mobilize. In either case, it is the lack of dilution by large quantities of process wastewater that caused the concentration of uranium in the groundwater to continue to rise during FY 1996. The total activity of uranium contributed by the soil column at the trenches during FY 1996 may actually be the same or even lower than it was prior to January 1995.

Uranium-234, -235, and -238 decay by alpha emission. Thus, the gross alpha measurements from 300 Area samples correlate strongly with uranium concentrations. Gross alpha measurements are used as contaminant indicators for RCRA compliance. The maximum concentration was at well 399-1-17A, where results ranged from 132 pCi/L in October 1995 to 116 pCi/L in April 1996. The MCL for gross alpha, excluding uranium, is 15 pCi/L.

Uranium concentration trends for a series of wells in the 300 Area along the Columbia River are shown in Figure 6.13-3. These trends show concentrations declining in the northern part of the area, increasing in the central part, and holding steady in the south. These data suggest that a pulse of contamination may be moving toward the southeast from the vicinity of the process trenches. The pulse reached the northern wells first and impacted wells farther south at later times.

Another zone of increased uranium concentration in the 300 Area is near the 324 building (well 399-3-11, see Figure 6.13-1). Uranium concentrations in samples from this well averaged 130 μg/L for FY 1996. Well 399-4-12, which supplies water for ponds used in trout research south of

the 331 building, contained 40.3 μg/L of uranium in August 1996. Well 399-4-12 is the southernmost well in the 300 Area where uranium was detected at levels above the proposed 20-μg/L MCL.

6.13.3.2 Strontium-90

Well 399-3-11, near the 324 building, also continued to show elevated levels of strontium-90 (8-pCi/L interim DWS) (Figure 6.13-4). Results include 8.7 pCi/L in December 1995 and 3.0 pCi/L in August 1996. Samples from this well were collected with a bailer and were not filtered, so it is probable that much of the strontium-90 is sorbed to sediment in the samples. Nonetheless, the data indicate a release of strontium-90 in the vicinity.

6.13.3.3 Trichloroethylene, cis-1,2-Dichloroethylene, and TOX

In past years, trichloroethylene was above the 5-μg/L MCL in wells 399-1-16B, 399-1-17B, and 399-4-12 but has been declining since the monitoring wells were installed (e.g., well 399-1-16B, Figure 6.13-5). Well 399-4-12, which monitors the top of the unconfined aquifer system in the southern portion of the 300 Area, was not monitored in FY 1996. The other two wells near the process trenches that monitor the deeper parts of the unconfined aquifer system just above an aquitard contained levels of trichloroethylene below the MCL in FY 1996. However, the concentration of cis-1,2-dichloroethylene (70-μg/L MCL) is increasing in well 399-1-16B (Figure 6.13-6). The levels in well 399-1-16B were 160 μg/L in October 1995 and 140 μg/L in June 1996. Note that some earlier analyses did not distinguish between cis- and trans-1,2-dichloroethylene. The presence of cis-1,2-dichloroethylene in well 399-1-16B indicates that anaerobic biodegradation of trichloroethylene occurred.

Concentrations of TOX (a RCRA contamination indicator parameter) are elevated in two network wells, probably in response to the presence of trichloroethylene and cis-1,2-dichloroethylene. Wells 399-1-16B and 399-1-17B show TOX results that range from 14.0 to 108.0 μg/L. Because the 300 Area process trenches are in a groundwater quality assessment program, contamination indicator parameters are not statistically compared to background results. Samples, however, are still analyzed for TOX to help in the monitoring for chlorinated hydrocarbons.

6.13.3.4 Iron and Manganese

The groundwater quality parameters of filtered iron (300-μg/L secondary MCL) and filtered manganese (50-μg/L secondary MCL) are above secondary DWSs in wells 399-1-16B and 399-1-17B. Secondary standards are based on aesthetic rather than health criteria. The exceedance of iron was at well 399-1-17B with a result of 400 μg/L. Exceedances of manganese occurred at both wells 399-1-16B and 399-1-17B and ranged from 55 to 77 μg/L. These wells are screened at the bottom of the unconfined aquifer system downgradient of the process trenches. Higher concentrations of iron and manganese in these wells do not necessarily indicate that the process trenches are the source. The elevated concentrations observed in the deep unconfined aquifer system are probably influenced by chemically

reducing conditions (i.e., the absence of oxygen and negative oxidation-reduction potentials). A similar relationship between sampling depth and concentration profiles for redox-sensitive species was documented in Johnson et al. (1994).

6.13.3.5 300 Area Fire Station

In April 1993, two groundwater-monitoring wells (399-5-4B and 399-6-2) were installed ~23 to 46 m southeast of the 3709-A building, specifically for the purpose of monitoring potential contamination downgradient of the former fueling facility. To date, samples were collected in May, September, and December 1993, April and October 1995, and April 1996. The samples were analyzed for total petroleum hydrocarbons (gasoline and diesel ranges), benzene, toluene, ethylbenzene, and total xylenes.

Low levels of diesel were detected in well 399-6-2 in the May and September 1993 and October 1995 samples. Concentrations for the remaining constituents have been below applicable detection limits for all sampling events. Additional samples from one upgradient and five downgradient wells have also been below detection.

6.13.4 Compliance Issues

6.13.4.1 316-5 Process Trenches

The groundwater near the 300 Area Process Trenches has been monitored by a RCRA interim status groundwater quality assessment well network since June 1985. The site continues to be regulated by the interim status regulations under the provisions of its RCRA permit (Ecology 1994). Monitoring wells were constructed in response to an order issued jointly by Ecology and the EPA (1986). Currently, the trenches are in the groundwater quality assessment stage of monitoring, as discussed in Schalla (1988b). A revised groundwater-monitoring plan was written in expectation of the site going into final status in late FY 1996 (Lindberg et al. 1995). The existing closure/postclosure plan for the trenches is described in DOE (1985).

The schedule for modifying the RCRA sitewide permit (Ecology 1994) requires that a closure plan and accompanying groundwater-monitoring plan be written. The closure plan (DOE 1994f) includes the groundwater-monitoring plan (Lindberg et al. 1995) as Appendix 5B. The closure plan and accompanying groundwater-monitoring plan are referenced in Modification B of the revised RCRA sitewide permit and became effective December 26, 1996 (Ecology 1996).

With the approval of Modifications B of the sitewide permit, the groundwater-monitoring status of these trenches changes from a groundwater quality assessment program (interim status) to a compliance-monitoring program (final status). The major changes are that the number of wells to be sampled and the number of constituents to be analyzed for are reduced. The sampling schedule changes from a quarterly/semiannual schedule of single samples at each well to a semiannual sampling schedule with four time-independent samples collected from each network well. Assessments of data change from quarterly to semiannual, and annual reporting remains a requirement.

Although the Columbia River was at high-river stage throughout much of FY 1996 and gradients in the 300 Area were changed somewhat, the overall gradient in the immediate vicinity of the process trenches was not changed significantly. Further, even if the groundwater-flow direction were to change significantly, the configuration of the well network around the process trenches is sufficient to monitor any emanating waste plumes. Therefore, no changes are proposed for the network while the facility remains in the groundwater quality assessment program.

6.13.4.2 CERCLA

The record of decision for the 300-FF-1 and 300-FF-5 Operable Units was approved in July 1996 (ROD 1996b). The major components of the selected remedy for the 300-FF-1 Operable Unit include the following:

- removal of contaminated soil and debris
- disposal of contaminated material at the Environmental Restoration Disposal Facility
- recontouring and backfilling of waste sites, followed by revegetation
- institutional controls to ensure that unexpected changes in land use do not occur that could result in unacceptable exposures to residual contamination.

The selected remedy for the 300-FF-5 Operable Unit is an interim remedial measure that involves imposing restrictions on the use of the groundwater until such time as health-based criteria are met for uranium, trichloroethylene, and cis-1,2-dichloroethylene. This is an interim measure because there are other constituents (e.g., tritium) migrating into the unit that have not yet been fully addressed and because a portion of the unit is overlaid by uncharacterized waste sites in the 300-FF-2 Operable Unit. A final remedial action decision for the 300-FF-5 Operable Unit will be made after these issues have been addressed. The selected interim measure includes the following:

- continued monitoring of groundwater that is contaminated above health-based levels to ensure that concentrations continue to decrease
- institutional controls to ensure that groundwater use is restricted to prevent unacceptable exposures to contamination.

An operation and maintenance plan for the 300-FF-5 Operable Unit was released in September 1996 (DOE 1996h). The purpose of this plan is to identify tasks necessary to verify the effectiveness of the selected alternative. The plan describes the monitoring program and administrative tasks that will be used as the selected alternative for the remediation of the groundwater in the operable unit. The routine operation and maintenance activities include three tasks:

- monitor groundwater (chemistry, depth to water)
- monitor near-shore river water (chemistry and river stage)
- post warning signs.

6.13.4.3 Drinking Water Standards and Derived Concentration Guides

No radiological constituents in 300 Area groundwater were detected at levels above the DCG in FY 1996. Tritium and strontium-90 were detected at levels above the interim DWS. The strontium-90 is very localized and not consistently above the DWS, apparently related to varying amounts of particulate matter in the samples. The tritium appears to reflect a suspect analytical result and, thus, is not representative of aquifer conditions. Uranium is detected at levels above the proposed MCL in much of the eastern part of the 300 Area. Trichloroethylene and cis,1-2-dichloroethylene are found at levels above the MCL in the deeper part of the unconfined aquifer system. Iron and manganese are found at levels above the secondary MCL in the deeper part of the unconfined aquifer system but this appears to be the result of naturally occurring dissolved solids.

6.14 Richland North Area

T. L. Liikala

The Richland North Area includes the 1100 and 3000 Areas, that part of the 600 Area adjacent to the 300 Area, and parts of nearby Richland between the Yakima and Columbia Rivers.

6.14.1 Operable Units

The 1100-EM-1 and 1100-EM-2 Operable Units are within the Richland North Area. The 1100-EM-1 Operable Unit contains the Horn Rapids Landfill. CERCLA investigation results for this operable unit are presented in the final remedial investigation/feasibility study (DOE 1992c) and the record of decision (ROD 1993). The selected remedy for groundwater is natural attenuation and monitoring, with institutional controls on drilling of new water-supply wells. This operable unit was removed from the National Priorities List (40 CFR 300, Appendix B) in September 1996. One groundwater well, downgradient of the 1171 building, is sampled annually for the 1100-EM-2 Operable Unit.

6.14.2 Facilities

Facilities or activities of interest with respect to groundwater in the Richland North Area include Siemens Power Corporation, the City of Richland's North Well Field and settling and recharge basins, the Horn Rapids Landfill, the Lamb-Weston Richland Plant, Interstate Nuclear Services, Allied Technology Group, and agricultural and residential irrigation. Of particular concern is the potential for future impacts from these facilities and activities as well as Hanford Site operations at the City of Richland's North Well Field, which serves as the city's secondary drinking water-supply system.

6.14.3 Extent of Contamination

A total of 35 groundwater wells were sampled in the Richland North Area during FY 1996. Of those, 32 were sampled annually and 3 were sampled semiannually. The samples were analyzed predominantly for tritium, trichloroethylene, and nitrate. Selected samples were also analyzed for

alkalinity, gross alpha, gross beta, gamma emitters, metals, technetium-99, and uranium. In addition, 14 offsite wells were sampled quarterly by Siemens Power Corporation (Siemens Power Corporation 1996). Analyses for these samples included trichloroethylene, anions, gross alpha, and gross beta.

Constituents of concern in groundwater in this area include trichloroethylene, nitrate, gross alpha, uranium, and technetium-99. The potential for tritium transport from the Hanford Site into the Richland North Area is also addressed in this section.

6.14.3.1 Tritium

Effluent discharges in the 200-East Area resulted in tritium being transported to the Columbia River as far south as the southeastern portion of the 300 Area (see Plate 3). The FY 1996 plume configuration is similar to 1995; however, the 2,000-pCi/L contour shifted ~300 m to the west/southwest. Average concentrations for FY 1996 ranged from 4.4 to 20,000 pCi/L. The highest concentration, detected in well 399-3-12, is suspect and is being reviewed. Well 399-1-18A had the next highest average concentration (13,000 pCi/L), which was comparable with other wells in the 300 Area. Tritium concentrations as a function of time in selected wells along a north-south transect through the 300 Area and Richland North Area are shown in Figure 6.14-1. Generally, tritium levels increased with time in the 316-5 Area but remained steady in the Richland North Area. Well 399-1-17A is unique, in that concentrations remained relatively low until December 1994 and then increased dramatically. This trend plot clearly indicates when discharge to the 316-5 process trenches and its dilution effect ceased. Tritium concentrations at the City of Richland's North Well Field are essentially equivalent to those in the Columbia River at the Richland Pumphouse (Dirkes and Hanf 1996).

The southward migration of the tritium plume and increasing concentrations with time raised concern over potential future impacts at the City of Richland's North Well Field. Several factors are believed to limit the migration significantly into this area. First, groundwater is recharged to the west by the Yakima River and flows east, discharging to the Columbia River. Second, artificial recharge from agricultural irrigation occurs west of the 1100 Area and contributes to the eastward flow. Third, the groundwater mound at the well field directs flow to the northeast and southeast, around the well field. These factors produce converging flow lines in the 300 Area and discharge to the Columbia River (see Plate 2). Although the current flow field is based, in part, on the net recharge to the infiltration ponds, modeling efforts indicate groundwater flow would still be predominantly west to east without this recharge, thus, there is still no indication that the well field will be impacted.

The tritium concentration for the August 22, 1996 sample from well 699-S29-E16A was reported as 2,030 pCi/L. This result was considerably higher than the January 1995 value of 65 pCi/L and other previous results. This well is located near the Columbia River, south of the 300 Area. The FY 1996 average tritium value for this well was 1,000 pCI/L (rounded to two significant figures). It is unknown if the high value represents an analytical error or an upward trend. The well is sampled semiannually, and the analysis for tritium is by the low-level tritium method (see Appendix E), so the trends will be assessed in FY 1997. If necessary, the monitoring frequency will be increased to quarterly.

6.14.3.2 Trichloroethylene

The distribution of trichloroethylene in the Richland North Area supports the interpretation that groundwater flows to the northeast, around the City of Richland's North Well Field (Figure 6.14-2). Trichloroethylene was found onsite adjacent to the Horn Rapids Landfill and offsite adjacent to Siemens Power Corporation. Compared with 1995, this plume in FY 1996 had a more northerly configuration near the point of compliance (i.e., the George Washington Way diagonal) established in the record of decision for the 1100-EM-1 Operable Unit (ROD 1993). In fact, the 5-μg/L MCL was exceeded in the northwest point-of-compliance well (6 μg/L in 699-S27-E12A). Concentrations in the other onsite wells ranged from 0.075 to 14 μg/L, with the highest concentration in well 699-S31-E10A. This well is located immediately downgradient of the Horn Rapids Landfill. In FY 1996, concentrations in wells immediately northeast and downgradient of the Horn Rapids Landfill decreased from 1995 levels. Concentrations also decreased in well 699-S31-E10C, which is located deeper in the unconfined aquifer system and contained 14 μg/L of trichloroethylene in FY 1996 (down from 29 μg/L in 1995). Concentrations in wells immediately east and downgradient of the landfill continued to decrease with time. Sufficient data have not been collected to establish trends with time in recently installed downgradient wells 699-S27-E12A, 699-S28-E13A, 699-S29-E10A, 699-S29-E13A, and 699-S30-E11A.

Concentrations of trichloroethylene in the Siemens Power Corporation wells through the second quarter of FY 1996 ranged from less than detection to 7 μg/L, with the highest concentration in well GM-8 (Siemens Power Corporation 1996). These are Siemens Power Corporation monitoring data and, thus, are not plotted on Figure 6.14-2 or included in Appendix H. Concentrations in these wells continue to decrease generally with time. The only potential source of trichloroethylene identified in the Richland North Area was the use of solvent in installing and maintaining pond liners at Siemens Power Corporation (DOE 1992c).

6.14.3.3 Nitrate

Nitrate distributions in the Richland North Area in FY 1996 appear similar to 1995 and also support the generally west-to-east groundwater-flow direction, with local influence from the groundwater mound at the City of Richland's North Well Field (see Plate 4). Concentrations above the 45-mg/L MCL are found offsite both upgradient and downgradient of the Siemens Power Corporation facility (Siemens Power Corporation 1996). Through the second quarter of FY 1996, concentrations in upgradient wells and downgradient wells to the east increased slightly from 1995 levels. Concentrations in downgradient wells to the north decreased slightly. The maximum concentration was 133 mg/L (as NO_3^-) in Siemens' well GM-9. Fertilizer and irrigation applied to upgradient agricultural fields as well as industrial activity at the Siemens Power Corporation facility are likely sources. Potential nitrate sources from Siemens Power Corporation are discussed in DOE (1992c).

Nitrate concentrations onsite ranged from 0.56 to 190 mg/L, with the highest concentration in well 699-S30-E10A. This well is located downgradient of the Horn Rapids Landfill. However, as discussed above, the apparent source of the nitrate is from offsite, upgradient industry and agriculture. Concentrations exceeding the MCL are found into the southwestern portion of the 300 Area and

throughout much of the Richland North Area (see Plate 4). Concentrations in wells at the City of Richland's North Well Field were lower than ambient groundwater, probably as a result of dilution from infiltration of river water at the settling and recharge basins.

Concentrations of ammonium in downgradient Siemens Power Corporation wells decreased slightly. The highest concentration detected was 19 mg/L (as N) in well GM-9 (Siemens Power Corporation 1996). Ammonia is typically absorbed by plants or soil microorganisms or is taken up as an exchangeable ion on soil particles (Hausenbuiller 1972). However, ammonia is usually less stable than nitrate in a biological system like the soil and is rapidly converted to nitrate by nitrification. The fact that ammonia is found in the groundwater suggests that relatively high concentrations reached the soil column. No samples from Hanford Site wells in the Richland North Area were analyzed for ammonia.

6.14.3.4 Gross Alpha, Uranium, and Technetium-99

Gross alpha levels in offsite wells downgradient from Siemens Power Corporation decreased nearly two-fold since maximums were noted between December 1993 and June 1995 (Siemens Power Corporation 1996). The maximum concentration to date in FY 1996 was 85 pCi/L in well GM-5. Although the gross alpha MCL excludes uranium and no uranium measurements were made offsite, it is probable that uranium makes a large contribution to the gross alpha measurements at this location because this facility produces fuel for commercial nuclear power plants. The maximum gross alpha measurement onsite (11 pCi/L) occurred in well 699-S31-E10B, downgradient of the Horn Rapids Landfill.

Low levels of technetium-99 (maximum of 38 pCi/L in well 699-S28-E12) were detected in groundwater near the Horn Rapids Landfill and may be correlated with gross beta measurements in wells adjacent to the Siemens Power Corporation (Siemens Power Corporation 1996).

6.14.4 Compliance Issues

6.14.4.1 CERCLA

As noted above, the 1100-EM-1 and 1100-EM-2 Operable Units are contained within the Richland North Area. The Horn Rapids Landfill is included as part of the 1100-EM-1 Operable Unit. Natural attenuation and monitoring, with institutional controls on drilling of new water-supply wells were the selected remedy for groundwater in the record of decision (ROD 1993).

A network of 14 groundwater-monitoring wells was chosen for sampling (Table 6.14-1). Three of these wells establish the downgradient point of compliance for the landfill and are approximately parallel to the George Washington Way diagonal. During FY 1996, the annual sample from the northwest point-of-compliance well (6 μg/L in 699-S27-E12A) exceeded the 5-μg/L MCL for trichloroethylene. Samples from the other two downgradient point-of-compliance wells were below the MCL. One groundwater well (699-S41-E12) is sampled annually for the 1100-EM-2 Operable Unit.

6.14.4.2 Drinking Water Standards and Derived Concentration Guides

Trichloroethylene and nitrate were detected at levels above the MCL in the Richland North Area. The source for these constituents appears to be offsite industry and agriculture.

6.15 Radiological and Chemical Monitoring for the Upper Basalt-Confined Aquifer

D. B. Barnett and W. D. Webber

The upper basalt-confined aquifer, which lies immediately below the unconfined aquifer system, is affected far less by Hanford Site contamination than the unconfined aquifer system. Minor amounts of contamination reached the upper basalt-confined aquifer through various mechanisms:

- local erosion of confining basalt layers, allowing intercommunication between aquifers
- disposal of large quantities of water, resulting in groundwater mounding in the unconfined aquifer system and a downward hydraulic gradient to the upper basalt-confined aquifer
- wells penetrating the confined aquifer(s), providing a pathway for downward contaminant migration.

These conditions can allow groundwater and any potential entrained contaminants to flow from the unconfined aquifer system to the underlying confined aquifer, thus increasing the potential to spread contamination. Because fewer wells are available to monitor the confined aquifer, it is important to consider contamination trends at levels well below the DWS to provide for timely detection of potentially higher levels.

Spane and Webber (1995) evaluated the hydrochemical and hydrogeologic conditions within the upper basalt-confined aquifer and evaluated the potential for offsite migration of contaminants through confined-aquifer pathways. The upper basalt-confined aquifer was monitored to determine the extent of groundwater contamination resulting from interaction between the unconfined and confined aquifers. Spane and Webber (1995) also identified several confined-aquifer wells north and east of the 200-East Area that show evidence of intercommunication with the overlying unconfined aquifer system. Groundwater chemical data from most confined-aquifer wells in other areas of the Hanford Site show no evidence of contamination, with the exception of wells that were previously open to both the unconfined and confined aquifers and, thus, provided routes for the downward transport of contamination.

Results of the 1995 sampling and analyses of groundwater from the upper basalt-confined aquifer indicated only a few areas of concern that warrant continued annual monitoring. Consequently, the number of wells sampled during FY 1996 was reduced to those with groundwater contamination or are downgradient hydraulically from areas with historical indications of contamination. Prominent analytical results and trends arising from FY 1996 sampling are discussed below. Figure 6.15-1 shows the locations of wells used for monitoring confined-aquifer groundwater chemistry.

Well 199-B3-2P (in the 100-B Area) is currently completed within the confined aquifer but was open to both the confined and unconfined aquifers between 1953 and 1970. This well likely provided a conduit for downward migration of contamination from the unconfined aquifer. The 6.97-pCi/L concentration for strontium-90 from this well in September 1996 was up from the 3.9-pCi/L result for 1995. Specific conductance has steadily declined in this well since 1994 and was 135 μS/cm in the single sample taken in FY 1996.

Intercommunication between the unconfined aquifer and underlying confined aquifer in the vicinity of the northern part of the 200-East Area was identified by Gephart et al. (1979) and Graham et al. (1984). This intercommunication was attributed to erosion of the upper Saddle Mountains Basalt and downward vertical gradients resulting from wastewater disposal that produced groundwater mounding within the unconfined aquifer system.

Well 699-42-40C monitors the confined aquifer immediately below the 216-B-3 pond system (see Section 6.10.4.4). Tritium in this well reached a high of 8,320 pCi/L in 1993, activity then declined until 1995, and began rising again. In FY 1996, tritium activity was 8,234 pCi/L. Likewise, the iodine-129 result for FY 1996 was 0.36 pCi/L, the highest since monitoring for this radionuclide began in this well in 1988. Conversely, nitrate concentrations in well 699-42-40C fell from 4,900 μg/L in January 1995 to 450 μg/L in June 1996. The hydraulic gradient at this well location is distinctly downward from the unconfined aquifer to the upper basalt-confined aquifer, with a head difference of $\sim$1.5 m (see Chapter 5.0).

A cluster of wells between the 200-East Area and Gable Mountain produced chemical analyses that indicated various types and degrees of contamination in the confined aquifer. Well 699-53-50 produced a nitrate result of 2,600 μg/L in 1995 but the concentration fell below the MDL in FY 1996. The concentration of nitrate in nearby well 699-56-53 rose from 50 μg/L in a sample taken in 1995 to 520 μg/L in FY 1996. Well 699-49-55B produced a cobalt-60 result of 154 pCi/L in 1995 but was dropped from sampling by the CERCLA characterization program and not picked up by other projects during FY 1996. However, adjacent well 699-49-57B produced a cobalt-60 result below the detection limit when sampled in June 1996. Well 699-56-53 produced a technetium-99 result of 6.7 pCi/L in April 1996, up from 0.7 pCi/L in 1995. Technetium-99 in well 299-E33-12 remained high in FY 1996 (1,283.8 pCi/L) but was down somewhat from the 1995 result of 1,560 pCi/L. Well 299-E33-12 also yielded a perennially high pH that averaged near the 8.5 DWS.

Results for specific conductance in well 699-42-E9B in FY 1996 indicated that this parameter was at its highest level (463 μS/cm) and has risen erratically since the first result from this well in 1992 (200 μS/cm). Measurements of pH in well 699-42-E9B have been consistently above the 8.5 DWS since 1992, with an average value of 8.8 (n = 8).

Table 6.1-1. Monitoring Wells and Constituents for 1301-N Liquid Waste-Disposal Facility (adapted from Hartman 1993b)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Well Standard	Other Networks
199-N-2[64]	Top of unconfined	Semiannual	PRE	100-NR-2
199-N-3[64]	Top of unconfined	Semiannual	PRE	100-NR-2, Sitewide
199-N-14[69]	Top of unconfined	Semiannual	PRE	100-NR-2
199-N-34[83]	Top of unconfined	Semiannual	PRE	--
199-N-57[87]	Top of unconfined	Semiannual	RCRA	--
199-N-67[88]	Top of unconfined	Semiannual	RCRA	100-NR-2, Sitewide
199-N-69[88]	Bottom of unconfined	Semiannual	RCRA	Sitewide
199-N-75[92]	Top of unconfined	Semiannual	RCRA	100-NR-2
199-N-76[92]	Top of unconfined	Semiannual	RCRA	100-NR-2, Sitewide

Contamination Indicator Parameters	Other Parameters	
pH (field)	Turbidity	Lead (filtered)
Specific conductance (field)	Alkalinity	Anions
Total organic carbon	Phenols	Gross alpha
Total organic halogen	ICP metals (filtered)	Gross beta

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-2. Monitoring Wells and Constituents for 1324-N/NA Liquid Waste-Disposal Facilities (adapted from Hartman 1993a, 1996b)

Well	Hydrologic Unit Monitored	Sampling Frequency	Well Standard	Other Networks
199-N-59[87]	Top of unconfined	Semiannual[(a)]	RCRA	--
199-N-71[91]	Top of unconfined	Semiannual[(a)]	RCRA	100-NR-2
199-N-72[91]	Top of unconfined	Semiannual[(a)]	RCRA	--
199-N-73[91]	Top of unconfined	Semiannual[(a)]	RCRA	100-NR-2
199-N-77[92]	Bottom of unconfined	Semiannual[(a)]	RCRA	100-NR-2

Contamination Indicator Parameters	Other Parameters	
pH (field)	Turbidity	Anions
Specific conductance (field)	Alkalinity	Volatile organics[(b)]
Total organic carbon	Total dissolved solids[(c)]	Gross alpha
Total organic halogen	ICP metals (filtered)	Gross beta

(a) 1324-N/NA was sampled quarterly under an assessment program until the March 1996 sampling, reverted to an indicator parameter evaluation program in May, and subsequently was sampled semiannually.
(b) Assessment parameter - Wells 199-N-72 and 199-N-77 only; through March 1996 sampling.
(c) Assessment parameter - through March 1996 sampling.
Shading = Upgradient well.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-3. Monitoring Wells and Constituents for 1325-N Liquid Waste-Disposal Facility (adapted from Hartman 1993b)

Well	Hydrologic Unit Monitored	Sampling Frequency	Well Standard	Other Networks
199-N-27[83(a)]	Top of unconfined	Semiannual	PRE	100-NR-2, Sitewide
199-N-32[83]	Top of unconfined	Semiannual	PRE	100-NR-2, Sitewide
199-N-41[84]	Top of unconfined	Semiannual	PRE	--
199-N-43[84]	Top of unconfined	Semiannual	PRE	--
199-N-70[88]	Bottom of unconfined	Semiannual	RCRA	100-NR-2
199-N-74[91]	Top of unconfined	Semiannual	RCRA	100-NR-2
199-N-81[93]	Top of unconfined	Semiannual	RCRA	Sitewide

Contamination Indicator Parameters	Other Parameters	
pH (field)	Turbidity	Lead (filtered)
Specific conductance (field)	Alkalinity	Anions
Total organic carbon	Phenols	Gross alpha
Total organic halogen	ICP metals (filtered)	Gross beta

(a) Although well 199-N-27 is currently upgradient of this facility, it was downgradient when the facility was active. The groundwater chemistry at this well is still affected by the facility, so it was monitored as a downgradient well.

Shading = Upgradient well.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-4. Monitoring Wells and Constituents for 120-D-1 Ponds (adapted from Hartman 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Well Standard	Other Networks
199-D5-13[91]	Top of unconfined	Quarterly[(a)]	RCRA	100-HR-3
199-D8-4[91]	Top of unconfined	Semiannual	RCRA	100-HR-3
199-D8-5[91]	Top of unconfined	Semiannual	RCRA	100-HR-3
199-D8-6[91]	Top of unconfined	Semiannual	RCRA	100-HR-3

Contamination Indicator Parameters	Other Parameters	
pH (field)	ICP metals (filtered)	Gross beta
Specific conductance (field)	Mercury (filtered)	Tritium
Total organic carbon	Anions	Alkalinity
Total organic halogen	Gross alpha	Turbidity (field)

(a) Upgradient well 199-D5-13 was sampled quarterly until May 1996 to reestablish background concentrations.

Shading = Upgradient well.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-5. Monitoring Wells and Constituents for 183-H Solar Evaporation Basins (adapted from Hartman and Chou 1995)

Well	Hydrologic Unit Monitored	Sampling Frequency	Well Standard	Other Networks
199-H3-2A[86]	Top of unconfined	Semiannual	RCRA	100-HR-3, Sitewide
199-H4-12A[86]	Top of unconfined	Semiannual	RCRA	100-HR-3, Sitewide
199-H4-12C[86]	Mid-depth unconfined	Semiannual	RCRA	100-HR-3, Sitewide
199-H4-18[87]	Top of unconfined	Semiannual	RCRA	--
199-H4-3[74]	Top of unconfined	Semiannual	PRE	100-HR-3
199-H4-4[83]	Top of unconfined	Semiannual	PRE	100-HR-3
199-H4-6[83]	Top of unconfined	Semiannual	PRE	100-HR-3
199-H4-9[86]	Top of unconfined	Semiannual	RCRA	--

Dangerous Constituents	Other Parameters	
Chromium (filtered)	ICP metals (filtered)	Alkalinity
Nitrate	Turbidity	Anions
Technetium-99	Specific conductance (field)	pH (field)
Uranium		

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-6. Monitoring Wells and Constituents for 216-S-10 Pond and Ditch (adapted from Airhart et al. 1990)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards
299-W26-7[91]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W26-8[90]	Top of unconfined	Quarterly	Quarterly	RCRA
299-W26-9[90]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W26-10[91]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W26-12[91]	Top of unconfined	Semiannual	Semiannual	RCRA
299-W27-2[92]	Base of unconfined	Semiannual	Semiannual	RCRA

Contamination Indicator Parameters	Quality Parameter	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameter
Barium	Gross beta	Alkalinity
Cadmium	Nitrate	
Chromium	Silver	
Fluoride	Turbidity	
Gross alpha		

Shading = Upgradient wells.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-7. Monitoring Wells and Constituents for 216-U-12 Crib (adapted from Jensen et al. 1990 and Williams and Chou 1993)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-W22-43[90]	Top of unconfined	Quarterly	Quarterly	RCRA	Operational and Sitewide
299-W22-40[90]	Top of unconfined	Quarterly	Quarterly	RCRA	Operational and Sitewide
299-W22-41[90]	Top of unconfined	Quarterly	Quarterly	RCRA	Operational and Sitewide
299-W22-42[90]	Top of unconfined	Quarterly	Quarterly	RCRA	Operational and Sitewide
699-36-70A[94]	Top of unconfined	Quarterly	Quarterly	RCRA	Operational, CERCLA, and Sitewide

Contamination Indicator Parameters	Site-Specific Parameters	
pH	Anions	Iodine-129
Specific conductance	ICP metals	Technetium-99
Total organic carbon	Gross alpha	Turbidity
Total organic halogen	Tritium	Total dissolved solids
	Alkalinity[(a)]	Gross beta

(a) Only analyzed in wells 299-W22-42, 299-W22-43, and 699-36-70A.
Shading = Upgradient well.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-8. Monitoring Wells and Constituents for Waste Management Area S-SX Single-Shell Tank Farms (adapted from Caggiano and Goodwin 1991, Caggiano 1996a)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-W22-39[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W22-44[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W22-45[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W22-46[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W23-13[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W23-14[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W23-15[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W23-7[69]	Top of unconfined	June 1996	Semiannual	PRE	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Fluoride	Tritium	Technetium-99
Cadmium	Nitrate		
Chromium			

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-9. Monitoring Wells and Constituents for Low-Level Waste Management Area-3 (adapted from Last and Bjornstad 1989)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards	Other Networks
299-W6-2[87]	Top of unconfined	Semiannual	Semiannual	RCRA	LLWMA-5, SST
299-W7-1[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-2[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-3[87]	Deep unconfined	Semiannual	Semiannual	RCRA	--
299-W7-4[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-5[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-6[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-7[89]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-8[89]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-9[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-10[90]	Top of unconfined	Semiannual	Semiannual	RCRA	LLWMA-5
299-W7-11[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-12[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W8-1[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W9-1[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W10-13[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W10-14[87]	Deep unconfined	Semiannual	Semiannual	RCRA	--
299-W10-19[92]	Top of unconfined	Semiannual	Semiannual	RCRA	SST
299-W10-20[93]	Top of unconfined	Semiannual	Semiannual	RCRA	SST
299-W10-21[92]	Top of unconfined	Semiannual	Semiannual	RCRA	SST

Contamination Indicator Parameters	Other Constituents	
pH	Alkalinity	Mercury (filtered)
Specific conductance	Gross alpha	Phenols
Total organic carbon	Gross beta	Tritium
Total organic halogen	ICP metals (filtered)	Volatile organic compounds
	Lead (filtered)	

Shading = Upgradient wells.
Superscript = Year of installation.
LLWMA = Low-level waste management area.
RCRA = Well constructed to RCRA standards.
SST = Single-shell tanks.

Table 6.1-10. Monitoring Wells and Constituents for Low-Level Waste Management Area-4 (adapted from Last and Bjornstad 1989)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards	Other Networks
299-W15-15[87]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W15-16[87]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W15-17[87]	Deep unconfined	Semiannual	Semiannual	RCRA	--
299-W15-18[87]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W15-19[89]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W15-20[89]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W15-23[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W15-24[89]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-21[87]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-22[87]	Deep unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-23[87]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-24[87]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-26[89]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-27[91]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-28[91]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-29[91]	Perched zone	Dry	Dry	RCRA	--
299-W18-32[92]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1

Contamination Indicator Parameters	Other Constituents	
pH	Alkalinity	Mercury (filtered)
Specific conductance	Gross alpha	Phenols
Total organic carbon	Gross beta	Tritium
Total organic halogen	ICP metals (filtered)	Volatile organic compounds
	Lead (filtered)	

Shading = Upgradient wells.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-11. Monitoring Wells and Constituents for Low-Level Waste Management Area-5 (adapted from Last and Bjornstad 1989)[a]

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards	Other Networks
299-W6-2[87]	Top of unconfined	Semiannual	Semiannual	RCRA	LLWMA-3, SST
299-W6-3[91]	Deep unconfined	Semiannual	Semiannual	RCRA	--
299-W6-4[91]	Top of unconfined	Semiannual	Semiannual	RCRA	SST
299-W6-5[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W6-6[91]	Deep unconfined	Semiannual	Semiannual	RCRA	SST
299-W6-7[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W6-8[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W6-9[92]	Top of unconfined	Semiannual	Semiannual	RCRA	SST
299-W6-10[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W6-11[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W6-12[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W7-10[90]	Top of unconfined	Semiannual	Semiannual	RCRA	LLWMA-3
299-W11-31[92]	Top of unconfined	Semiannual	Semiannual	RCRA	SST

Analytical Constituents	
Alkalinity	Phenols
Gross alpha	Specific conductance
Gross beta	Total organic carbon
ICP metals (filtered)	Total organic halogen
Lead (filtered)	Tritium
Mercury (filtered)	Volatile organic compounds
pH	

(a) No longer monitored (after March 1996).
Shading = Upgradient wells.
Superscript = Year of installation.
LLWMA = Low-level waste management area.
RCRA = Well constructed to RCRA standards.
SST = Single-shell tanks.

Table 6.1-12. Monitoring Wells and Constituents for Waste Management Area T Single-Shell Tank Farm (adapted from Caggiano and Goodwin 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-W10-15[89]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W10-16[89]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W11-27[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W11-28[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W10-8[73]	Top of unconfined	--	Quarterly	PRE	--
299-W10-9[73]	Top of unconfined	--	Quarterly	PRE	--
299-W10-11[74]	Top of unconfined	--	Quarterly	PRE	--
299-W10-12[74]	Top of unconfined	--	Quarterly	PRE	--
299-W11-23[73]	Top of unconfined	--	Quarterly	PRE	--
299-W11-24[73]	Top of unconfined	--	Quarterly	PRE	--
299-W6-2[87(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA 3/5
299-W6-4[91(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5
299-W6-6[91(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5
299-W6-9[92(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5
299-W10-19[92(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-3
299-W10-20[93(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-3
299-W10-21[93(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-3
299-W11-31[92(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross beta	Ammonium	Cobalt-60
Cadmium	Nitrate	Technetium-99	Iodine-129
Chromium	Silver	Gamma scan	Tritium
Fluoride	Turbidity	Cesium-137	
Gross alpha			

(a) Wells used for expanded assessment monitoring.
Shading = Upgradient well.
Superscript = Year of installation.
LLWMA = Low-level waste management area.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-13. Monitoring Wells and Constituents for Waste Management Area TX-TY Single-Shell Tank Farm (adapted from Caggiano and Goodwin 1991, Caggiano and Chou 1993)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-W10-17[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W10-18[90]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W14-12[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W15-22[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-W15-12[73]	Top of unconfined	--	Quarterly	PRE	--
299-W15-13[73]	Top of unconfined	--	Quarterly	PRE	--
299-W6-2[87(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA 3/5
299-W6-4[91(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5
299-W6-6[91(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5
299-W6-9[92(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5
299-W10-19[92(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-3
299-W10-20[93(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-3
299-W10-21[93(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-3
299-W11-31[92(a)]	Top of unconfined	Quarterly	--	RCRA	LLWMA-5

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross beta	Ammonium	Cobalt-60
Cadmium	Nitrate	Technetium-99	Iodine-129
Chromium	Silver	Gamma scan	Tritium
Fluoride	Turbidity	Cesium-137	
Gross alpha			

(a) Wells used for expanded assessment monitoring.
Shading = Upgradient well.
Superscript = Year of installation.
LLWMA = Low-level waste management area.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-14. Monitoring Wells and Constituents for Waste Management Area U Single-Shell Tank Farm (adapted from Caggiano and Goodwin 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-W18-25[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W18-30[91]	Top of unconfined	Semiannual	Semiannual	RCRA	200-ZP-1
299-W18-31[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-W19-31[90]	Top of unconfined	Quarterly[(a)]	Quarterly[(a)]	RCRA	--
299-W19-32[91]	Top of unconfined	Quarterly[(a)]	Quarterly[(a)]	RCRA	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross beta	Tritium	Technetium-99
Cadmium	Nitrate		
Chromium	Silver		
Fluoride	Turbidity		
Gross alpha			

(a) Quarterly sampling for total organic halogen only.
Shading = Upgradient wells.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-15. Monitoring Wells and Constituents for 216-A-36B Crib (adapted from Kasza 1994)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E17-14[88]	Top of unconfined	Semiannual	Quarterly	RCRA	
299-E17-15[88]	Top of unconfined	Semiannual	Quarterly	RCRA	
299-E17-16[88]	Top of unconfined	Semiannual	Quarterly	RCRA	
299-E17-17[88]	Top of unconfined	Semiannual	Quarterly	RCRA	
299-E17-18[88]	Top of unconfined	Semiannual	Quarterly	RCRA	
299-E24-18[88]	Top of unconfined	Semiannual	Quarterly	RCRA	216-A-10
299-E25-36[88]	Top of unconfined	Semiannual	Quarterly	RCRA	216-A-10 216-A-29
299-E17-9[68]	Top of unconfined	Semiannual	Quarterly	PRE	
299-E17-5[65]	Top of unconfined	Not sampled	Quarterly	PRE	

Contamination Indicator Parameters	Other Constituents
Total organic halogen	Alkalinity
Total organic carbon	Anions
pH	ICP metals
Specific conductance	Iodine-129
	Phenols
	Gross beta
	Turbidity
	Gross alpha
	Tritium

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-16. Monitoring Wells and Constituents for 216-A-10 Crib (adapted from Kasza 1994)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards	Other Networks
299-E24-18[88]	Top of unconfined	Semiannual	Quarterly	RCRA	216-A-36B
299-E25-36[88]	Top of unconfined	Quarterly	Quarterly	RCRA	216-A-29 216-A-36B
299-E17-19[88]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E17-20[88]	Top of unconfined	Quarterly	Quarterly	RCRA	216-A-29
299-E24-16[88]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E24-17[88]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E17-1[55]	Top of unconfined	Semiannual	Quarterly	PRE	--
299-E24-2[56]	Top of unconfined	Semiannual	Quarterly	PRE	--

Contamination Indicator Parameters	Other Constituents
Total organic halogen	Alkalinity
Total organic carbon	Anions
pH	ICP metals
Specific conductance	Iodine-129
	Phenols
	Gross beta
	Turbidity
	Gross alpha
	Tritium

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-17. Monitoring Wells and Constituents for 216-A-29 Ditch (adapted from Kasza and Goodwin 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E25-26[85]	Upper unconfined	Semiannual	Quarterly	RCRA	--
299-E25-28[86]	Deep unconfined	Semiannual	Quarterly	RCRA	--
299-E25-34[88]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-35[88]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-42[91]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-43[91]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-47[92]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-48[92]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E26-12[91]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E26-13[91]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-32P[88]	Top of unconfined	Semiannual	Quarterly	RCRA	--
699-43-43[88]	Top of unconfined	Semiannual	Quarterly	RCRA	B-3 Pond
699-43-45[89]	Top of unconfined	Semiannual	Quarterly	RCRA	B-3 Pond

Contamination Indicator Parameters
pH
Specific conductance
Total organic carbon
Total organic halogen

Quality Parameters
Chloride
Iron
Manganese
Phenols
Sodium
Sulfate

Table 6.1-17. (contd)

Drinking Water Parameters	
2,4-D	Lead
2,4,5-TP Silvex	Lindane
Arsenic	Mercury
Barium	Methoxychlor
Cadmium	Nitrate
Chromium	Radium
Coliform bacteria	Selenium
Endrin	Silver
Fluoride	Toxaphene
Gross alpha	Turbidity
Gross beta	

Site-Specific Parameters	
Ammonium	Tritium
Hydrazine	

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-18. Monitoring Wells and Constituents for 216-B-3 Pond (adapted from Harris 1990 and Sweeney 1995)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards	Other Networks
299-E18-1[85]	Top of uppermost	Quarterly	Quarterly	RCRA	--
299-E32-4[87]	Top of uppermost	Quarterly	Quarterly	RCRA	LLWMA-2
699-40-40A[91]	Lower uppermost	Quarterly	Quarterly	RCRA	--
699-41-40[89]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-41-42[92]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-42-39B[91]	Lower uppermost	Quarterly	Quarterly	RCRA	--
699-42-41[91]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-42-42B[88]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-43-40[91]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-43-41E[89]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-43-41G[91]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-43-45[89]	Top of uppermost	Quarterly	Quarterly	RCRA	216-A-29
699-44-39B[92]	Top of uppermost	Quarterly	Quarterly	RCRA	--
699-44-43B[89]	Top of uppermost	Quarterly	Quarterly	RCRA	--

Contamination Indicator Parameters	Site-Specific Parameters	
pH	Semivolatile organic compounds	ICP metals (filtered)
Specific conductance	Gross alpha	Gross beta
Total organic carbon	Alkalinity	Anions
Total organic halogen	Turbidity	

Shading = Upgradient wells.
Superscript = Year of installation.
LLWMA = Low-level waste management area.
RCRA = Well constructed to RCRA standards.

Table 6.1-19. Monitoring Wells and Constituents for 216-B-63 Trench (adapted from Bjornstad and Dudziak 1989)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E27-11[89]	Top of unconfined	Semiannual	Quarterly	RCRA	LLWMA-2
299-E27-16[90]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E27-8[87]	Top of unconfined	Semiannual	Quarterly	RCRA	LLWMA-2
299-E27-9[87]	Top of unconfined	Semiannual	Quarterly	RCRA	LLWMA-2
299-E33-33[90]	Top of unconfined	Semiannual	Quarterly	RCRA	SST B-BX-BY
299-E33-36[90]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E33-37[90]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E34-8[90]	Top of unconfined	Semiannual	Quarterly	RCRA	LLWMA-2
299-E34-10[91]	Top of unconfined	Semiannual	Quarterly	RCRA	LLWMA-2
299-E27-17[91]	Top of unconfined	Semiannual	Quarterly	RCRA	LLWMA-2
299-E27-18[92]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E27-19[92]	Top of unconfined	Semiannual	Quarterly	RCRA	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Site-Specific Parameters	
Alkalinity	Gross beta
Gross alpha	Turbidity

Shading = Upgradient wells.
Superscript = Year of installation.
LLWMA = Low-level waste management area.
RCRA = Well constructed to RCRA standards.
SST = Single-shell tank.

Table 6.1-20. Monitoring Wells and Constituents for Low-Level Waste Management Area-1 (adapted from Last and Bjornstad 1989)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E28-26[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E28-27[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E28-28[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-2[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-3[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-4[87]	Top of unconfined	Semiannual	Semiannual	RCRA	B-3 Pond
299-E32-5[89]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-6[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-7[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-8[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-9[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E32-10[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E33-28[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E33-29[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E33-30[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E33-34[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E33-35[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--

Contamination Indicator Parameters	Other Constituents	
pH	Alkalinity	Lead (filtered)
Specific conductance	Gross alpha	Mercury (filtered)
Total organic carbon	Gross beta	Phenols
Total organic halogen	ICP metals (filtered)	Tritium

Shading = Upgradient wells.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-21. Monitoring Wells and Constituents for Low-Level Waste Management Area-2 (adapted from Last and Bjornstad 1989)

Well	Hydrogeologic Unit Monitored	Sampling frequency	Water-Level Measurements	Well Standards	Other Networks
299-E27-8[87]	Top of unconfined	Semiannual	Semiannual	RCRA	B-63 Trench
299-E27-9[87]	Top of unconfined	Semiannual	Semiannual	RCRA	B-63 Trench
299-E27-10[90]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E27-11[89]	Top of unconfined	Semiannual	Semiannual	RCRA	B-63 Trench
299-E27-17[91]	Top of unconfined	Semiannual	Semiannual	RCRA	B-63 Trench
299-E34-2[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E34-3[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E34-4[87]	Top of unconfined	--	Dry	RCRA	--
299-E34-5[87]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E34-6[87]	Top of unconfined	--	Dry	RCRA	--
299-E34-7[89]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E34-9[91]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E34-10[91]	Top of unconfined	Semiannual	Semiannual	RCRA	B-63 Trench
299-E34-11[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E34-12[92]	Top of unconfined	Semiannual	Semiannual	RCRA	--
299-E35-1[89]	Top of unconfined	--	Dry	RCRA	--

Contamination Indicator Parameters	Other Constituents	
pH	Alkalinity	Lead (filtered)
Specific conductance	Gross alpha	Mercury (filtered)
Total organic carbon	Gross beta	Polychlorinated biphenyls
Total organic halogen	ICP metals (filtered)	Phenols
		Tritium

Shading = Upgradient wells.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-22. Monitoring Wells and Constituents for Liquid Effluent Retention Facility (adapted from Schmid 1990)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E26-11[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E26-10[90]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E26-9[87]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E35-2[87]	Top of unconfined	Semiannual	Quarterly	RCRA	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Site-Specific Parameters	
Alkalinity	Gross beta
Gross alpha	Turbidity

Shading = Upgradient well.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.

Table 6.1-23. Monitoring Wells and Constituents for Waste Management Area A-AX Single-Shell Tank Farms (adapted from Caggiano and Goodwin 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E24-19[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E24-20[91]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-40[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-2[55]	Top of unconfined	--	Quarterly	PRE	--
299-E25-41[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E25-46[92]	Top of unconfined	Semiannual	Quarterly	RCRA	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross beta	Ammonium	Iodine-129
Cadmium	Nitrate	Technetium-99	Tritium
Chromium	Silver		
Fluoride	Turbidity		
Gross alpha			

Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-24. Monitoring Wells and Constituents for Waste Management Area B-BX-BY Single-Shell Tank Farms (adapted from Caggiano and Goodwin 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E33-31[89]	Top of unconfined	Quarterly[(a)]	Quarterly[(a)]	RCRA	--
299-E33-32[89]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-33[89]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-36[90]	Top of unconfined	Quarterly	Quarterly	RCRA	216-B-63
299-E33-41[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-38[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-39[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-42[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-43[91]	Top of unconfined	Quarterly	Quarterly	RCRA	--
299-E33-1[54]	Top of unconfined	--	Quarterly	PRE	--
299-E33-5[55]	Top of unconfined	--	Quarterly	PRE	--
299-E33-8[53]	Top of unconfined	--	Quarterly	PRE	--
299-E33-18[50]	Top of unconfined	--	Quarterly	PRE	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross beta	Ammonium	Iodine-129
Cadmium	Nitrate	Technetium-99	Tritium
Chromium	Silver		
Fluoride	Turbidity		
Gross alpha			

(a) Semiannual until June 1996.
Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-25. Monitoring Wells and Constituents for Waste Management Area C Single-Shell Tank Farm (adapted from Caggiano and Goodwin 1991)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
299-E27-12[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E27-13[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E27-14[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E27-15[89]	Top of unconfined	Semiannual	Quarterly	RCRA	--
299-E27-7[82]	Top of unconfined	Semiannual[(a)]	Quarterly	PRE	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross beta	Ammonium	Iodine-129
Cadmium	Nitrate	Technetium-99	Tritium
Chromium	Silver		
Fluoride	Turbidity		
Gross alpha			

(a) Well is sampled for supporting data.
Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-26. Monitoring Wells and Constituents for Nonradioactive Dangerous Waste Landfill (adapted from Hodges 1992b)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
699-26-33[86]	Top of unconfined	Semiannual	Monthly	RCRA	--
699-26-34A[92]	Top of unconfined	Semiannual	Monthly	RCRA	--
699-26-34B[92]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-26-35A[86]	Top of unconfined	Semiannual	Monthly	RCRA	SWL
699-26-35C[87]	Top of LPU[(a)]	Semiannual	Monthly	RCRA	--
699-25-33A[87]	Top of LPU[(a)]	Semiannual	Monthly	RCRA	--
699-25-34A[86]	Top of unconfined	Semiannual	Monthly	RCRA	--
699-25-34B[86]	Top of unconfined	Semiannual	Monthly	RCRA	--
699-25-34D[92]	Top of unconfined	Quarterly	Monthly	RCRA	--

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Phenols
Specific conductance	Iron	Sodium
Total organic carbon	Manganese	Sulfate
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Barium	Gross alpha	Tritium	Volatile chlorinated hydrocarbons
Cadmium	Gross beta		
Chromium	Nitrate		
Coliform bacteria	Silver		
Fluoride	Turbidity		

(a) Low-permeability unit in upper Ringold Formation.
Shading = Upgradient wells.
Superscript = Year of installation.
RCRA = Well constructed to RCRA standards.
SWL = Solid Waste Landfill.

Table 6.1-27. Monitoring Wells and Constituents for 316-5 Process Trenches (adapted from Schalla 1988b)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standards
399-1-10A[86]	Top of unconfined	Semiannual	Quarterly	RCRA
399-1-11[86]	Top of unconfined	Semiannual	Quarterly	RCRA
399-1-12[86]	Top of unconfined	Semiannual	Quarterly	RCRA
399-1-14A[86]	Top of unconfined	Semiannual	Quarterly	RCRA
399-1-16A[86]	Top of unconfined	Semiannual	Quarterly	RCRA
399-1-16B[87]	Bottom of unconfined	Semiannual	Quarterly	RCRA
399-1-17A[86]	Top of unconfined	Quarterly	Quarterly	RCRA
399-1-17B[86]	Bottom of unconfined	Semiannual	Quarterly	RCRA
399-1-18A[86]	Top of unconfined	Semiannual	Quarterly	RCRA
399-2-1[48]	Top of unconfined	Semiannual[(a)]	Quarterly	PRE
399-3-10[76]	Top of unconfined	Semiannual[(a)]	Quarterly	PRE

Contamination Indicator Parameters	Quality Parameters	
pH	Chloride	Sodium
Specific conductance	Iron	Sulfate
Total organic carbon	Manganese	
Total organic halogen		

Drinking Water Parameters		Site-Specific Parameters	
Arsenic	Gross alpha	Alkalinity	Nitrite
Barium	Gross beta	Aluminum	Phosphate
Cadmium	Silver	Antimony	Potassium
Chromium	Mercury	Beryllium	Strontium
Lead	Nitrate	Bromide	Strontium-90
Coliform	Radium	Calcium	Tin
Fluoride	Selenium	Cobalt	Tritium
		Copper	Uranium
		Gamma scan	Vanadium
		Isotopic uranium	Volatile organics
		Magnesium	Zinc
		Nickel	

(a) Well is sampled for supporting data.
Shading = Upgradient wells.
Superscript = Year of installation.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-28. Monitoring Wells and Constituents for Solid Waste Landfill (adapted from Hodges 1993b)

Well	Hydrogeologic Unit Monitored	Sampling Frequency	Water-Level Measurements	Well Standard	Other Networks
699-22-35[93]	Top of unconfined	Quarterly	--	RCRA	--
699-23-34A[87]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-23-34B[93]	Top of unconfined	Quarterly	--	RCRA	--
699-24-33[48]	Top of unconfined	Quarterly[(a)]	Monthly	PRE	Sitewide
699-24-35[87]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-24-34A[87]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-24-34B[87]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-24-34C[87]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-25-34C[87]	Top of unconfined	Quarterly	Monthly	RCRA	--
699-26-35A[86]	Top of unconfined	Quarterly	Monthly	RCRA	NRDWL

Parameters/Constituents Required by WAC 173-304-490		Site-Specific Constituents	
Ammonia as nitrogen	Nitrate	1,1,1-trichloroethane	Trichloroethylene
Chemical oxygen demand	Nitrite	Total organic halogen	
Chloride	pH		
Specific conductance	Sulfate	Other	
Dissolved iron	Temperature		
Dissolved zinc	Total coliform	Tritium	
Manganese	Total organic carbon		

(a) Well sampled for supporting data.
Shading = Upgradient wells.
Superscript = Year of installation.
NRDWL = Nonradioactive Dangerous Waste Landfill.
PNNL = Well sampled by PNNL sitewide monitoring program.
PRE = Well not constructed to RCRA standards.
RCRA = Well constructed to RCRA standards.

Table 6.1-29. Maximum Contaminant Levels and Interim Drinking Water Standards

Constituent	Primary MCL	Interim DWS	Agency[a]	EPA Status
Fluoride	4 mg/L		EPA, DOH	Final/under review
Nitrate, as NO_3^-	45 mg/L		EPA, DOH	Final
Chromium	100 μg/L 50 μg/L		EPA DOH	Final
Trichlorethylene	5 μg/L		EPA, DOH	Final
Tetrachloroethylene	5 μg/L		EPA, DOH	Final
Carbon tetrachloride	5 μg/L		EPA, DOH	Final
Chloroform (THM)[b]	100 μg/L		EPA, DOH	
Uranium	20 μg/L		EPA	Proposed
Total alpha (excluding uranium)	15 pCi/L		EPA, DOH	Final
Beta particle and photon activity	4 mrem/yr[c]		EPA, DOH	Final
Tritium		20,000 pCi/L[d]	EPA	Interim DWS
Carbon-14		2,000 pCi/L[d]	EPA	Interim DWS
Cobalt-60		100 pCi/L[d]	EPA	Interim DWS
Strontium-90		8 pCi/L[d]	EPA	Interim DWS
Technetium-99		900 pCi/L[d]	EPA	Interim DWS
Ruthenium-106		30 pCi/L[d]	EPA	Interim DWS
Antimony-125		300 pCi/L[d]	EPA	Interim DWS
Iodine-129		1 pCi/L[d]	EPA	Interim DWS
Cesium-137		200 pCi/L[d]	EPA	Interim DWS
Mercury (inorganic)	0.002 mg/L		EPA, DOH	Final
Antimony	0.006 mg/L		EPA	Final
Nickel	0.1 mg/L		EPA	Final/being remanded
Manganese[e]	0.05 mg/L		EPA, DOH	Final
Iron[e]	0.3 mg/L		EPA	Final
Barium	2 mg/L 1 mg/L		EPA DOH	Final
Copper[e]	1.0 mg/L		EPA, DOH	Final
Sulfate	500 mg/L; 250 mg/L[e]		EPA EPA	Proposed Final
Cis-1,2-dichloroethylene	0.07 mg/L		EPA	Final
1,1,1-trichloroethane	0.2 mg/L		EPA	Final

Table 6.1-29. (contd)

Constituent	Primary MCL	Interim DWS	Agency[a]	EPA Status
Chloride[e]	250 mg/L		EPA, DOH	Final
Silver[e]	0.1 mg/L		EPA, DOH	Final
Zinc[e]	5 mg/L		EPA, DOH	Final
Arsenic	0.05 mg/L		EPA, DOH	Under review
Selenium	0.05 mg/L 0.01 mg/L		EPA DOH	Final
Lead	0.015 mg/L[f] 0.05 mg/L		EPA DOH	Final
pH[f]	6.5 to 8.5		EPA	Final

(a) DOH = State of Washington Department of Health at WAC 246-290; EPA = U.S. Environmental Protection Agency at 40 CFR 141-143 and EPA (1996).
(b) Standard is for total trihalomethanes (THM).
(c) Beta and gamma radioactivity from anthropogenic radionuclides. Annual average concentration shall not produce an annual dose from anthropogenic radionuclides equivalent to the total body or any internal organ dose greater than 4 mrem/yr. If two or more radionuclides are present, the sum of their annual dose equivalents shall not exceed 4 mrem/yr. Compliance may be assumed if annual average concentrations of total beta, tritium, and strontium-90 are <50, 20,000, and 8 pCi/L, respectively.
(d) Concentration assumed to yield an annual dose equivalent of 4 mrem/yr.
(e) Secondary maximum contaminant level.
(f) Action level.
DWS = Drinking water standard.
MCL = Maximum contaminant level.

Table 6.1-30. Derived Concentration Guides[a,b,c] and 4-mrem Effective Dose Equivalent Concentrations for Drinking Water[d]

Radionuclide	Derived Concentration Guide, pCi/L	4-mrem Effective Dose Equivalent, pCi/L
Tritium	2,000,000	80,000
Carbon-14	70,000	2,800
Chromium-51	1,000,000	40,000
Manganese-54	50,000	2,000
Cobalt-60	5,000	200
Zinc-65	9,000	360
Krypton-85	NS	NS
Strontium-90	1,000	40
Technetium-99	100,000	4,000
Ruthenium-103	50,000	2,000
Ruthenium-106	6,000	240
Antimony-125	60,000	2,400
Iodine-129	500	20
Iodine-131	3,000	120
Cesium-134	2,000	80
Cesium-137	3,000	120
Cerium-144	7,000	280
Uranium-234	500	20
Uranium-235	600	24
Uranium-238	600	24
Plutonium-238	40	1.6
Plutonium-239	30	1.2
Plutonium-240	30	1.2
Americium-241	30	1.2

(a) Concentration of a specific radionuclide in water that could be continuously consumed at average annual rates and not exceed an effective dose equivalent of 100 mrem/yr.
(b) Values in this table represent the lowest, most conservative derived concentration guides considered potentially applicable to Hanford Site operations, and may be adjusted upward (larger) if accurate solubility information is available.
(c) From DOE Order 5400.5.
(d) Concentration of a specific radionuclide in water that would produce an effective dose equivalent of 4 mrem/yr if consumed at average annual rates.
NS = No standard.

Table 6.4-1. Average Radionuclide Concentrations in KE Reactor Fuel-Storage Basins, FY1996

Radionuclide	Concentration
Alpha	3.13E-02 μCi/L
Americium-241	7.48E-03 μCi/L
Cesium-137	2.75 μCi/L
Tritium	2.86 μCi/L
Plutonium-238	2.50E-03 μCi/L
Plutonium-239/240	1.36E-02 μCi/L
Strontium-90	1.37 μCi/L
Uranium	2.36E-05 g/L

Table 6.4.2. Summary Statistics and Upper Tolerance Limit for Gross Alpha and Gross Beta for 100-K Area Fuel-Storage Basin

	Gross Alpha (pCi/L) (DWS = 15 pCi/L)					Gross Beta (pCi/L) (DWS = 50 pCi/L)				
Basin:Well	Number of Samples	Mean	Standard Deviation	k[a]	$UTL_{95/95}$[b]	Number of Samples	Mean	Standard Deviation	k[a]	$UTL_{95/95}$[b]
KW:										
199-K-108A, UG	7	4.59	1.04	3.399	8.14[c]	7	8.73	2.44	3.399	17.01[c]
199-K-107A, DG	7	1.64	0.98	3.399	4.98[d]	7	93.25	17.48	3.399	152.65[d]
199-K-34, DG	7	3.22	1.33	3.399	7.75[d]	7	64.99	19.84	3.399	132.43[d]
KE:										
199-K-110A, UG	7	4.89	2.95	3.399	14.91[c]	7	8.23	3.75	3.399	20.97[c]
199-K-109A, DG	8	3.94	1.85	3.188	9.84[d]	9	5,827	5,205	3.031	21,603[d]
199-K-27, DG	8	4.05	1.08	3.188	7.50[d]	8	17.12	2.36	3.188	24.63[d]
199-K-28, DG	7	4.34	0.86	3.399	7.26[d]	7	9.24	1.34	3.399	13.79[d]
199-K-29, DG	7	1.52	0.69	3.399	3.88[d]	7	6.82	4.96	3.399	23.67[d]

(a) Values obtained from Natrella (1966, Table A-7).

(b) Calculated as: $UTL_{95/95} = \bar{x}_i + k \times s$, where the first 95 in the subscript denotes the coverage and the second 95 denotes the confidence level; $\bar{x}_i$ is the mean; k is a multiplier (from Natrella 1966); and s is the standard deviation.

(c) Used in leak-detection decisions. Value will be compared with future individual samples collected from each point-of-compliance (downgradient) well. Exceedance, after confirmation sampling, indicates leakage from the facility.

(d) Used in regulatory compliance decisions. Value will be compared with drinking water standard (DWS) to determine whether groundwater-protection standard is being exceeded.

DG = Downgradient well.

UG = Upgradient well.

UTL = Upper tolerance limit.

Table 6.9-1. Results of 200-UP-1 Operable Unit Pump-and-Treat System (from Myers et al. 1996)

Reporting Period	Liters Treated	Mass Technetium-99 Removed, kg	Mass Total Uranium Removed, kg	Mass Carbon Tetrachloride Removed, kg
March 1994 through November 1994[a]	3,900,000	0.34	4.4	Not reported
December 1994 through August 1995	11,400,000	0.78	9.8	0.99
September 1995 through November 1995	17,200,000	0.40	3.9	0.63
December 1995 through March 1996	31,300,000	0.91	9.1	1.6
April 1996 through June 1996	22,500,000	0.54	6.8	1.6
July 1996 through September 1996	22,400,000	0.40	5.1	2.8
Total[b]	109,000,000	3.4	39.2	7.6

(a) Data from the treatability test as reported in Gustafson et al. (1995).
(b) Rounded.

Table 6.12.-1. Ranges of Concentrations (μg/L) of Chlorinated Hydrocarbons in Groundwater at Solid Waste Landfill, November 1995 to August 1996

	699-22-35	699-23-34A	699-23-34B	699-24-34A	699-24-34B	699-24-34C	699-25-34C	699-24-35	699-26-35A
1,1,1-Trichloroethane	13-26	8.2-9.4	10-15	5.3-6.7	3.1-5.8	4.2-5.1	1.9-2.5	1.7-3.7	1.0-1.4
Trichloroethylene	1.2-1.5	0.75-1.2	0.76-1.4	0.47-0.93	0.42-1.1	0.89-1.2	0.68-0.80	0.17-0.25	<0.56-0.20
Tetrachloroethylene	1.3-1.7	1.8-2.6	1.2-2.1	1.6-2.3	1.9-2.8	2.8-3.1	0.98-1.5	0.45-0.90	0.29-0.50
1,1-Dichloroethane	3.8-4.1	1.6-2.4	2.5-4.0	0.82-1.8	0.71-1.3	0.92-1.4	<0.05-0.40	<0.05-0.20	<0.05-<0.20
Chloroform	0.38-2.9	<0.03-0.2	0.09-0.39	<0.20-0.04	<0.03-0.21	<0.03-0.05	<0.03-0.20	<0.04-<0.20	<0.03-0.03
Carbon tetrachloride	<2.5-3.2	<0.04-<0.50	<0.04-1.6	<0.04-<0.20	<0.03-0.21	<0.03-0.05	<0.03-0.20	<0.04-<0.20	<0.04-0.92
1,1,2-Trichloroethane	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07	<0.05-<0.07
1,2-Dichloroethane	<0.05-<0.20	<0.05-<0.20	0.05-<0.20	0.05-<0.20	0.05-<0.20	0.05-<0.20	0.05-<0.20	0.05-<0.20	0.05-<0.20
cis-1,2-Dichloroethylene	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20
Trans-1,2-Dichloroethylene	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-0.23	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20	<0.05-<0.20
Total organic halogen	27-36	11-16	20-30	6.6-17	7.1-15	<6.9-11	<2.65-9.9	<6.9-13	<2.65-10

Table 6.14-1. Summary of Horn Rapids Landfill Groundwater Wells Sampled[a]

Well Name	Well Identification	Location
MW-8	699-S28-E12	Downgradient of Horn Rapids Landfill
MW-10	699-S30-E10A	Downgradient of Horn Rapids Landfill
MW-11	699-S30-E10B	Downgradient of Horn Rapids Landfill[b]
MW-12	699-S31-E10A	Downgradient of Horn Rapids Landfill
MW-14	699-S31-E10C	Downgradient of Horn Rapids Landfill
MW-15	699-S31-E10D	Downgradient of Horn Rapids Landfill
MW-20	699-S29-E11	Downgradient of Horn Rapids Landfill
MW-22	699-S31-E11	Downgradient of Horn Rapids Landfill[b]
	699-S29-E12	Downgradient of Horn Rapids Landfill[b]
MW-3	699-S41-E12	Downgradient of 1171 building
COE-1[c]	699-S29-E13A	Southeast point of compliance
COE-2[c]	699-S28-E13A	Center point of compliance
COE-3[c]	699-S27-E12A	Northwest point of compliance
COE-4[c]	699-S30-E11A	Upgradient point of compliance
COE-5[c]	699-S29-E10A	Upgradient point of compliance

(a) From Kemp and Ford (1996).
(b) Sampled by Pacific Northwest National Laboratory (Bisping 1996).
(c) U.S. Army Corps of Engineers (COE) wells installed August 1995.

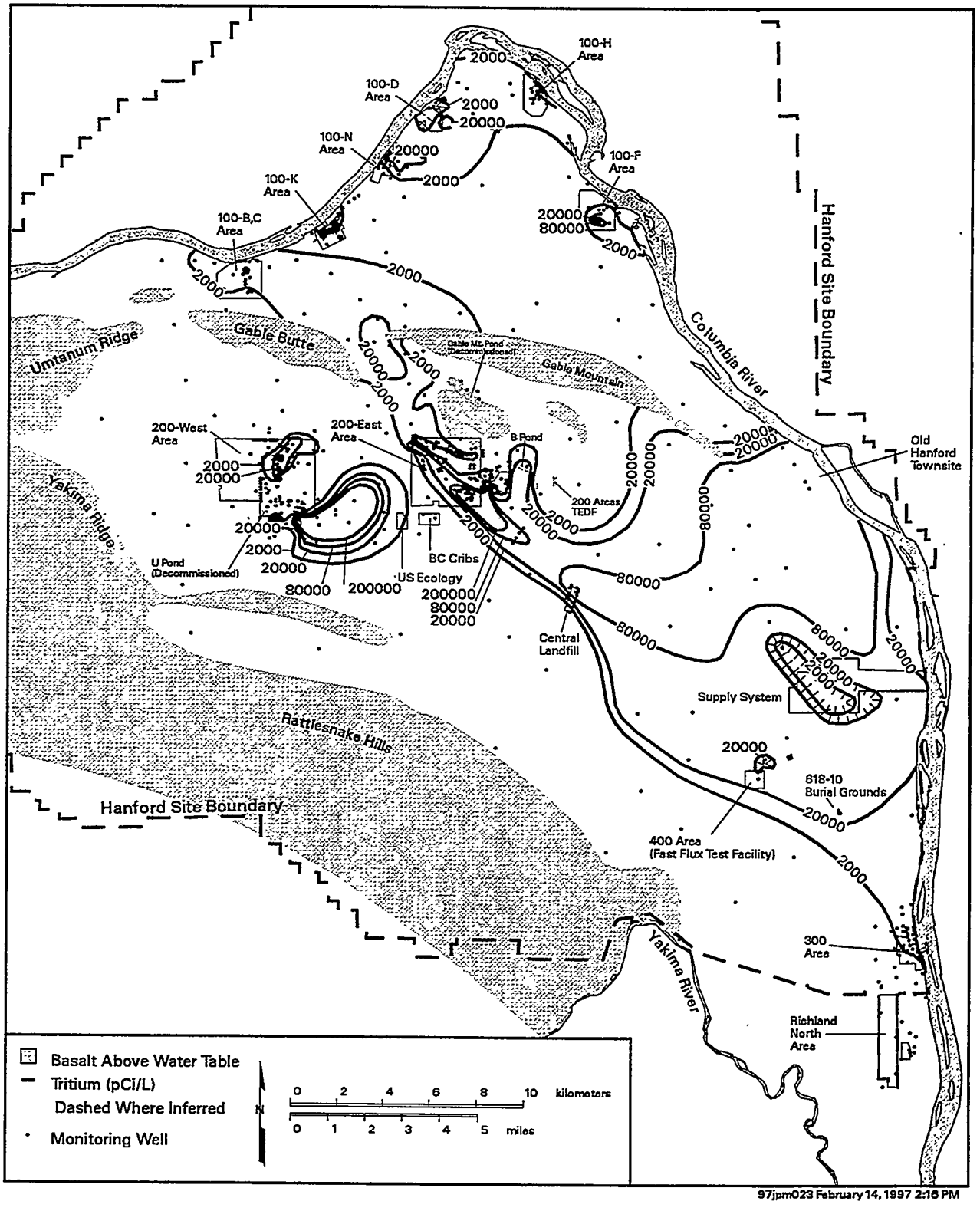


Figure 6.2-1. Average FY 1996 Tritium Concentration Contours

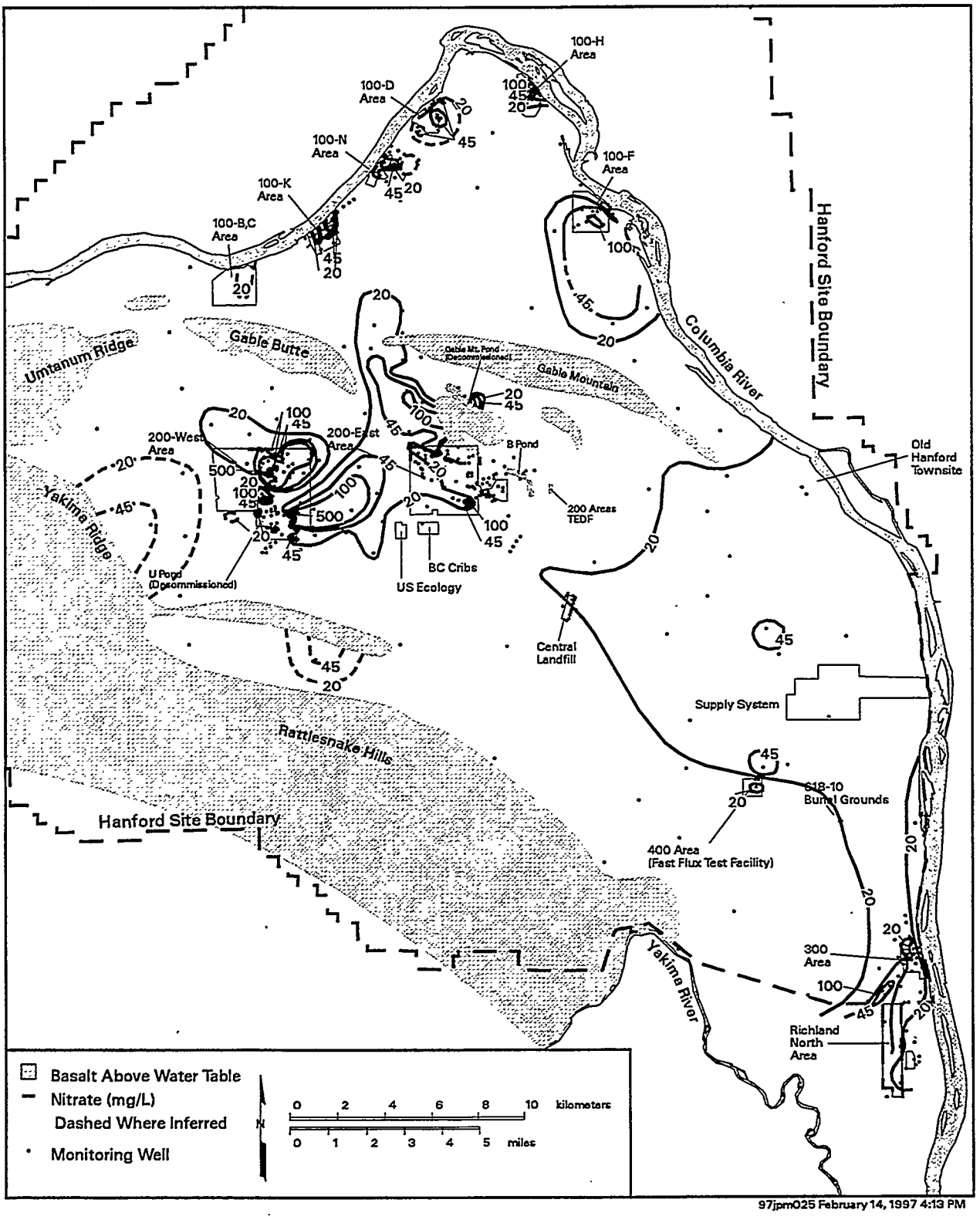


Figure 6.2-2. Average FY 1996 Nitrate Concentration Contours

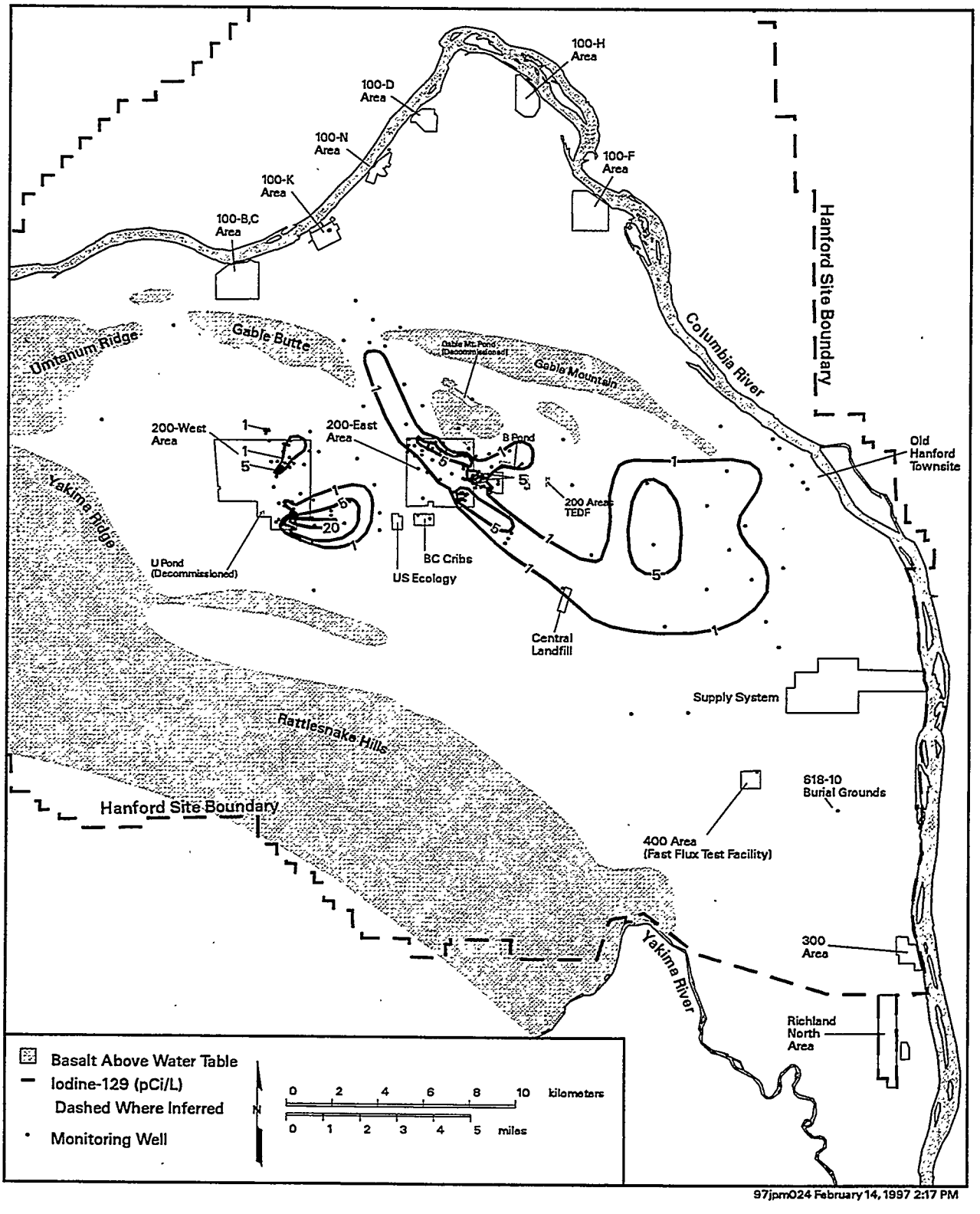


Figure 6.2-3. Average FY 1996 Iodine-129 Concentration Contours

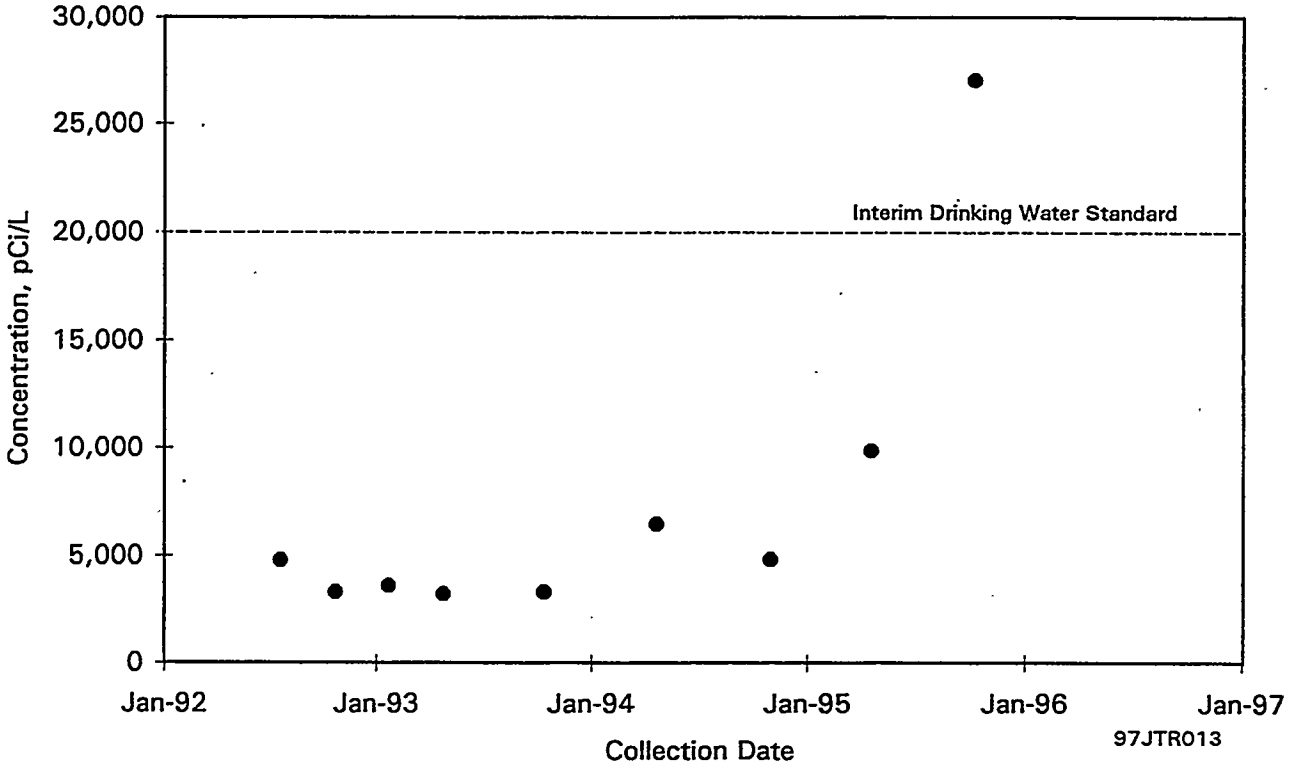


Figure 6.3-1. Tritium Concentrations in Well 199-B-5-2

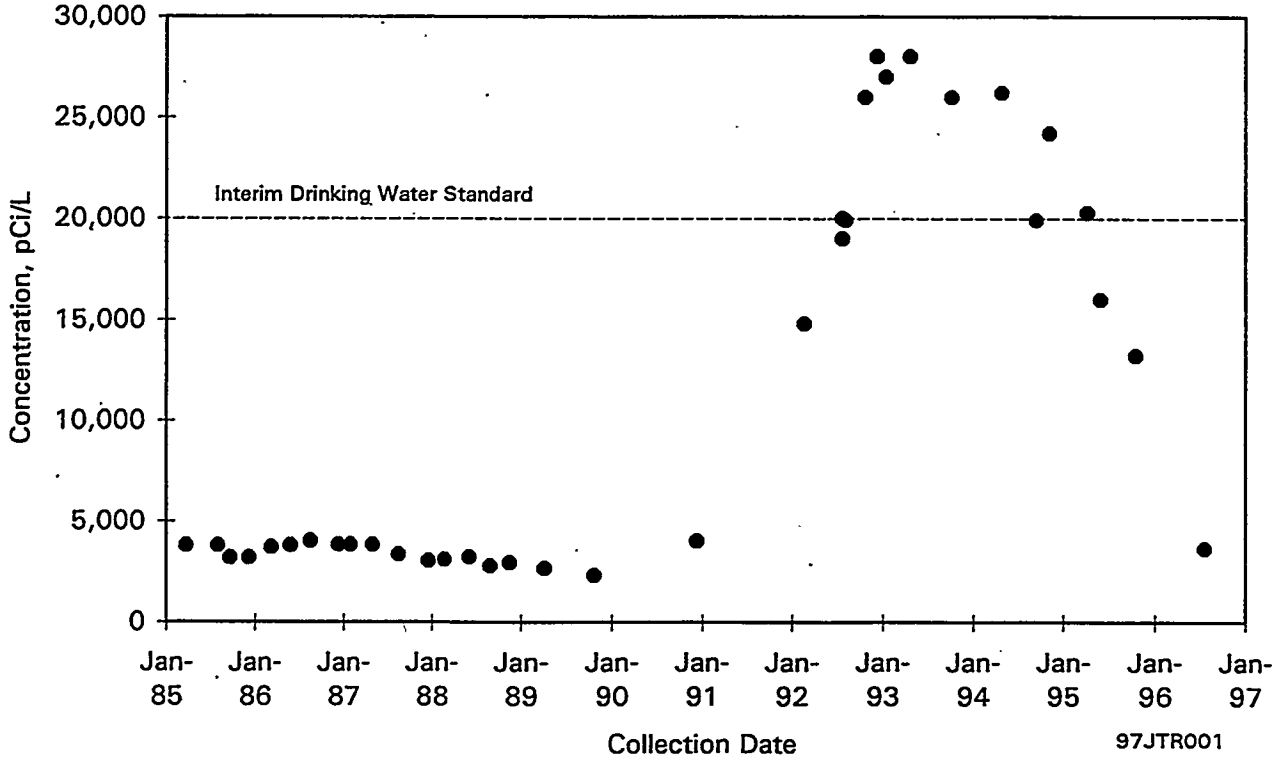


Figure 6.3-2. Tritium Concentrations in Well 699-65-72

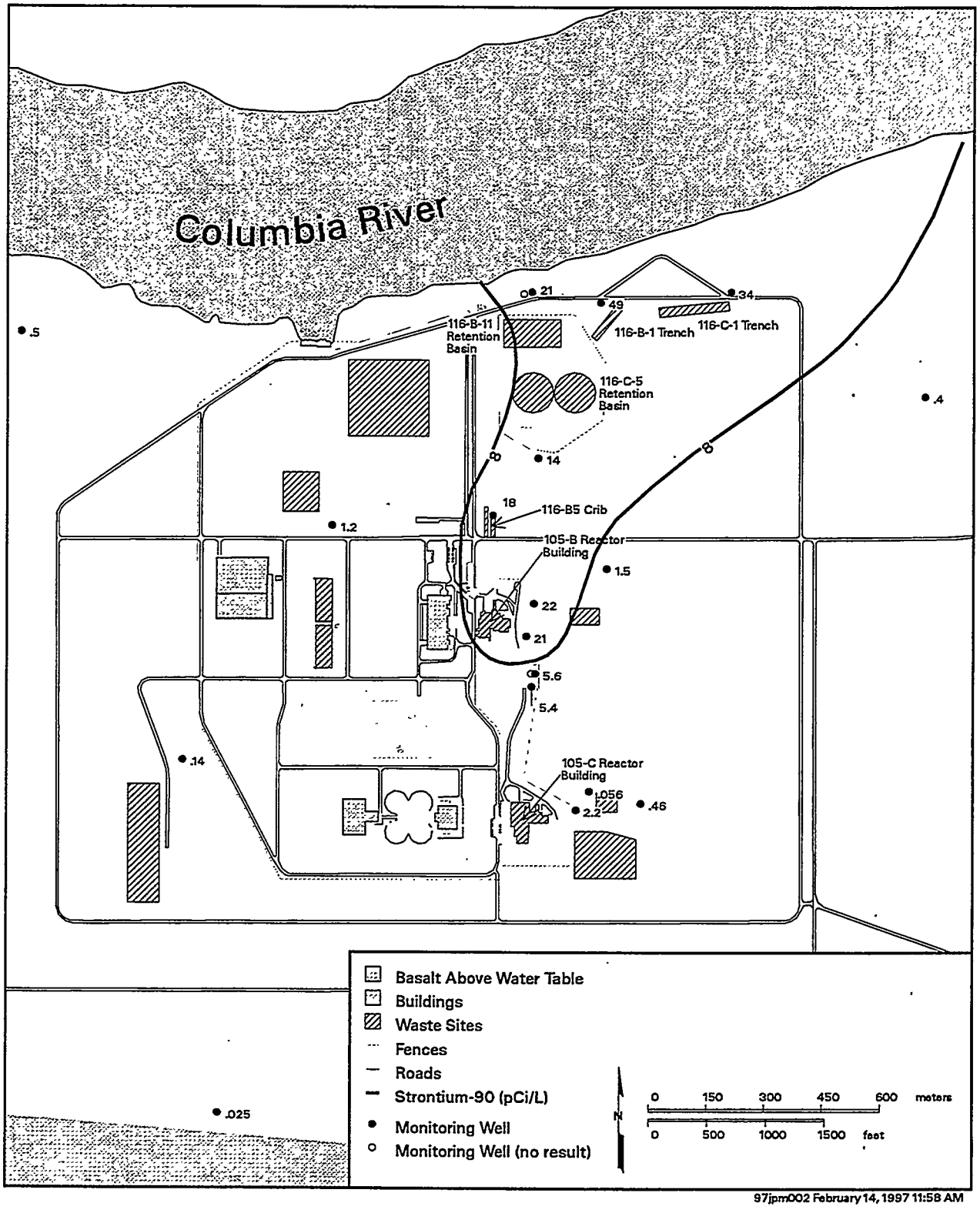


Figure 6.3-3. Average FY 1996 Strontium-90 Concentrations in 100-B,C Area

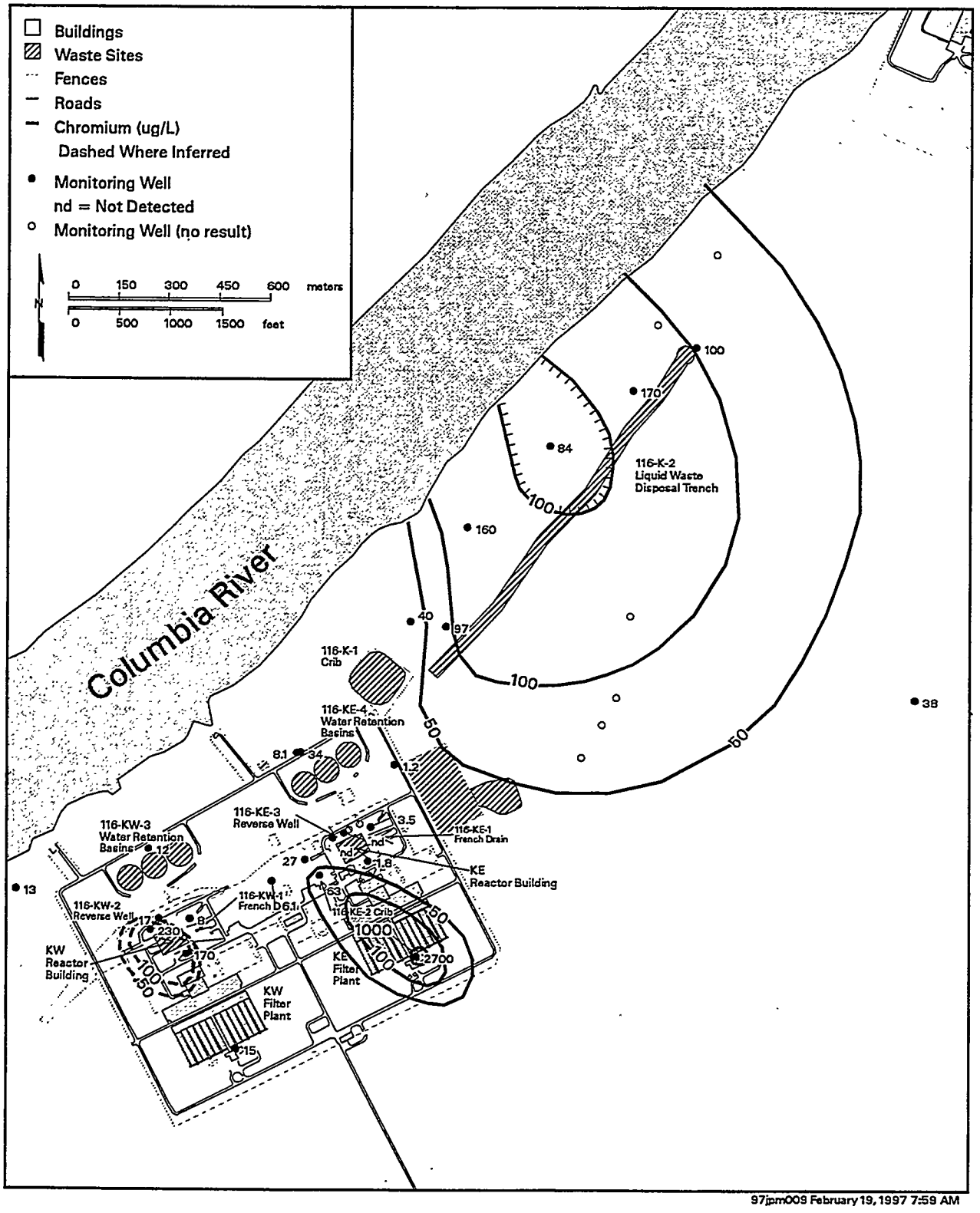
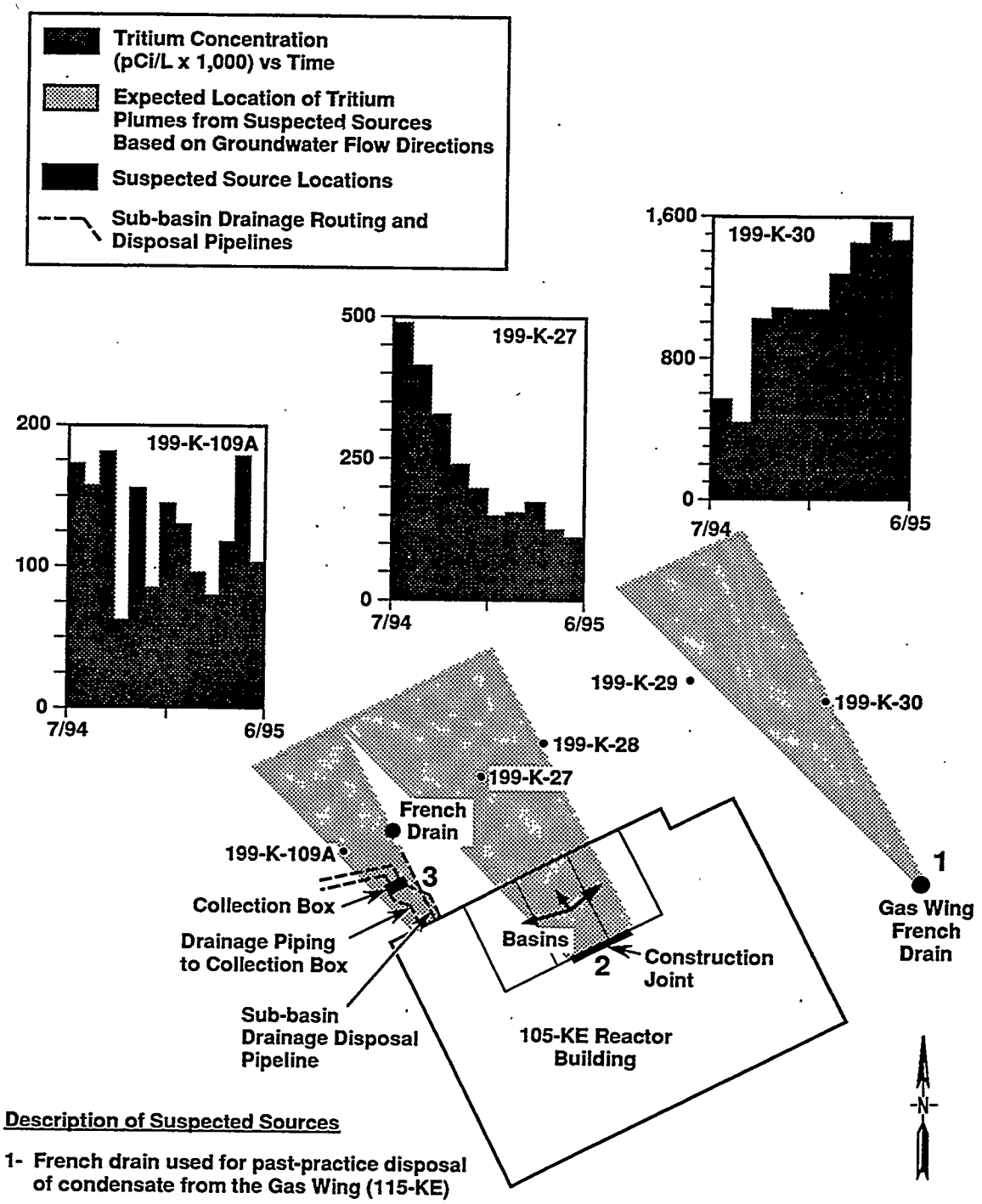


Figure 6.4-1. Average FY 1996 Chromium Concentrations in 100-K Area



Description of Suspected Sources

1- French drain used for past-practice disposal of condensate from the Gas Wing (115-KE)

2- Seepage from construction joint in bottom of spent nuclear fuel storage basin

3- Leakage from sub-basin collection and/or distribution piping

H9509029.2

Figure 6.4-2. Correlation of Tritium in Groundwater and Suspected Sources in 100-K Area

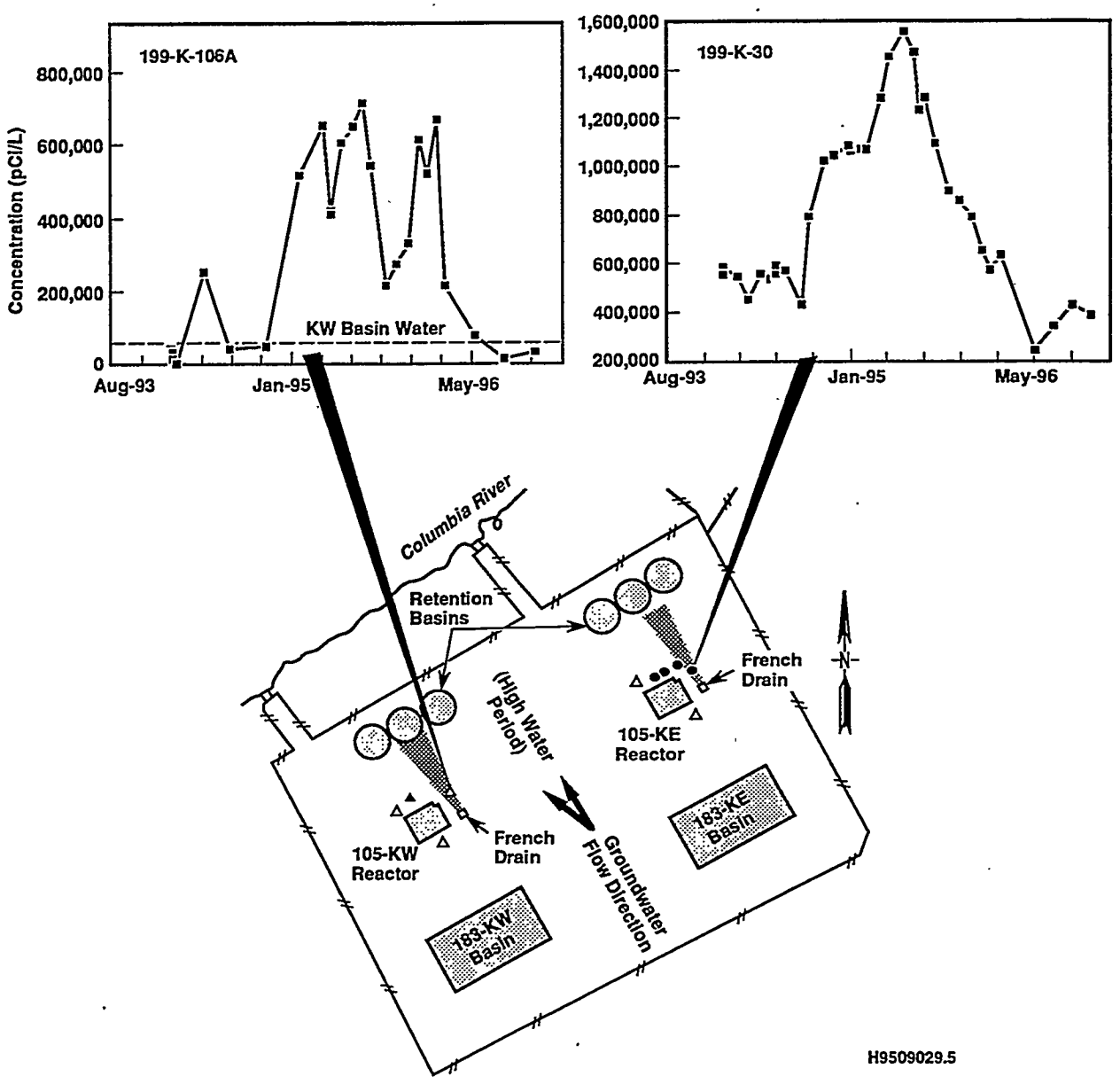


Figure 6.4-3. Tritium Concentration Versus Time in 100-K Area

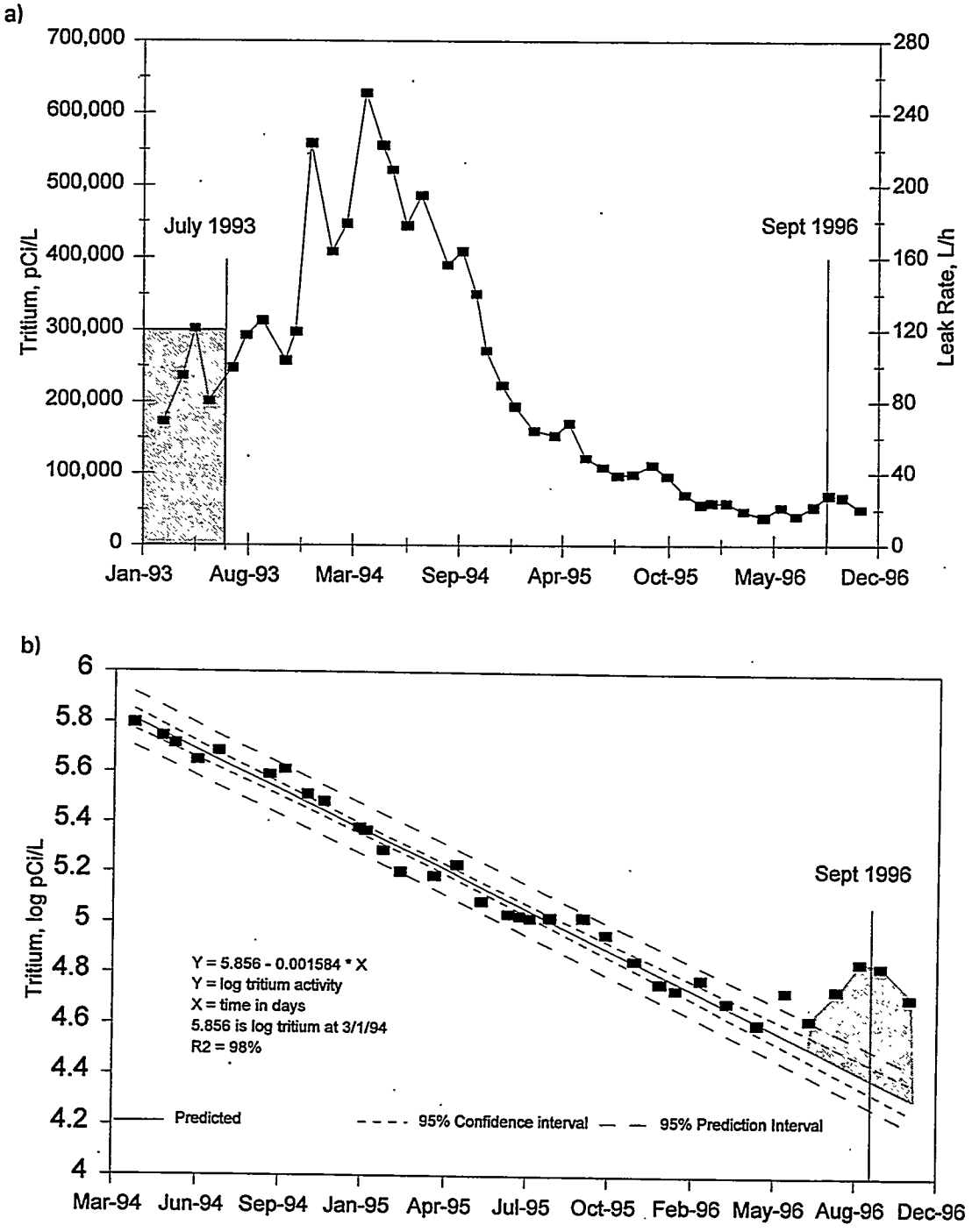


Figure 6.4-4. Correlation of Declining Tritium Concentrations in Well 199-K-109A and KE Basin Leak Rates. The predicted baseline (solid line in Figure 6.4-4b) is from the regression of log tritium on time (from 3/94 to 6/96). The small deviation (shaded area) from baseline near the end of 1996 was probably due to a small but undetectable basin leak. The concentration versus time plot (6.4-4a) shows tritium concentrations began to decline exponentially ~9 months after correction of a major leak (average of 120 L/hr) in July 1993. Basin water loss rates have been undetectable since July 1993.

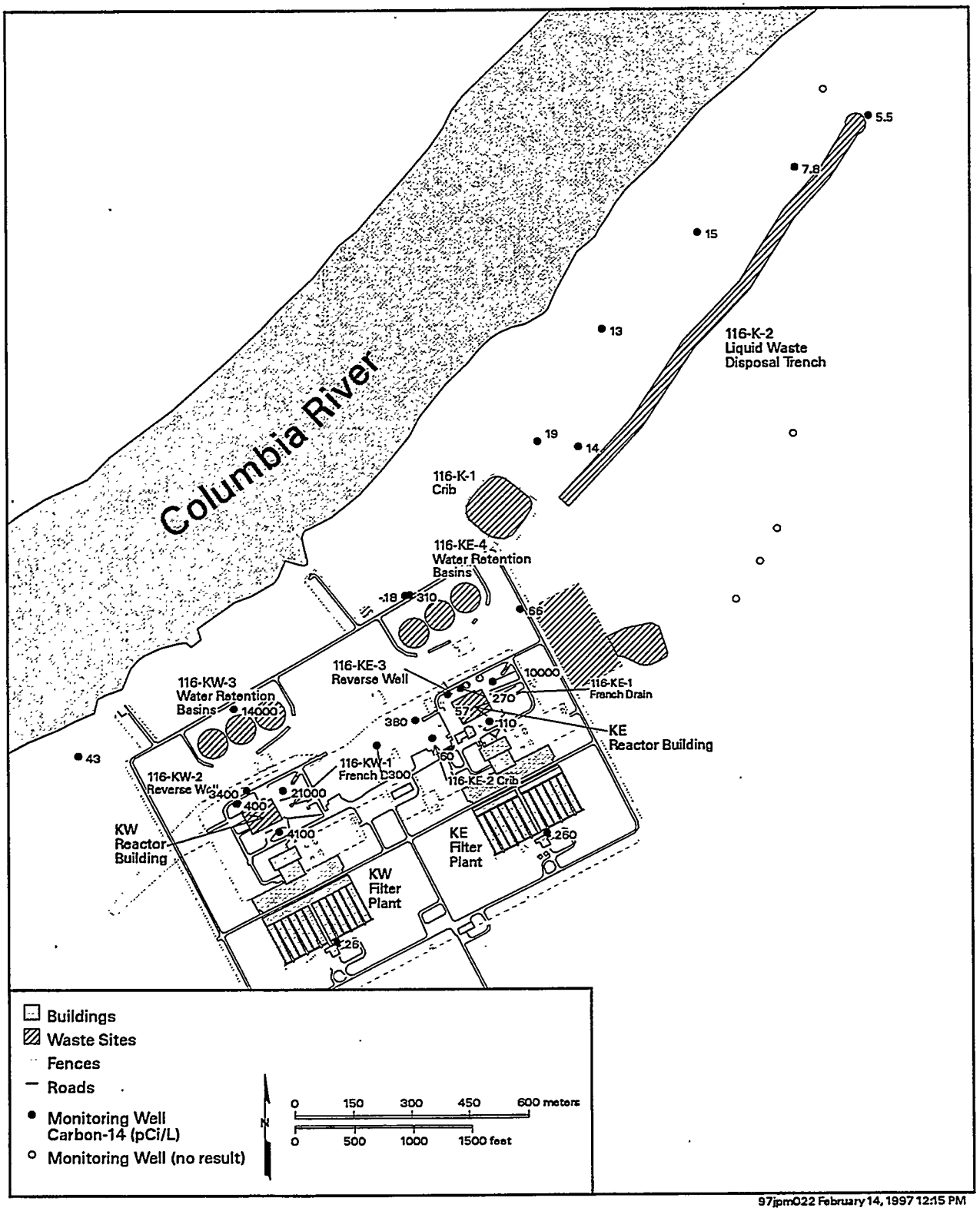


Figure 6.4-5. Average FY 1996 Carbon-14 Concentrations in 100-K Area

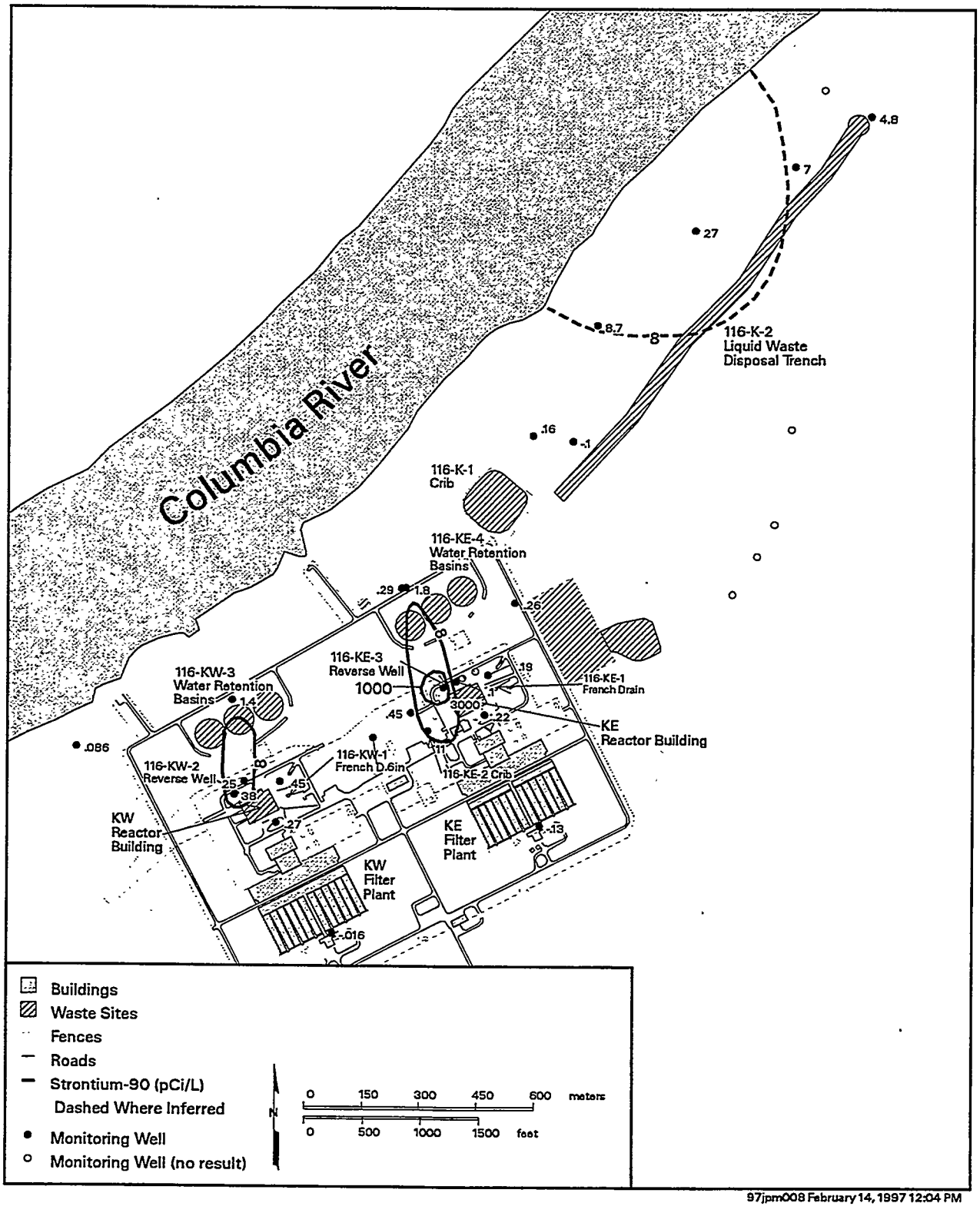


Figure 6.4-6. Average FY 1996 Strontium-90 Concentrations in 100-K Area

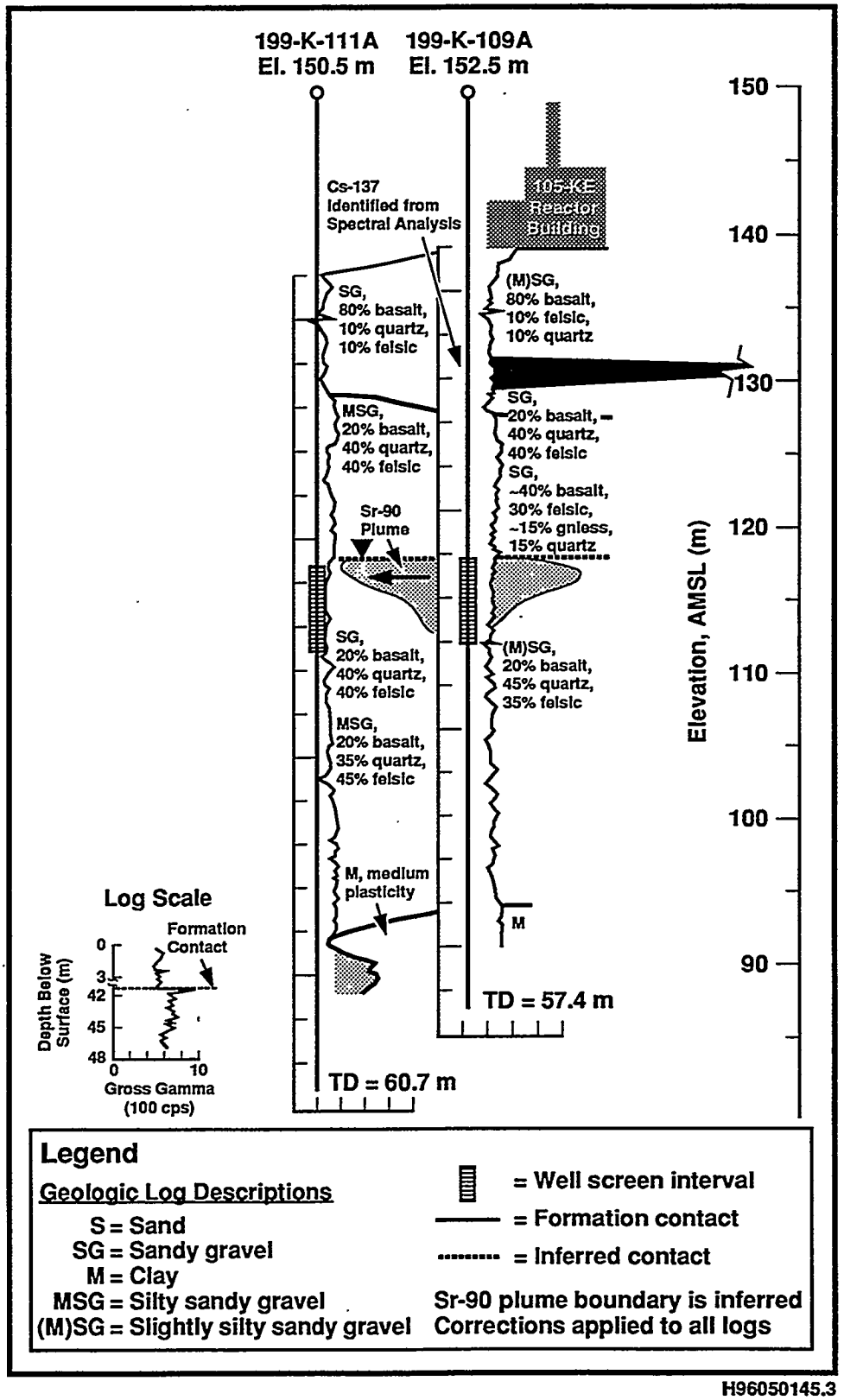


Figure 6.4-7. Correlation of Gross Gamma Log and Soil-Column Contamination at Well 199-K-109A

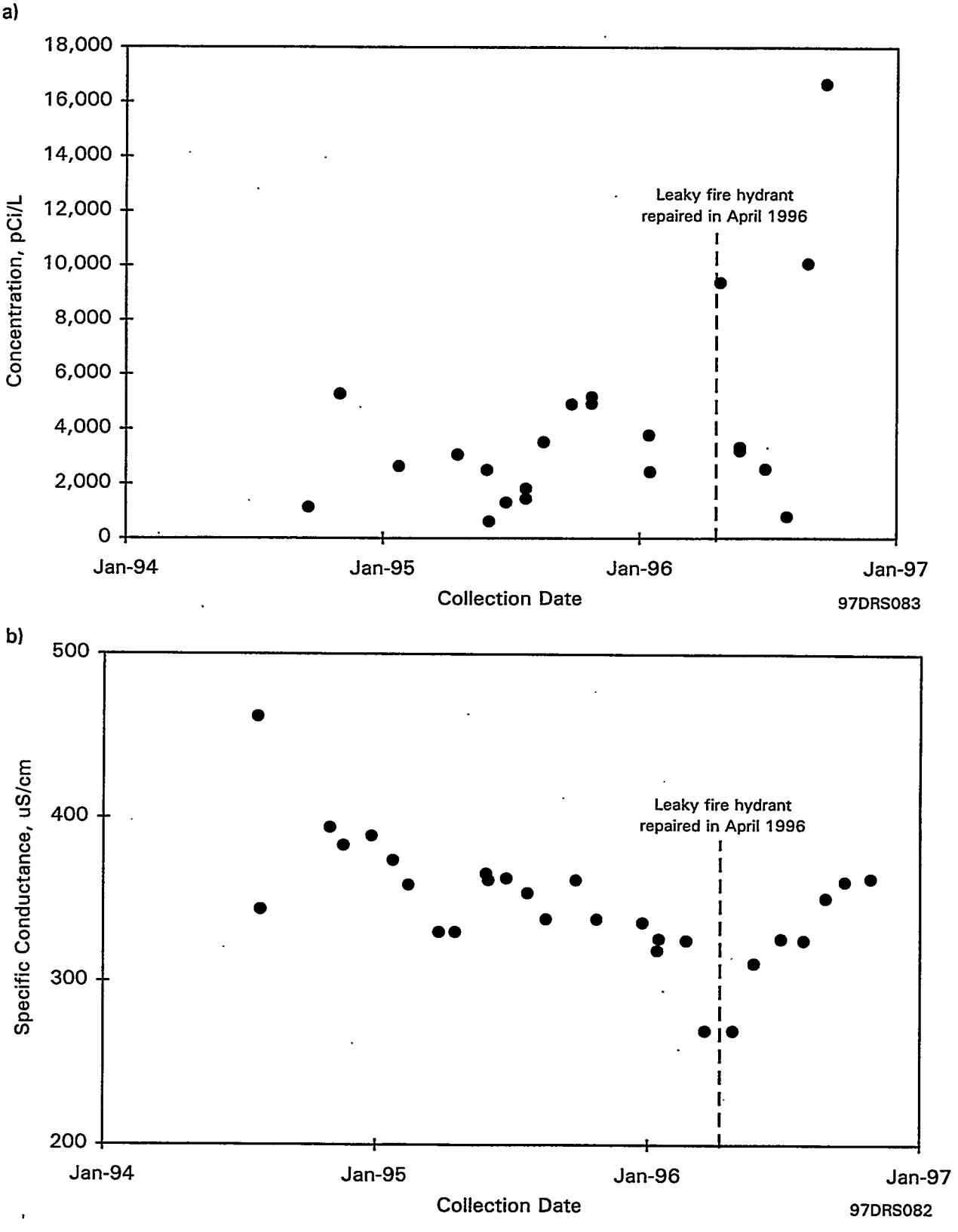


Figure 6.4-8. Gross Beta Concentrations and Specific Conductance in Well 199-K-109A

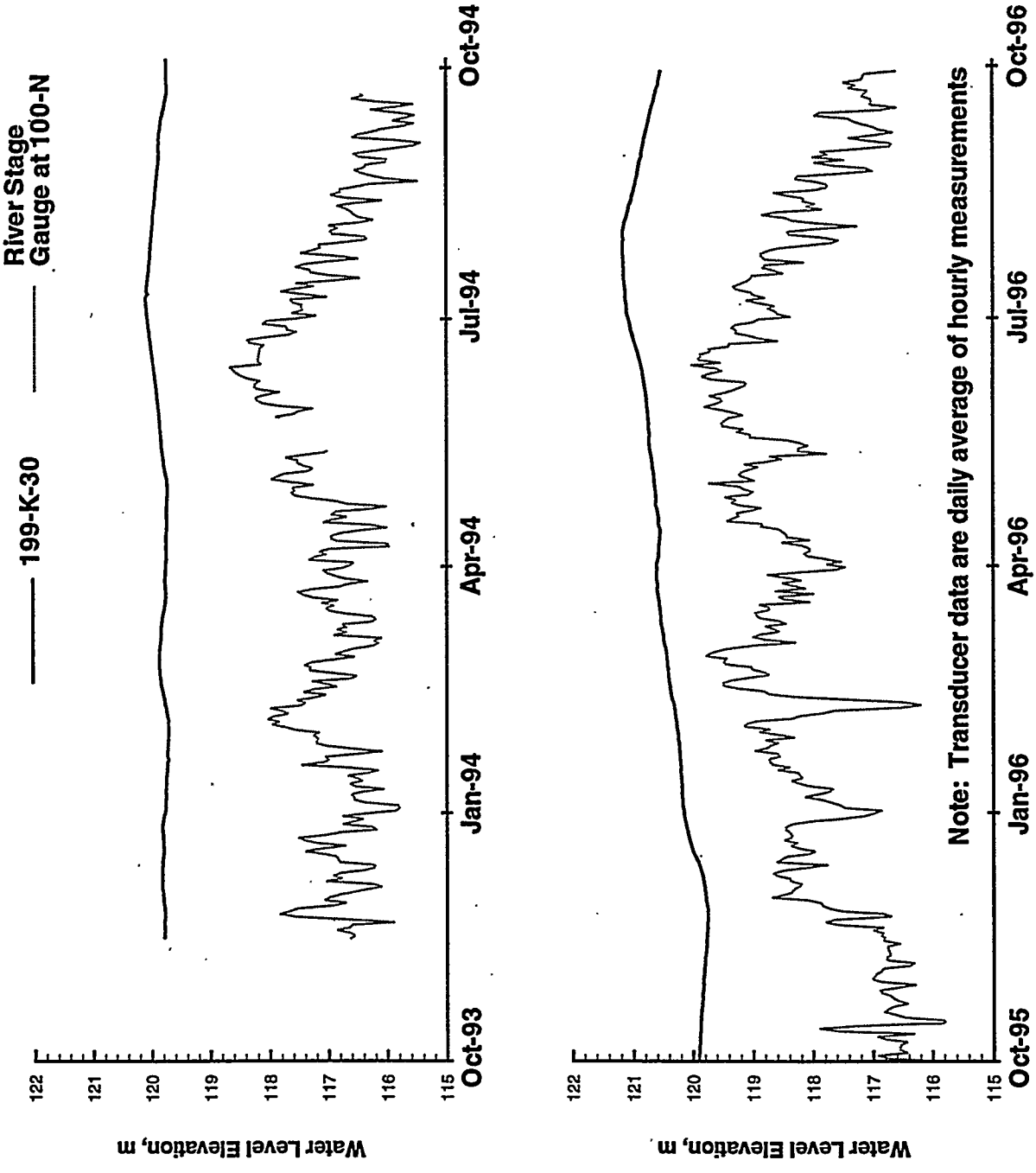


Figure 6.4-9. Water Levels in Well 199-K-30

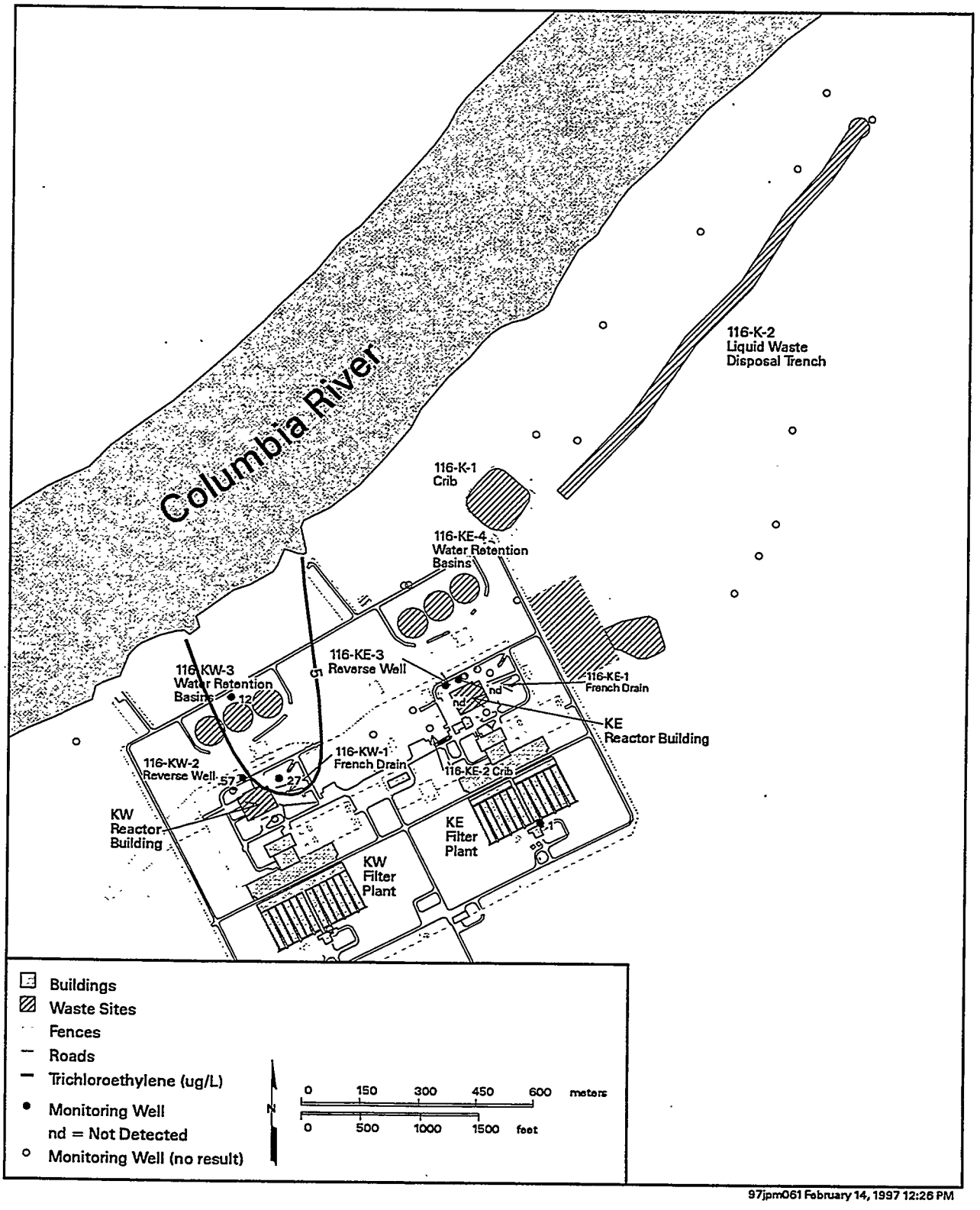


Figure 6.4-10. Average FY 1996 Trichloroethylene Concentrations in 100-K Area

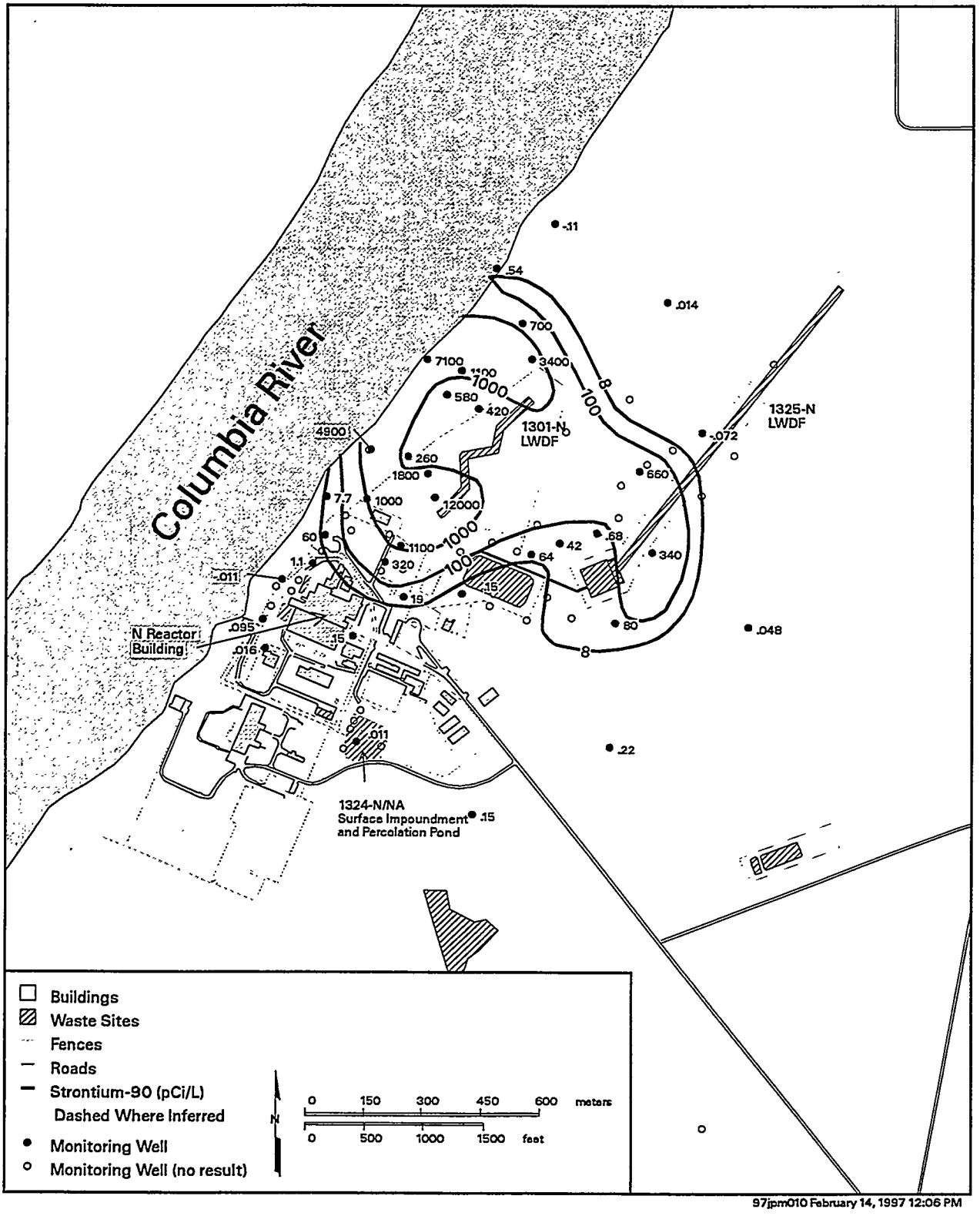


Figure 6.5-1. Average FY 1996 Strontium-90 Concentrations in 100-N Area

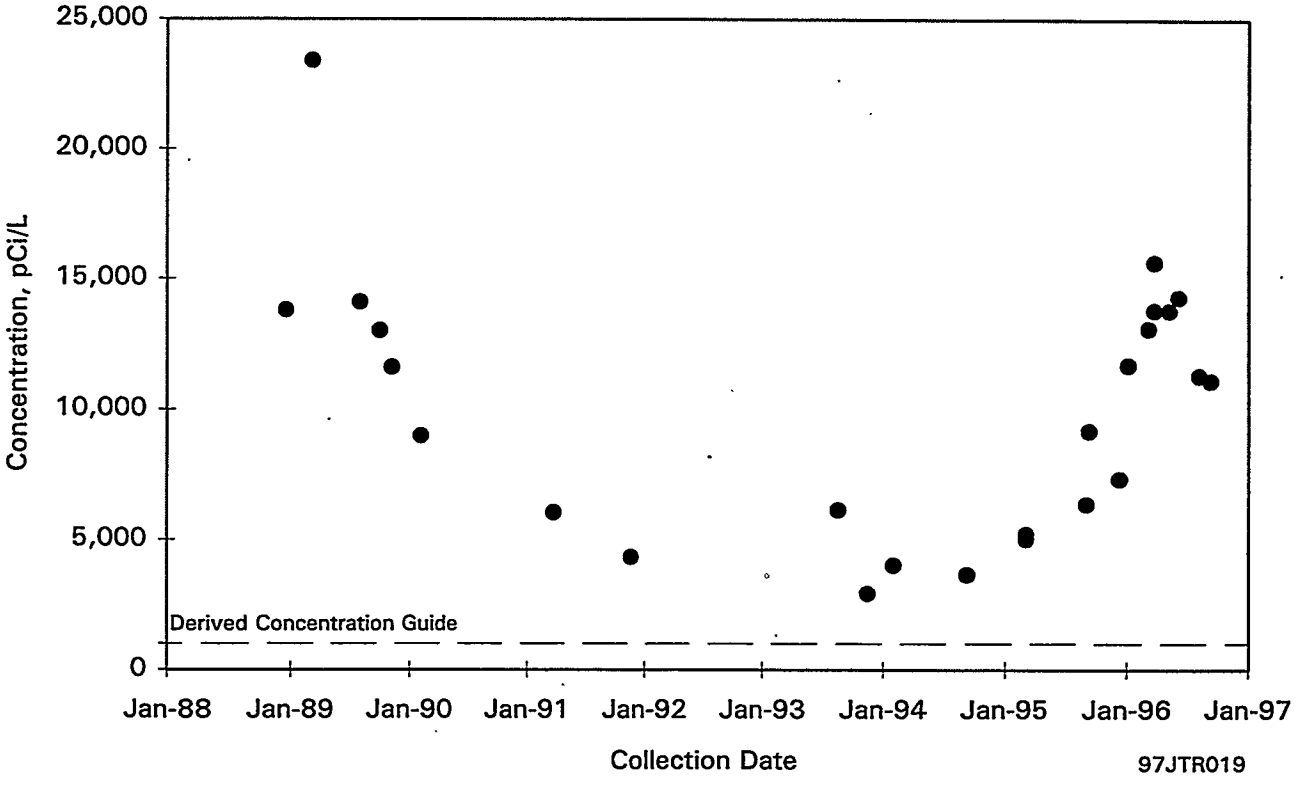


Figure 6.5-2. Strontium-90 Concentrations in Well 199-N-67

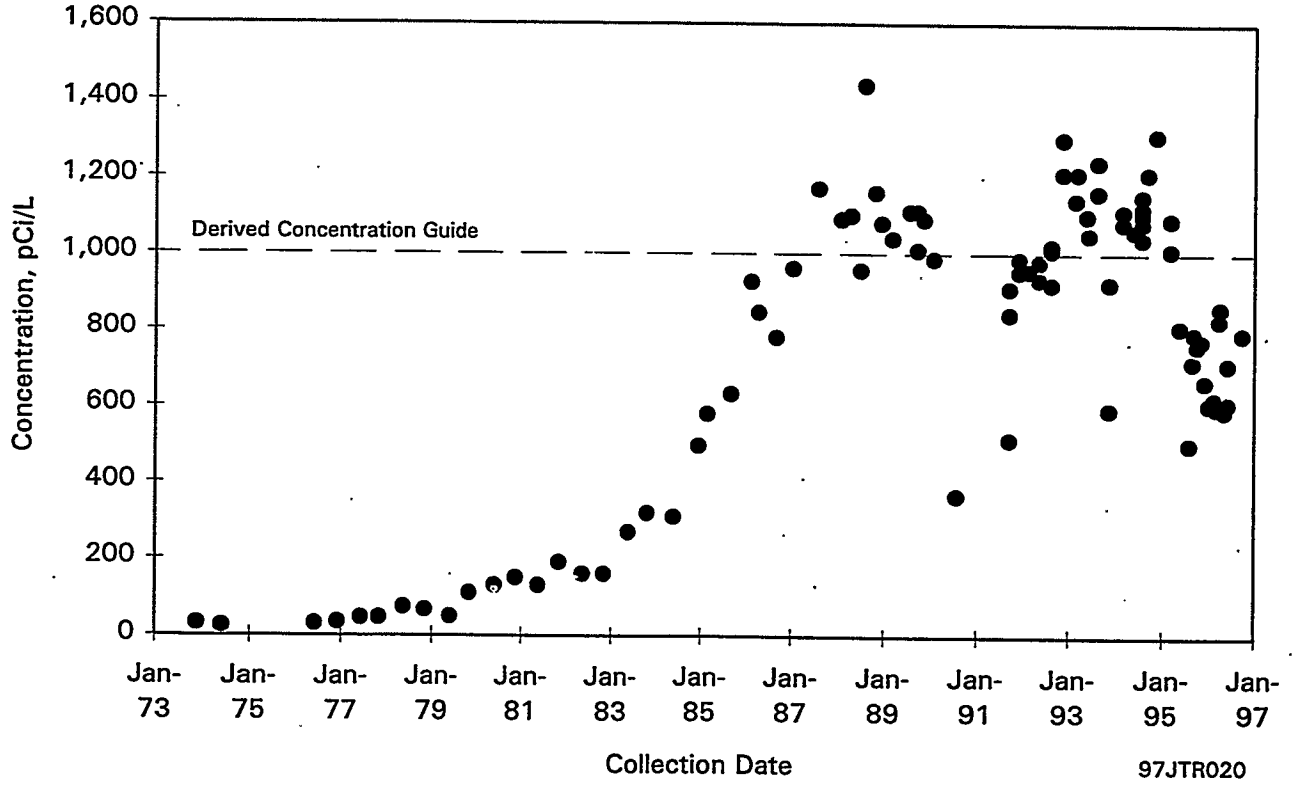


Figure 6.5-3. Strontium-90 Concentrations in Well 199-N-14

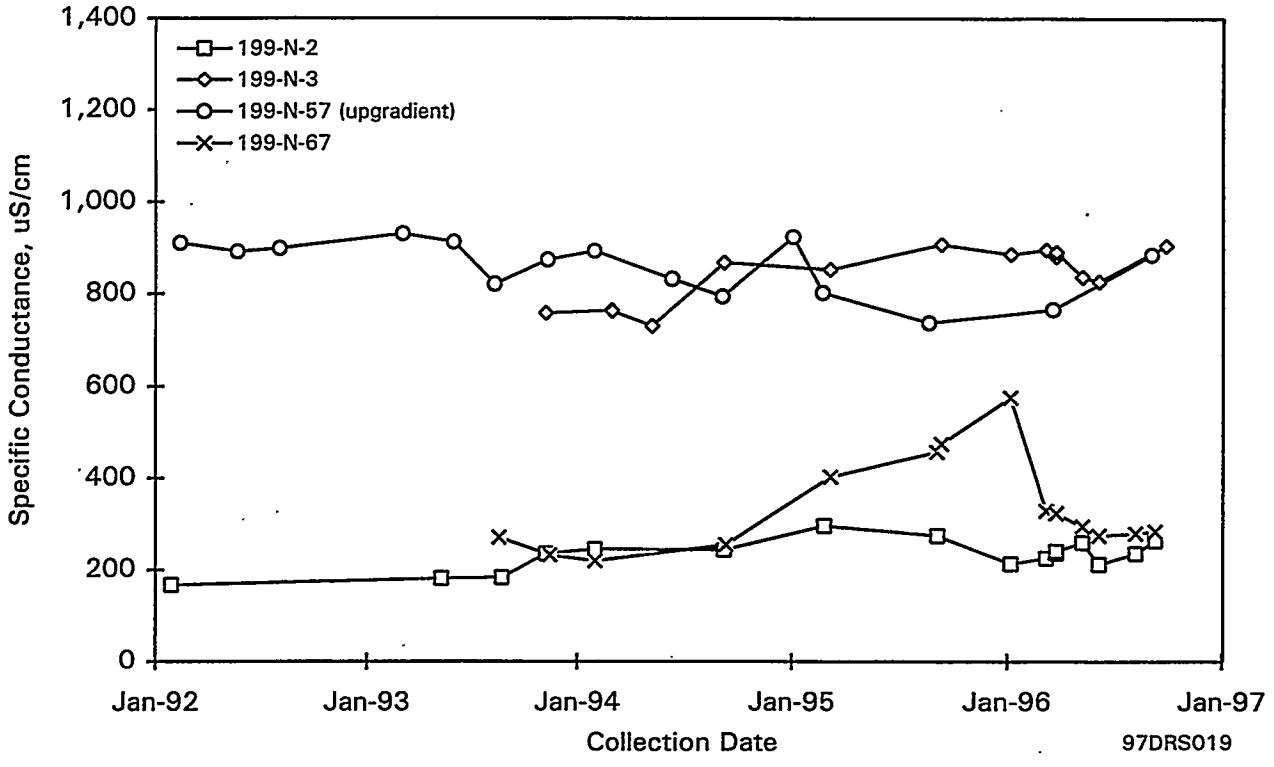


Figure 6.5-4. Specific Conductance in Wells Monitoring 1301-N Liquid Waste-Disposal Facility

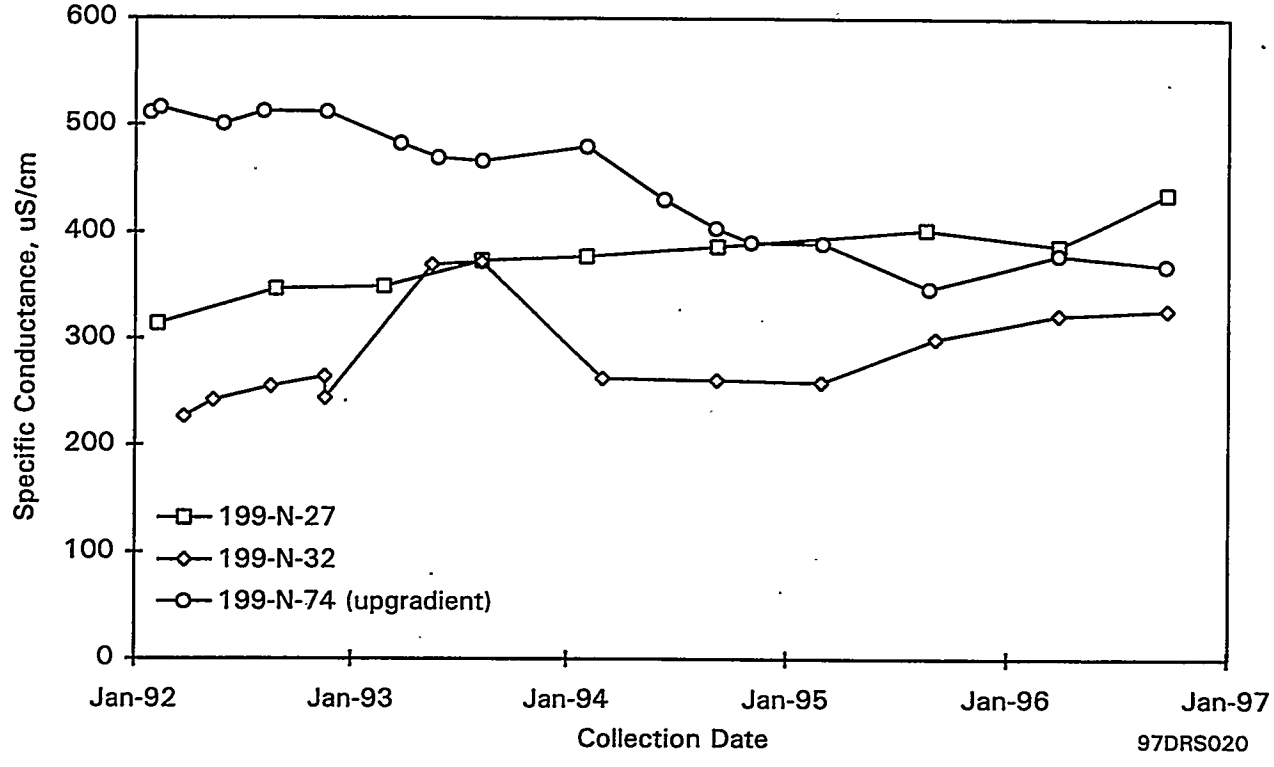


Figure 6.5-5. Specific Conductance in Wells Monitoring 1325-N Liquid Waste-Disposal Facility

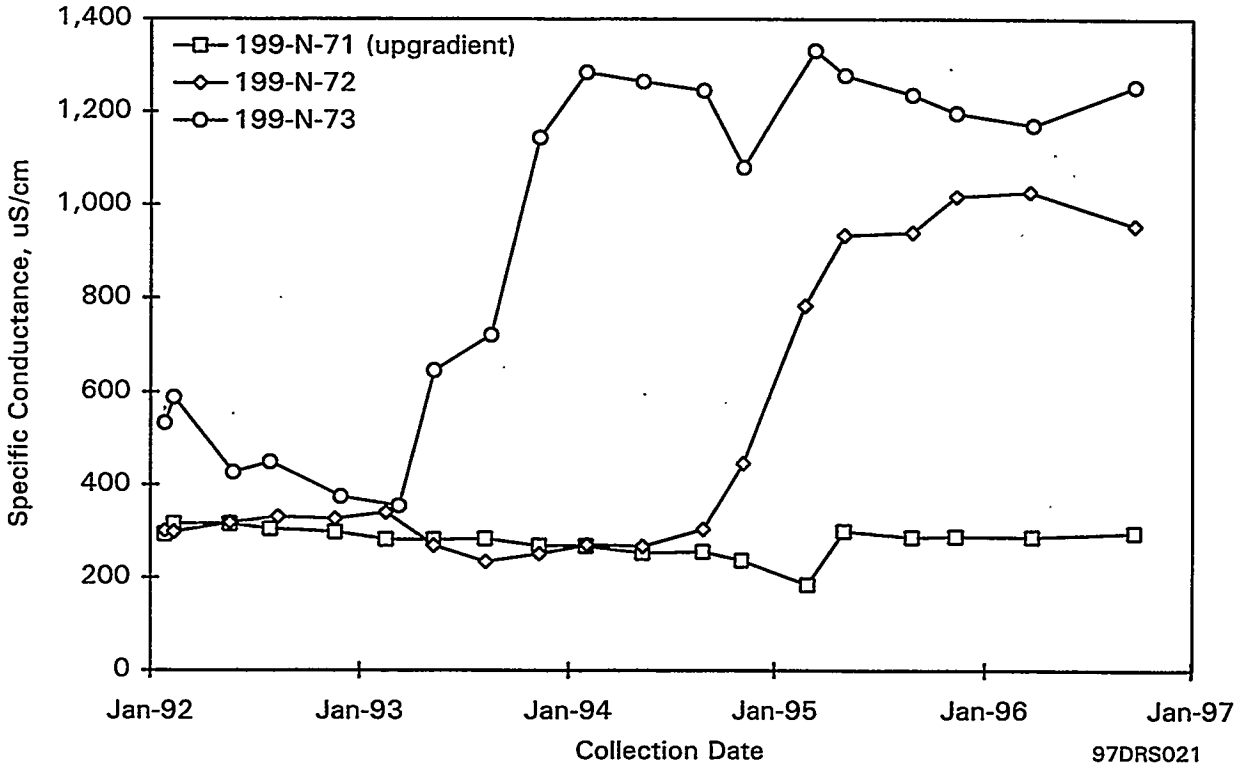


Figure 6.5-6. Specific Conductance in Wells Monitoring 1324-N/NA Liquid Waste-Disposal Facilities

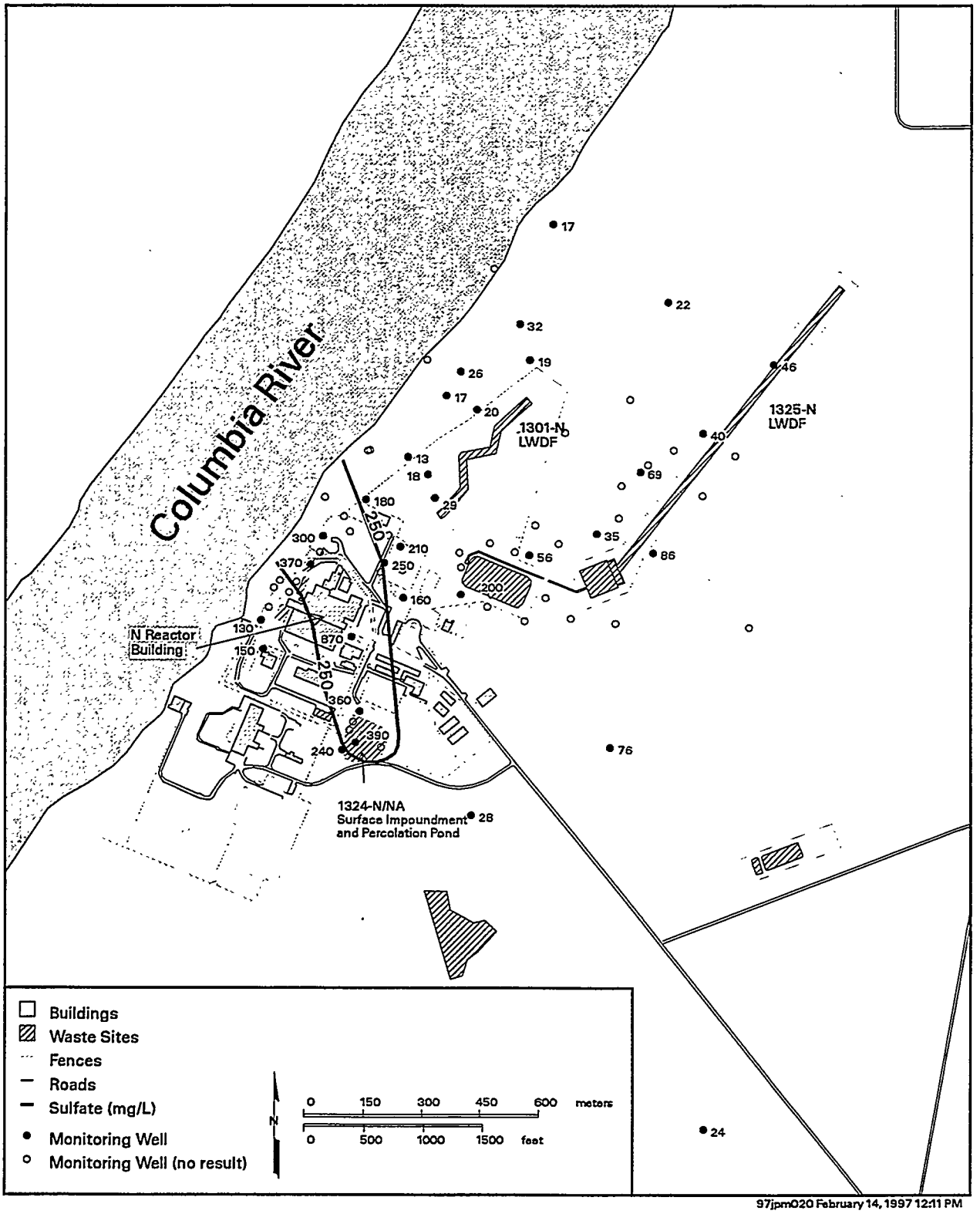


Figure 6.5-7. Average FY 1996 Sulfate Concentrations in 100-N Area

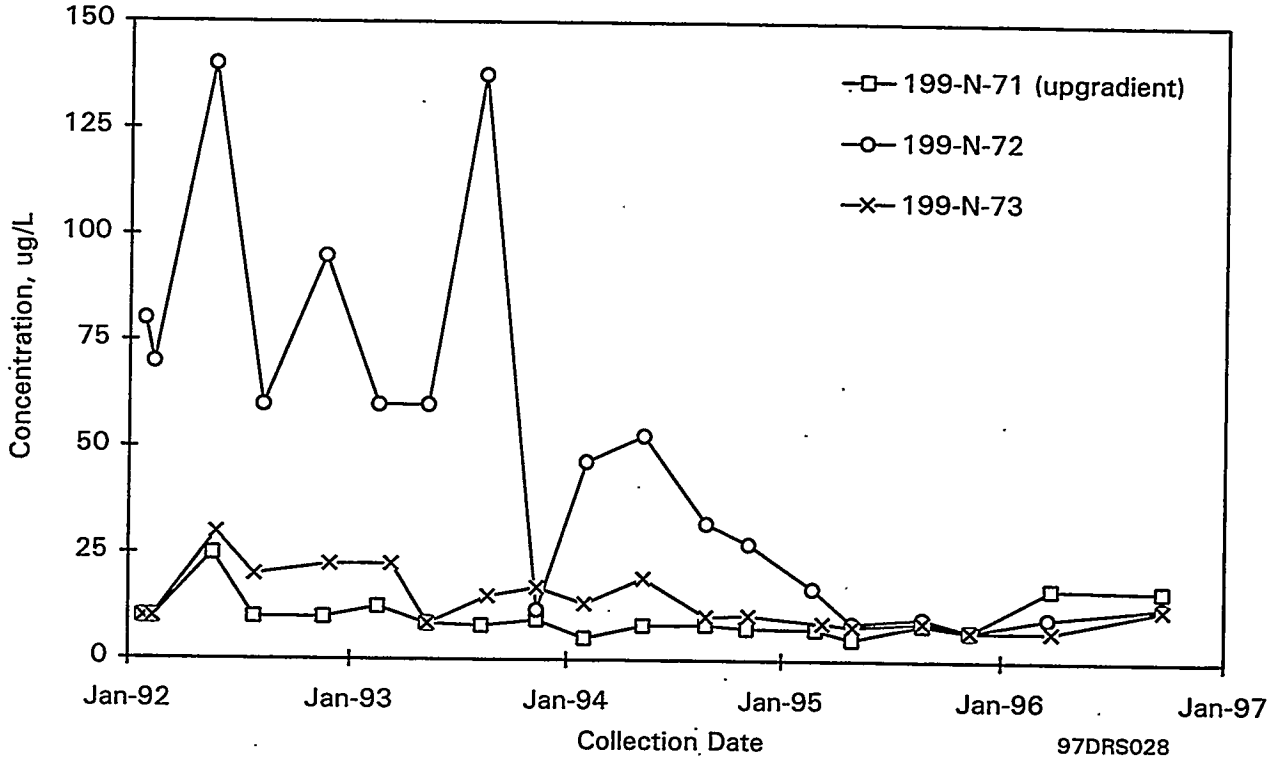


Figure 6.5-8. Total Organic Halide Concentrations in Wells Monitoring 1324-N/NA Liquid Waste-Disposal Facilities

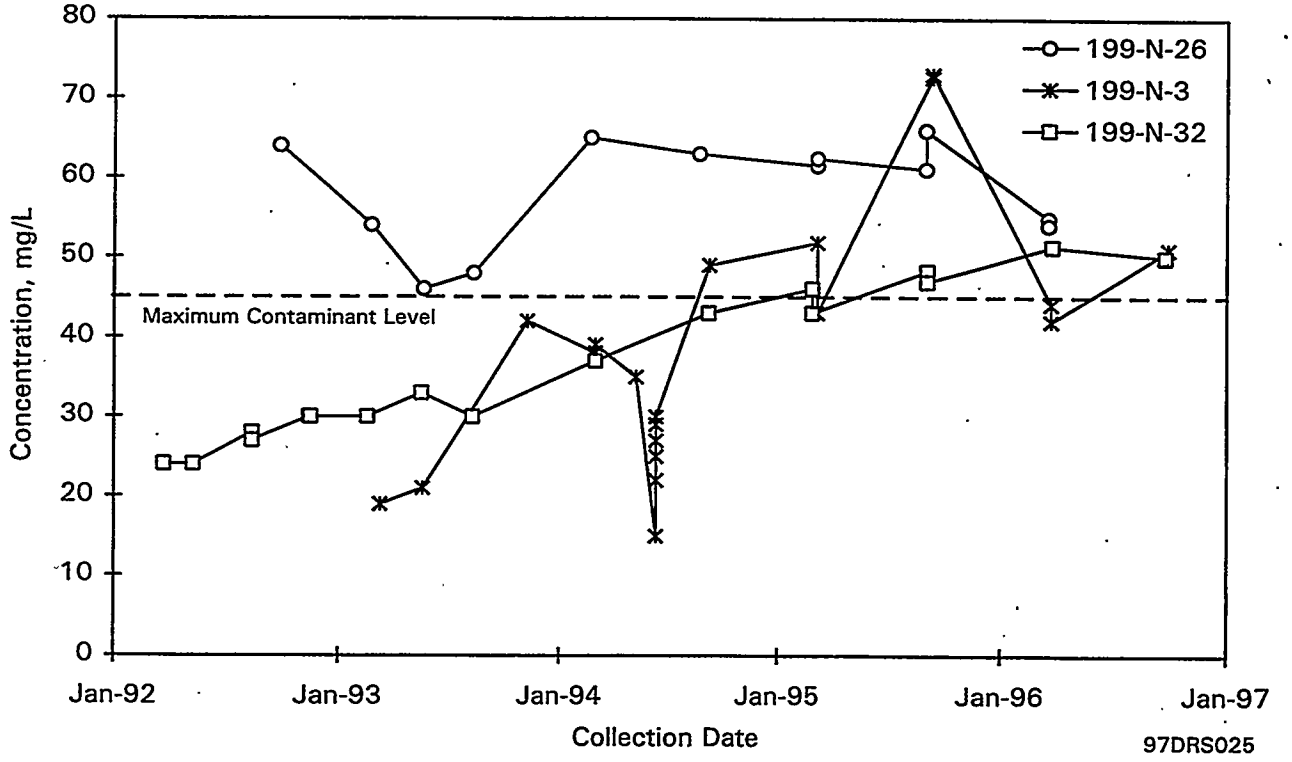


Figure 6.5-9. Nitrate Concentrations in 100-N Area Wells

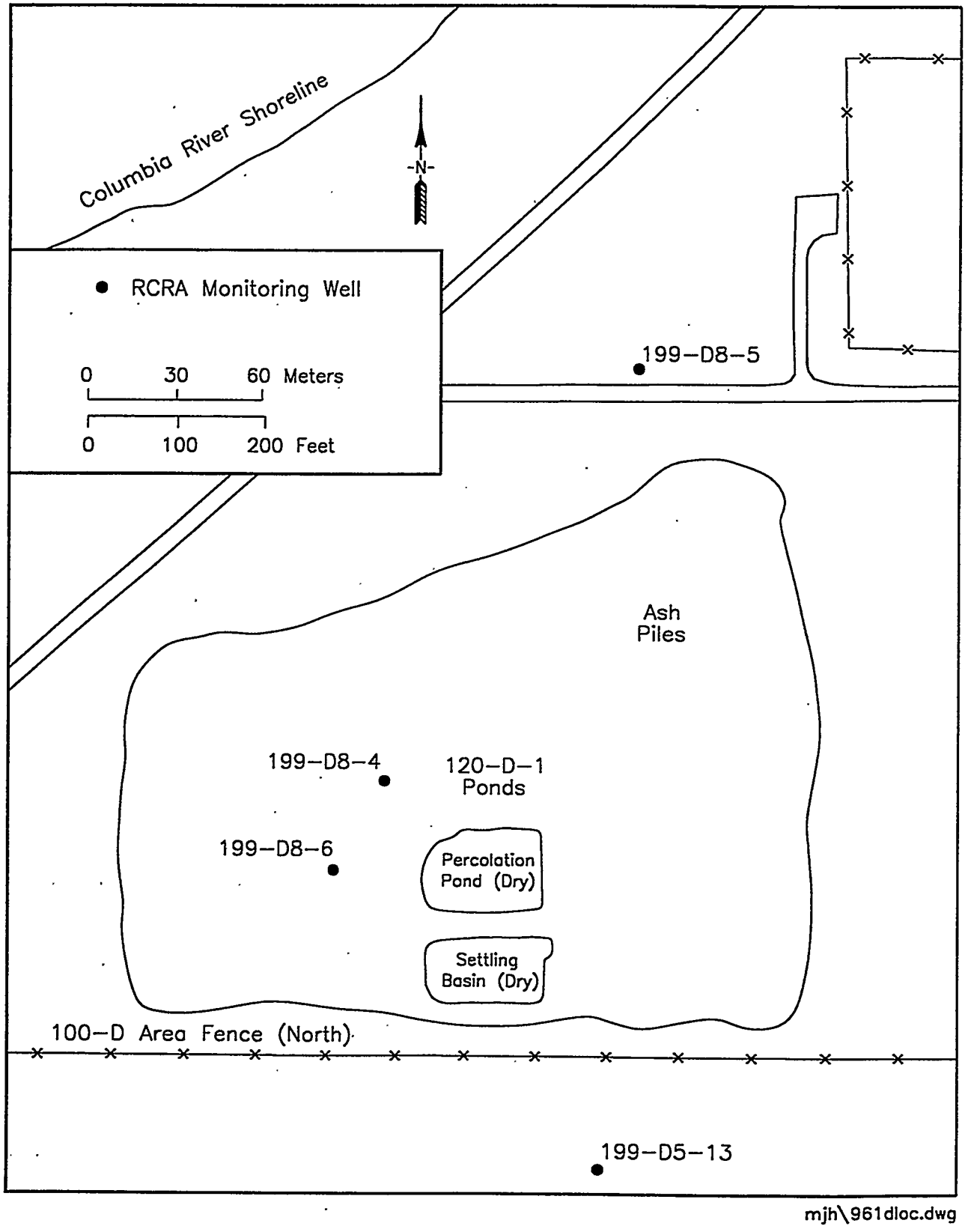


Figure 6.6-1. 120-D-1 Ponds and Monitoring Well Network

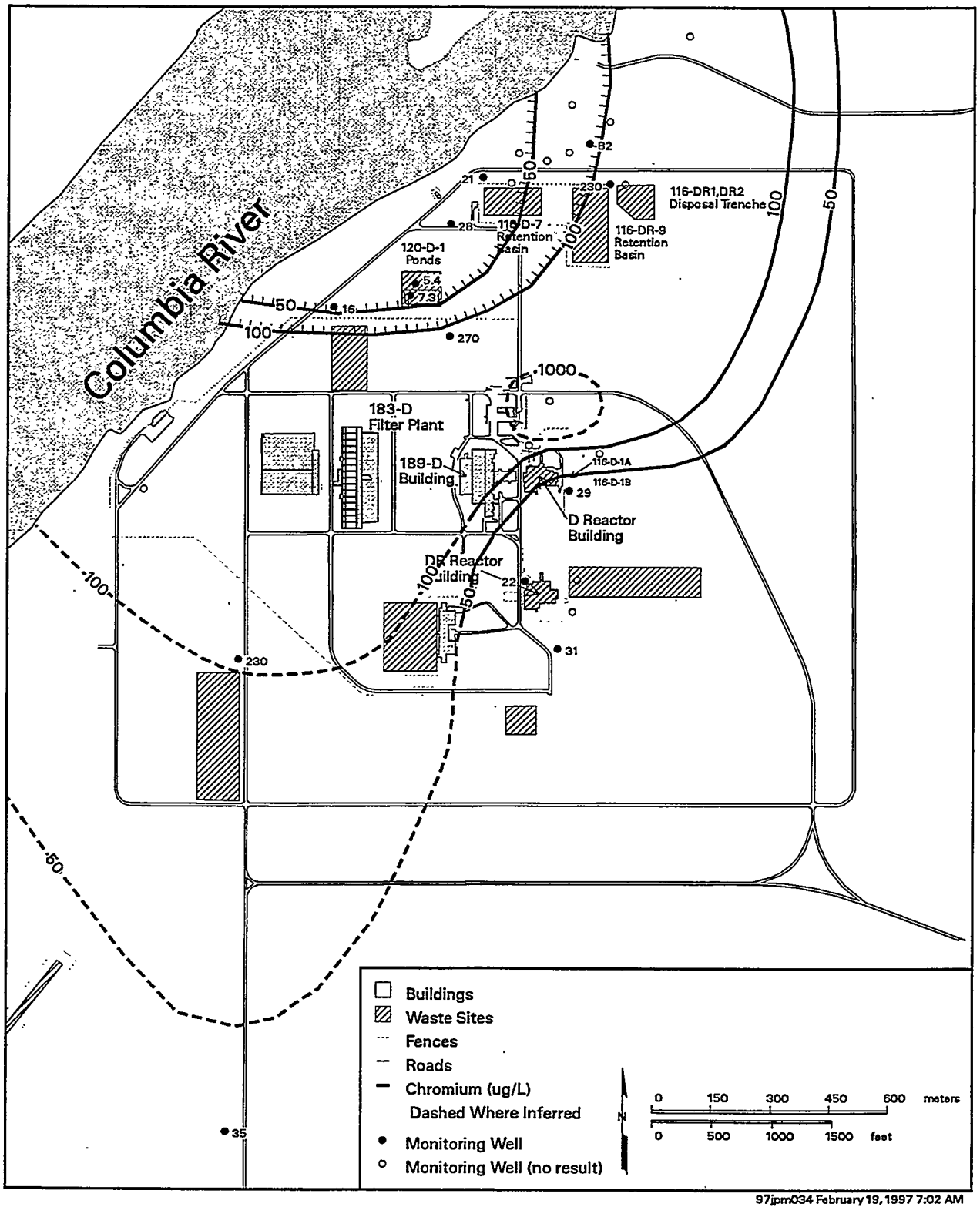


Figure 6.6-2. Average FY 1996 Chromium Concentrations in 100-D/DR Area

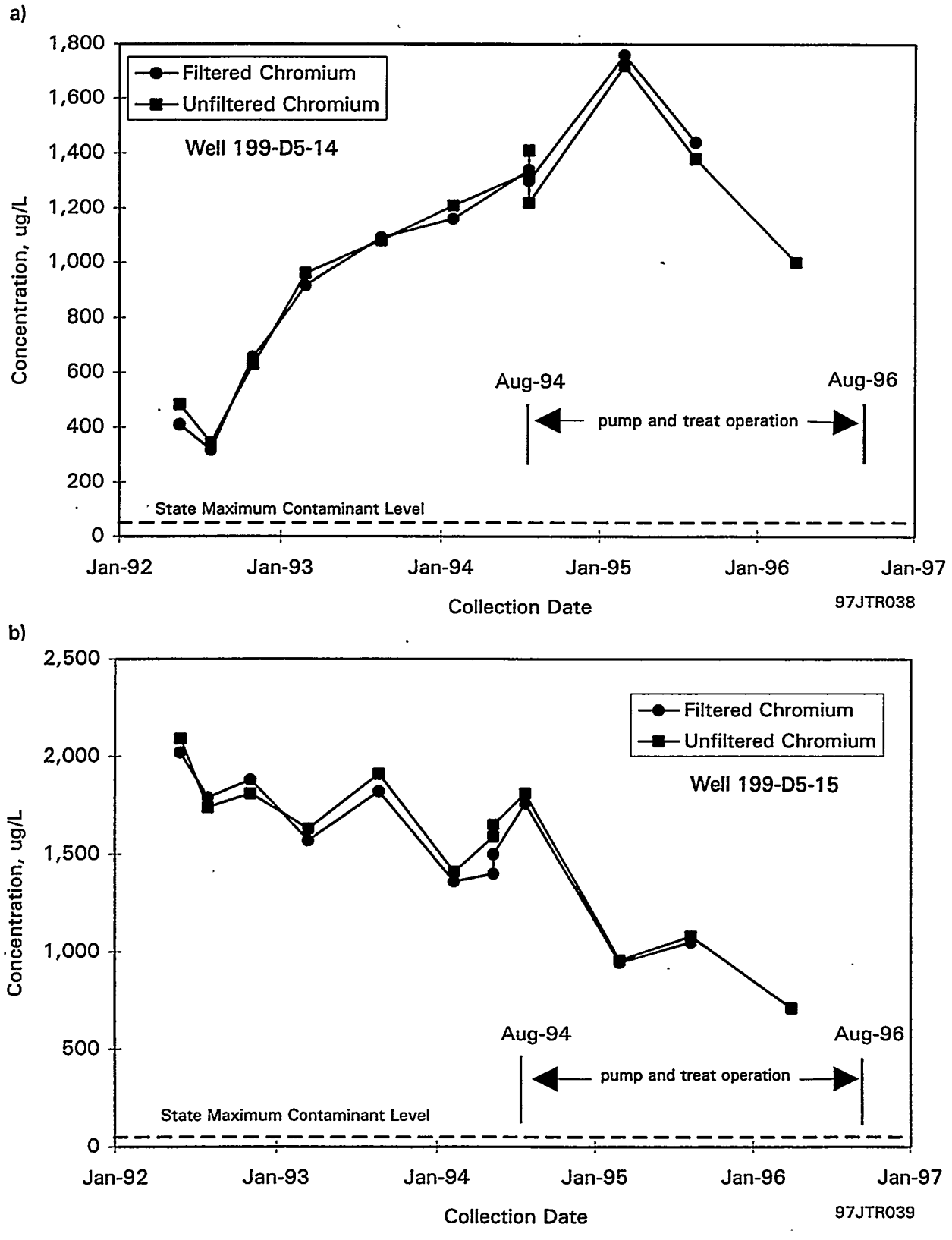


Figure 6.6-3. Chromium Concentrations in Wells Near Suspected D Reactor Source

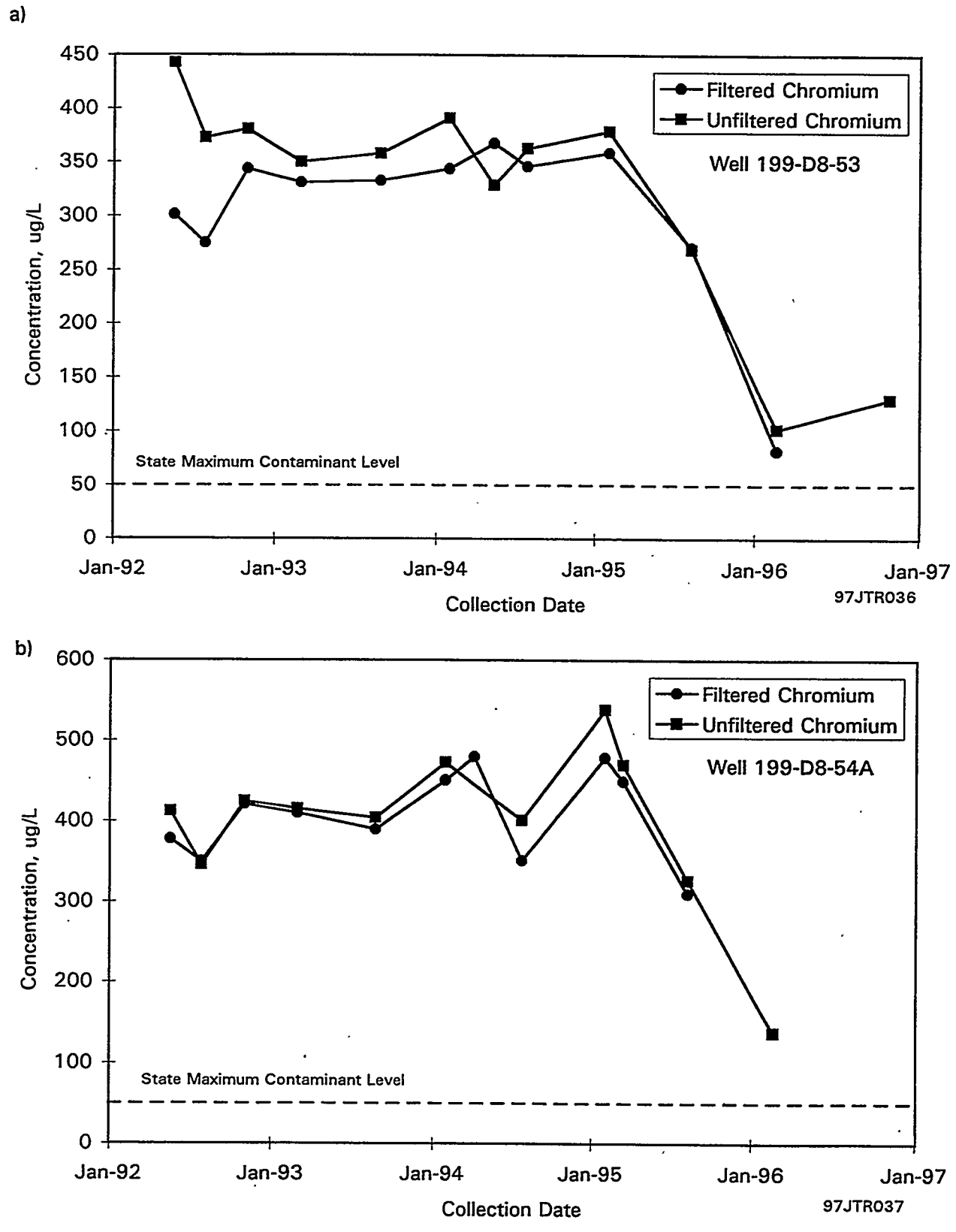


Figure 6.6-4. Chromium Concentrations in Wells near Columbia River

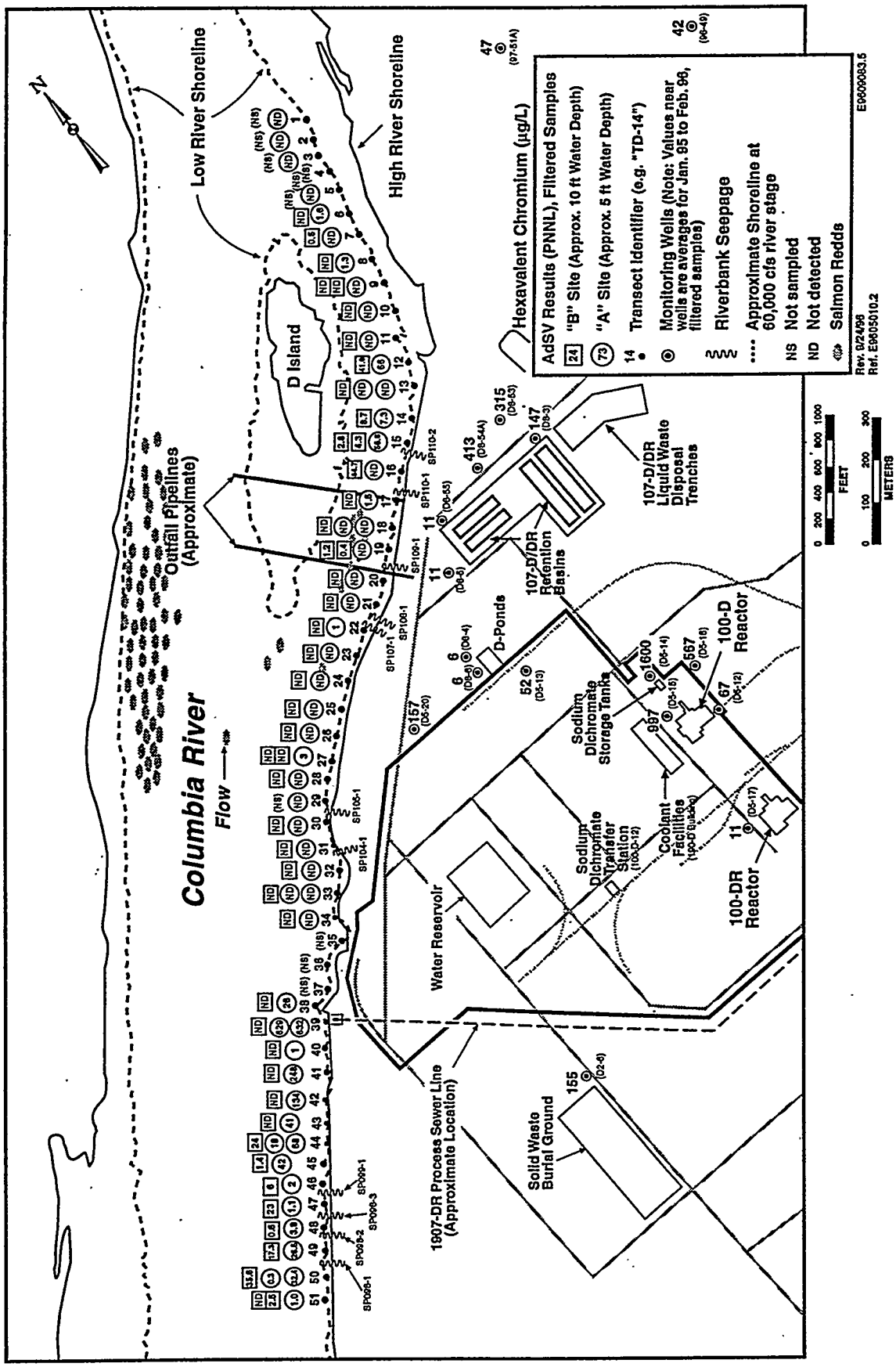


Figure 6.6-5. 100-D Area River Substrate Pore-Water Results (October/November 1995) (from Peterson et al. 1996)

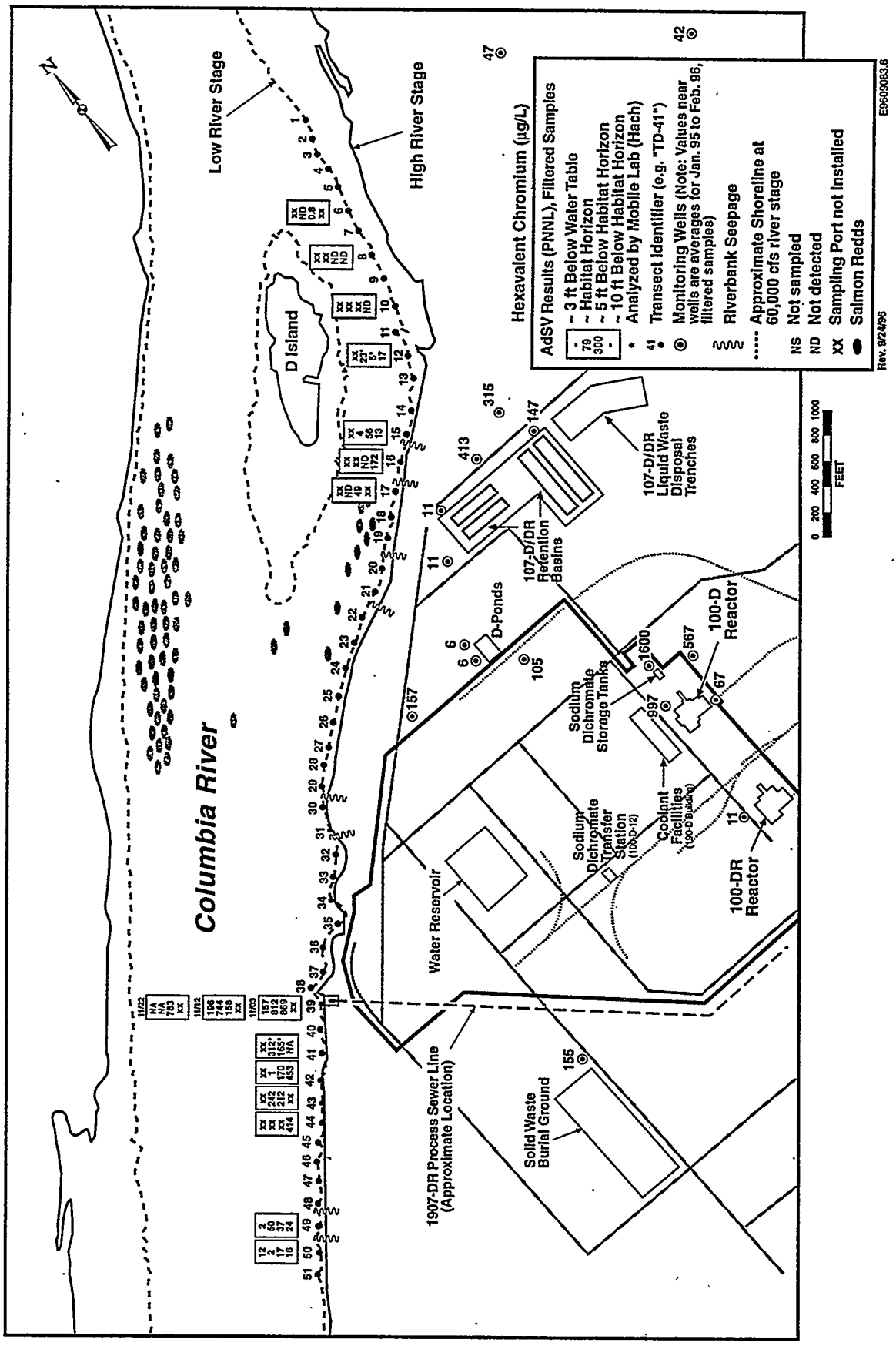


Figure 6.6-6. 100-D Area Aquifer-Sampling Tube Results (October/November 1995) (from Peterson et al. 1996)

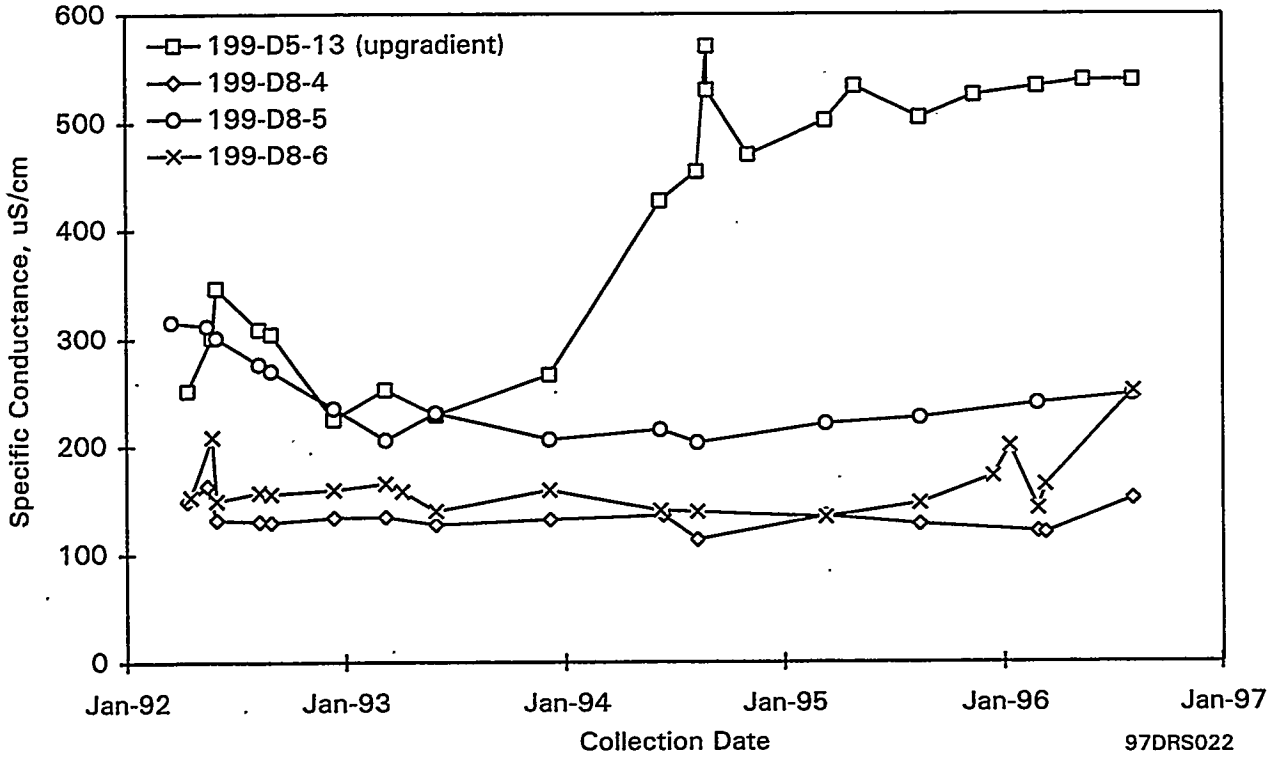


Figure 6.6-7. Specific Conductance in Wells Monitoring 120-D-1 Ponds

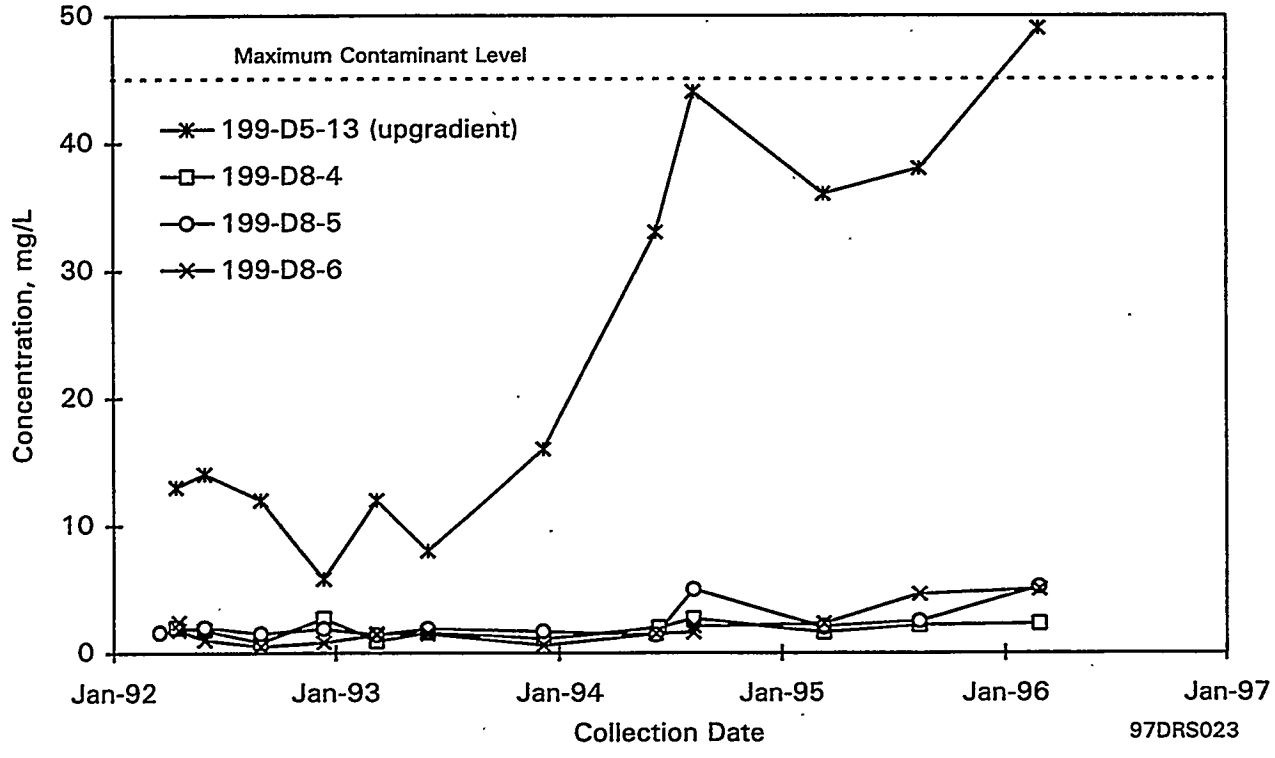


Figure 6.6-8. Nitrate Concentrations in Wells Monitoring 120-D-1 Ponds

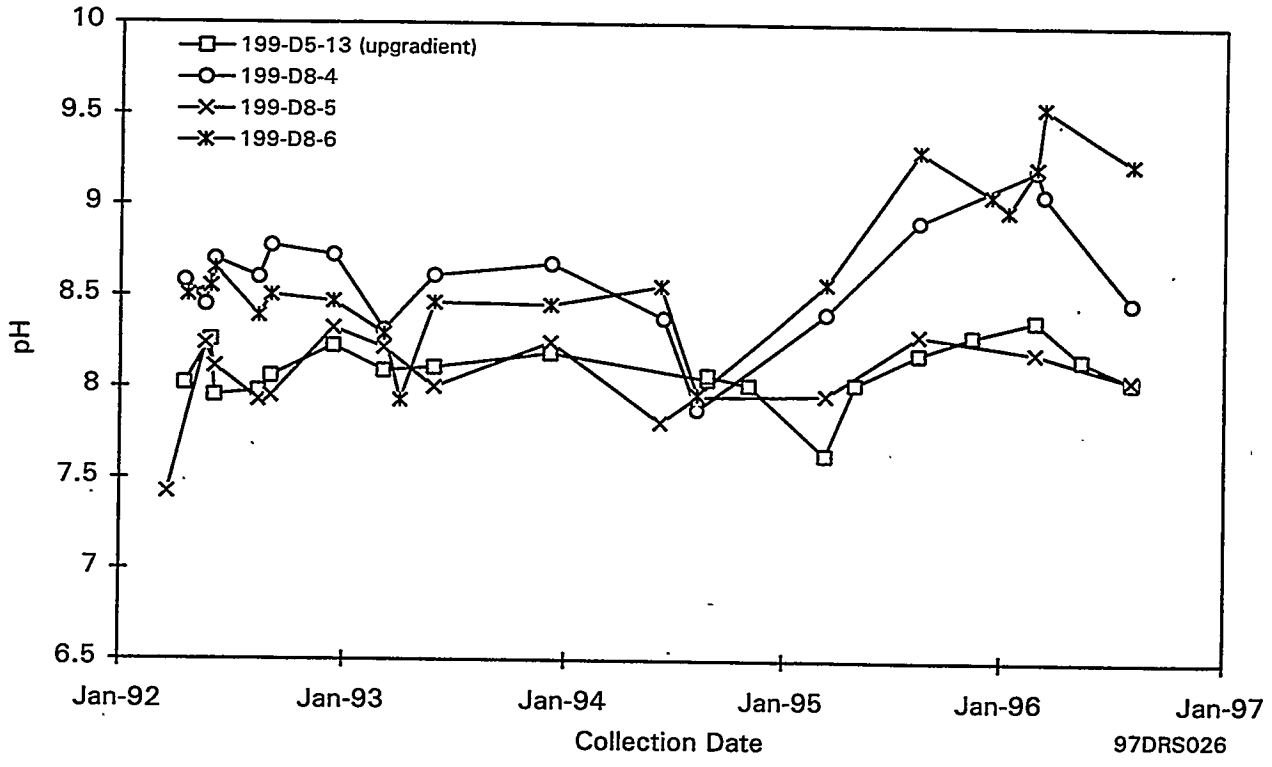


Figure 6.6-9. pH Concentrations in Wells Monitoring 120-D-1 Ponds

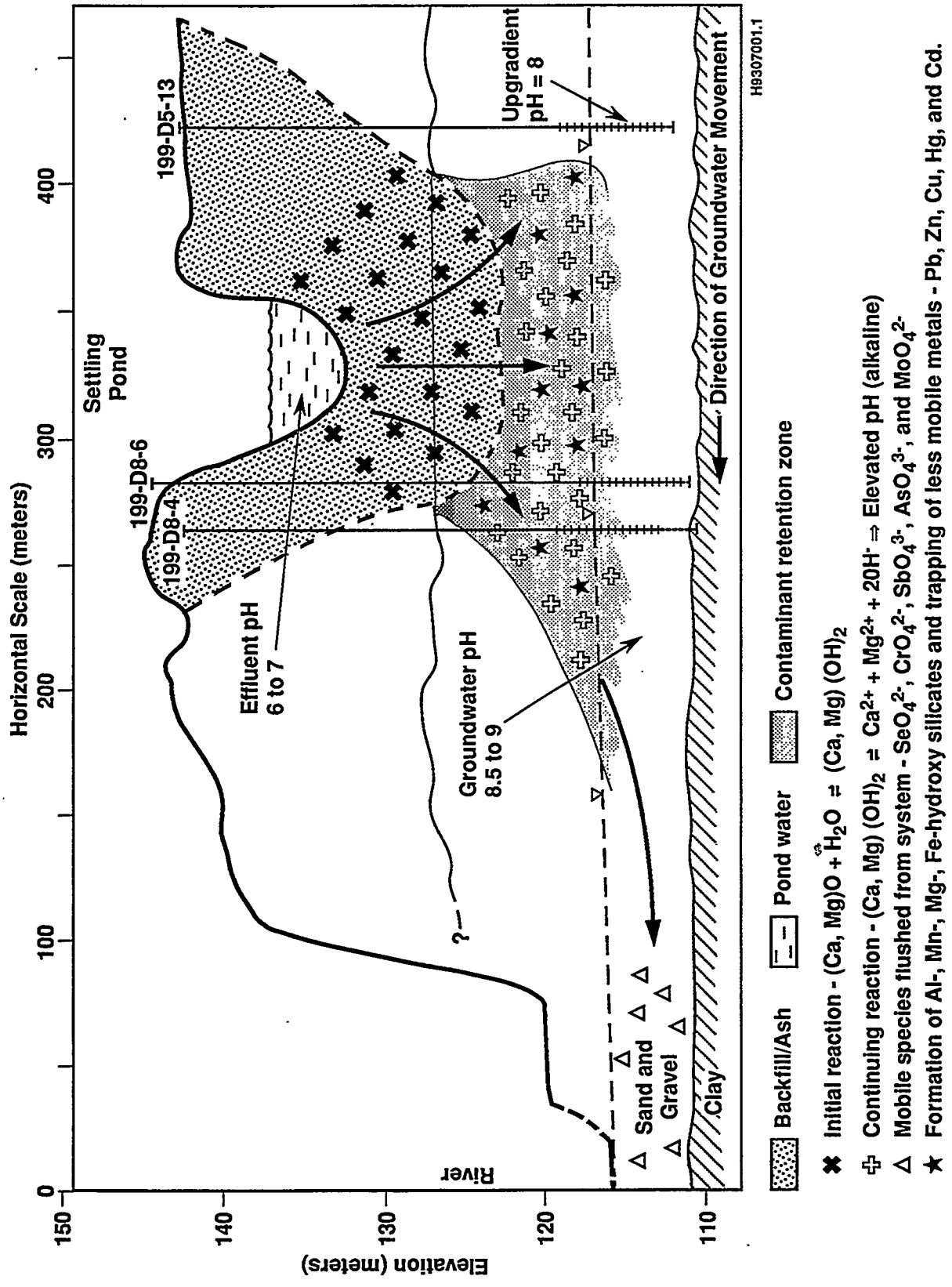


Figure 6.6-10. Conceptual Model for 120-D-1 Ponds (from Alexander 1993)

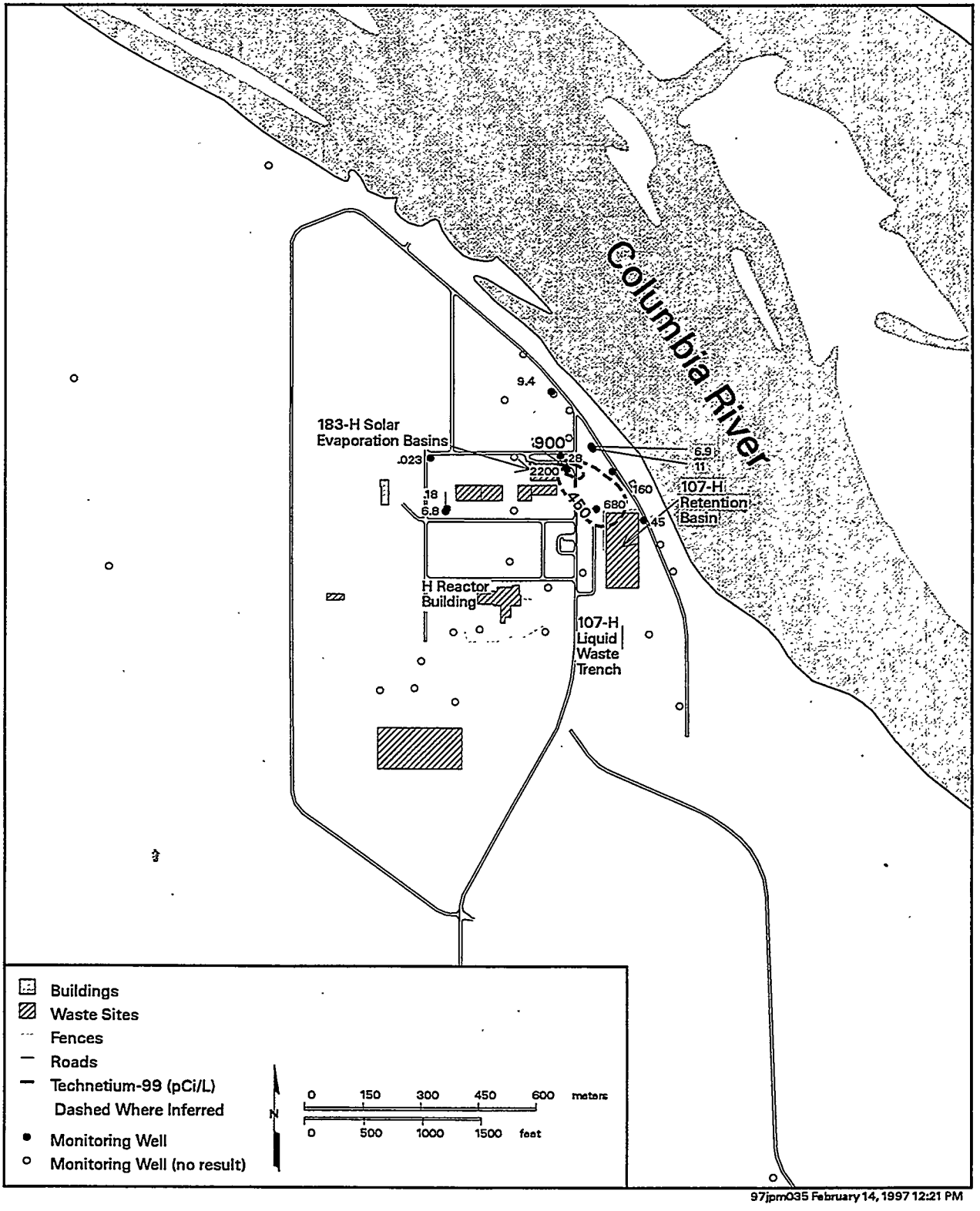


Figure 6.7-1. Average FY 1996 Technetium-99 Concentrations in 100-H Area

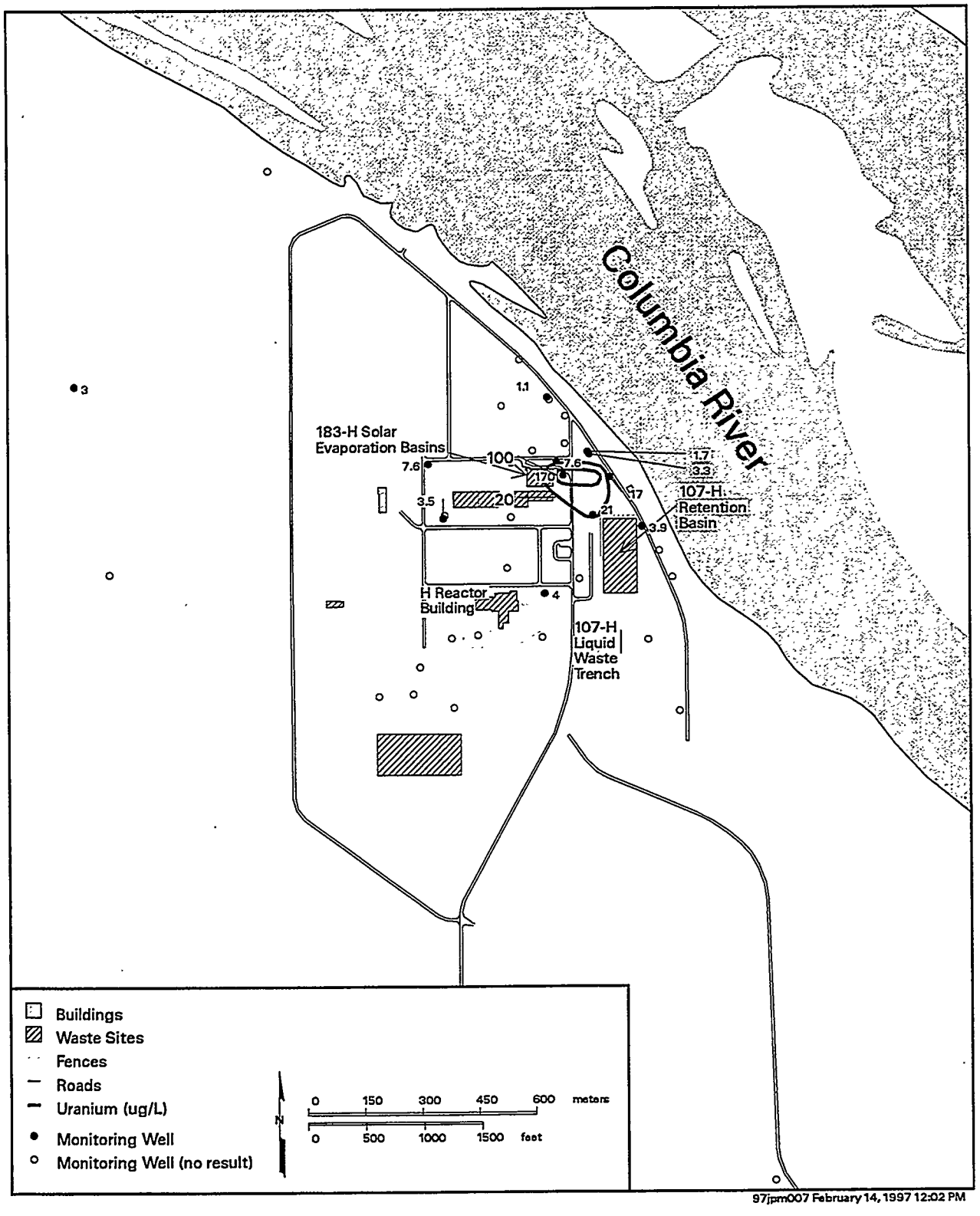


Figure 6.7-2. Average FY 1996 Uranium Concentrations in 100-H Area

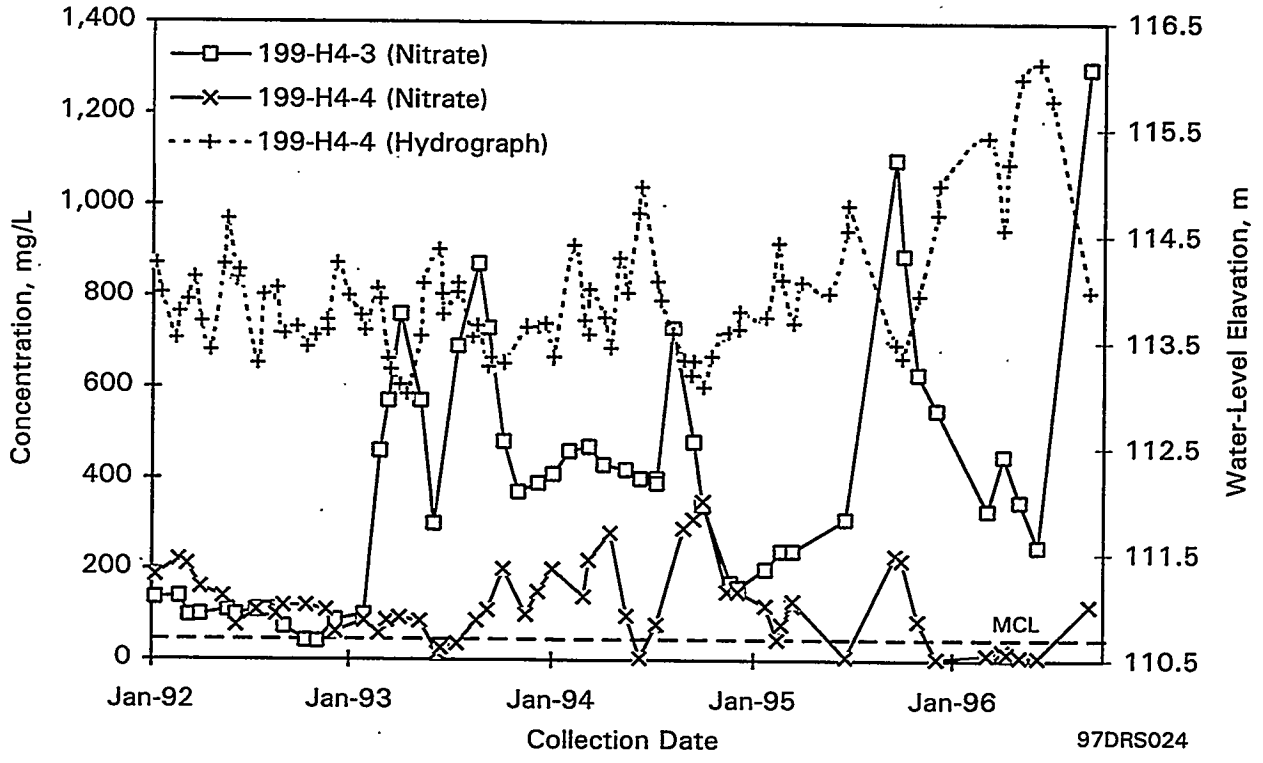


Figure 6.7-3. Nitrate Concentrations in Wells Monitoring 183-H Solar Evaporation Basins

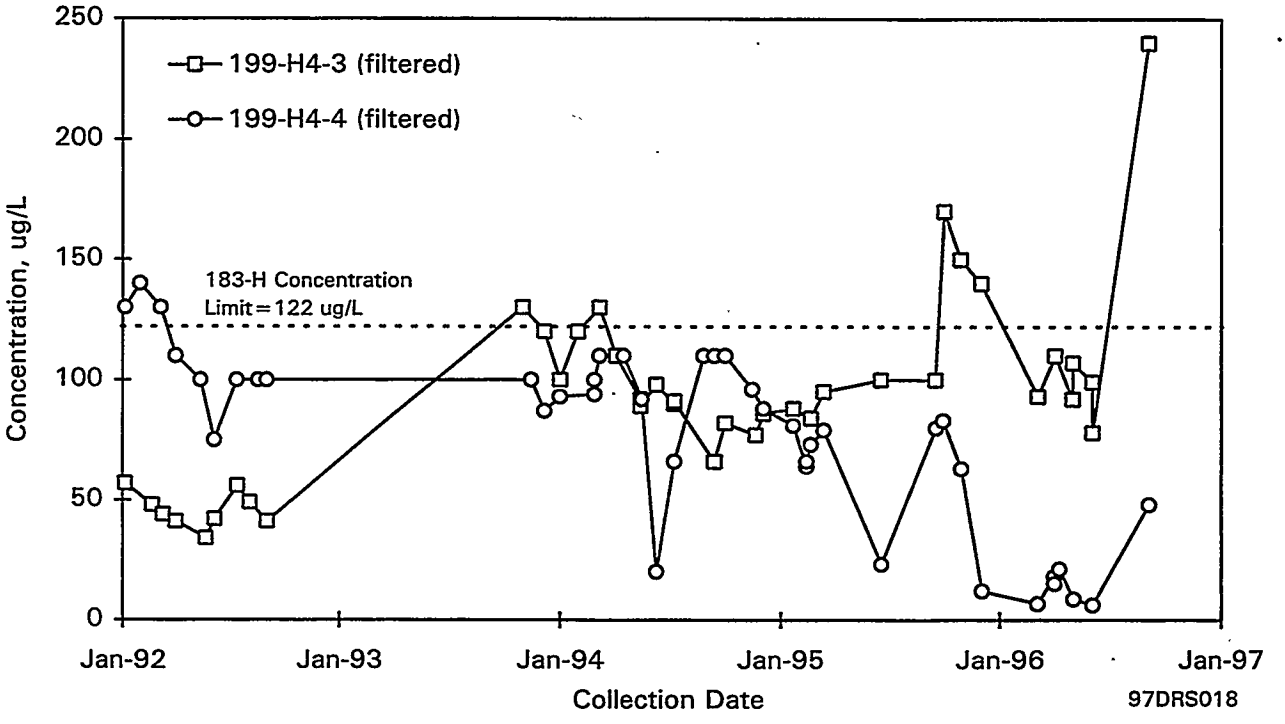


Figure 6.7-4. Chromium Concentrations in Wells Monitoring 183-H Solar Evaporation Basins

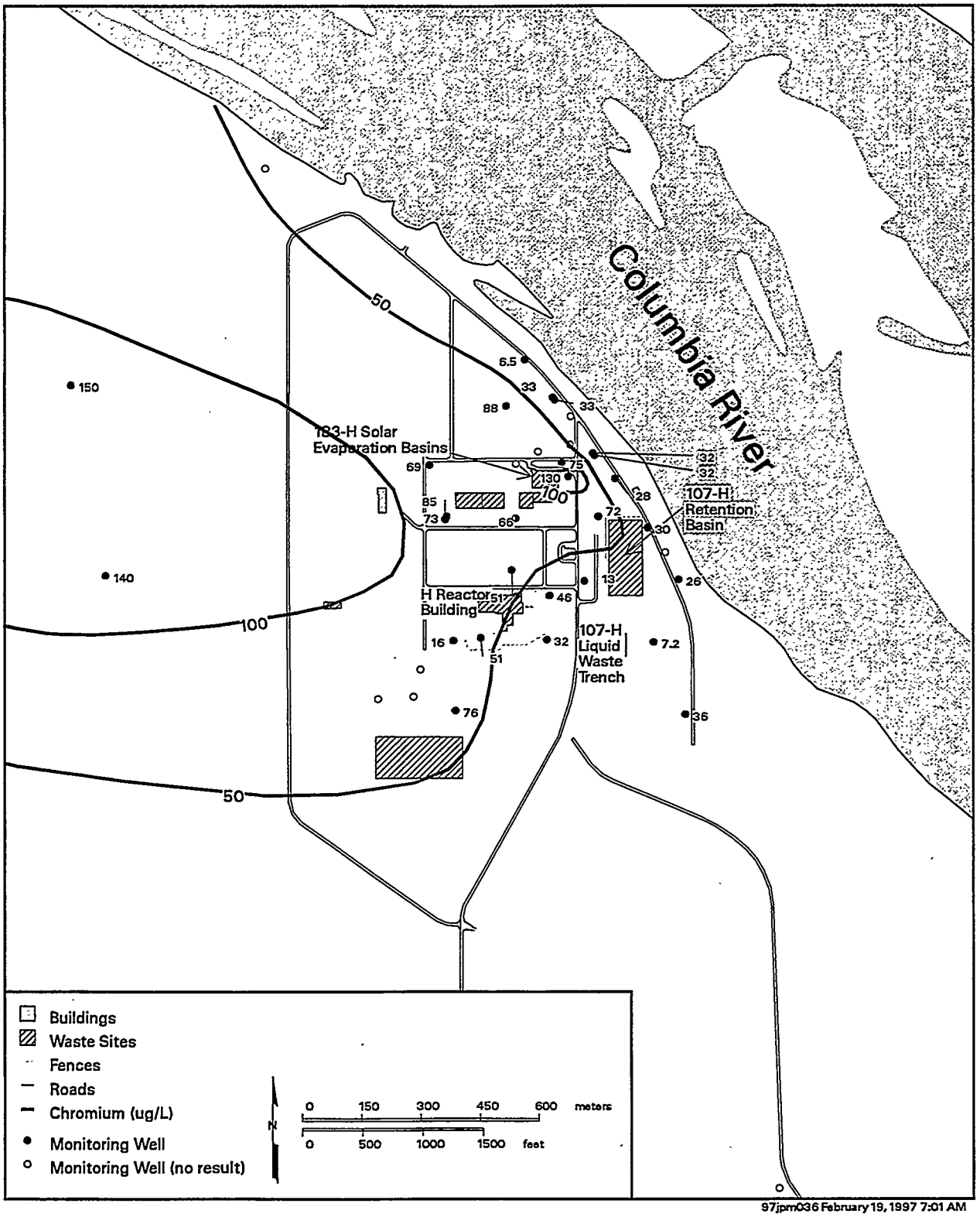


Figure 6.7-5. Average FY 1996 Chromium Concentrations in 100-H Area

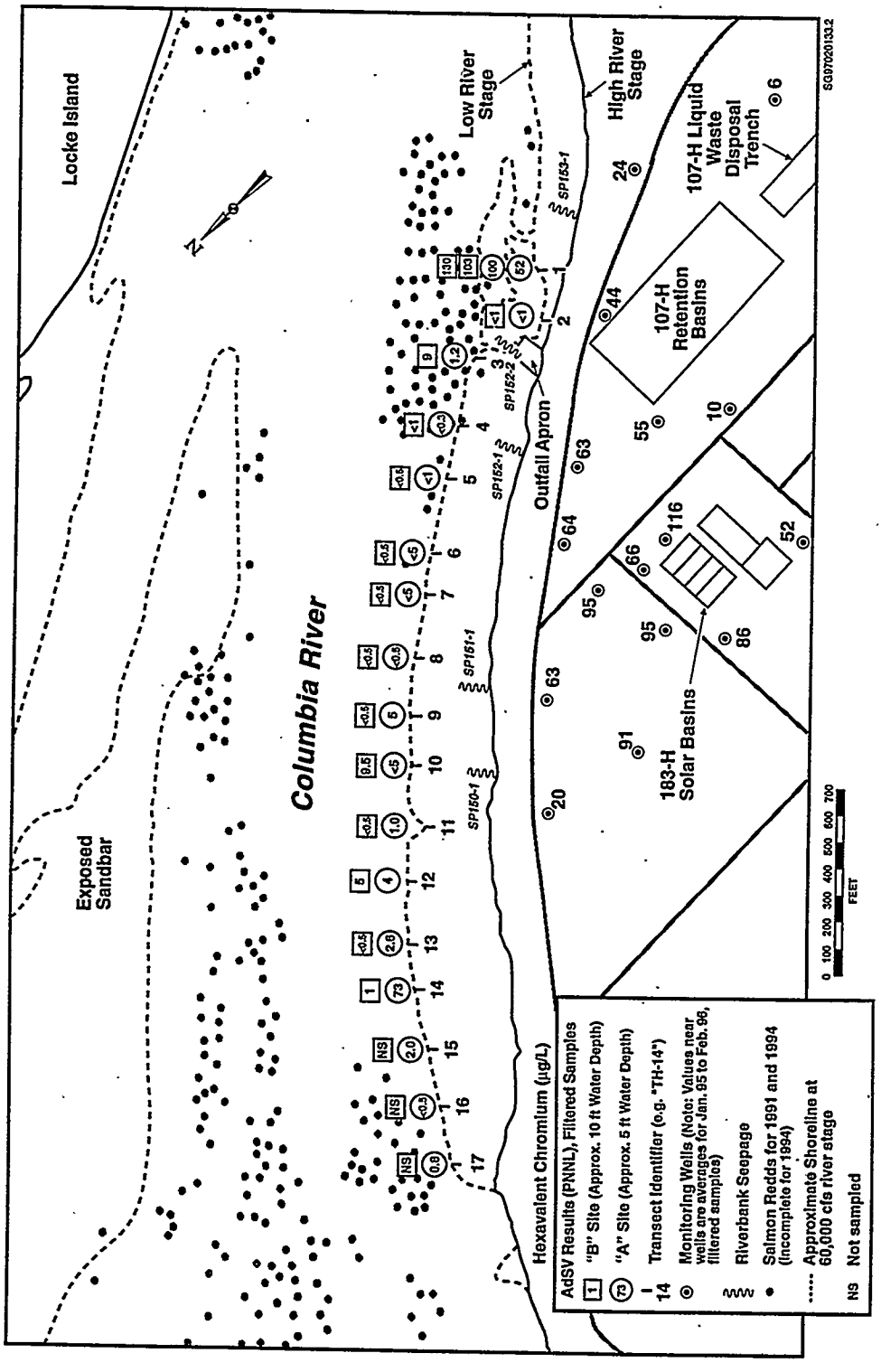


Figure 6.7-6. 100-H Area River Substrate Pore-Water Results (March/April 1995)(from Peterson et al. 1996)

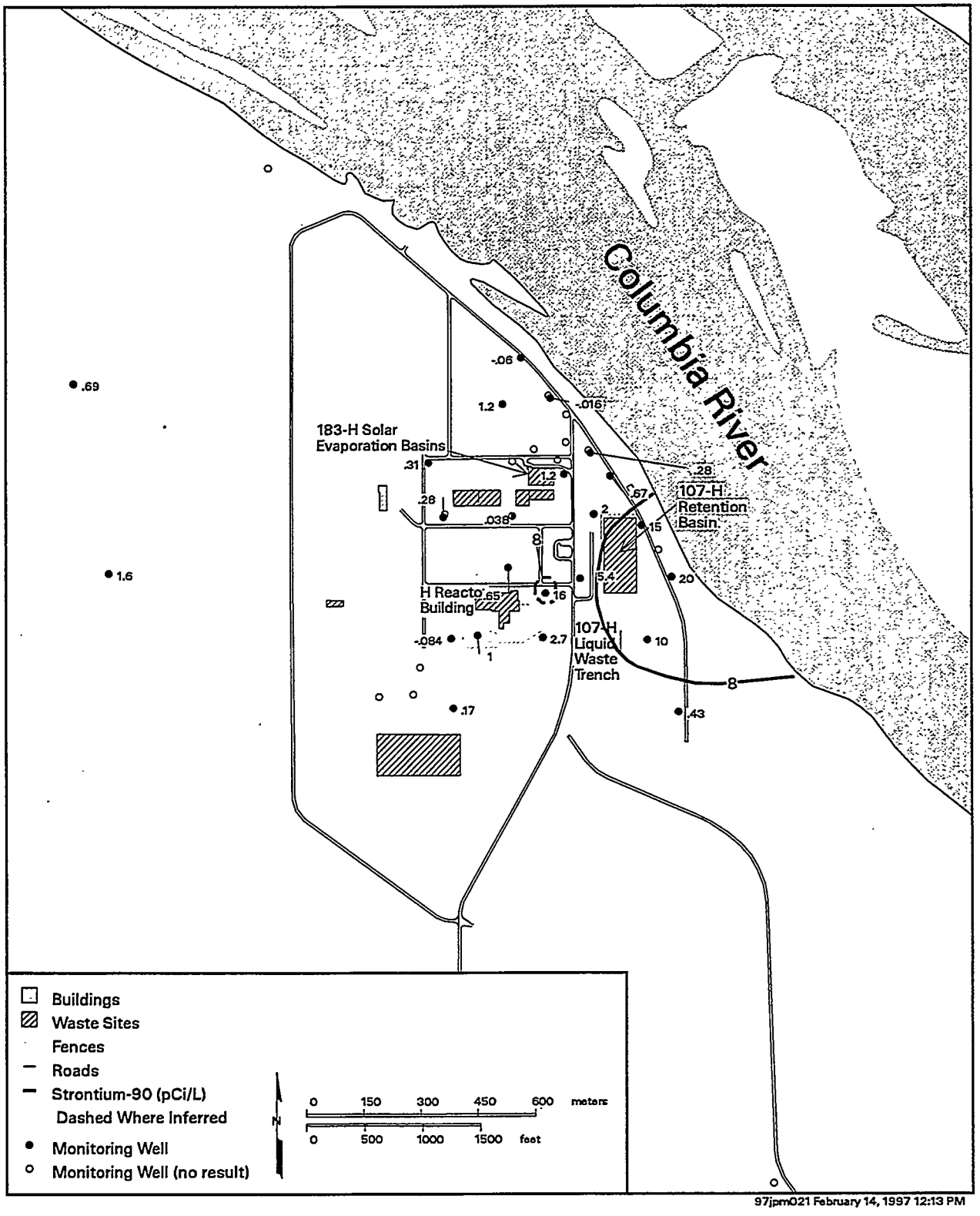


Figure 6.7-7. Average FY 1996 Strontium-90 Concentrations in 100-H Area

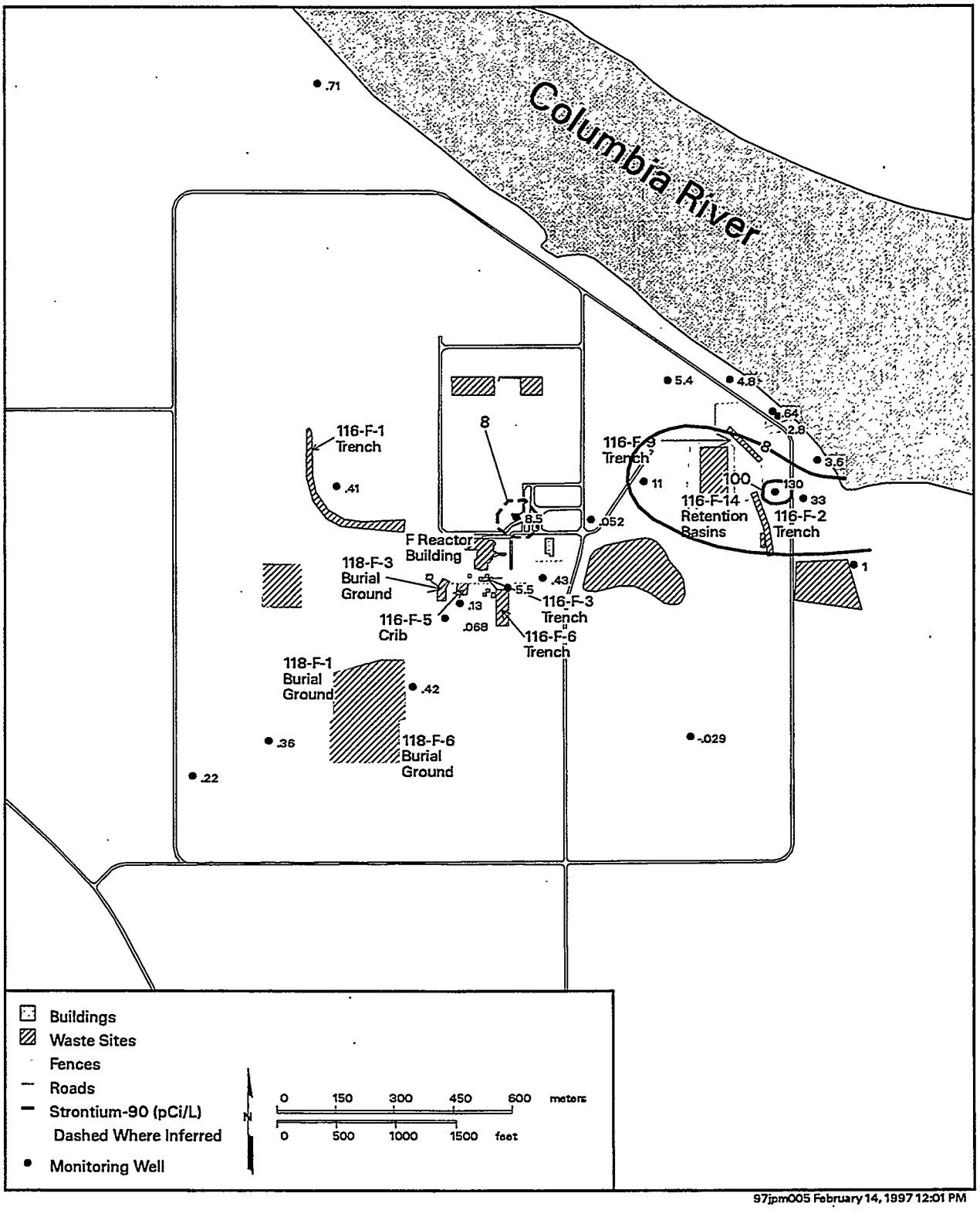


Figure 6.8-1. Average FY 1996 Strontium-90 Concentrations in 100-F Area

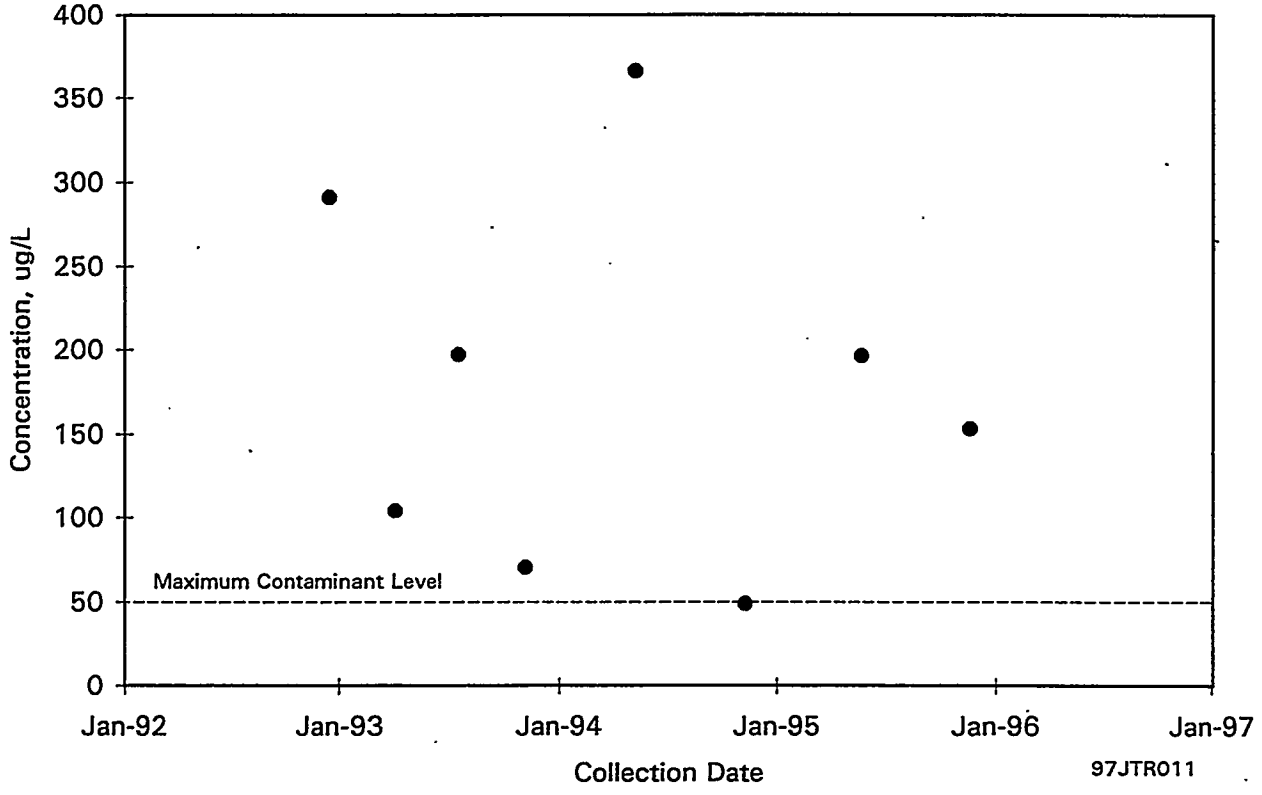


Figure 6.8-2. Filtered Chromium Concentrations in Well 199-F5-46

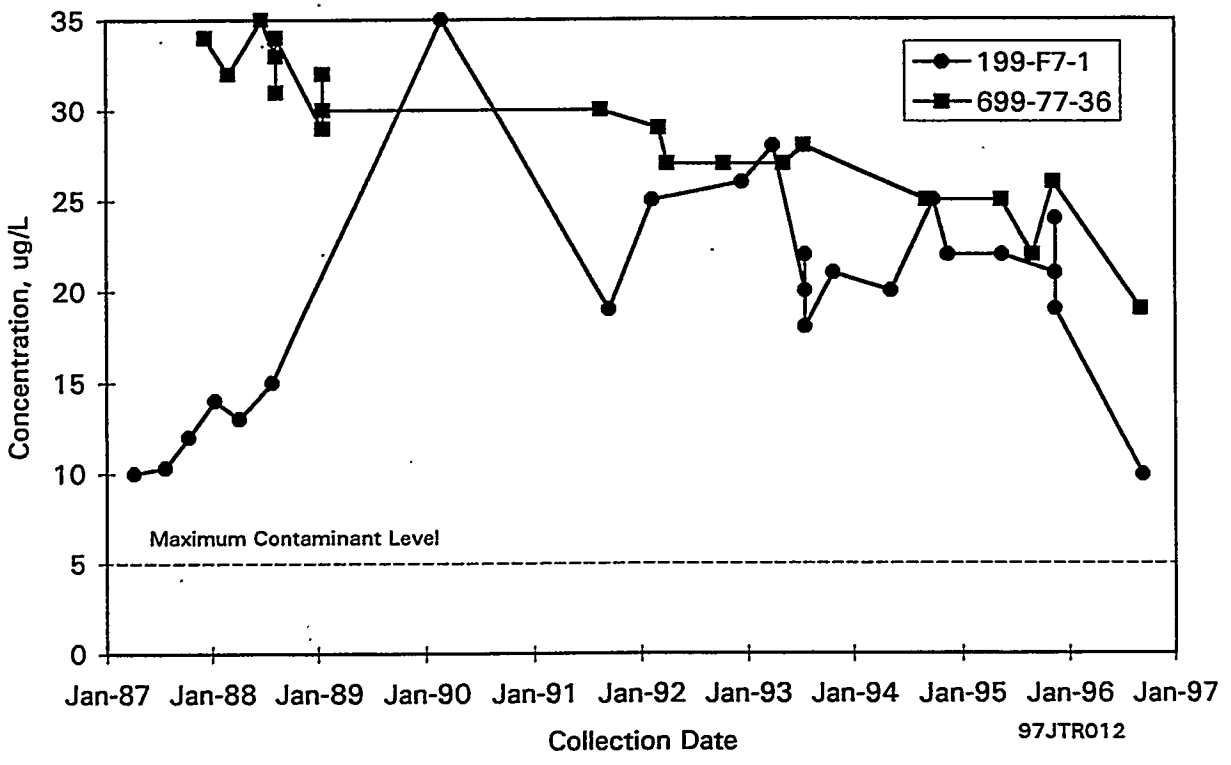


Figure 6.8-3. Trichloroethylene Concentrations in Wells 199-F7-1 and 699-77-36

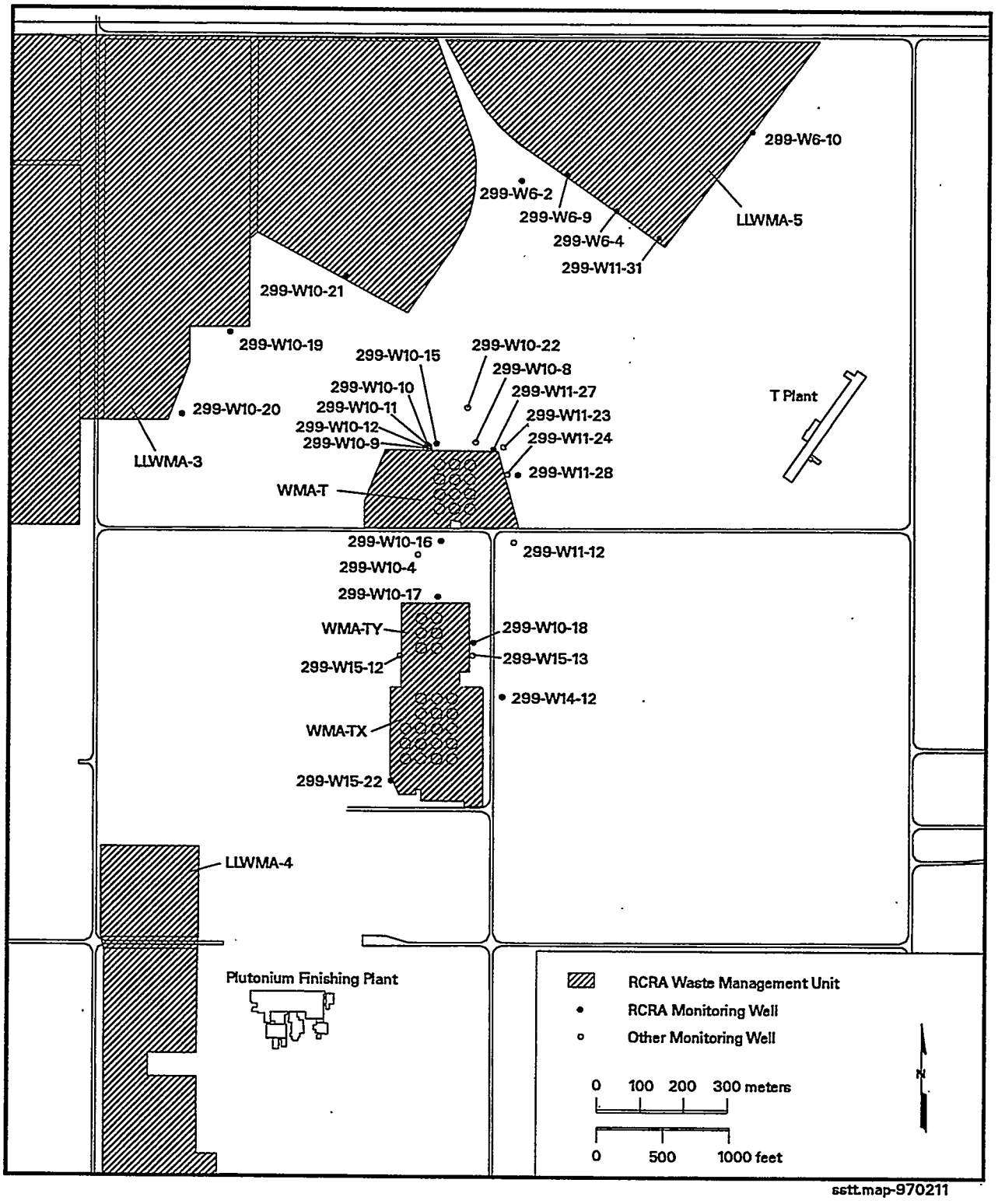


Figure 6.9-1a. Monitoring Well Locations for WMA-TX-TY Single-Shell Tank Farms

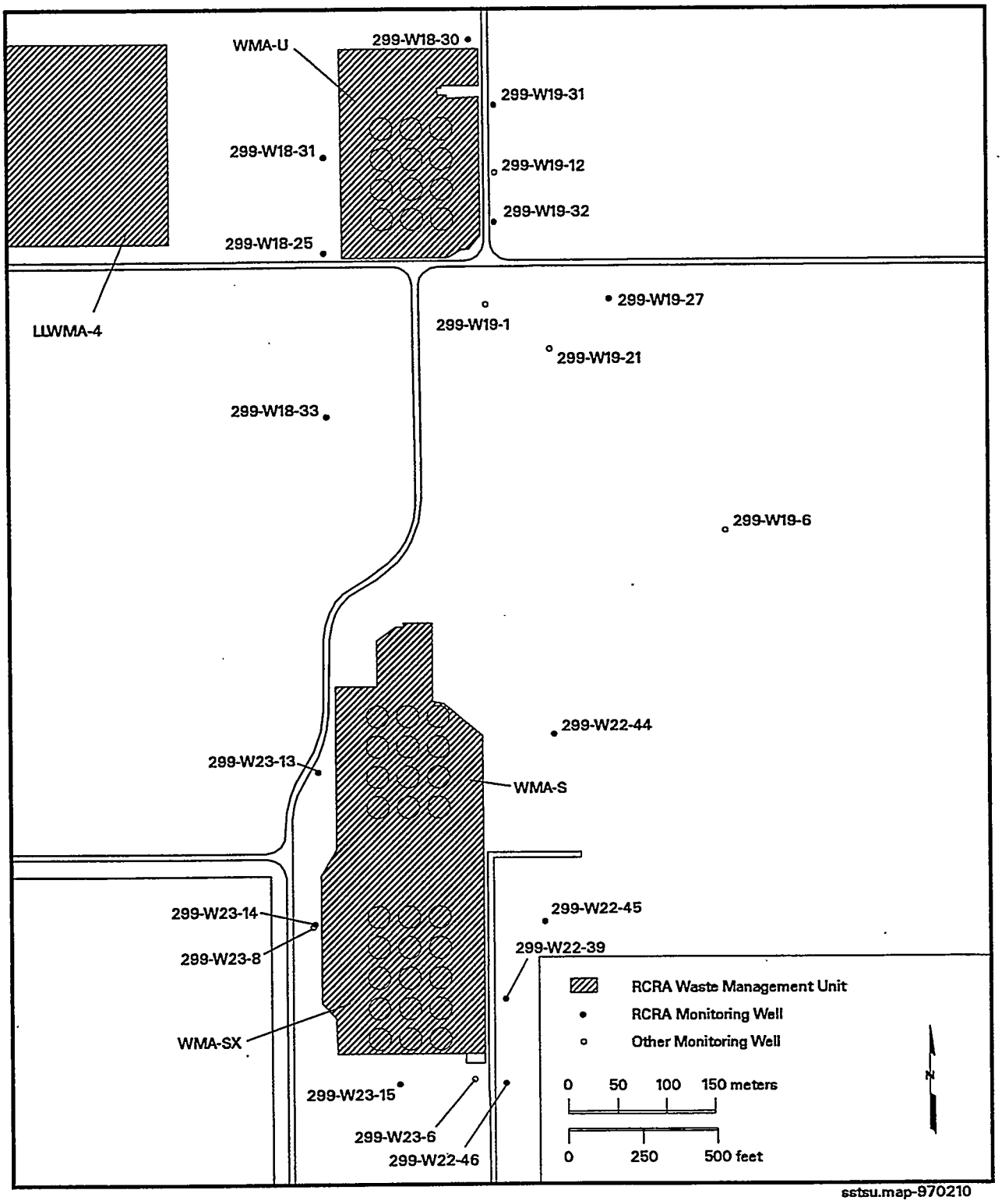


Figure 6.9-1b. Monitoring Well Locations for WMA-S-SX and -U Single-Shell Tank Farms

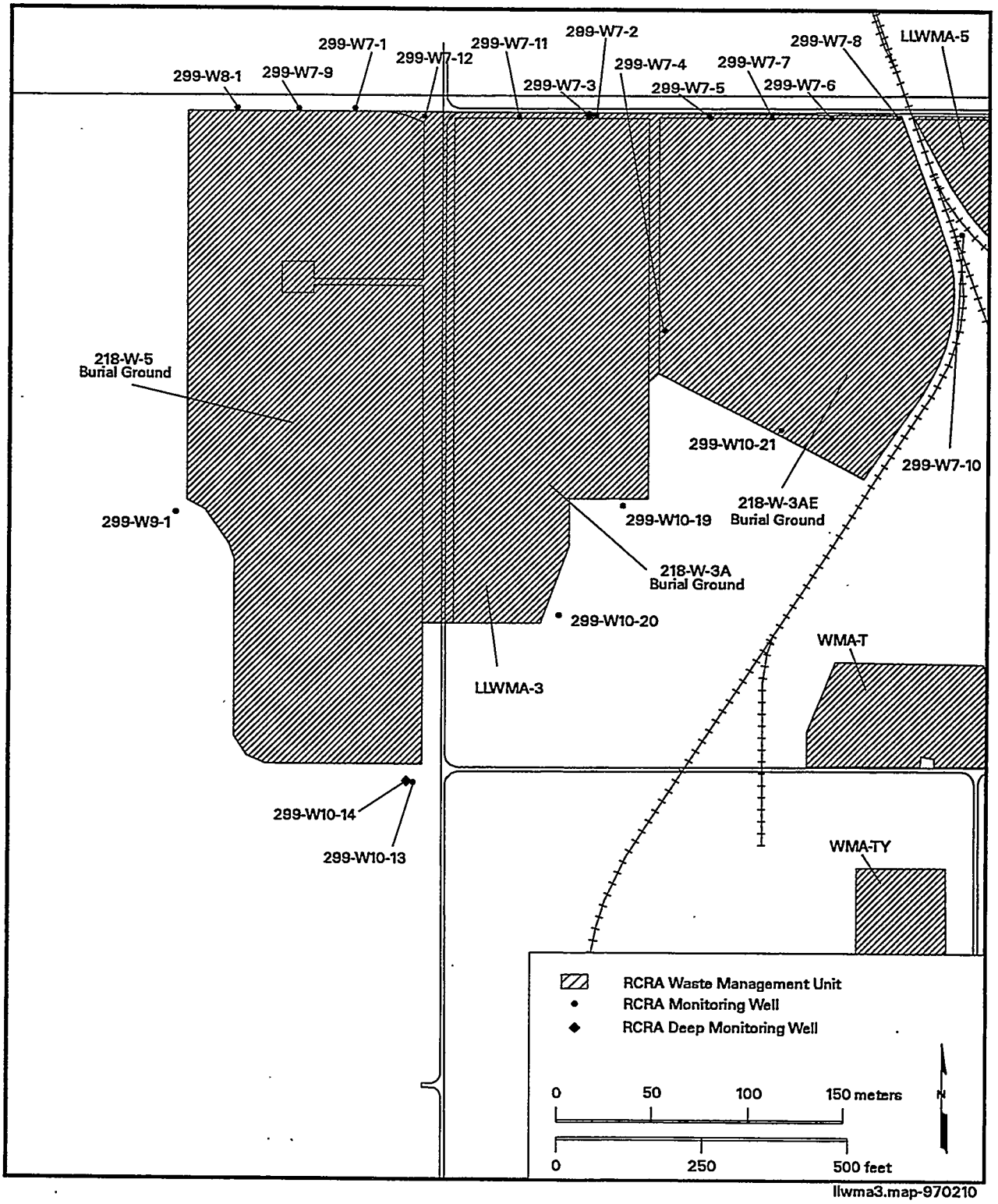


Figure 6.9-2. Monitoring Well Locations for LLWMA-3

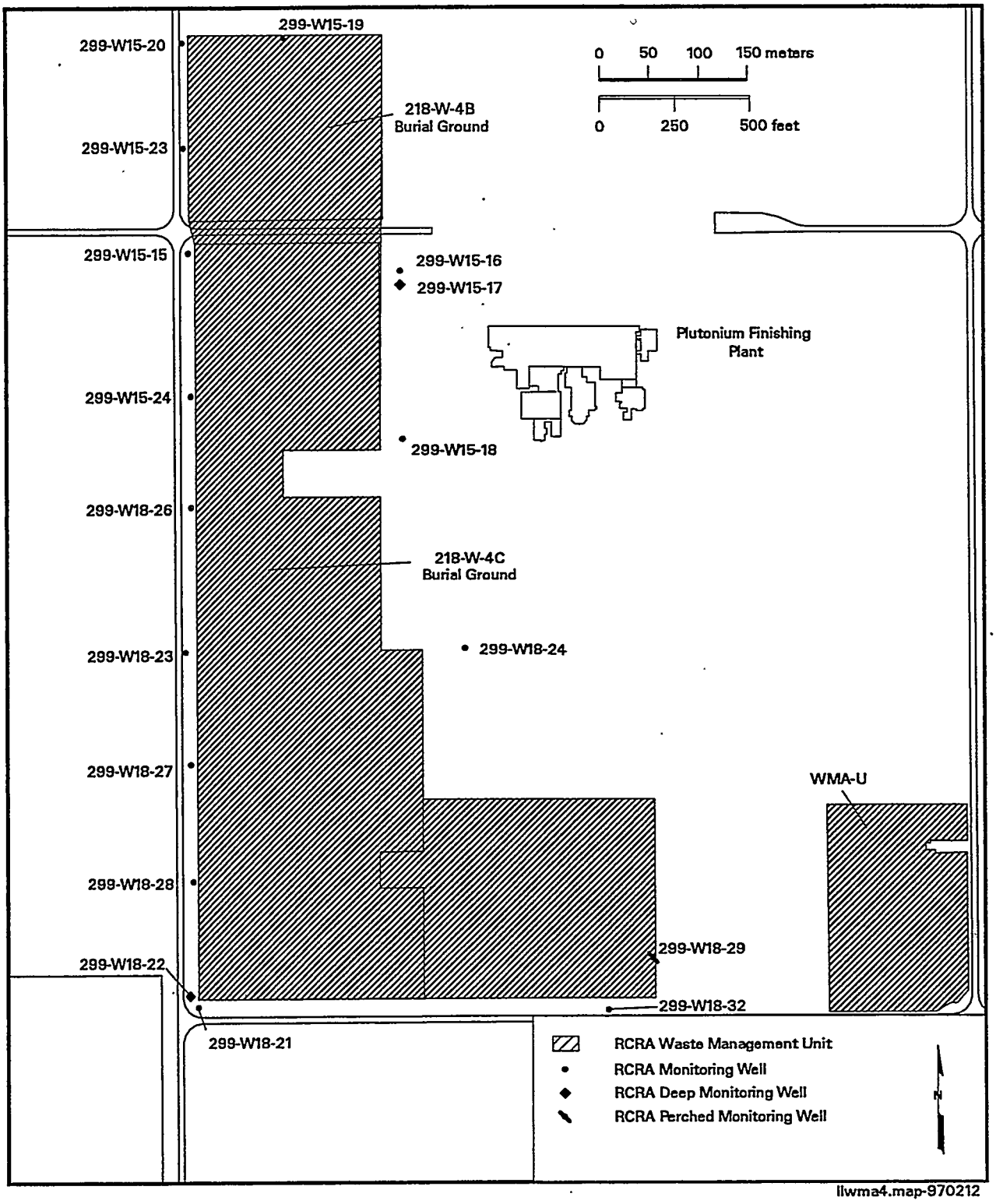


Figure 6.9-3. Monitoring Well Locations for LLWMA-4

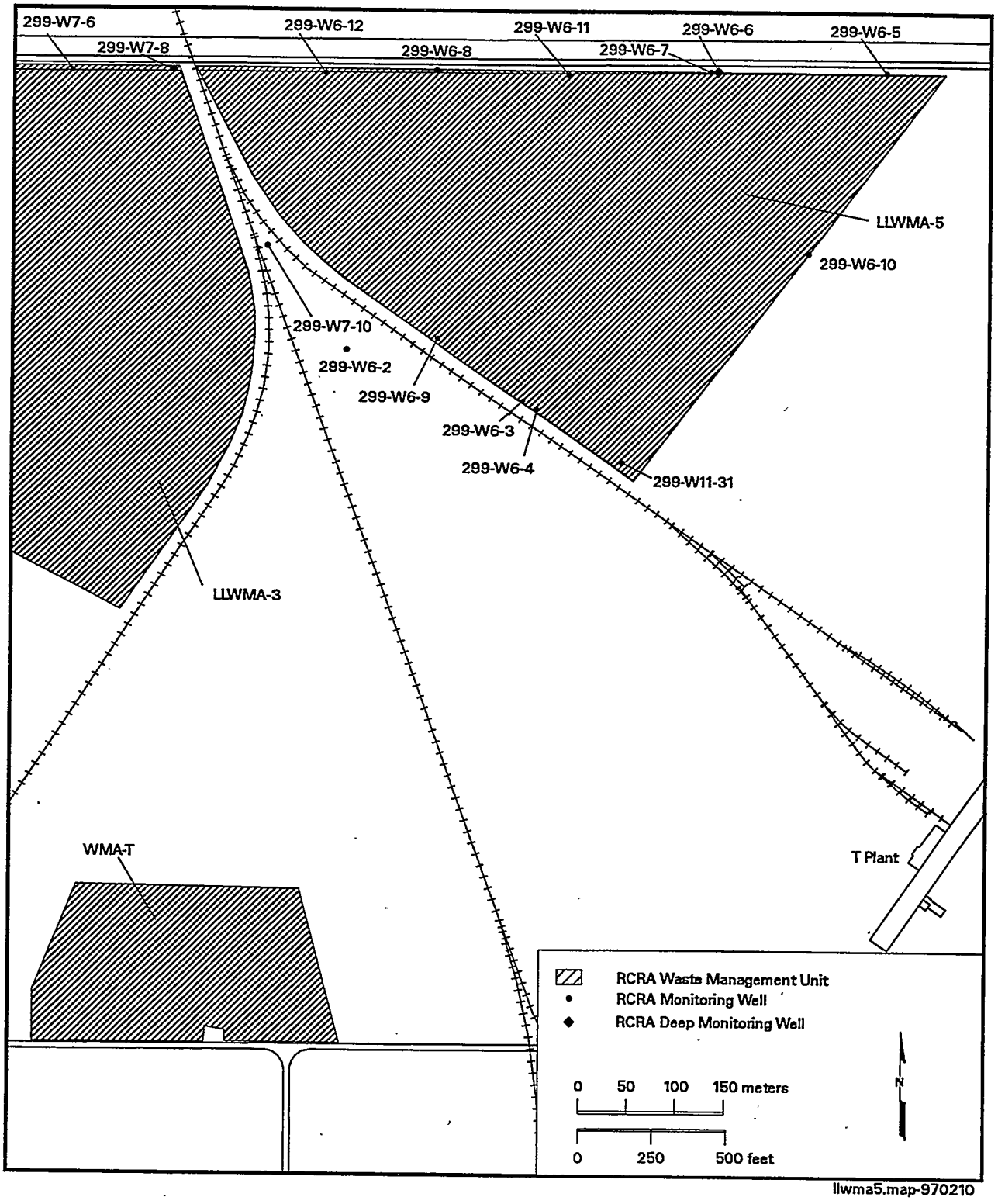


Figure 6.9-4. Monitoring Well Locations for LLWMA-5

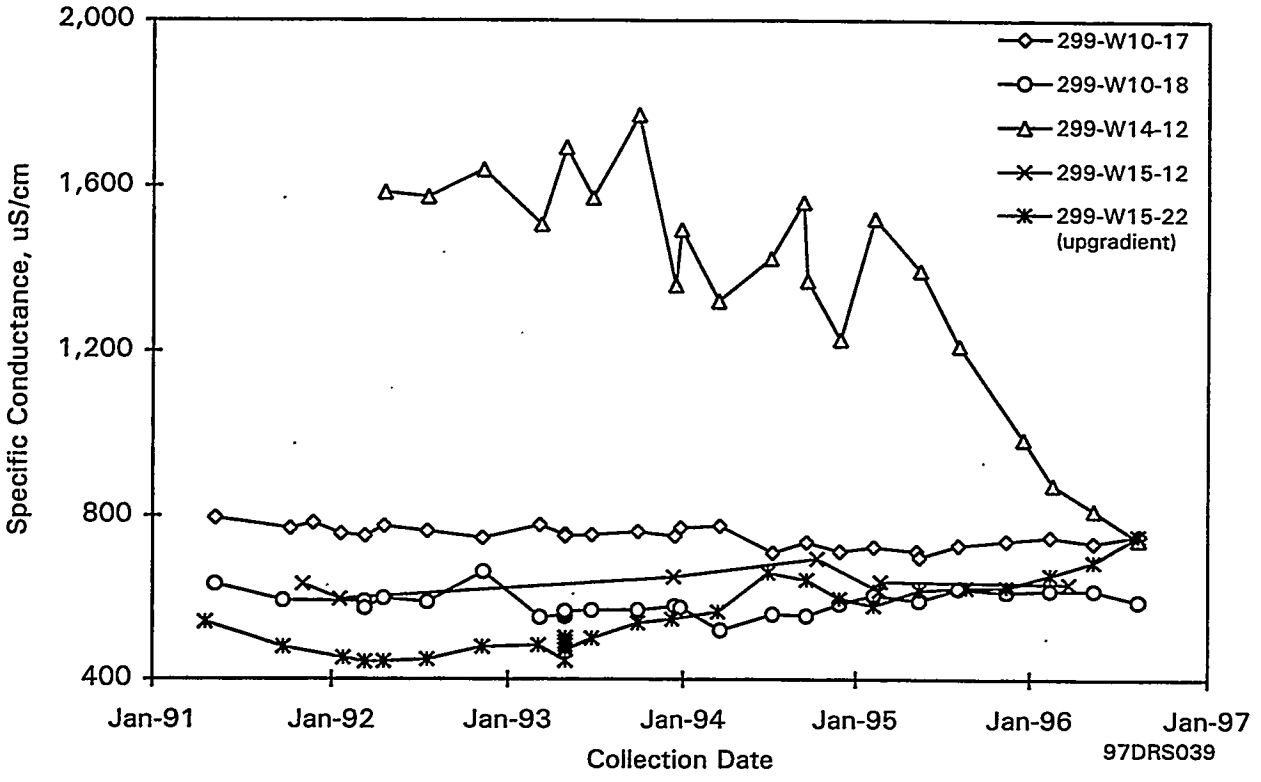


Figure 6.9-5. Specific Conductance Trends for WMA-TX-TY Single-Shell Tank Farms

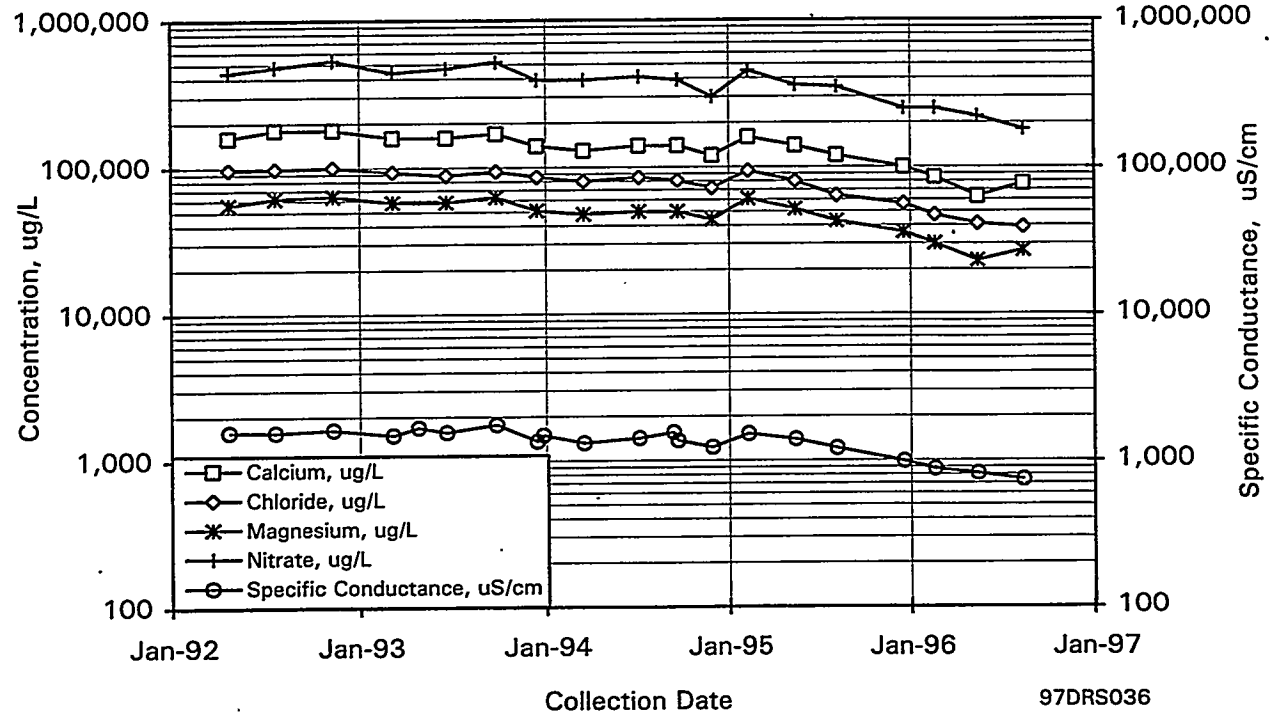


Figure 6.9-6. Comparison of Anions, Cations, and Specific Conductance in Well 299-W14-12 Monitoring WMA-TX-TY Single-Shell Tank Farms

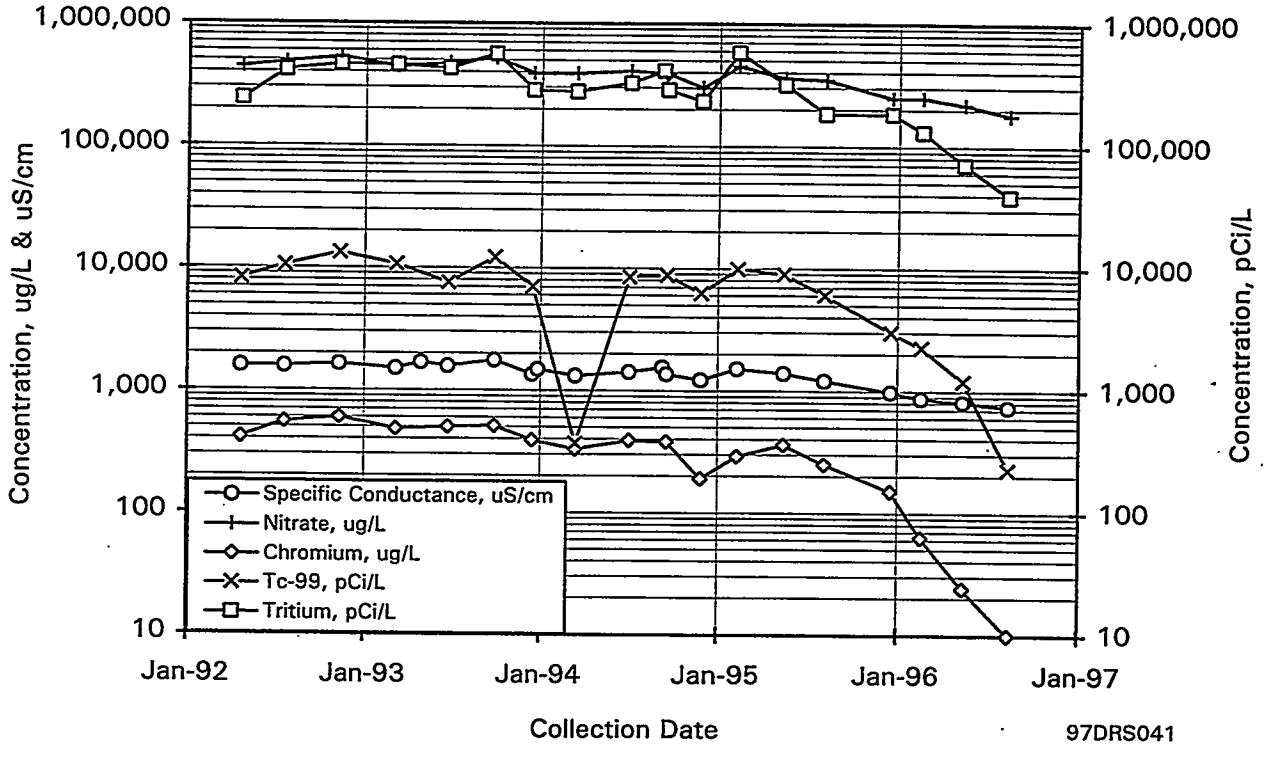


Figure 6.9-7. Specific Conductance, Nitrate, Chromium, Technetium-99, and Tritium in Well 299-W14-12 Monitoring WMA-TX-TY Single-Shell Tank Farms

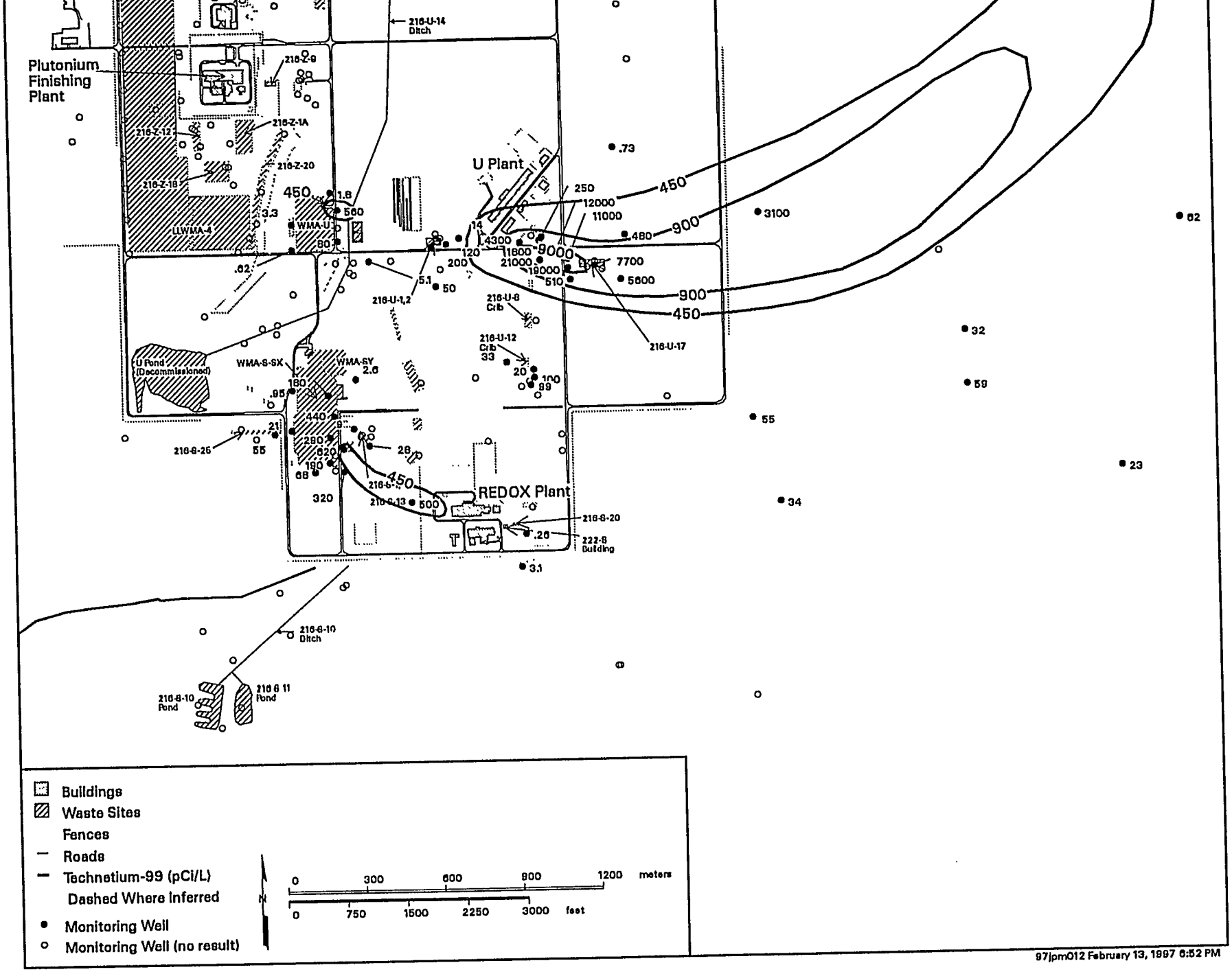
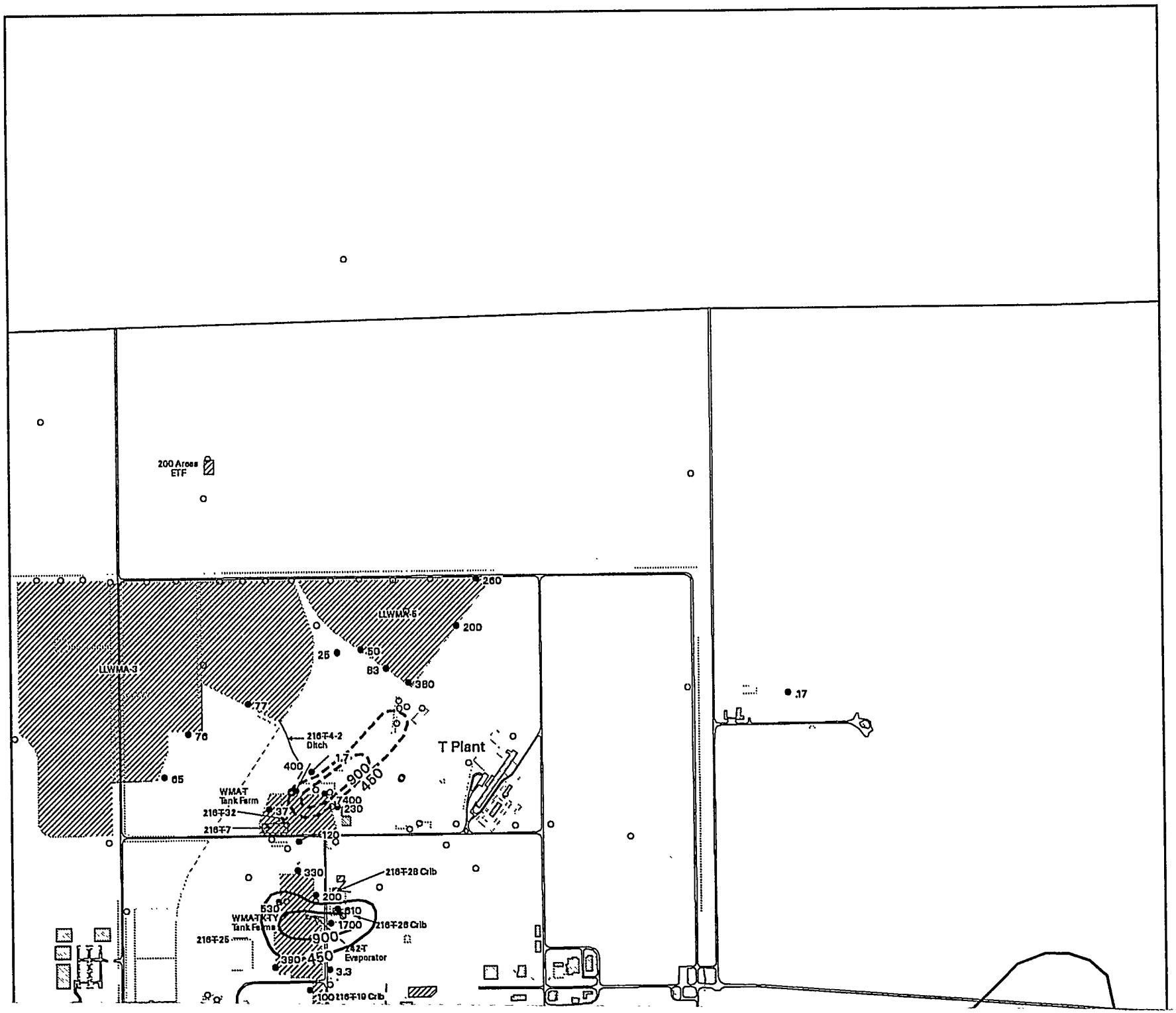
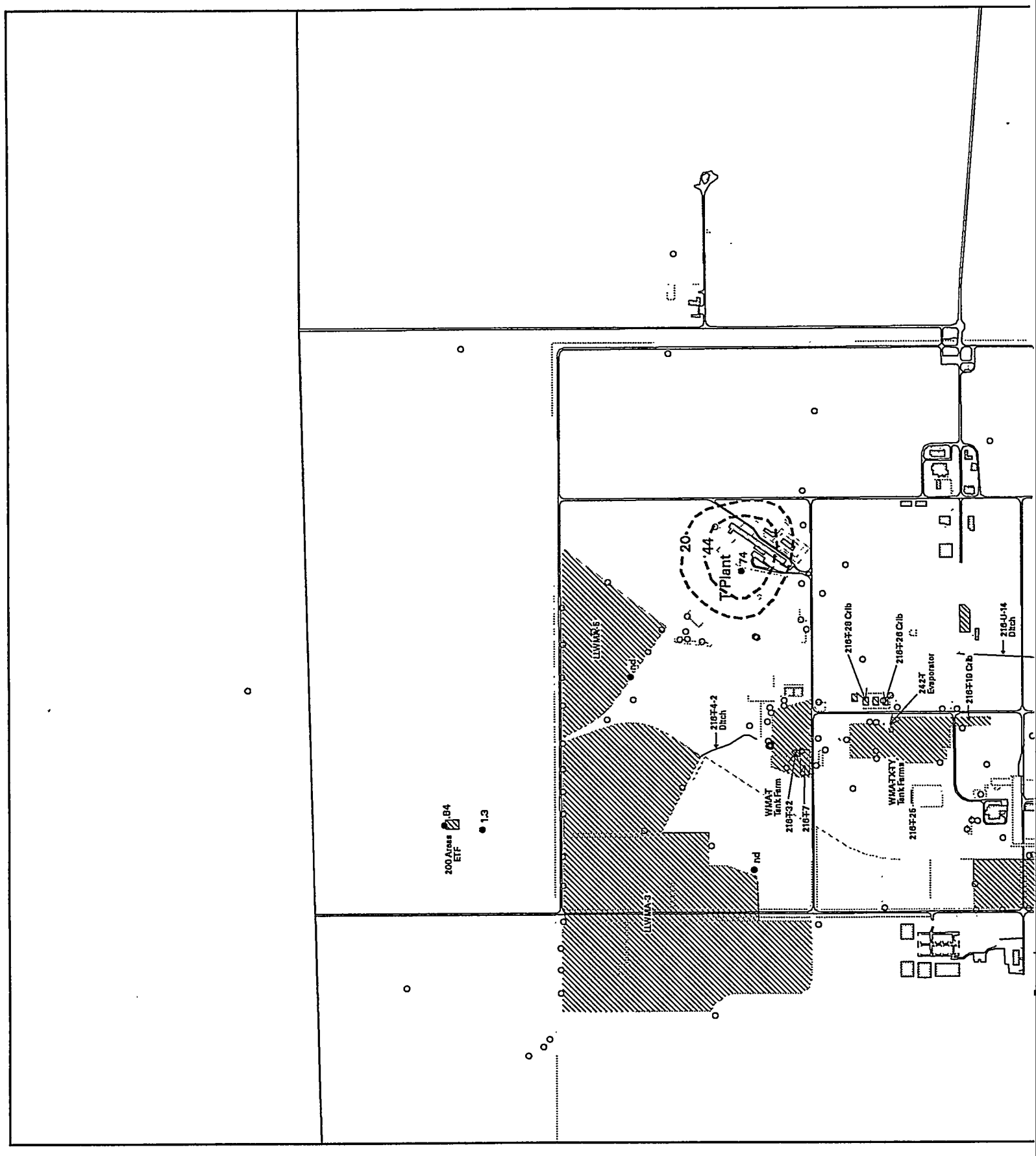


Figure 6.9-8. Average FY 1996 Technetium-99 Concentrations in 200-West Area


200 Areas ETF
LLWMA-5
LLWMA-3
260
200
25
50
83
380
77
76
65
17
216-T-4-2 Ditch
T Plant
400
1.7
900
450
WMA-T Tank Farm
216-T-32
37
400
230
216-T-7
120
330
216-T-28 Crib
200
530
610
WMA-TY Tank Farms
1700
216-T-28 Crib
216-T-25
900
242-T Evaporator
380
450
3.3
100
216-T-19 Crib


T Plant
20
44
74
LLWMA-6
LLWMA-3
nd
216-T-28 Crib
216-T-26 Crib
216-U-14 Ditch
242-T Evaporator
216-T-10 Crib
216-T-4-2 Ditch
WMA-T Tank Farm
WMA-TX-TY Tank Farms
216-T-32
216-T-7
216-T-26
200 Areas ETF
B4
1-3

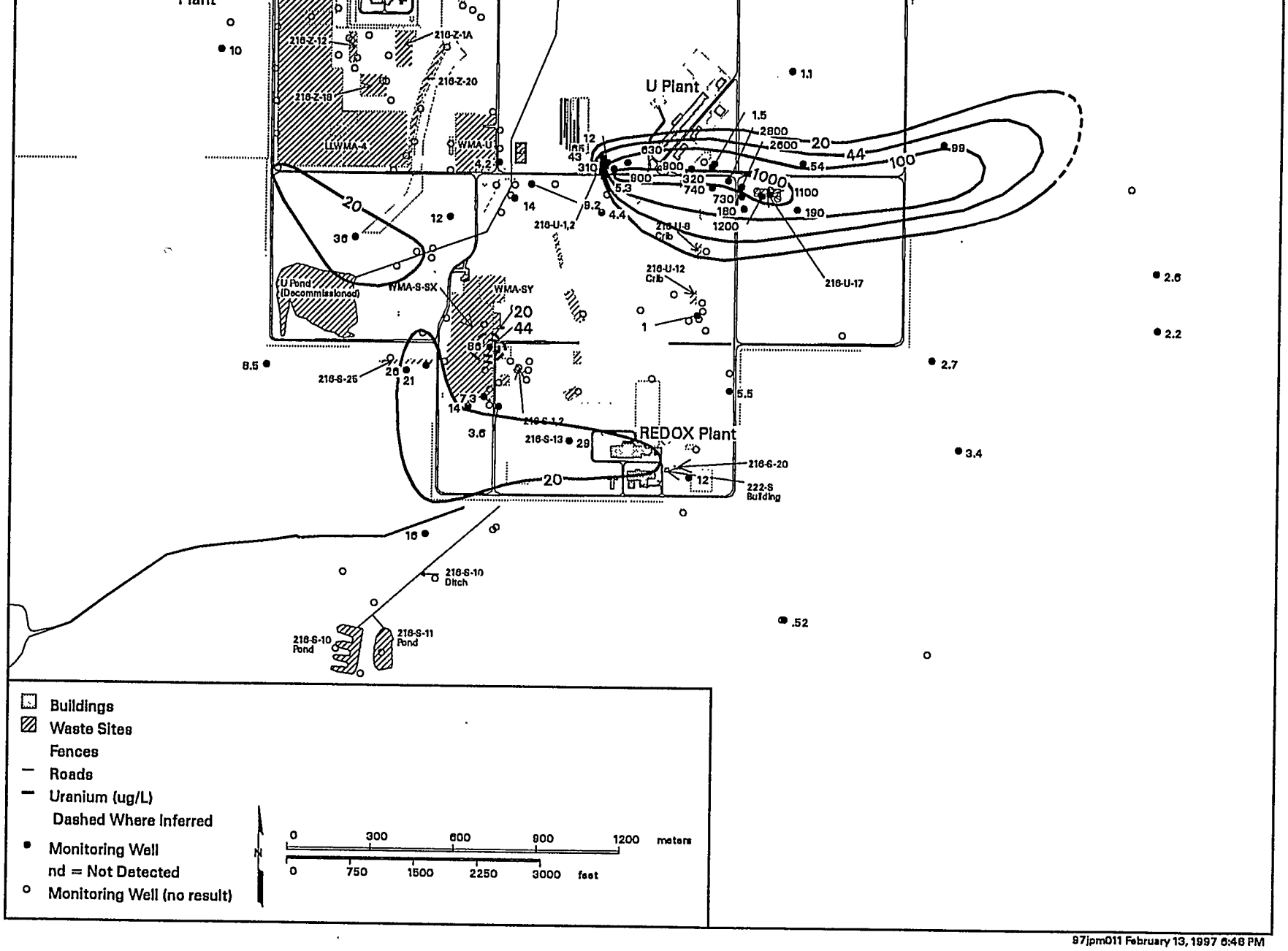


Figure 6.9-9. Average FY 1996 Uranium Concentrations in 200-West Area

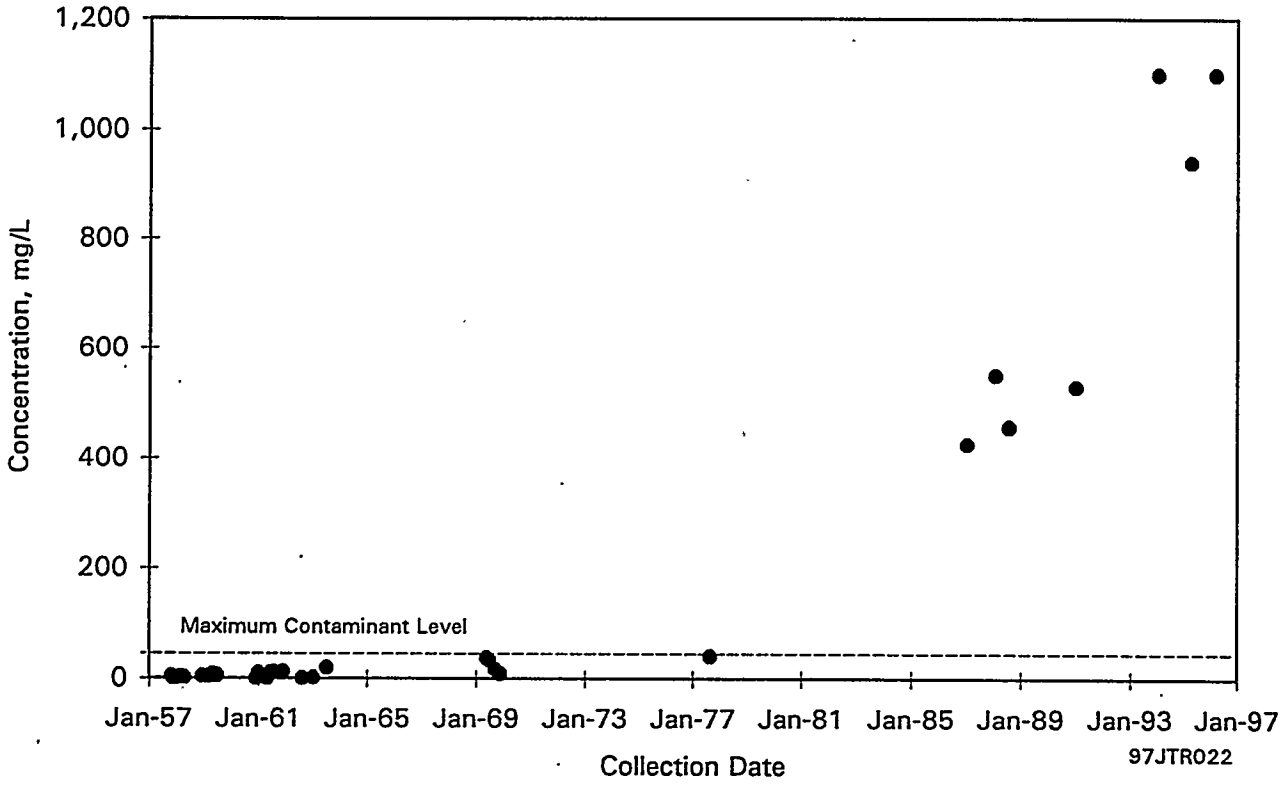
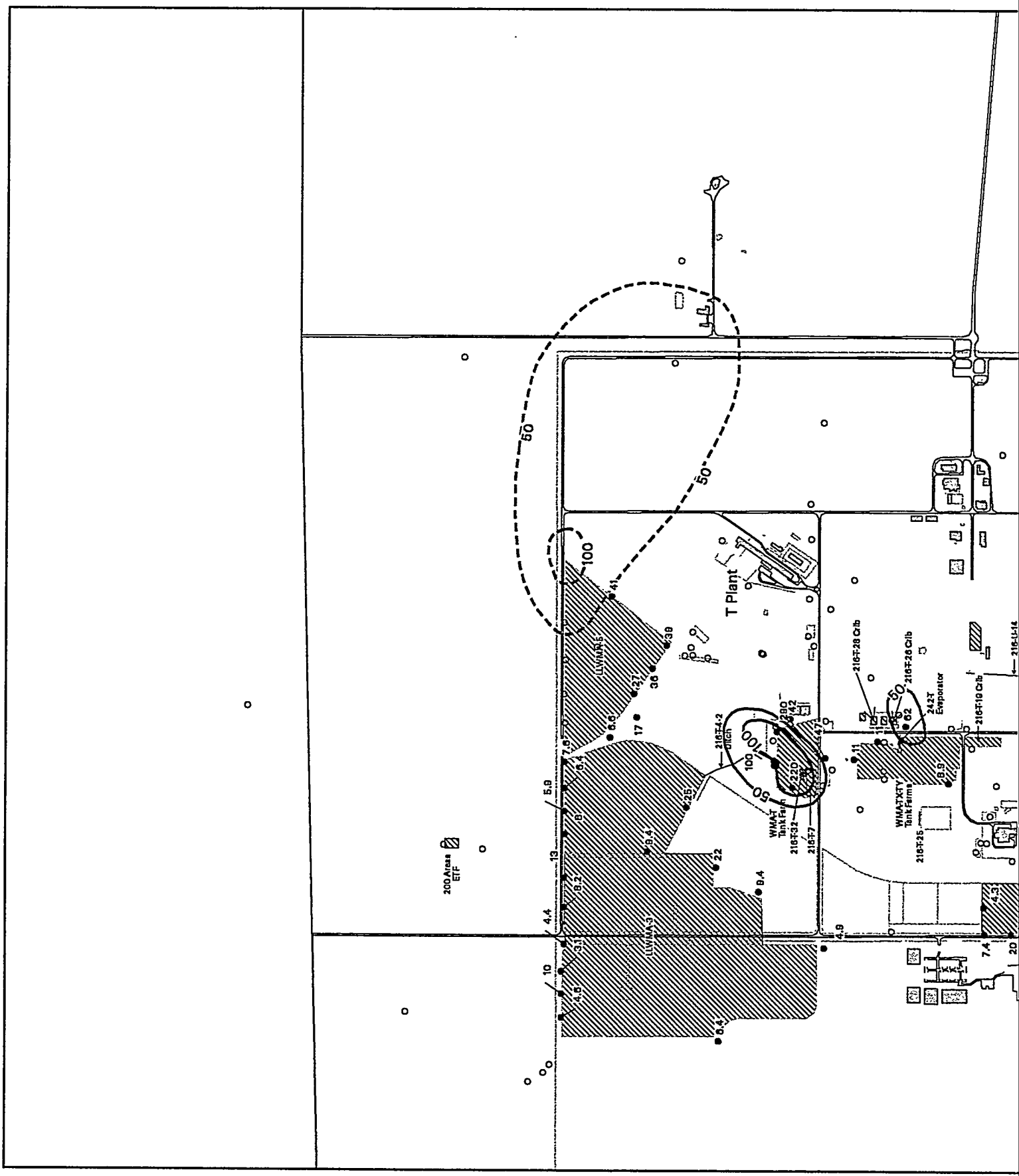


Figure 6.9-10. Nitrate Concentrations in Well 299-W10-1


T Plant
200 Area ETF
LLWMA-3
LLWMA-4
WMA T Tank Farm
WMA TX-TY Tank Farms
242T Evaporator
216-T-4-2 Ditch
216-T-28 Crib
216-T-26 Crib
216-T-19 Crib
216-T-32
216-T-7
216-T-25
50
100
41
38
27
36
17
7.6
6.4
5.8
6
25
8.4
22
13
6.2
4.4
3.1
10
4.6
6.4
8.4
280
242
220
47
62
11
8.9
4.8
4.3
7.4

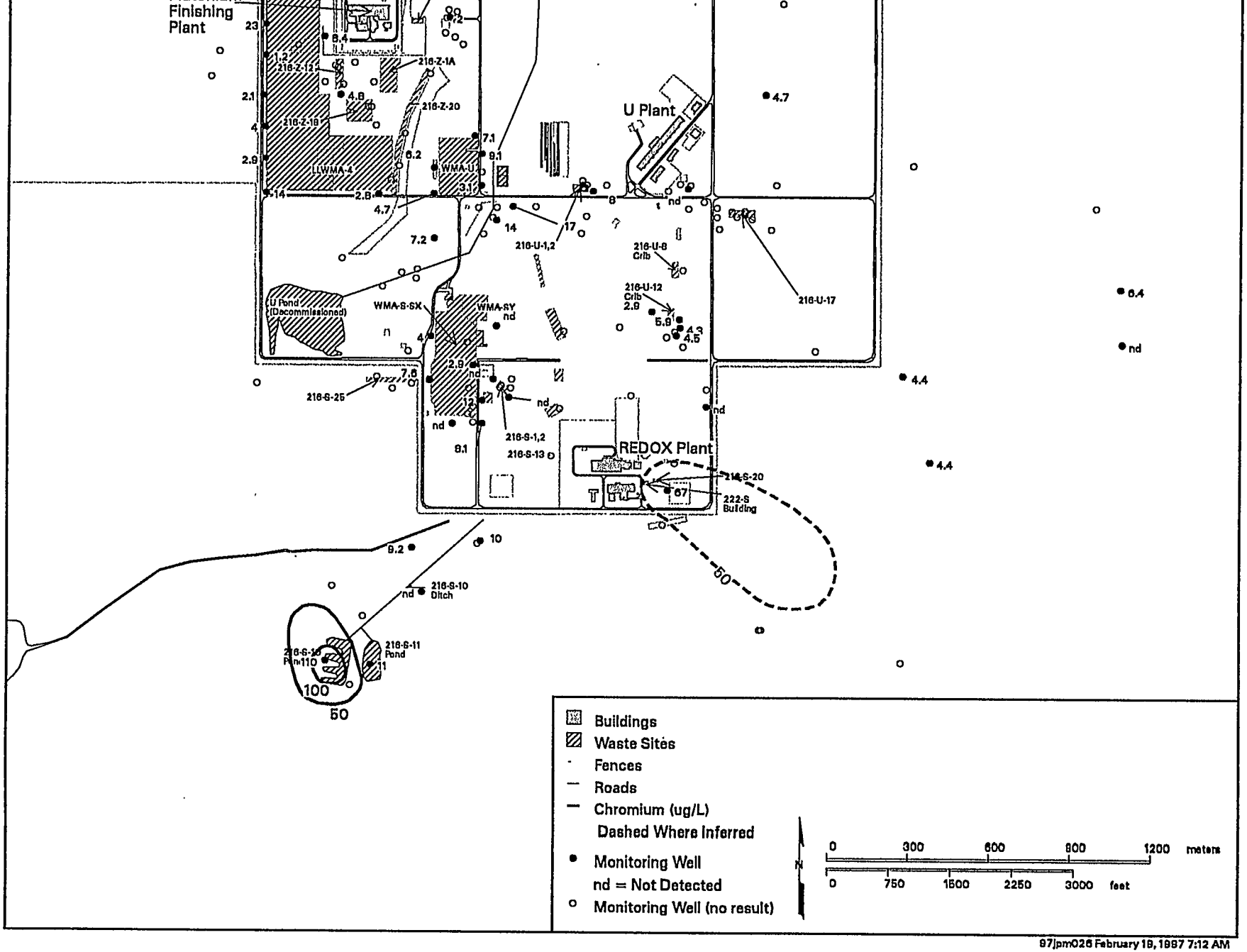


Figure 6.9-11. Average FY 1996 Chromium Concentrations in 200-West Area

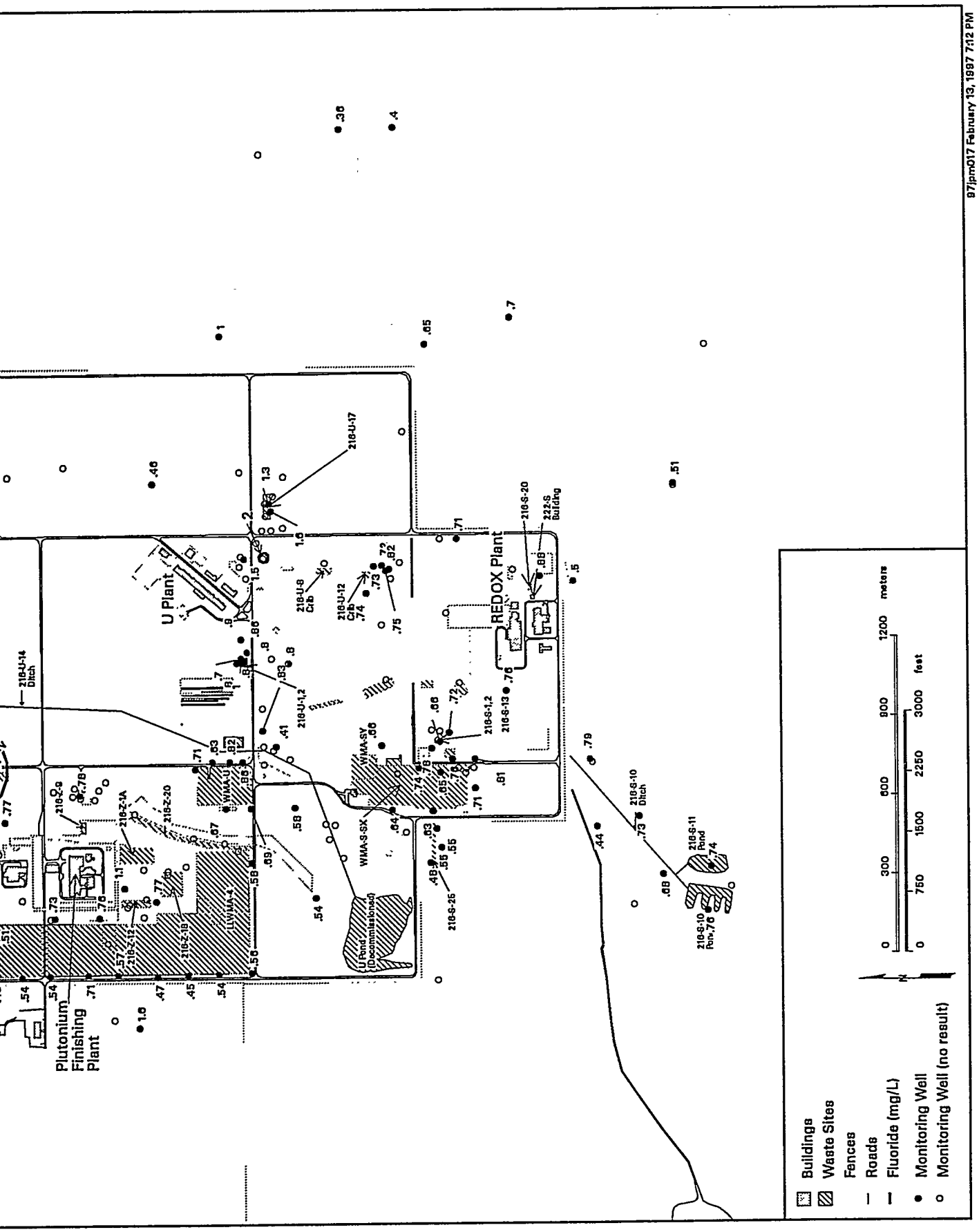
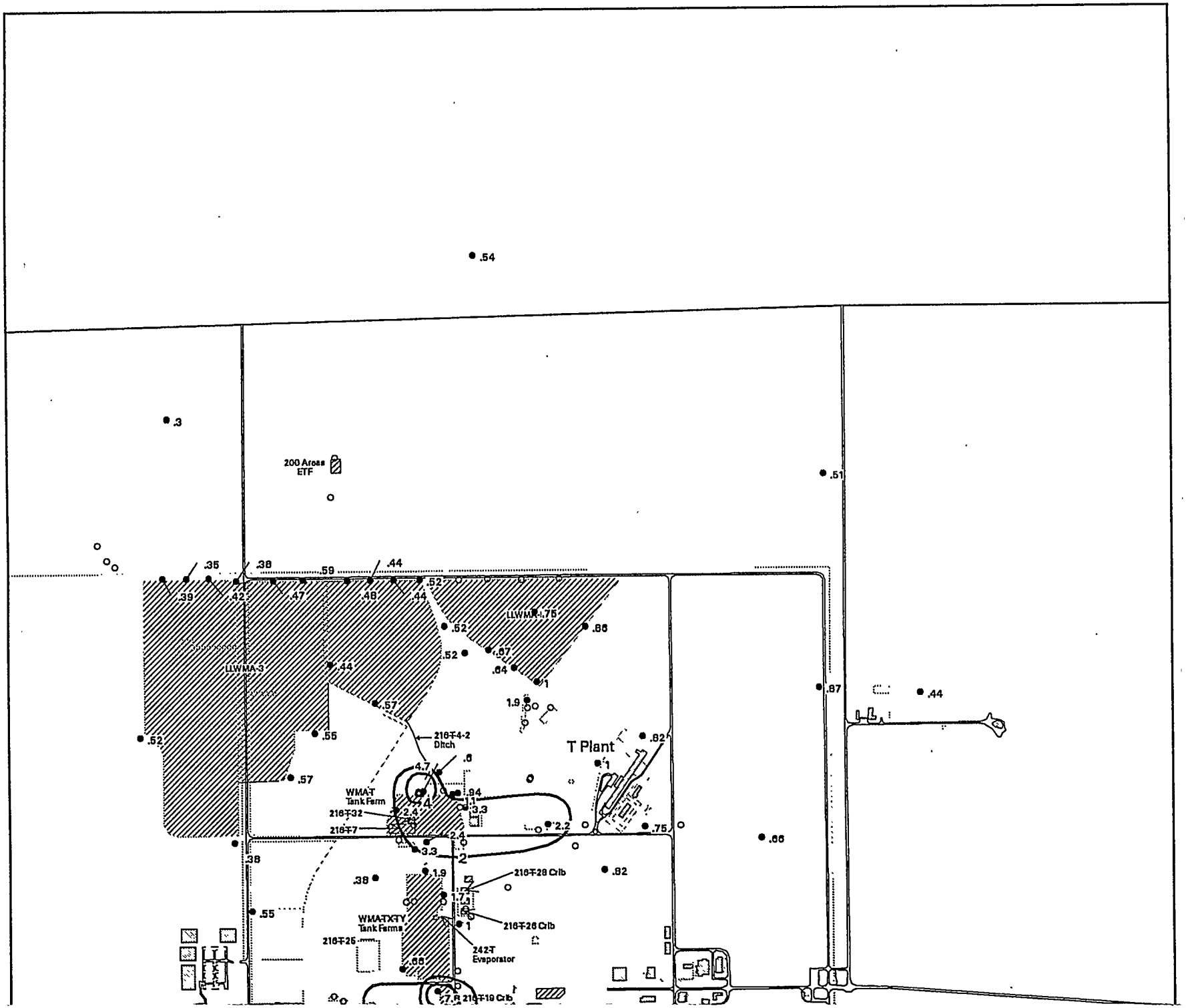
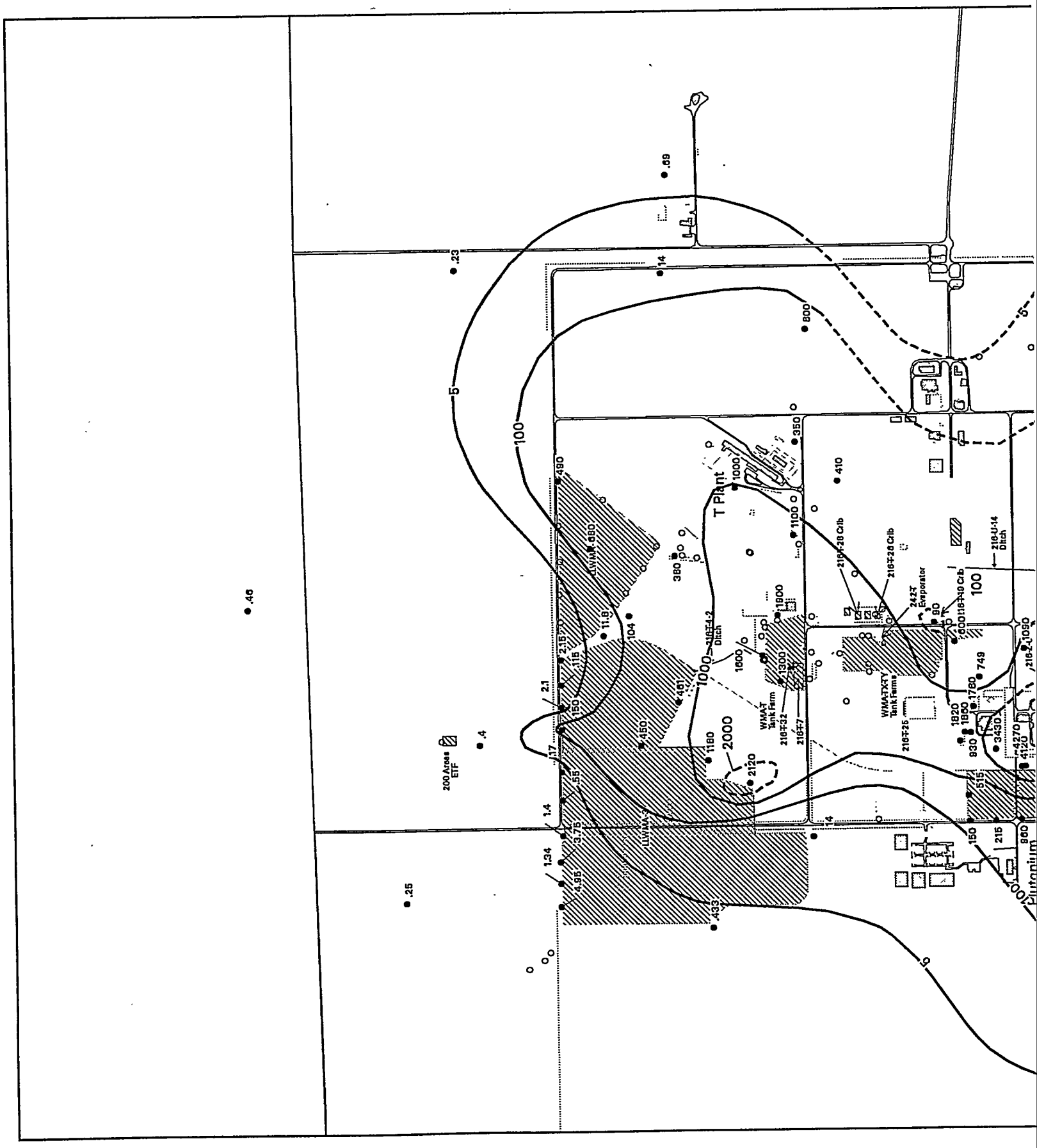


Figure 6.9-12. Average FY 1996 Fluoride Concentrations in 200-West Area


.54
.3
200 Areas
ETF
.51
.35
.38
.59
.44
.39
.42
.47
.48
.44
.52
LLWMA-3
LLWMA-4
.76
.86
.52
.52
.67
.64
.1
.44
.87
.44
1.9
.57
.52
.55
216-T-4-2
Ditch
T Plant
.82
.6
4.7
.57
WMA-T
Tank Farm
.94
1.1
3.3
216-T-32
2.4
216-T-7
2.2
.75
.66
2.4
3.3
2
.38
.38
1.9
216-T-28 Crib
.82
1.7
.55
WMA-TX-TY
Tank Farms
216-T-26 Crib
1
216-T-25
242-T
Evaporator
.68
216-T-19 Crib


T Plant
200 Area ETF
LLWMA-3
LWMA-4
WMA-T Tank Farm
WMA-TX-TY Tank Farms
216-T-26 Crib
216-T-28 Crib
216-T-29 Crib
216-U-14 Ditch
216-T-2 Ditch
242-T Evaporator
Plutonium

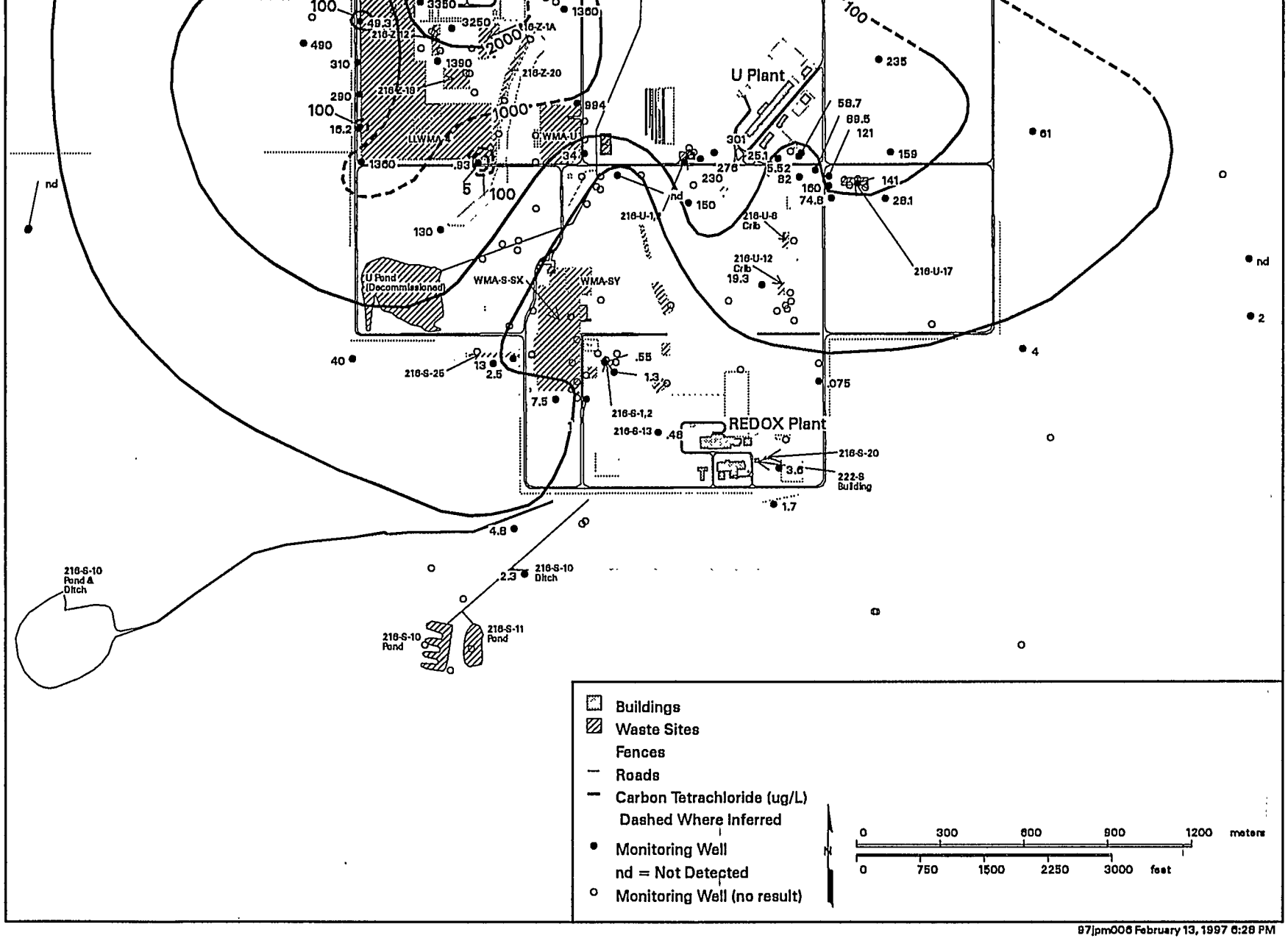
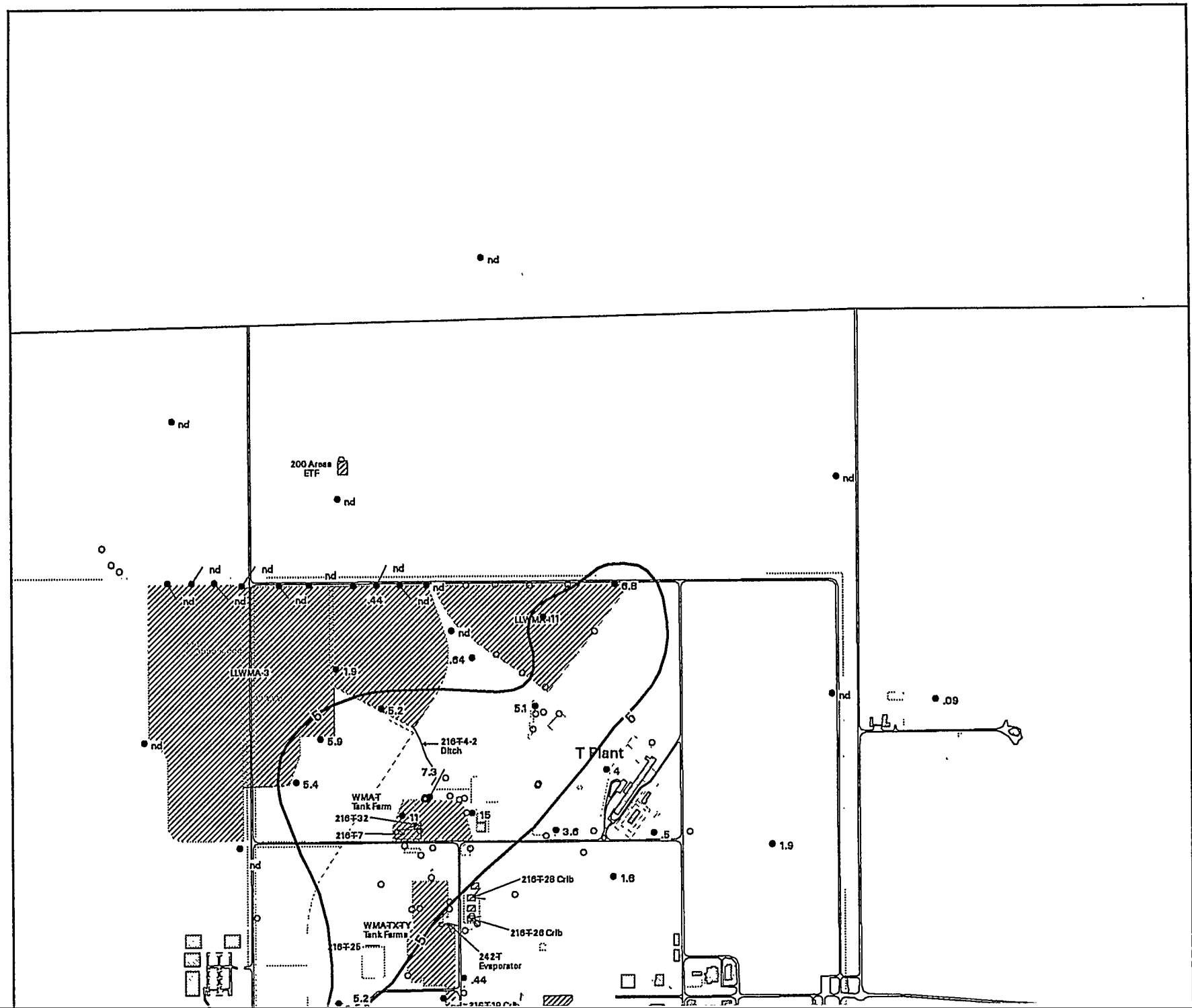


Figure 6.9-13. Average FY 1996 Carbon Tetrachloride Concentrations in 200-West Area


nd
200 Areas ETF
nd
nd
nd

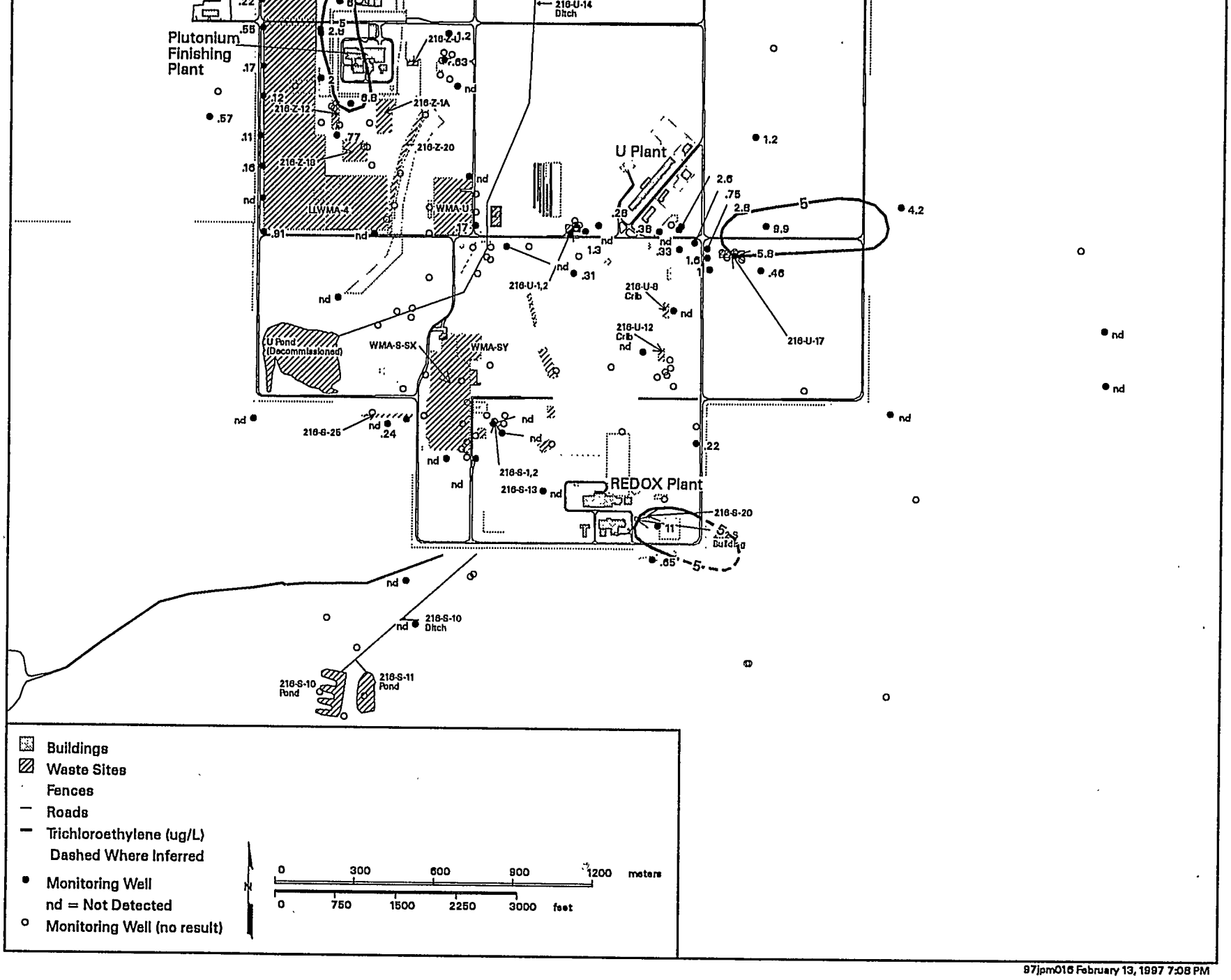


Figure 6.9-14. Average FY 1996 Trichloroethylene Concentrations in 200-West Area

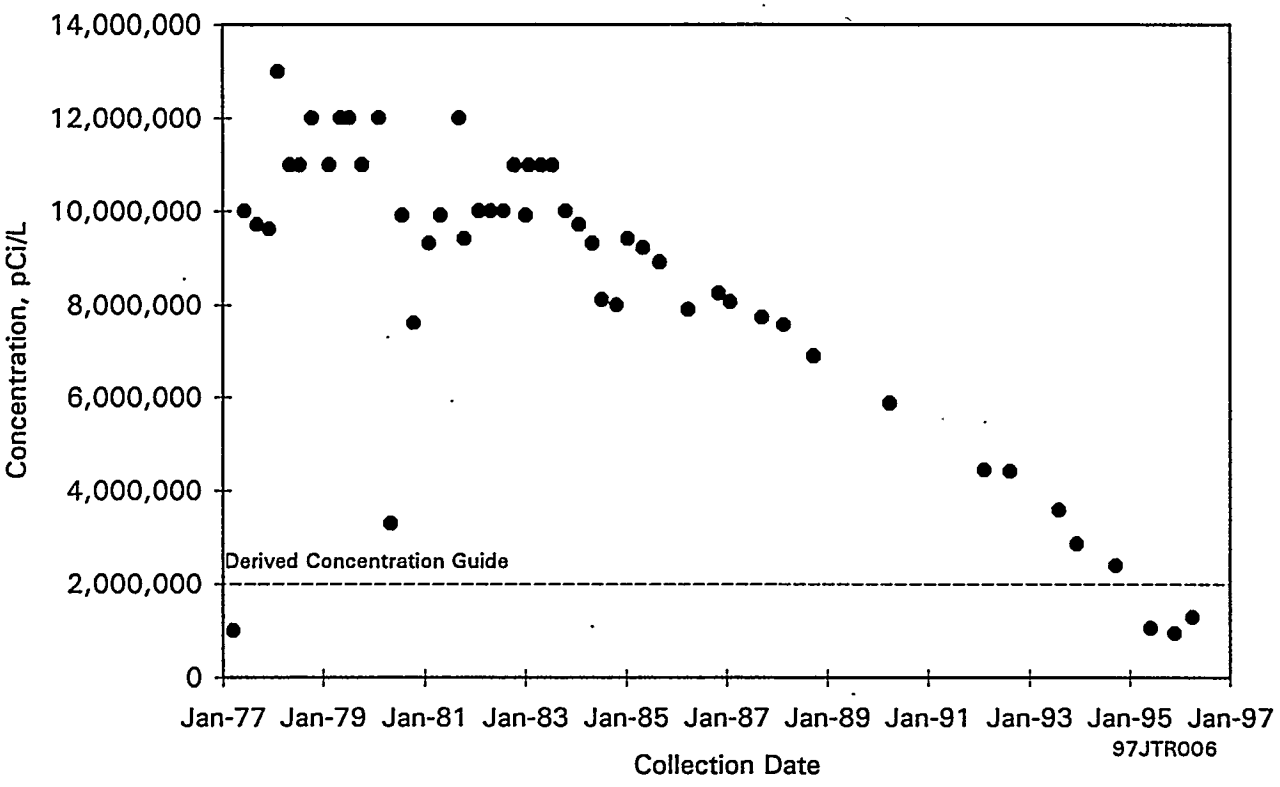


Figure 6.9-15. Tritium Concentrations in Well 299-W22-9

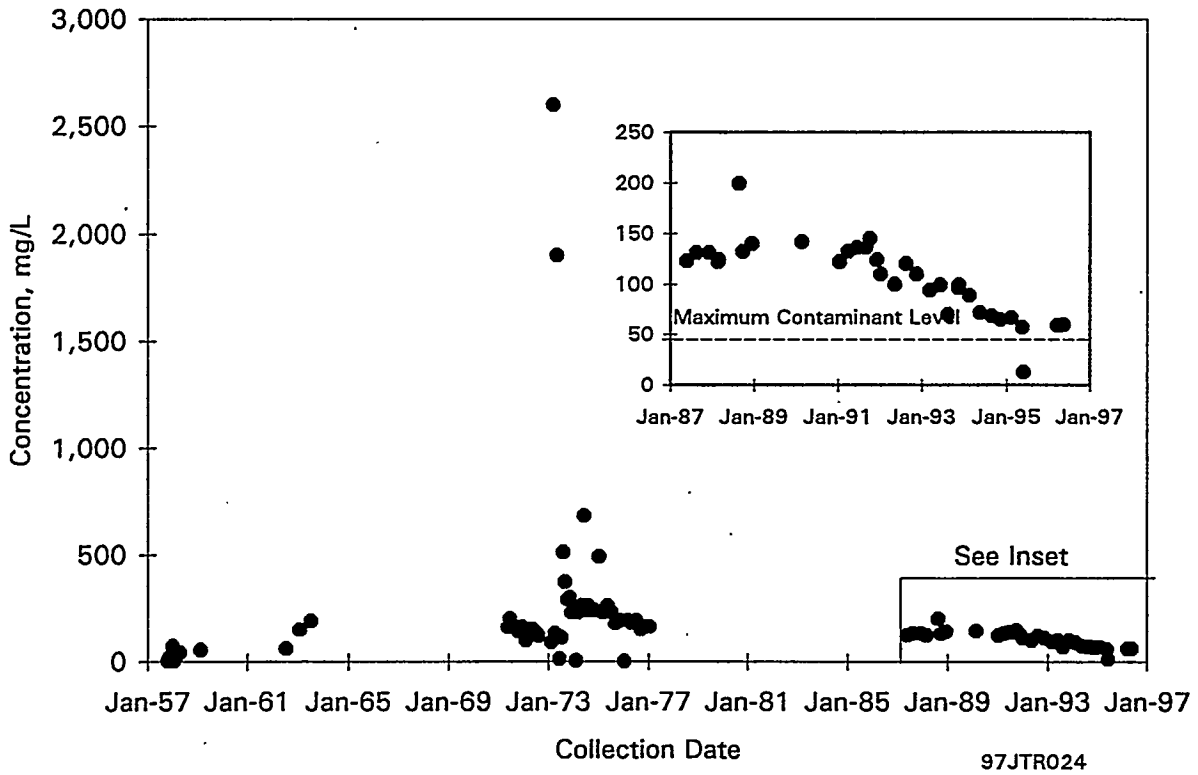


Figure 6.9-16. Nitrate Concentrations in Well 299-W22-20

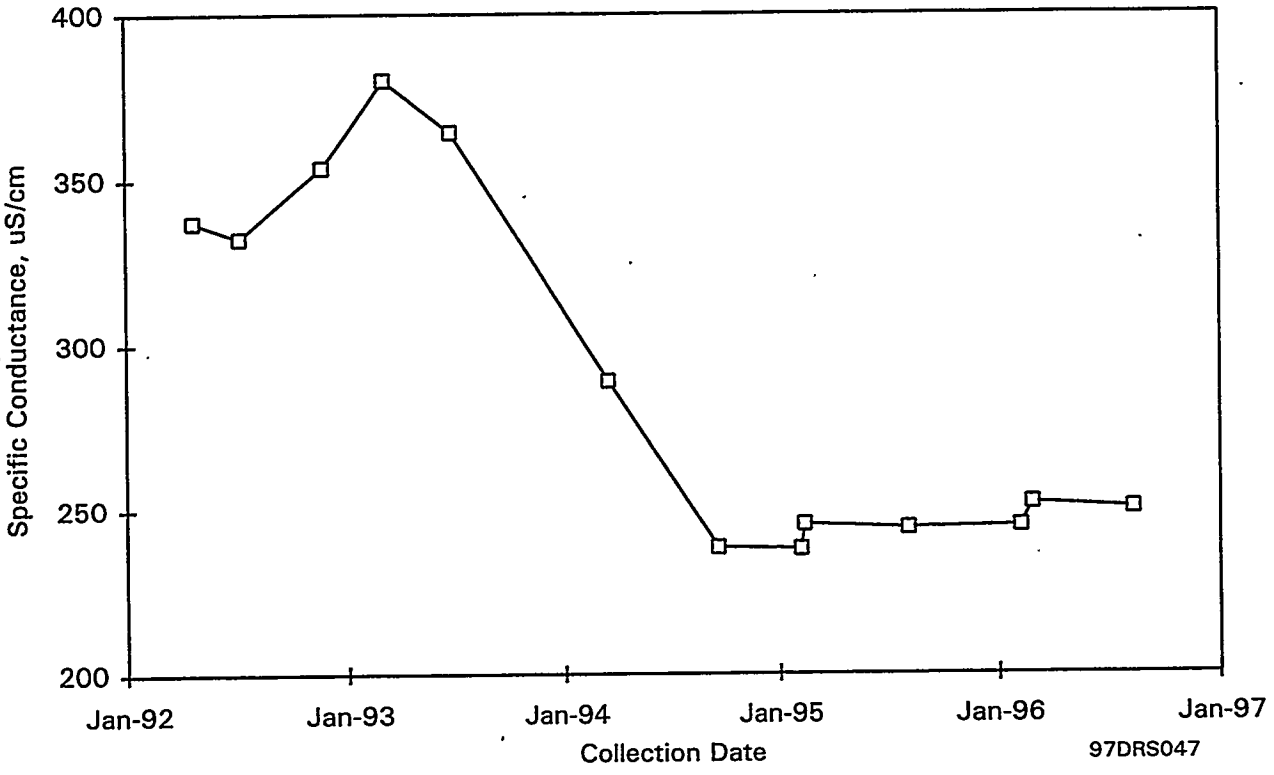


Figure 6.9-17. Specific Conductance in Well 299-W23-15

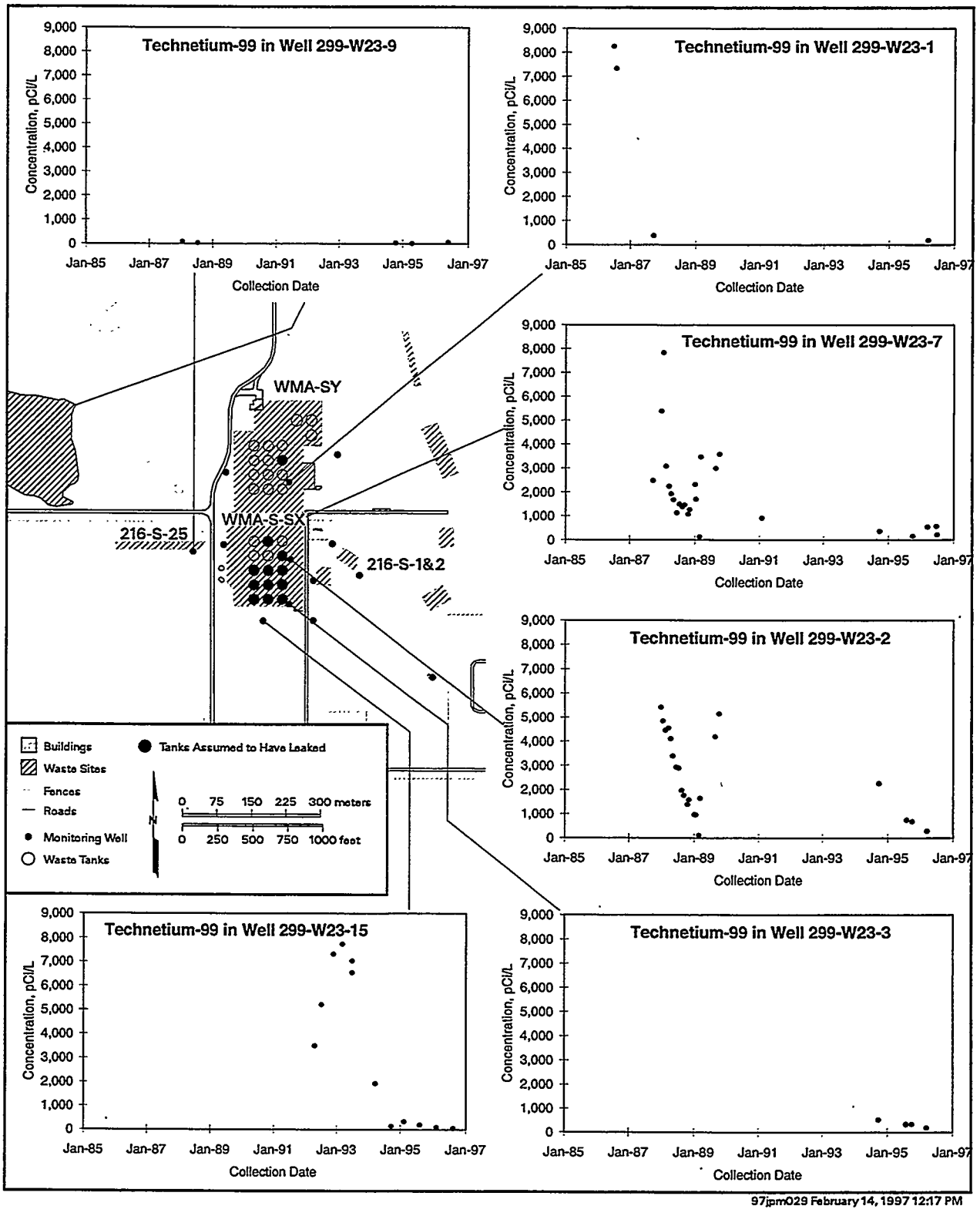


Figure 6.9-18. Technetium-99 Concentration Trends in Wells Near WMA-SX Single-Shell Tank Farm

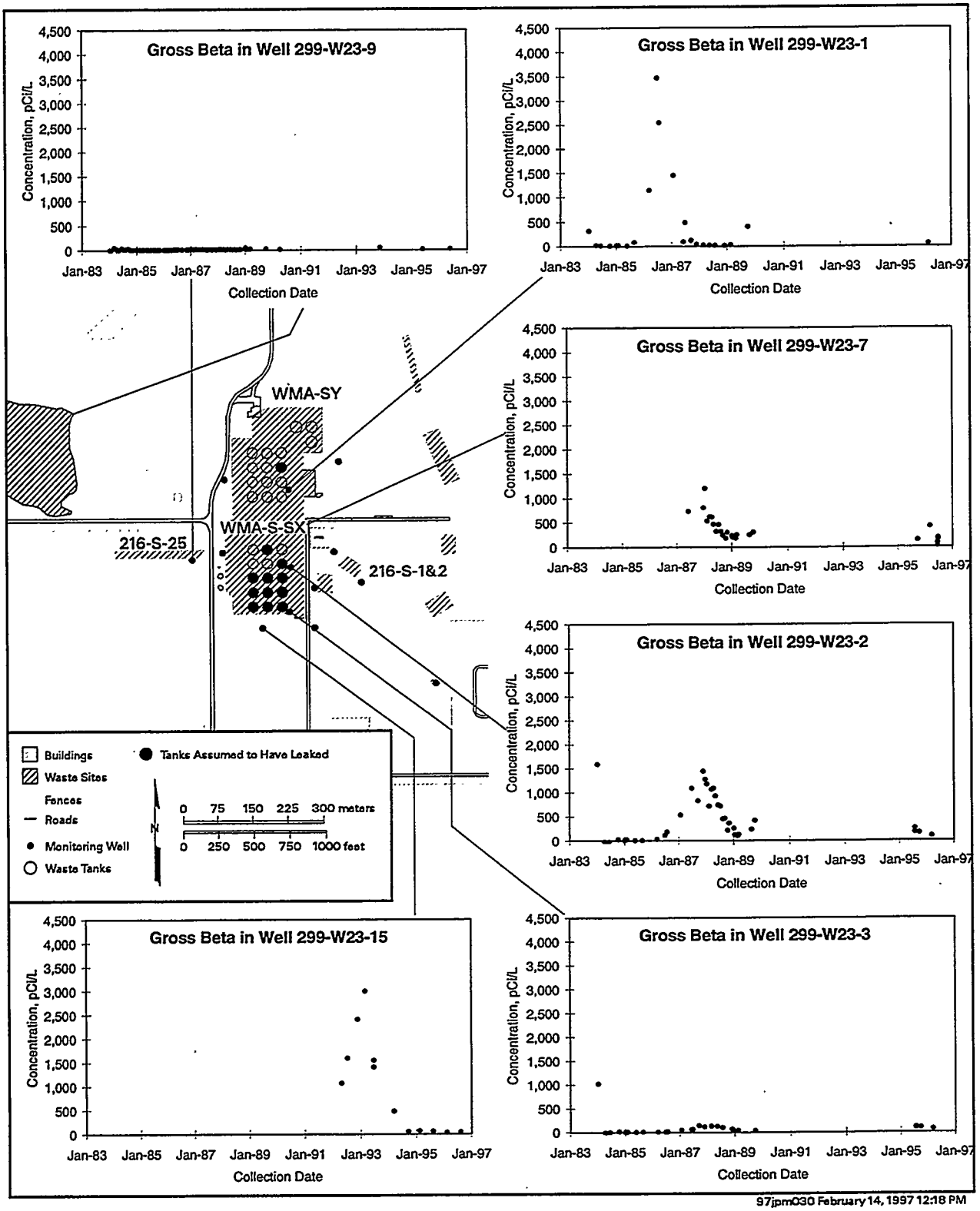


Figure 6.9-19. Gross Beta Concentration Trends in Wells Near WMA-SX Single-Shell Tank Farm

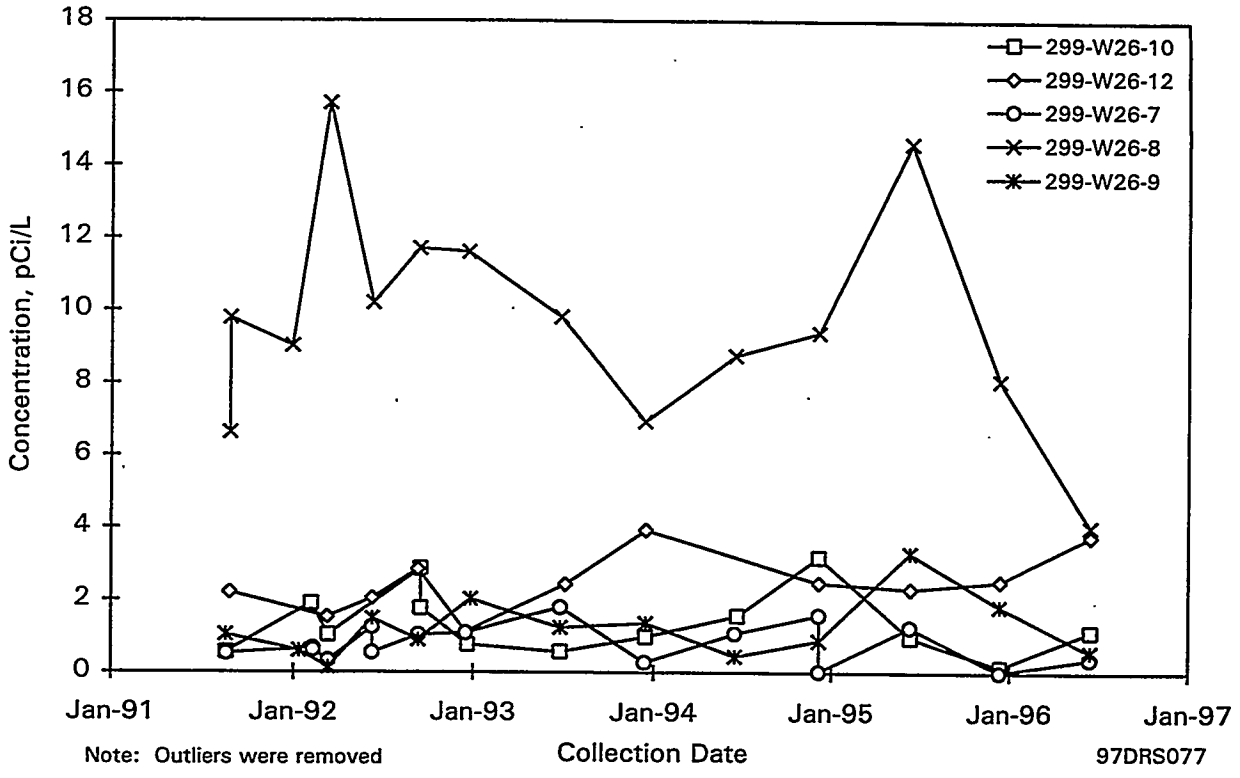


Figure 6.9-20. Gross Alpha Concentrations in Wells Monitoring 216-S-10 Pond and Ditch

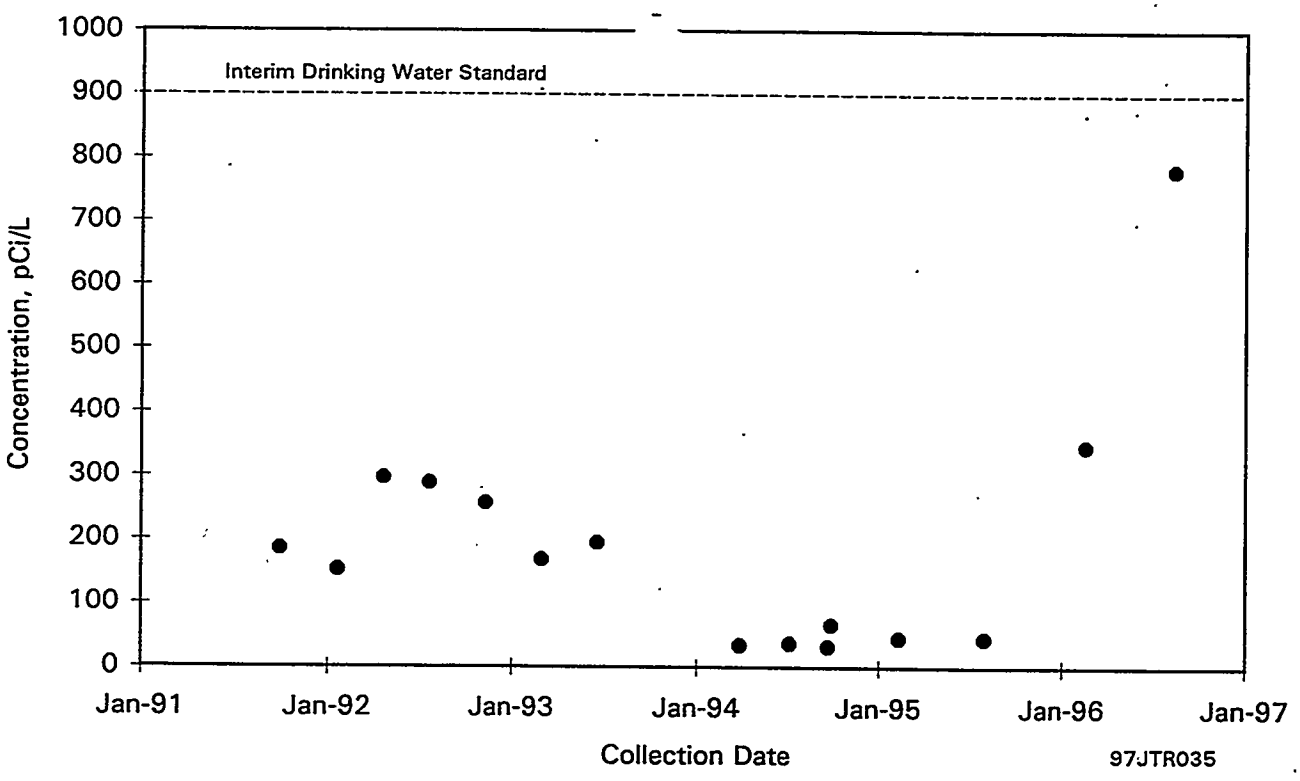


Figure 6.9-21. Technetium-99 Concentrations in Well 299-W19-31

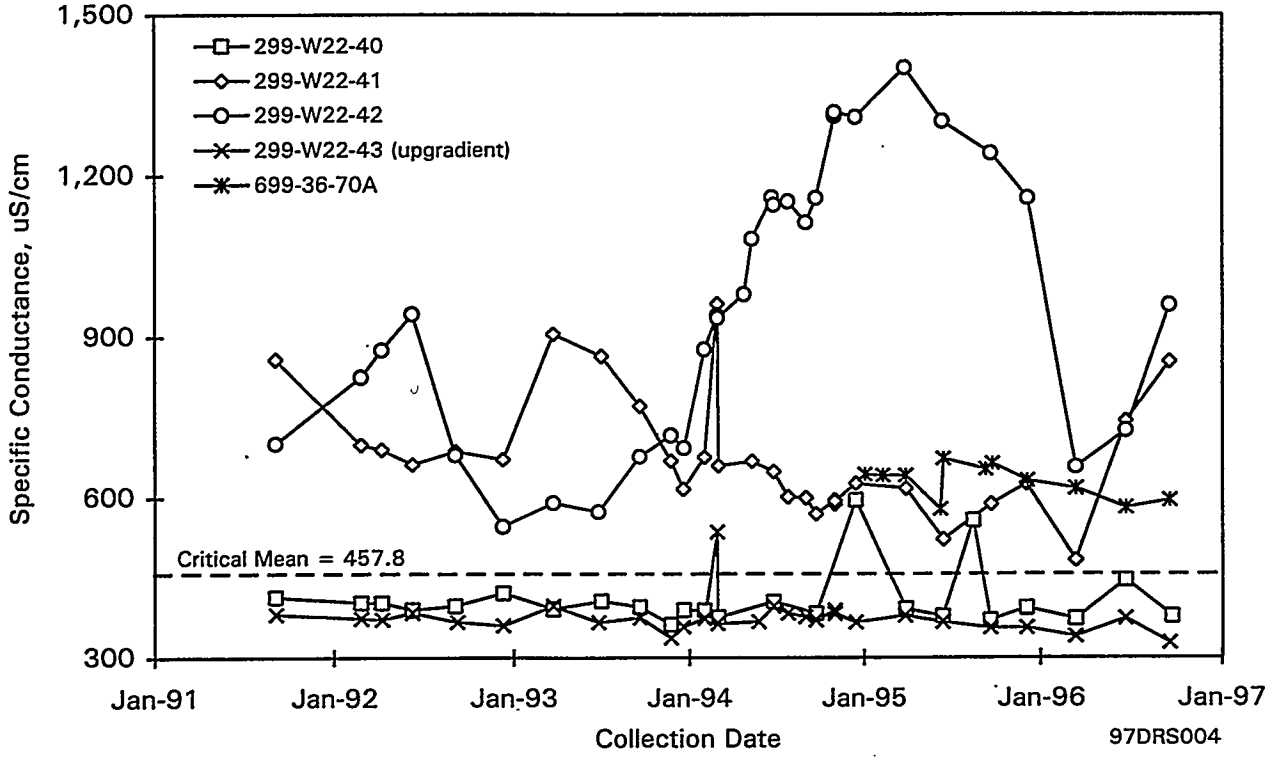


Figure 6.9-22. Specific Conductance in Wells Monitoring 216-U-12 Crib

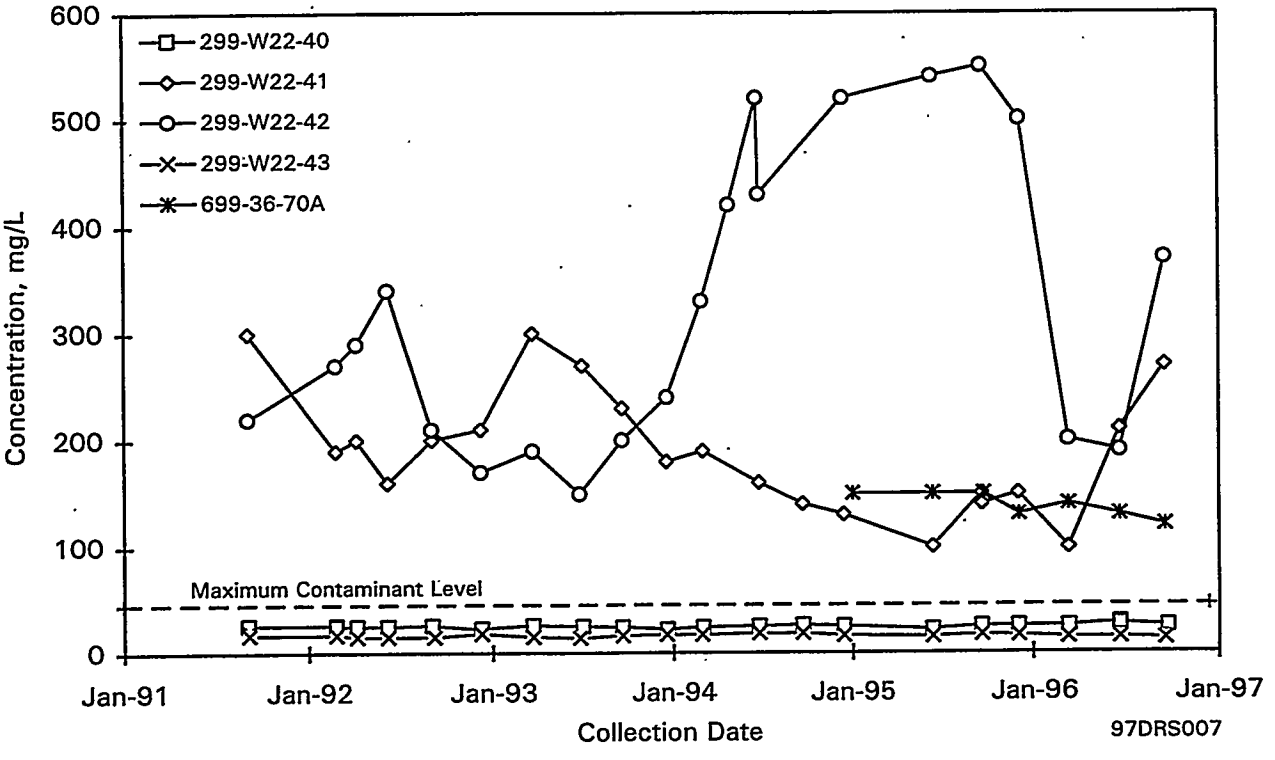


Figure 6.9-23. Nitrate Concentrations in Wells Monitoring 216-U-12 Crib

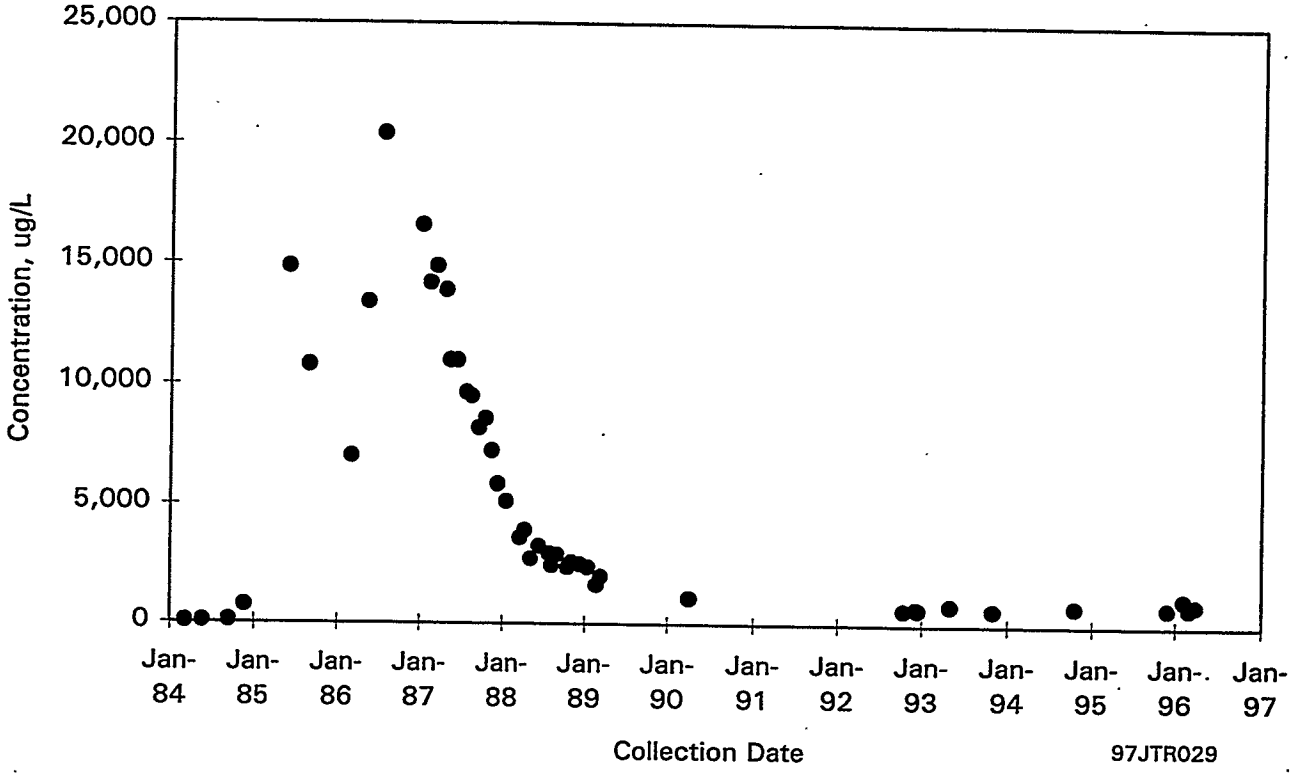


Figure 6.9-24. Uranium Concentrations in Well 299-W19-3

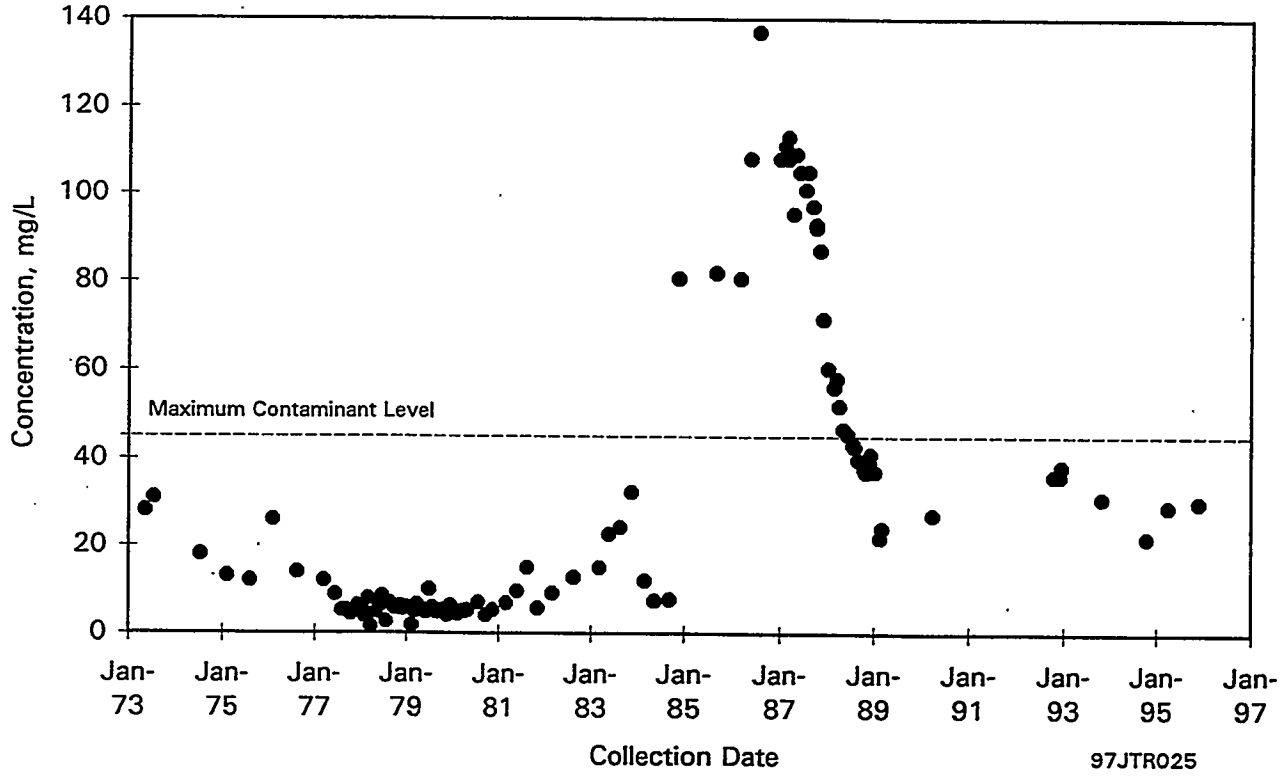


Figure 6.9-25. Nitrate Concentrations in Well 299-W19-3

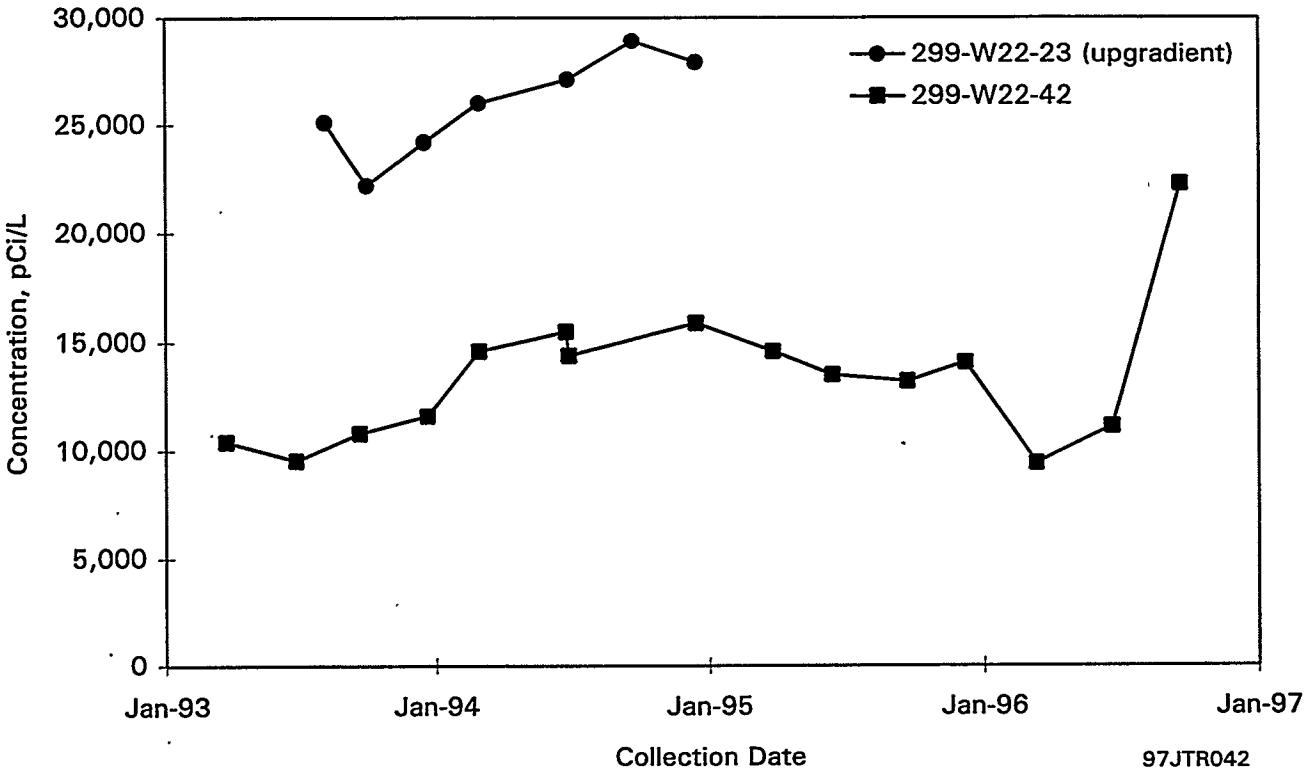


Figure 6.9-26. Tritium Concentrations at 216-U-12 Crib

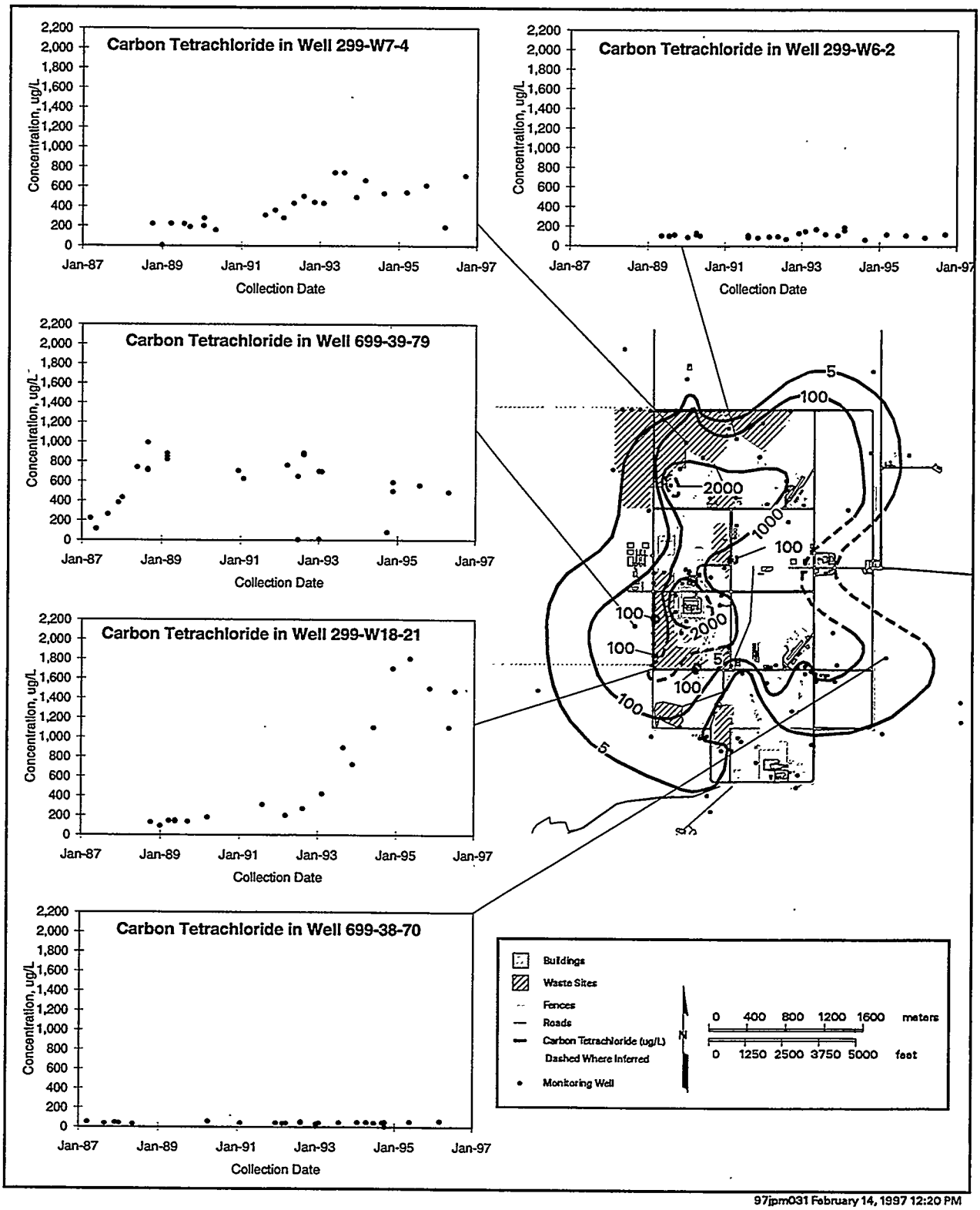


Figure 6.9-27. Carbon Tetrachloride Concentration Trends in 200-West Area Wells

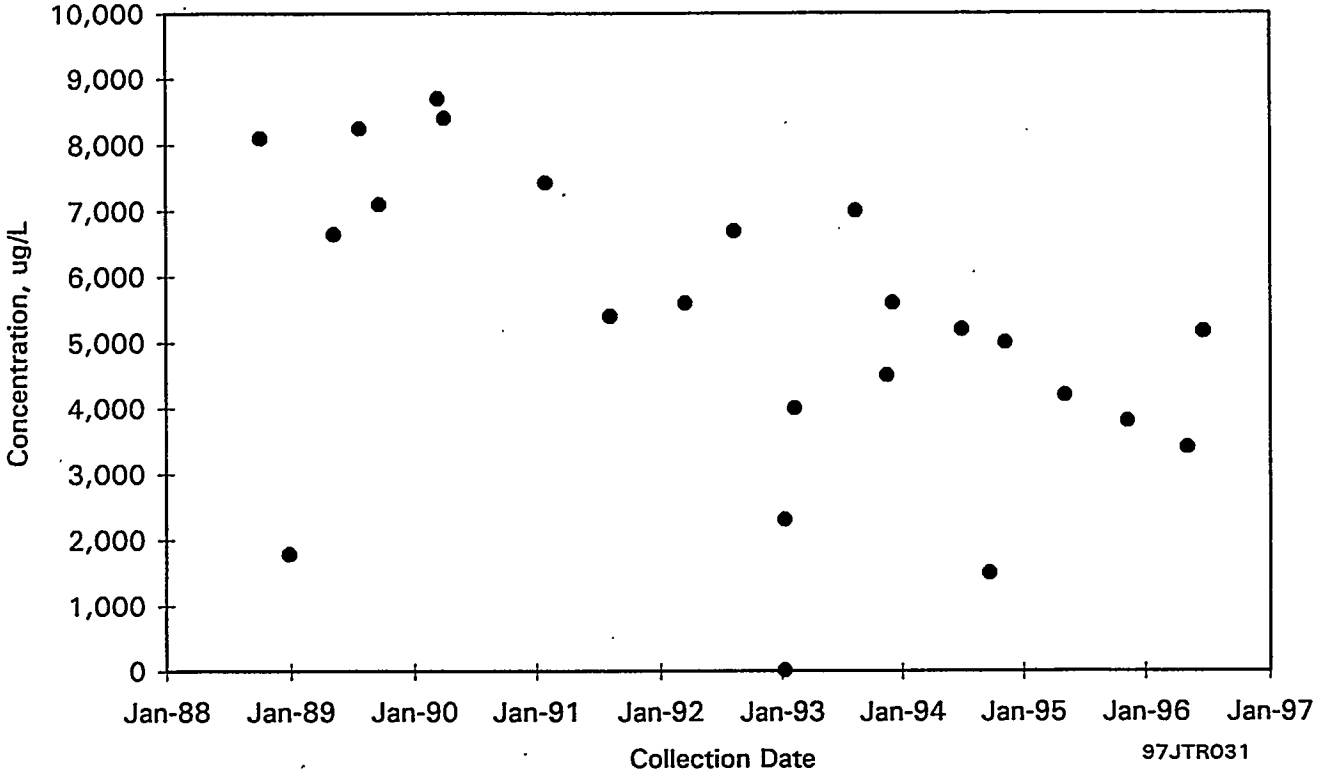


Figure 6.9-28. Carbon Tetrachloride Concentrations in Well 299-W15-16

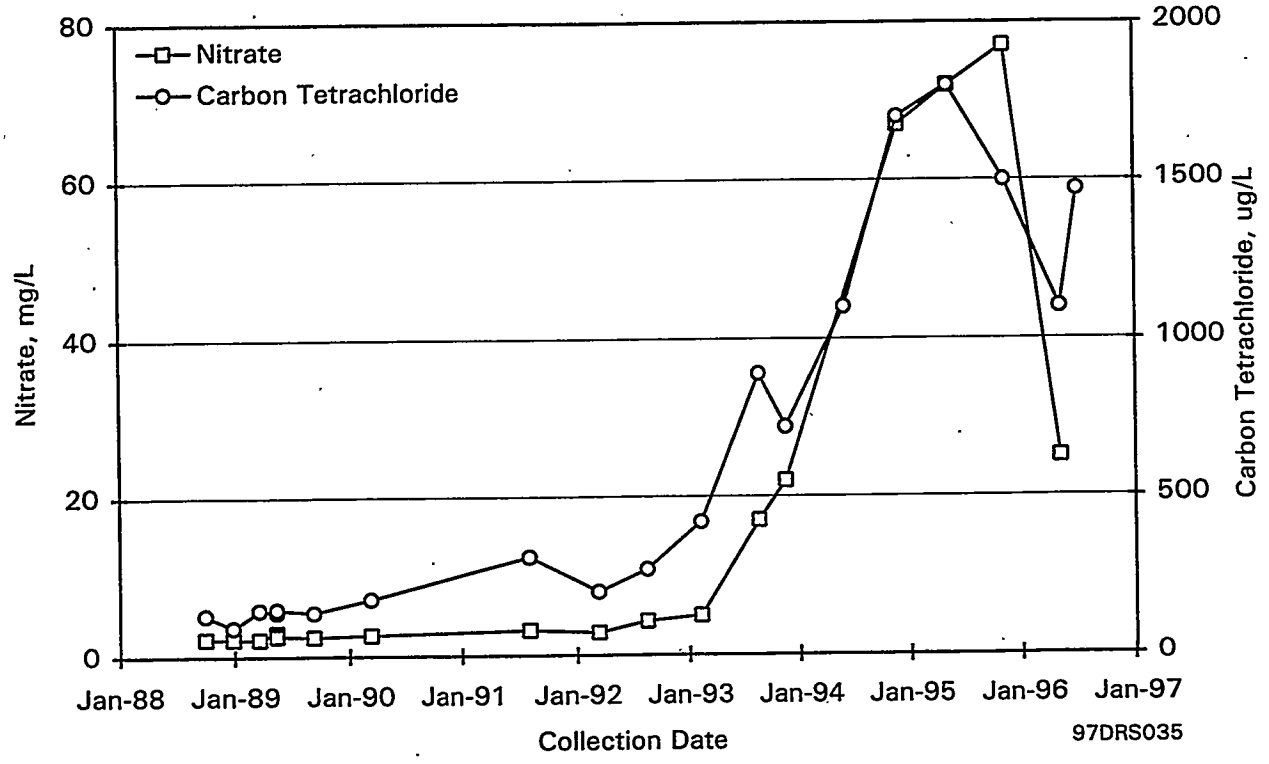


Figure 6.9-29. Nitrate and Carbon Tetrachloride Concentrations in Well 299-W18-21

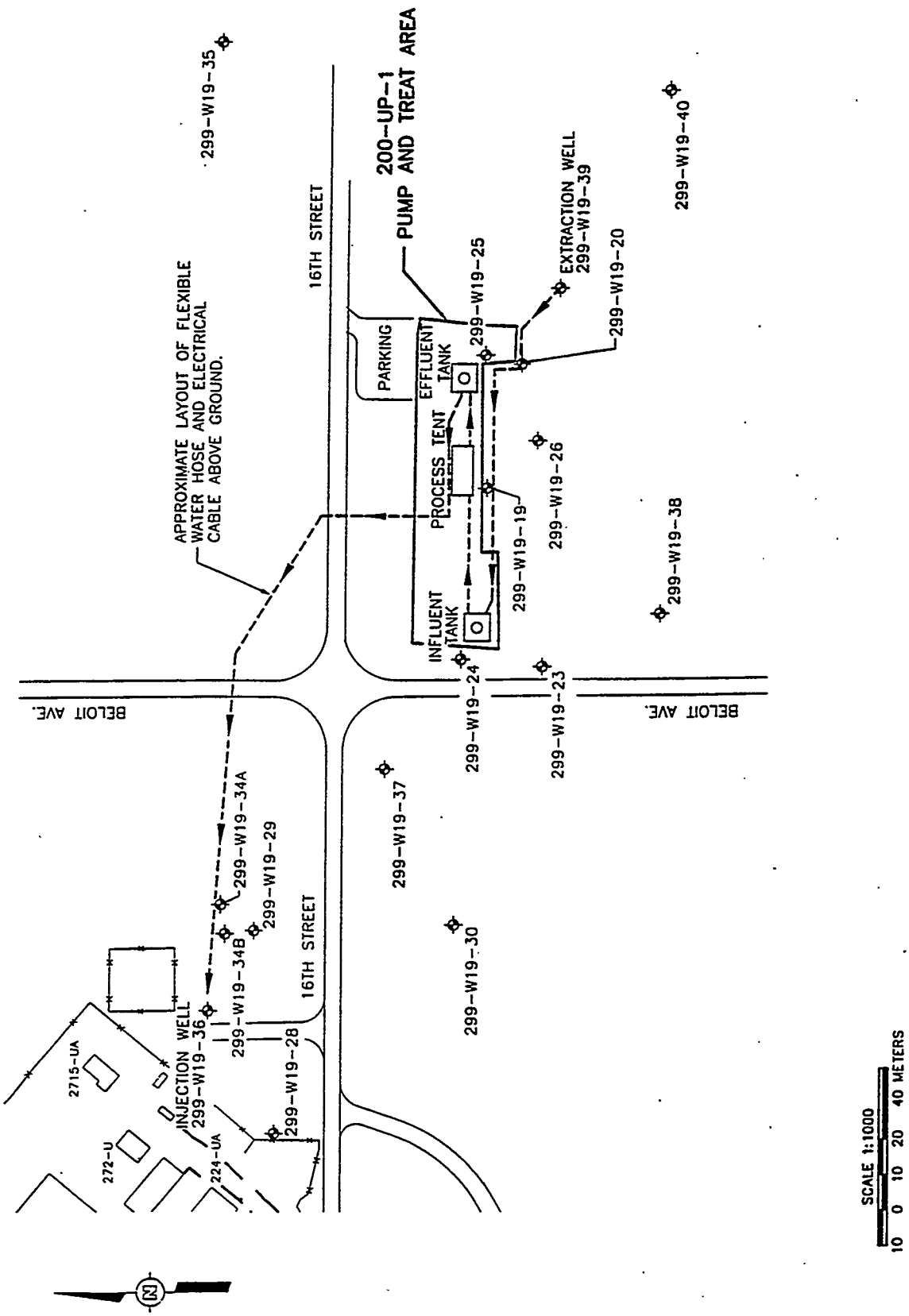


Figure 6.9-30. Plan View of Pump-and-Treat System in 200-UP-1 Operable Unit (from Myers et al. 1996)

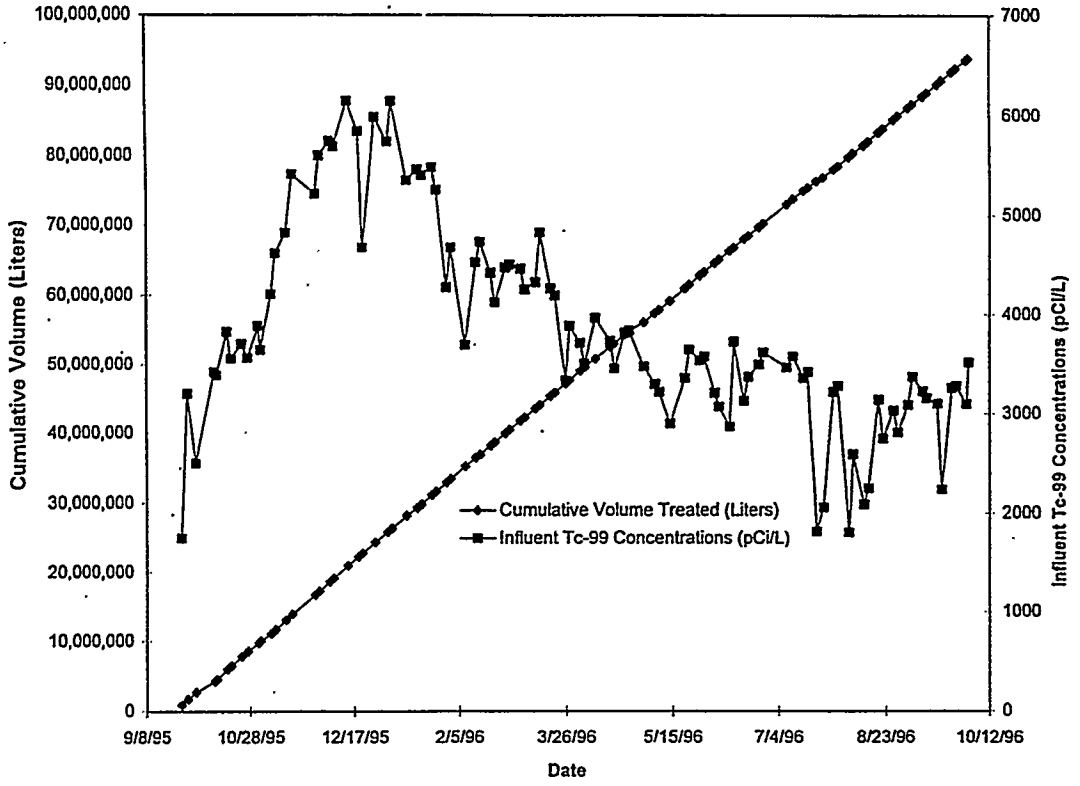


Figure 6.9-31. Technetium-99 Concentration Trends in 200-UP-1 Operable Unit (from Myers et al. 1996)

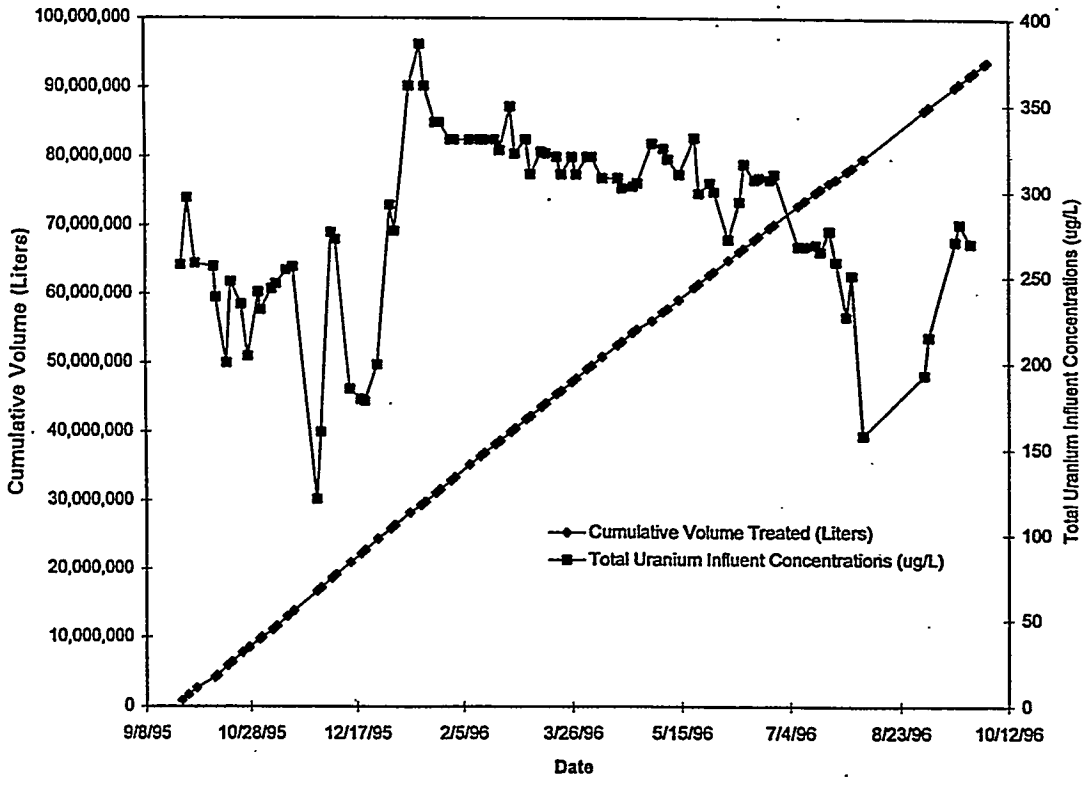


Figure 6.9-32. Uranium Concentration Trends in 200-UP-1 Operable Unit (from Myers et al. 1996)

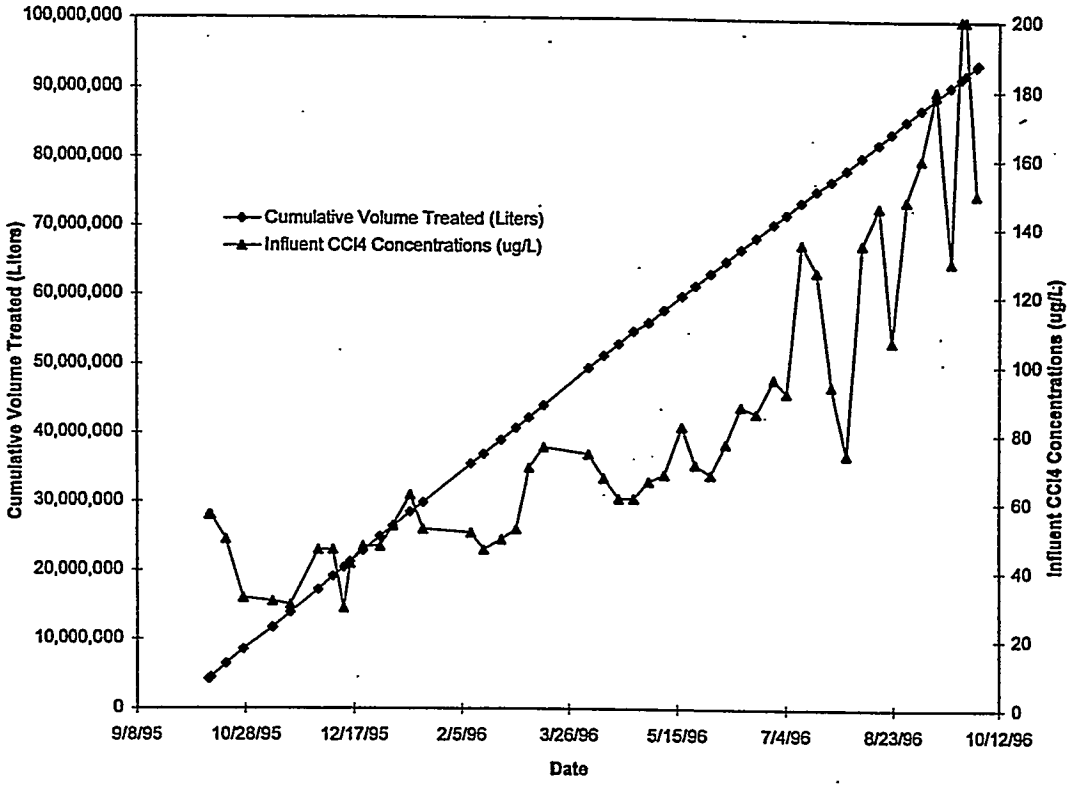


Figure 6.9-33. Carbon Tetrachloride Trends in 200-UP-1 Operable Unit (from Myers et al. 1996)

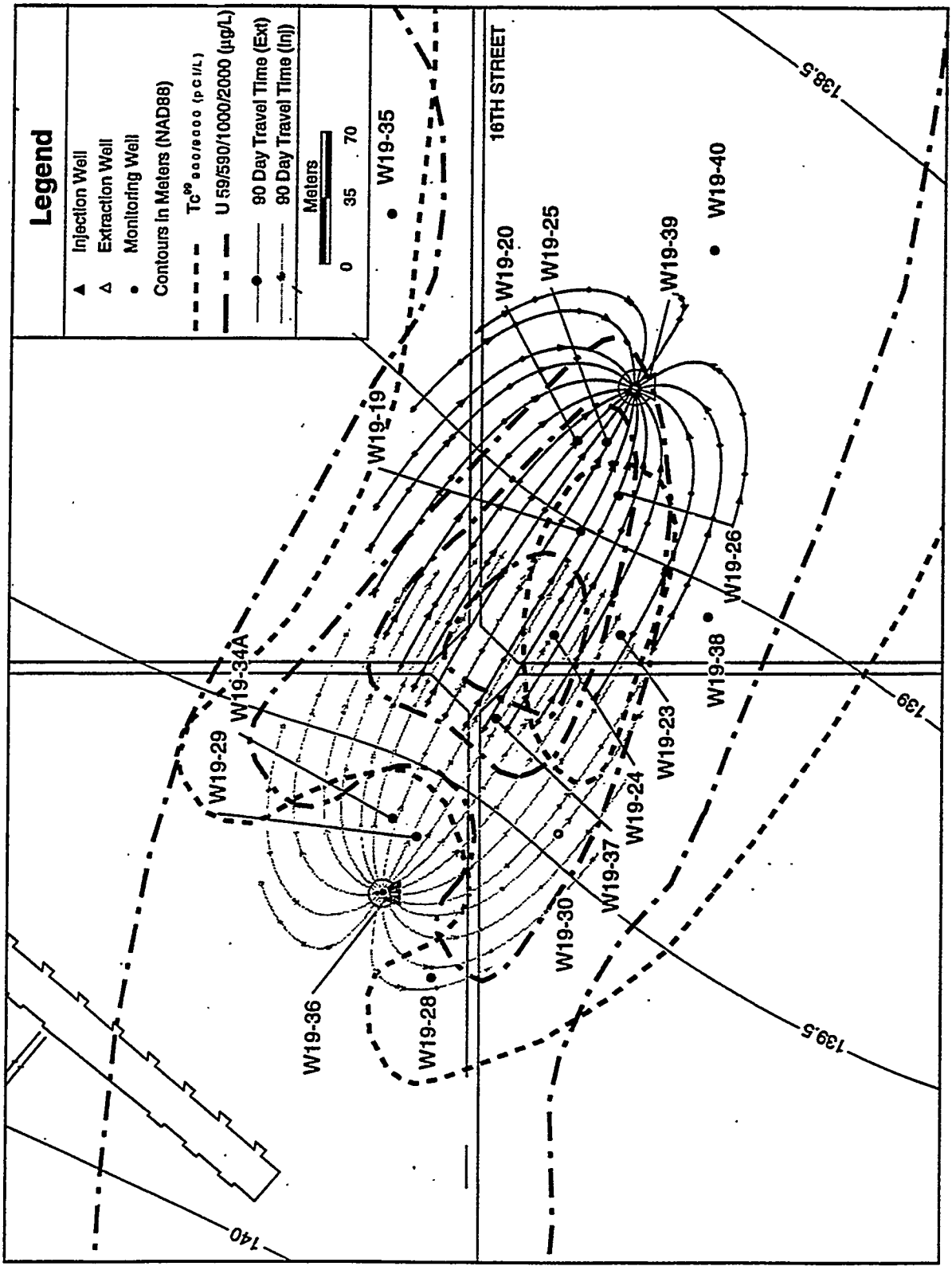


Figure 6.9-34. Pump-and-Treat Capture Zone Analysis for 200-UP-1 Operable Unit (from Myers et al. 1996)

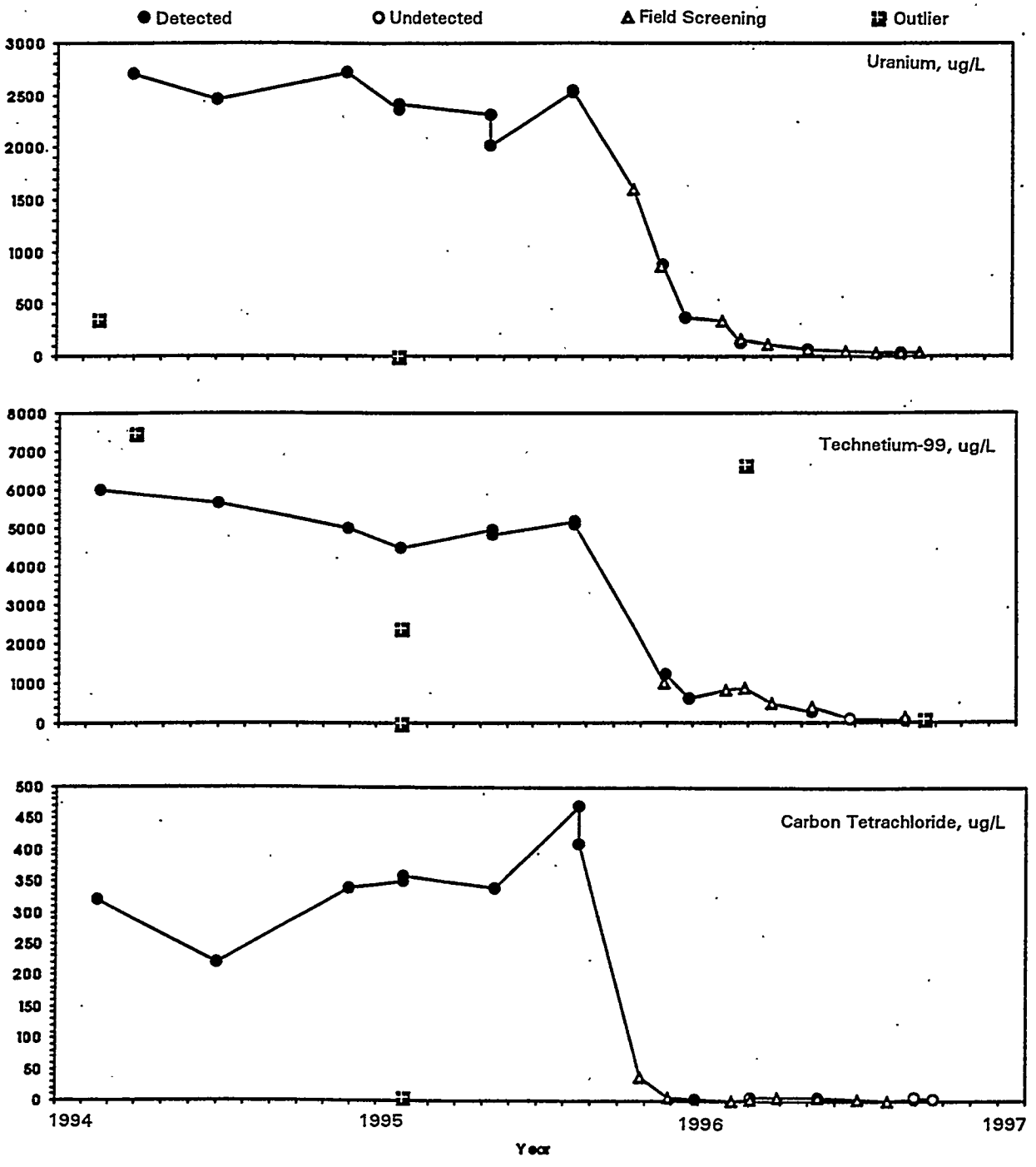


Figure 6.9-35. Contaminant Concentration Decreases in Well 299-W19-29

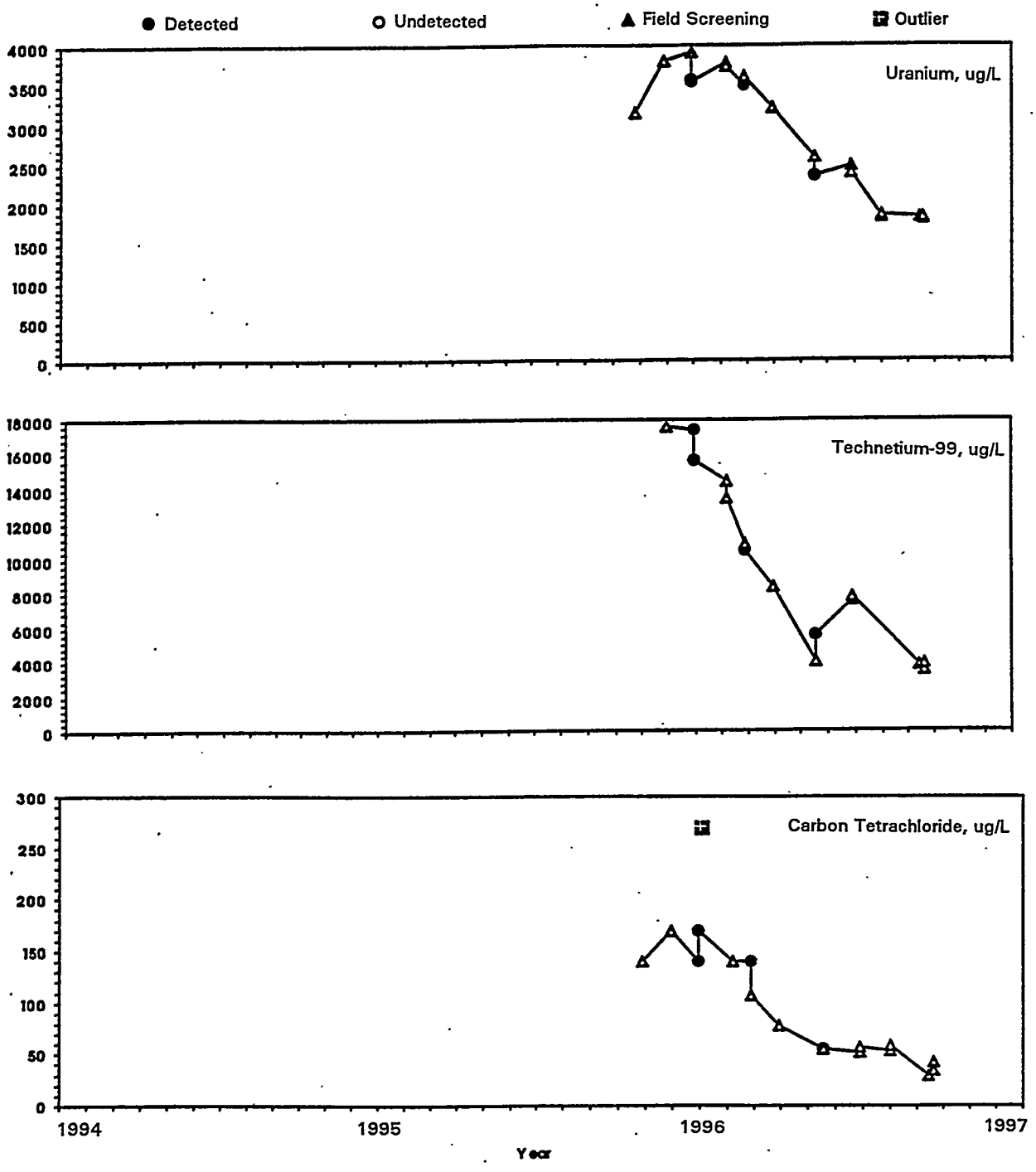


Figure 6.9-36. Contaminant Concentration Decreases in Well 299-W19-37

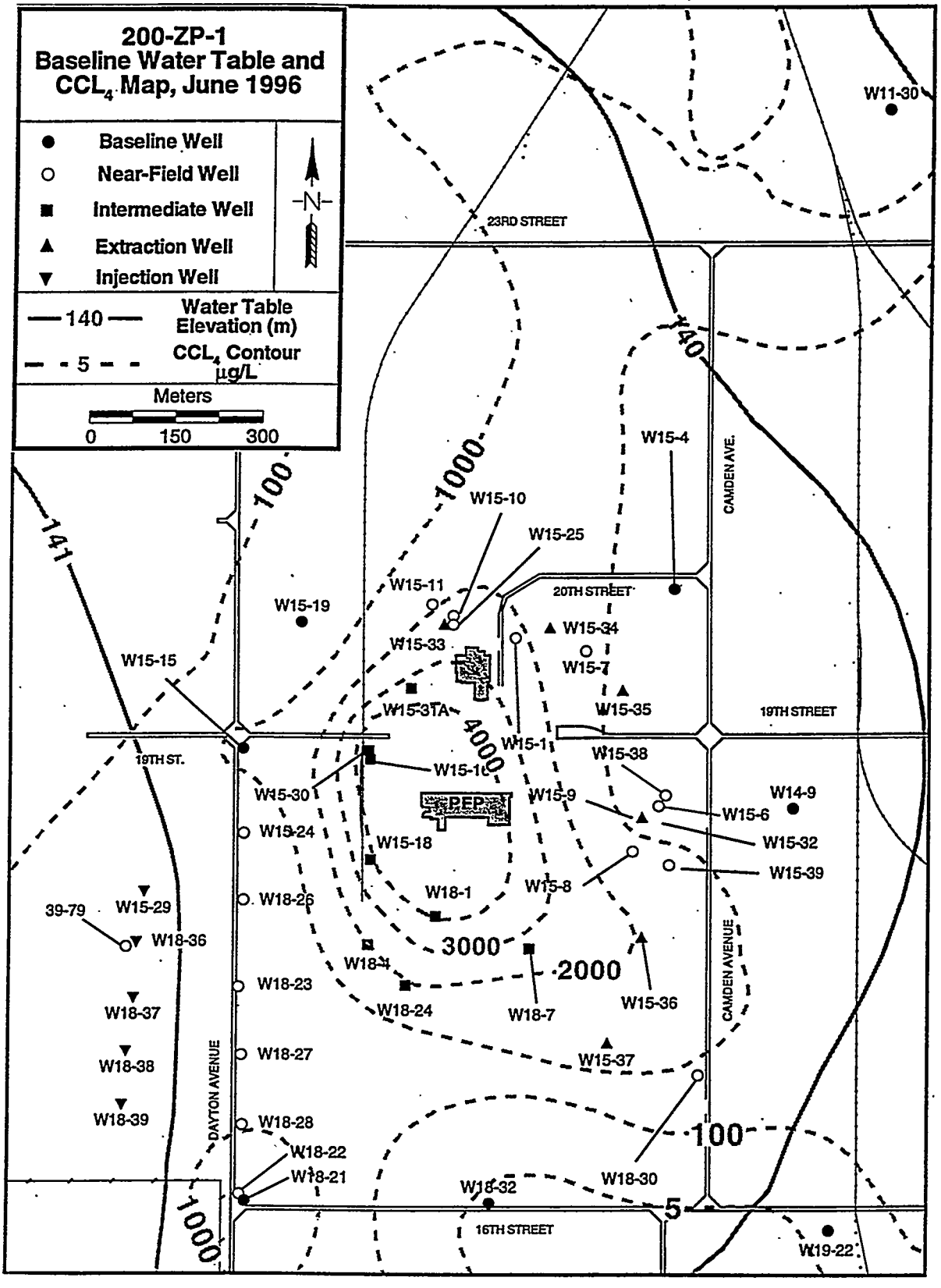


Figure 6.9-37. Baseline Water-Table Map and Carbon Tetrachloride Concentrations for 200-ZP-1 Operable Unit (from Freeman-Pollard et al. 1996) (Elevation datum is NAVD88)

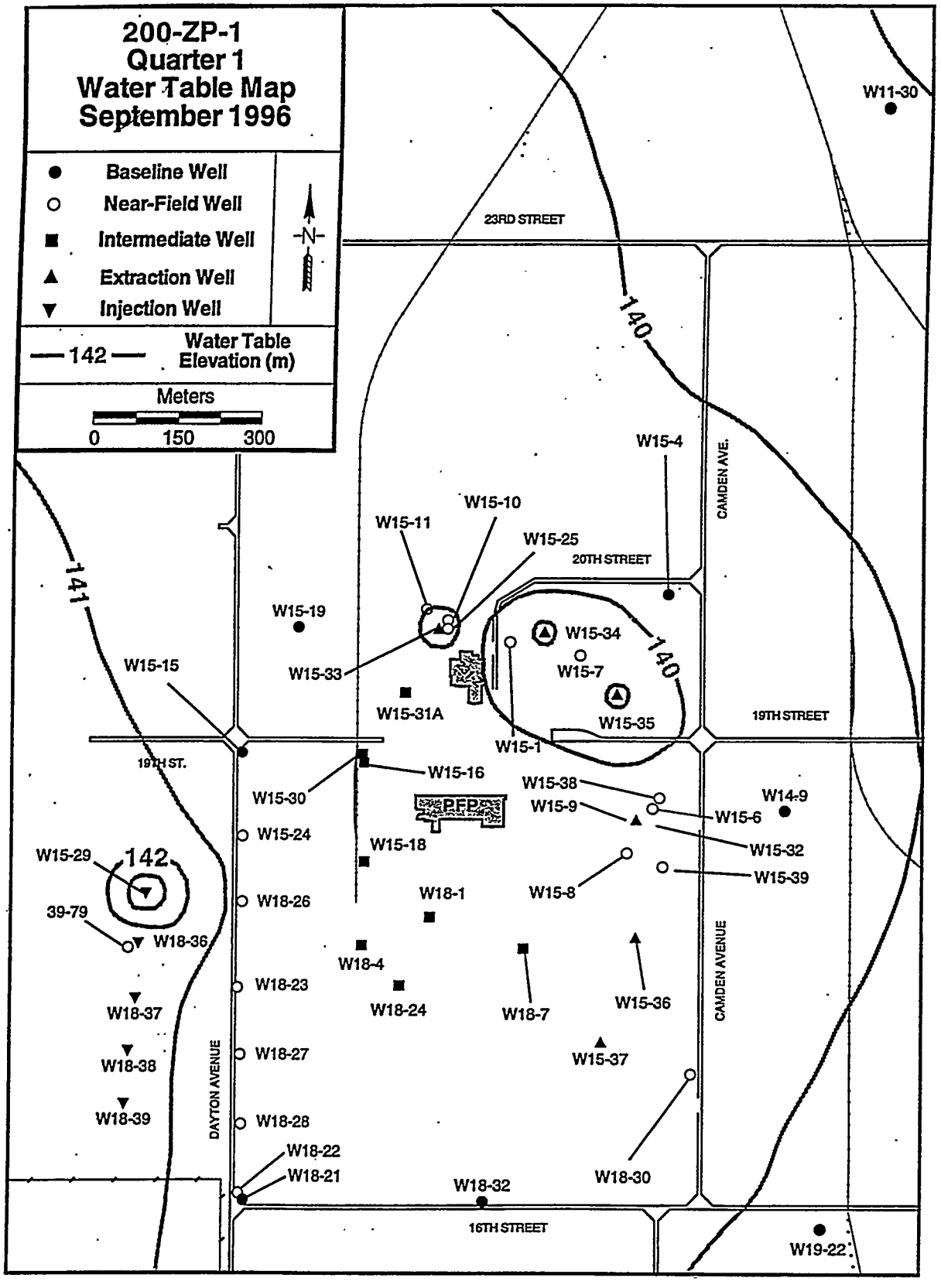


Figure 6.9-38. Water-Table Map Showing Effects of Pump-and-Treat Operations for 200-ZP-1 Operable Unit (from Freeman-Pollard et al. 1996) (Elevation datum is NAVD88)

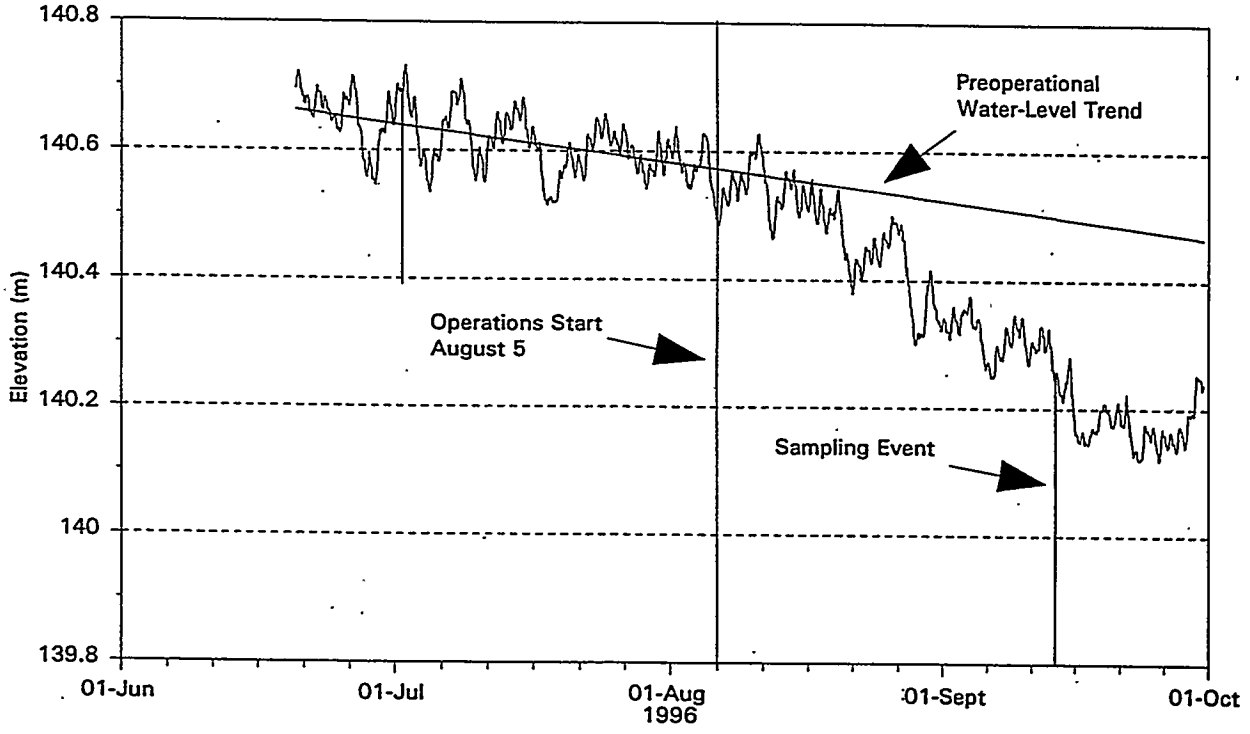


Figure 6.9-39. Water-Level Trends for 200-ZP-1 Operable Unit Pump-and-Treat System (from Freeman-Pollard et al. 1996)

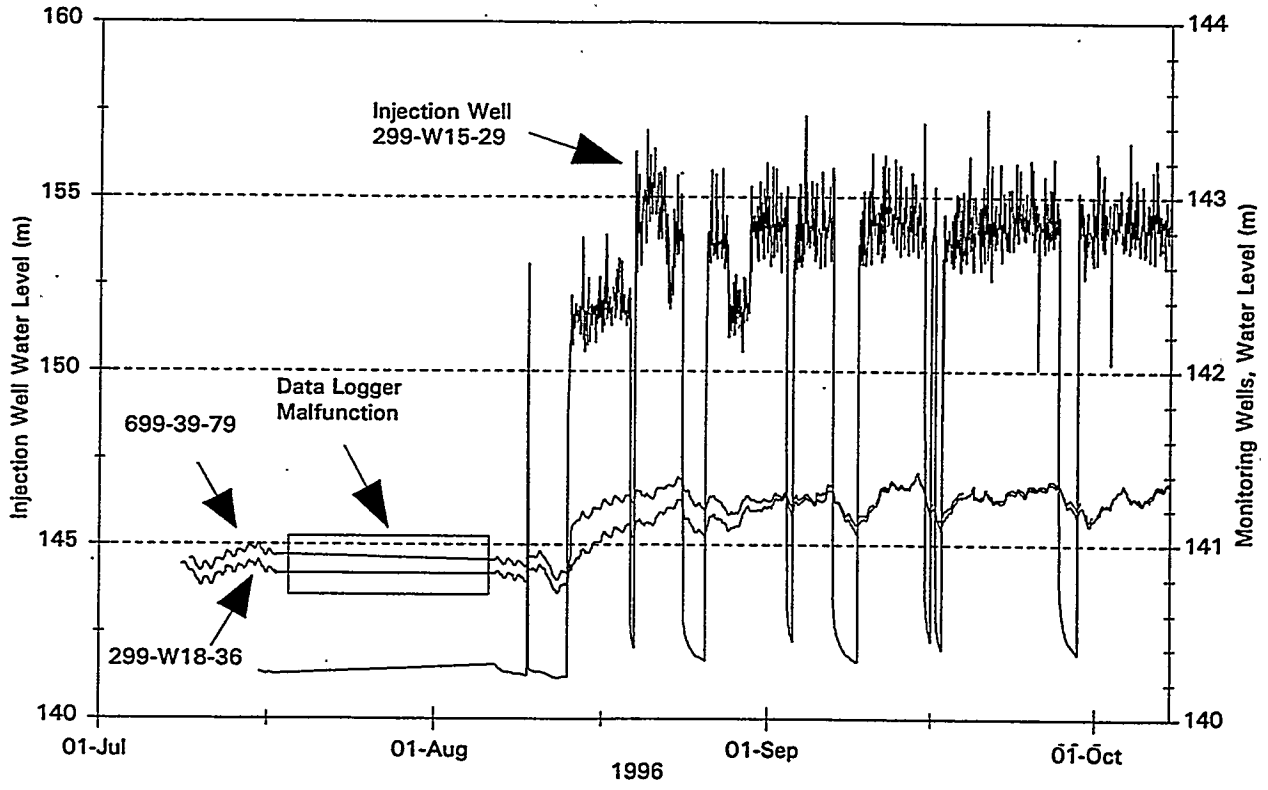


Figure 6.9-40. Injection Well Water-Level Trends for 200-ZP-1 Operable Unit Pump-and-Treat System (from Freeman-Pollard et al. 1996)

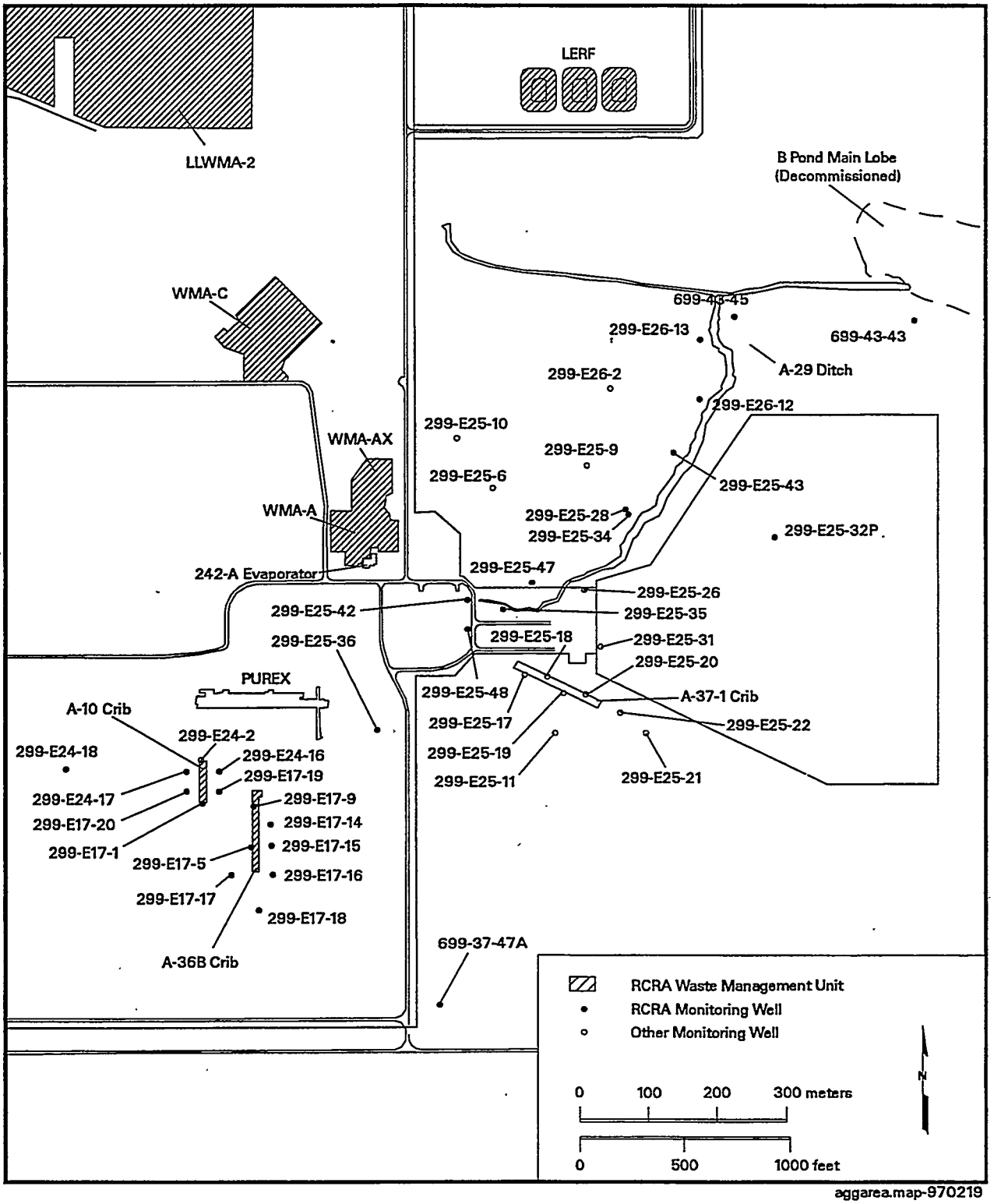


Figure 6.10-1. Monitoring Well Network for 216-A-10 Crib, 216-A-36-B Crib, and 216-A-29 Ditch

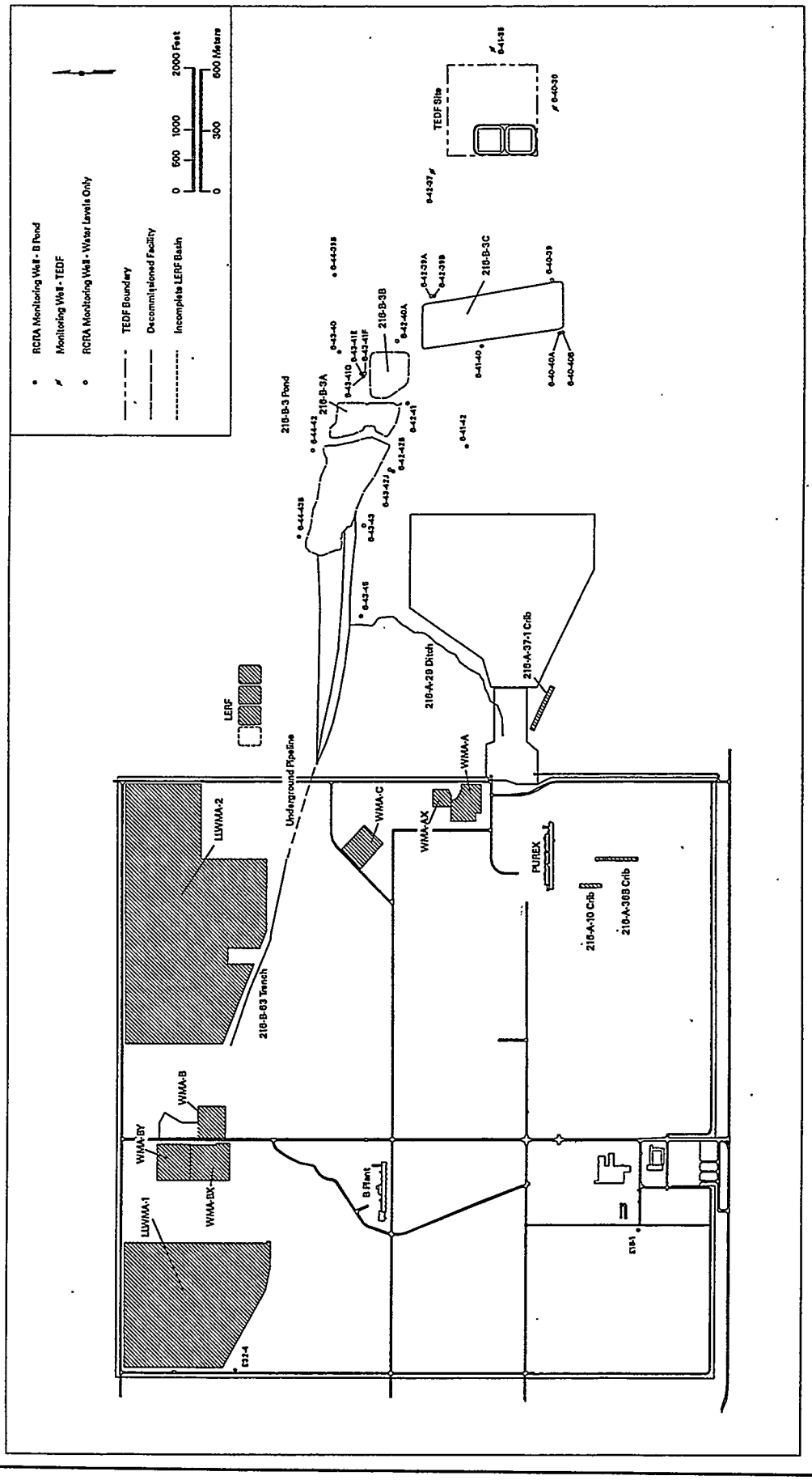


Figure 6.10-2. Monitoring Well Network for 216-B-3 Pond

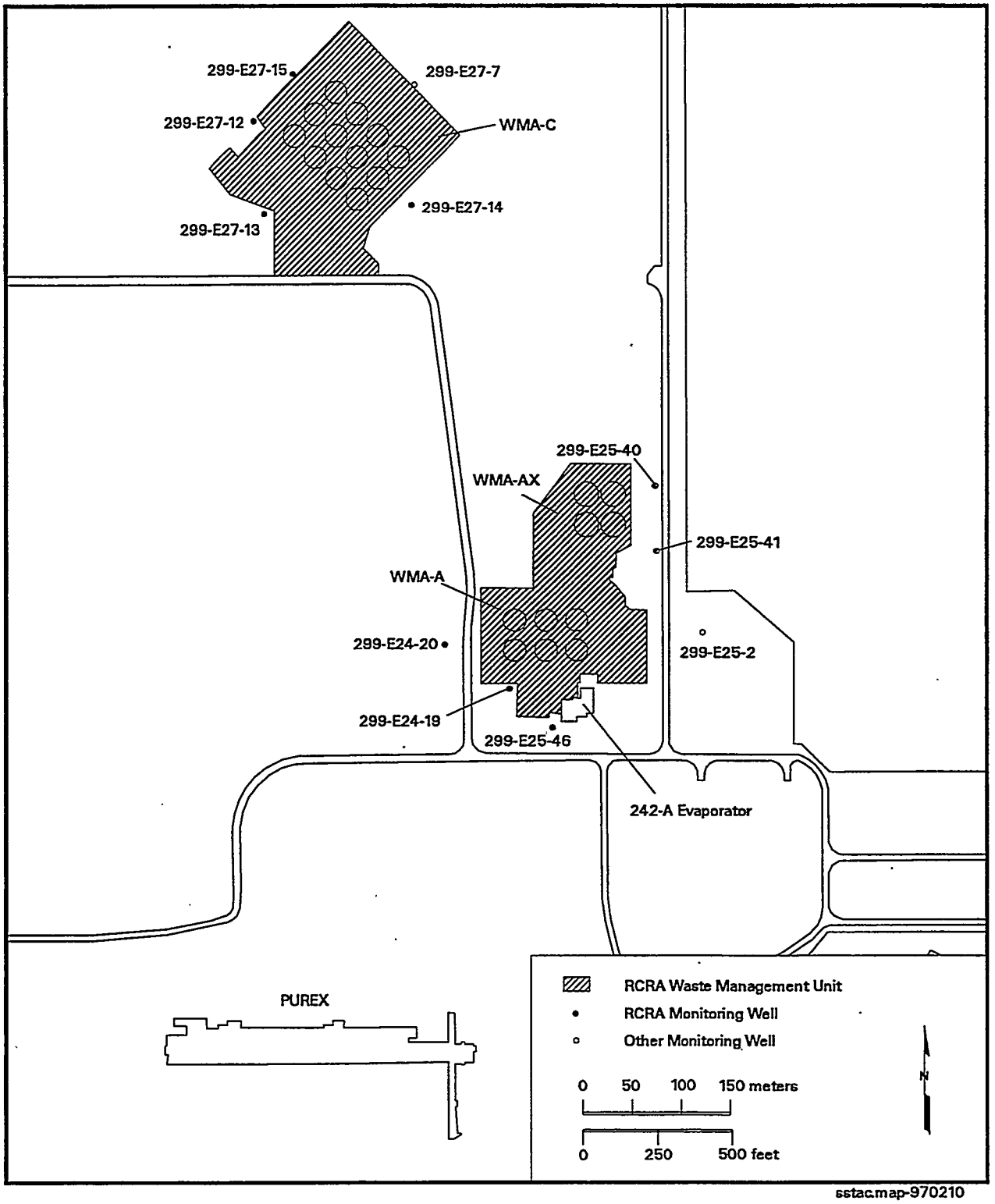


Figure 6.10-3a. Monitoring Well Network for WMA-A, -AX, and -C Single-Shell Tank Farms

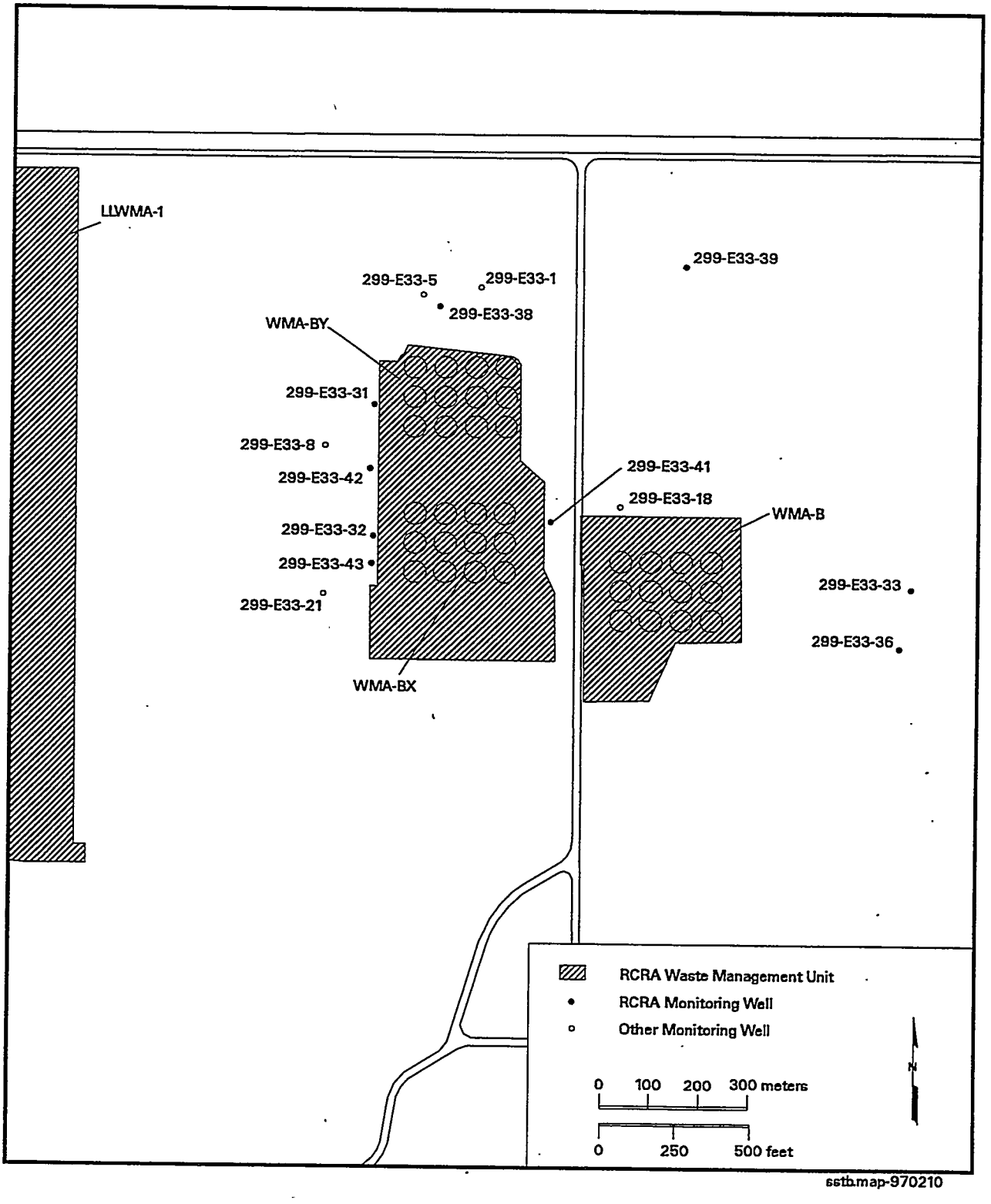


Figure 6.10-3b. Monitoring Well Network for WMA-B-BX-BY Single-Shell Tank Farms

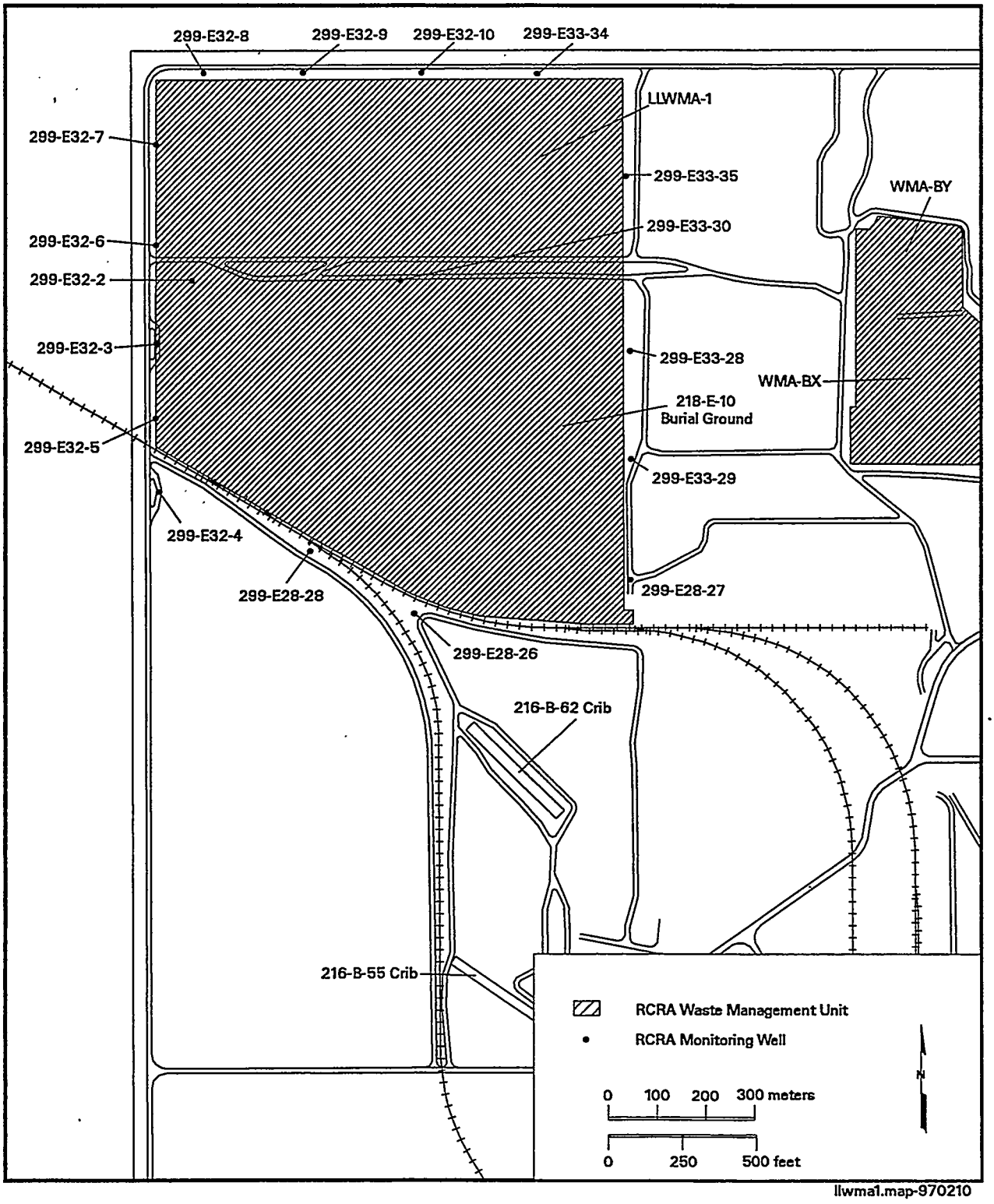


Figure 6.10-4. Monitoring Well Network for LLWMA-1

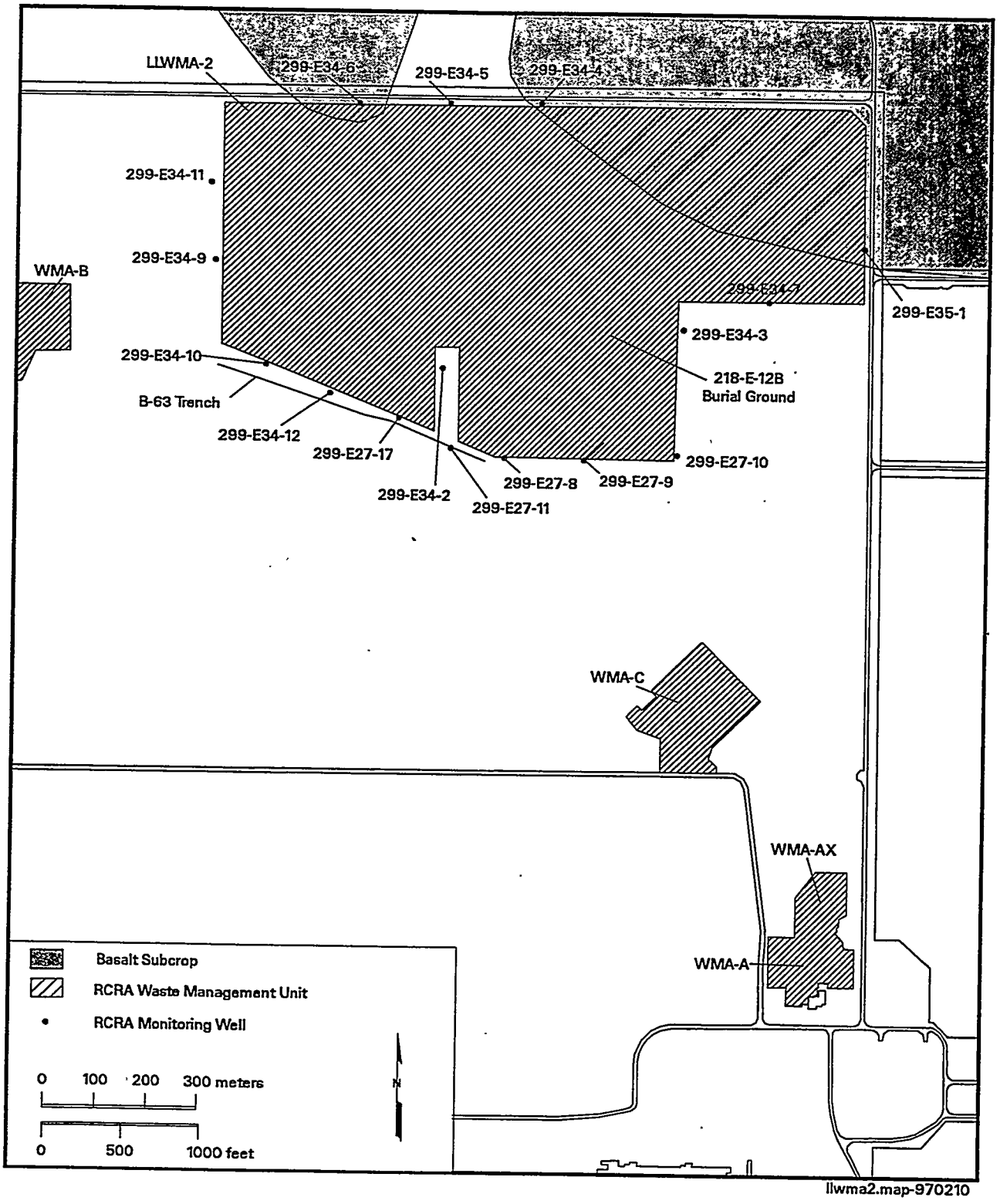


Figure 6.10-5. Monitoring Well Network for LLWMA-2

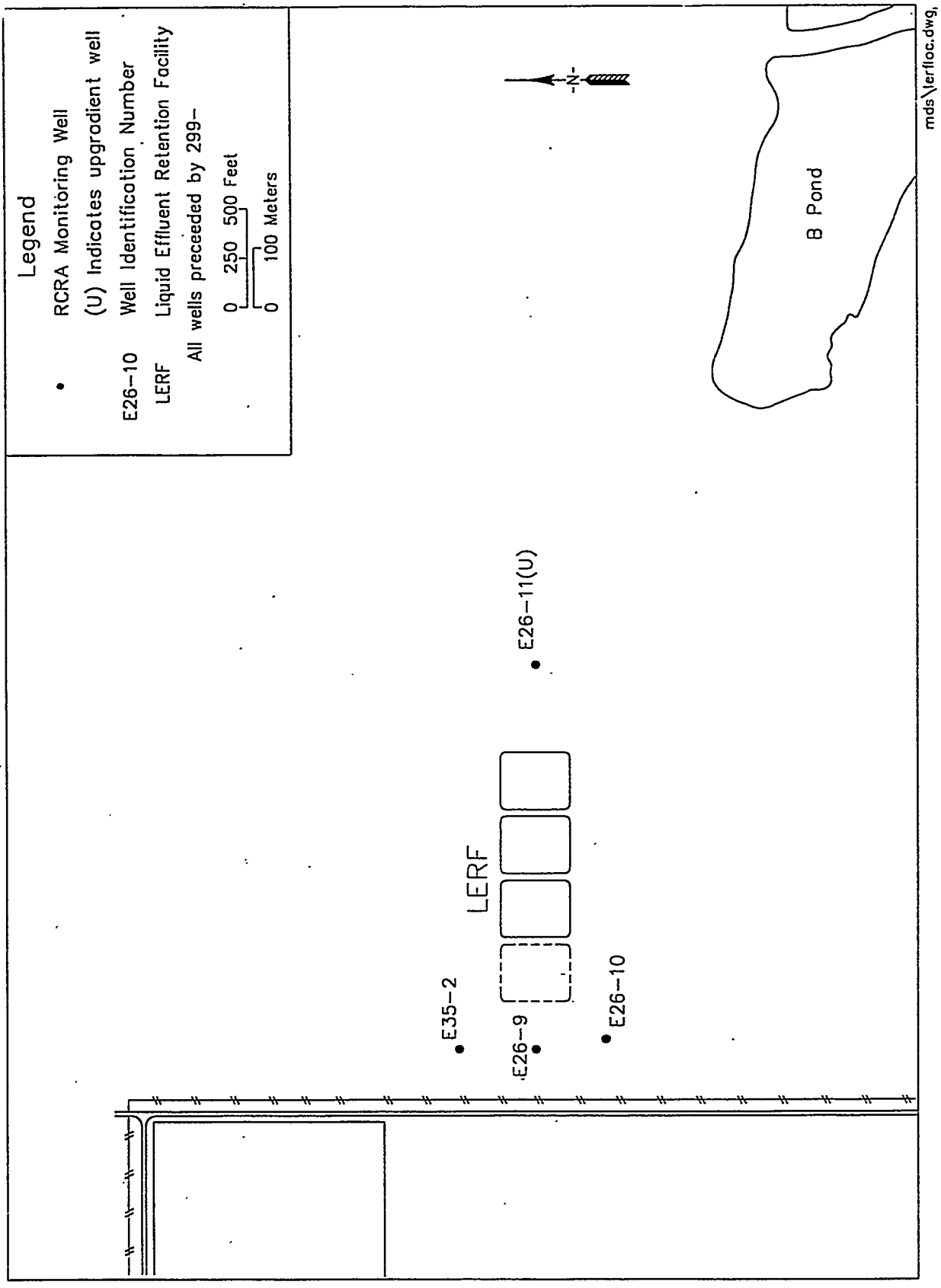


Figure 6.10-6. Monitoring Well Network for 200 Areas Liquid Effluent Retention Facility

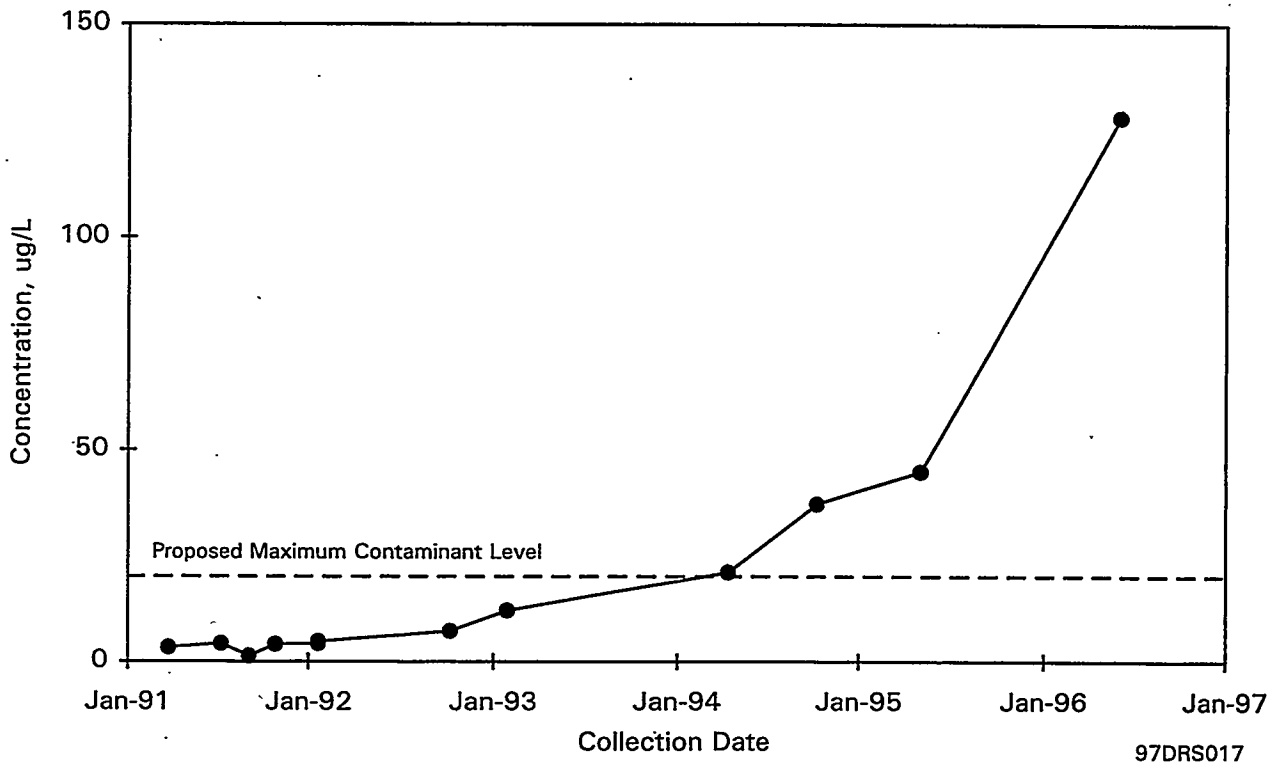


Figure 6.10-7. Uranium Concentrations in Well 299-E33-13

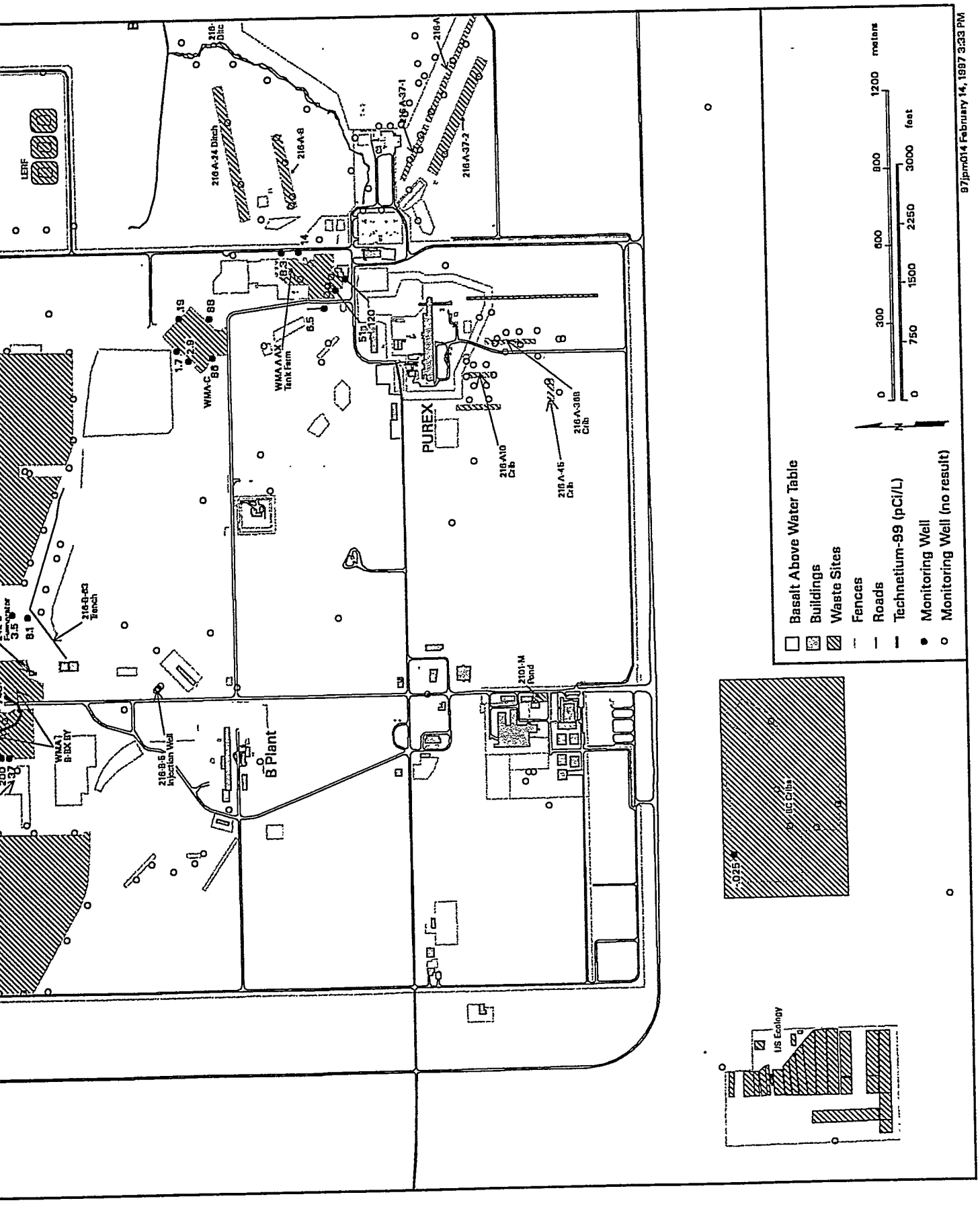
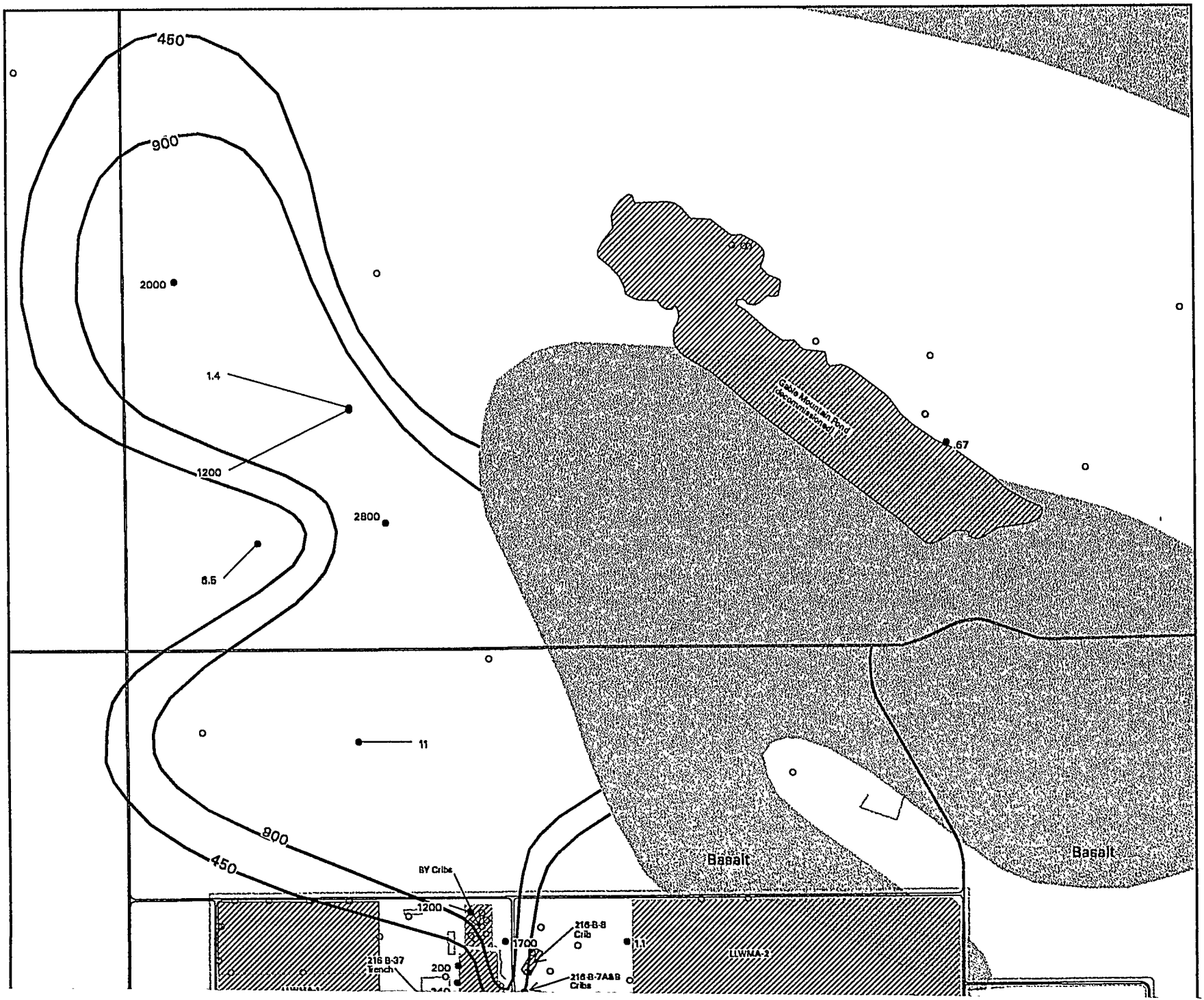


Figure 6.10-8. Average FY 1996 Technetium-99 Concentrations in 200-East Area


450
900
2000
1.4
1200
2800
6.5
11
800
450
Basalt
Basalt
Cable Mountain Pond
(decommissioned)
.67
BY Cribs
1200
1700
216-B-8
Crib
1.1
216 B-37
Trench
200
216-B-7A&B
Cribs
LLWMA-3

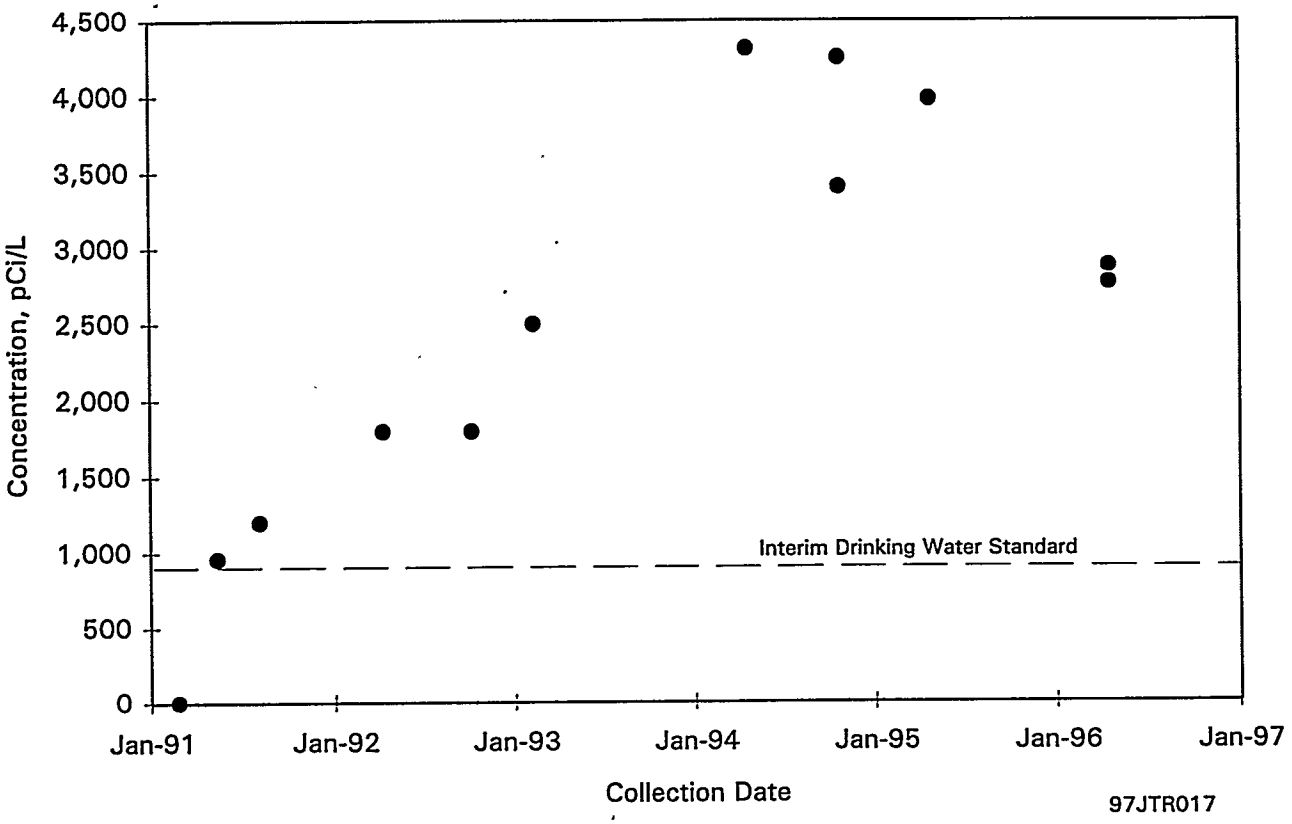


Figure 6.10-9. Technetium-99 Concentrations in Well 699-52-54

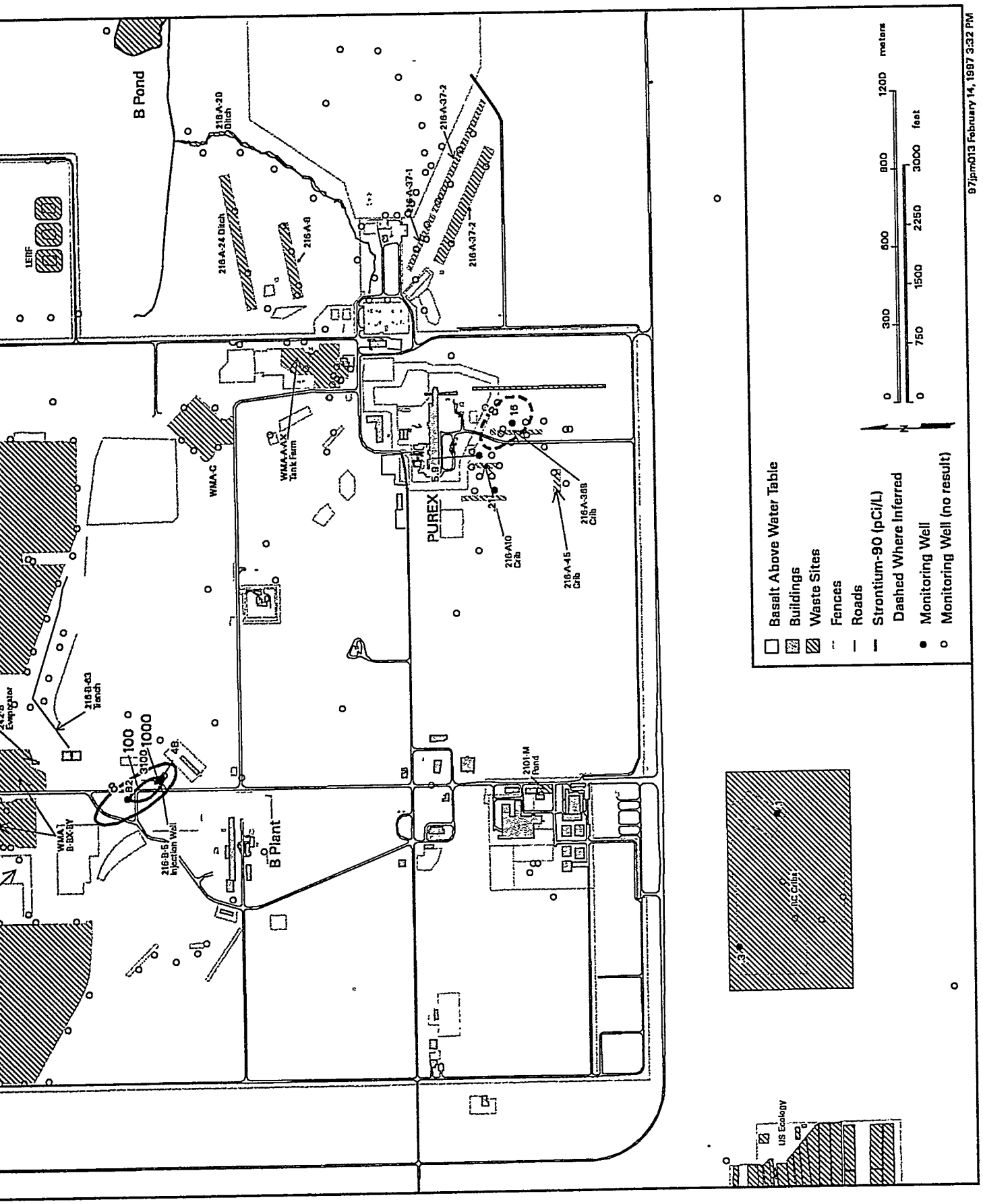
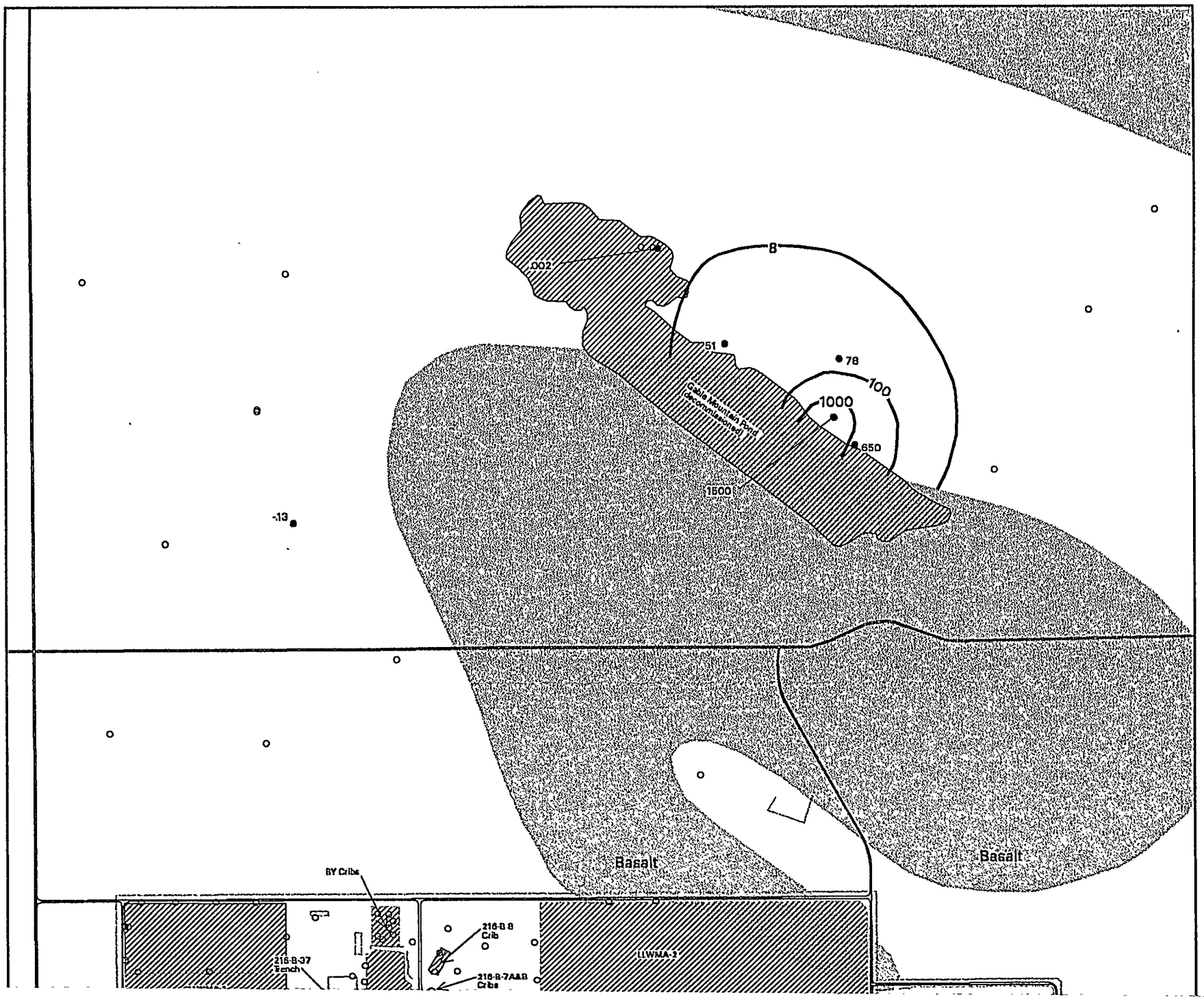


Figure 6.10-10. Average FY 1996 Strontium-90 Concentrations in 200-East Area


.002
8
51
78
100
1000
650
1500
-13
Gable Mountain Pond
(decommissioned)
Basalt
Basalt
BY Cribs
216-B-8
Crib
216-B-37
Trench
216-B-7A&B
Cribs
LLWMA-2

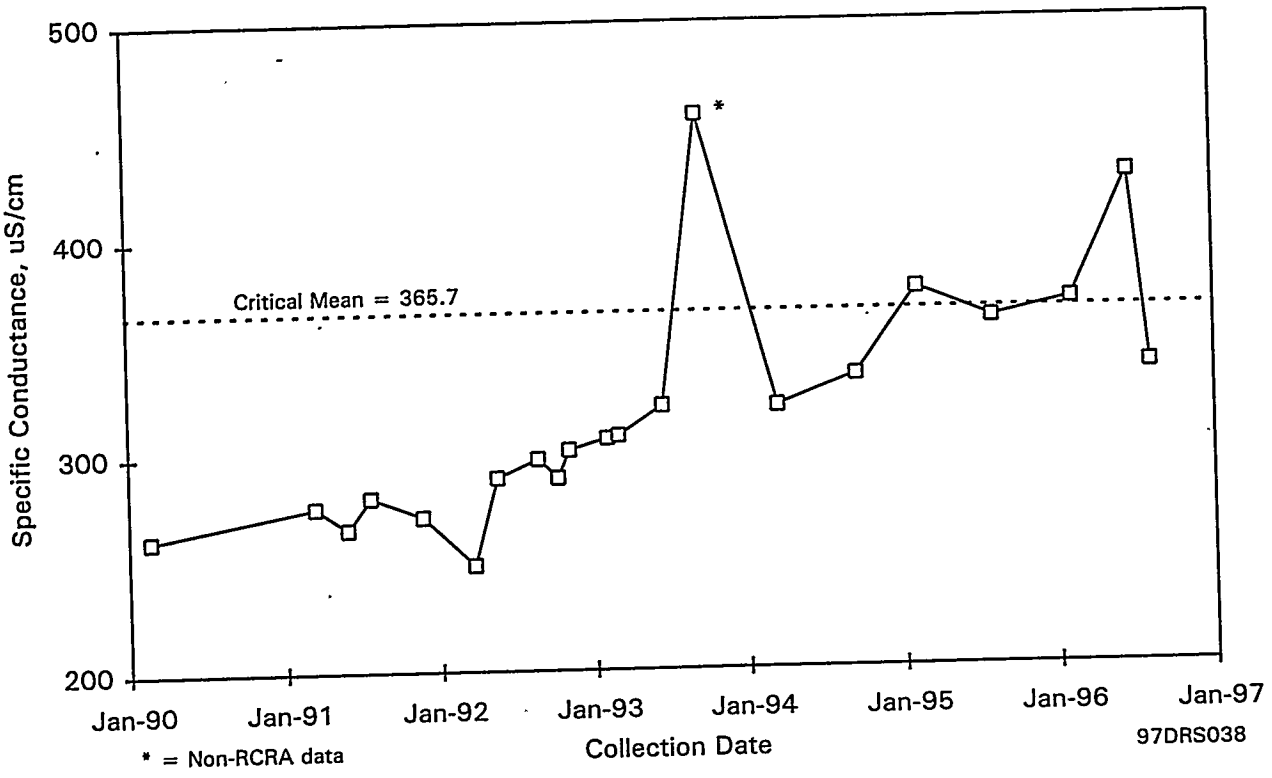


Figure 6.10-11. Specific Conductance in Well 299-E33-32

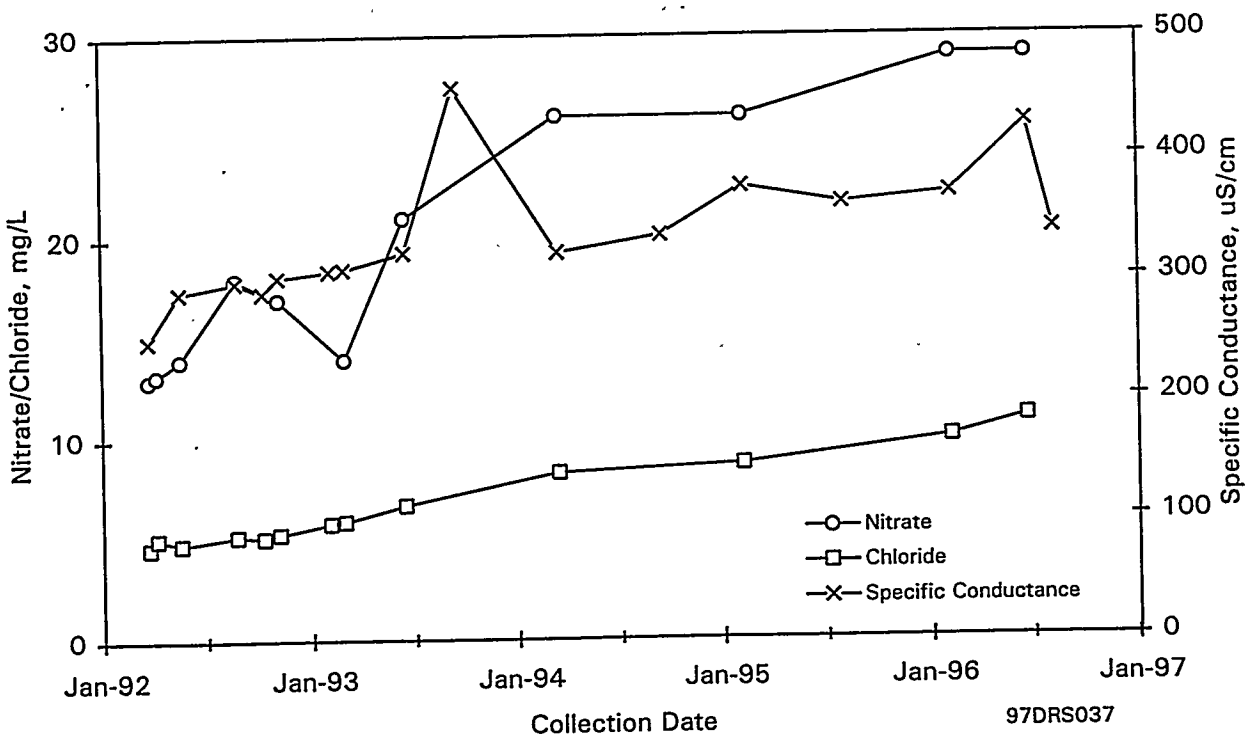


Figure 6.10-12. Nitrate and Chloride Concentrations in Well 299-E33-32

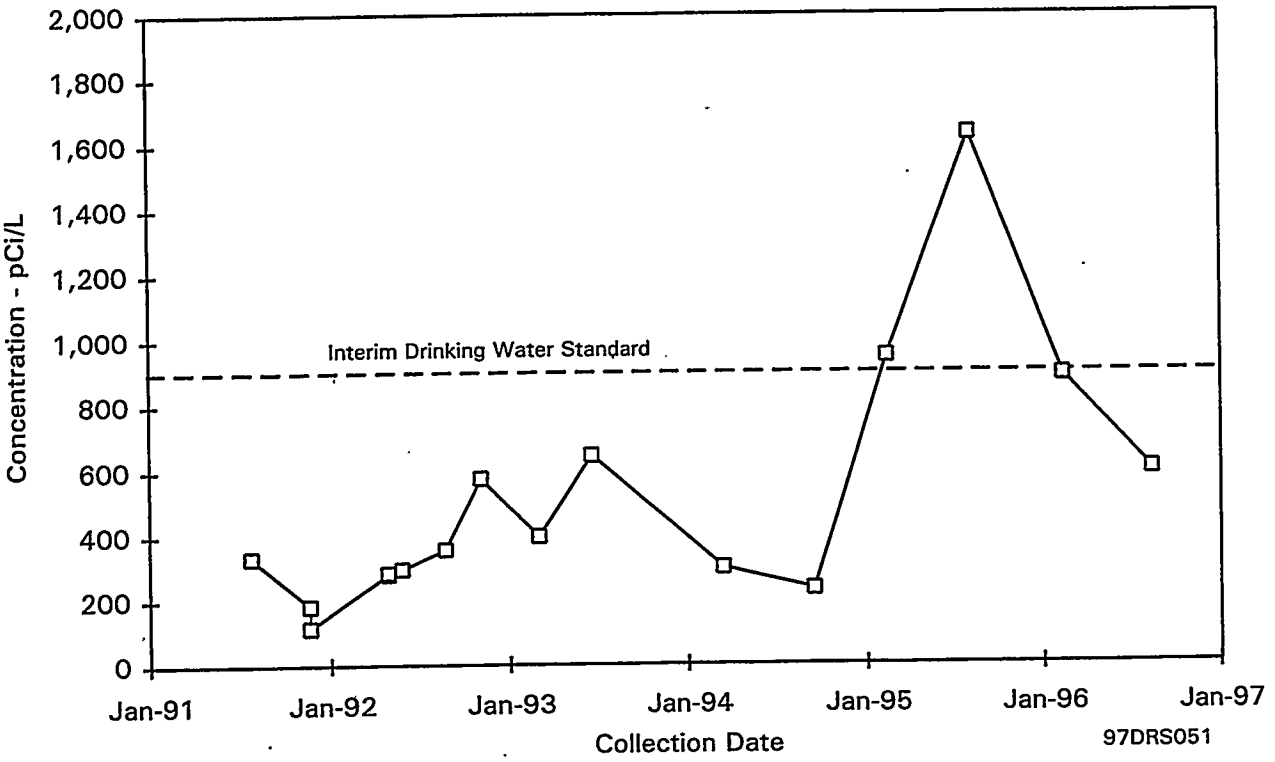


Figure 6.10-13. Technetium-99 Concentrations in Well 299-E33-41

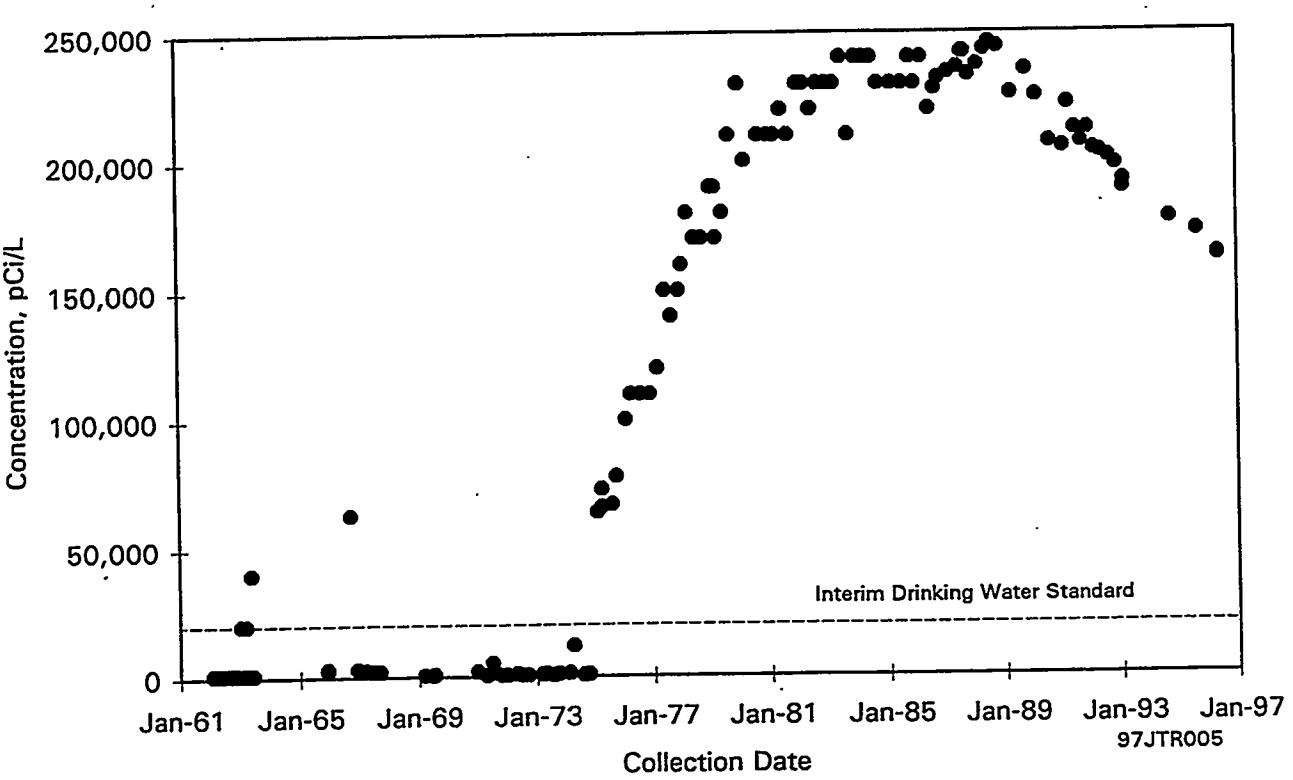


Figure 6.10-14. Tritium Concentrations in Well 699-40-1

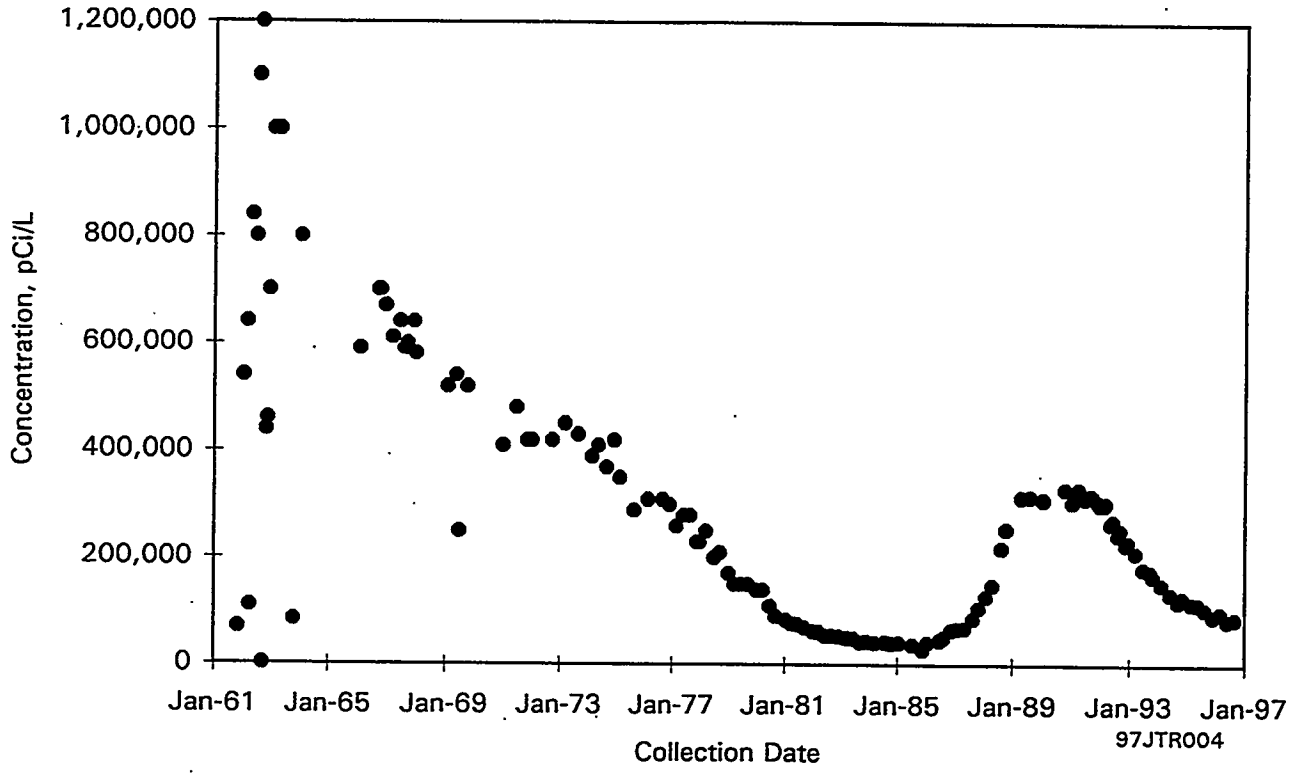


Figure 6.10-15. Tritium Concentrations in Well 699-24-33

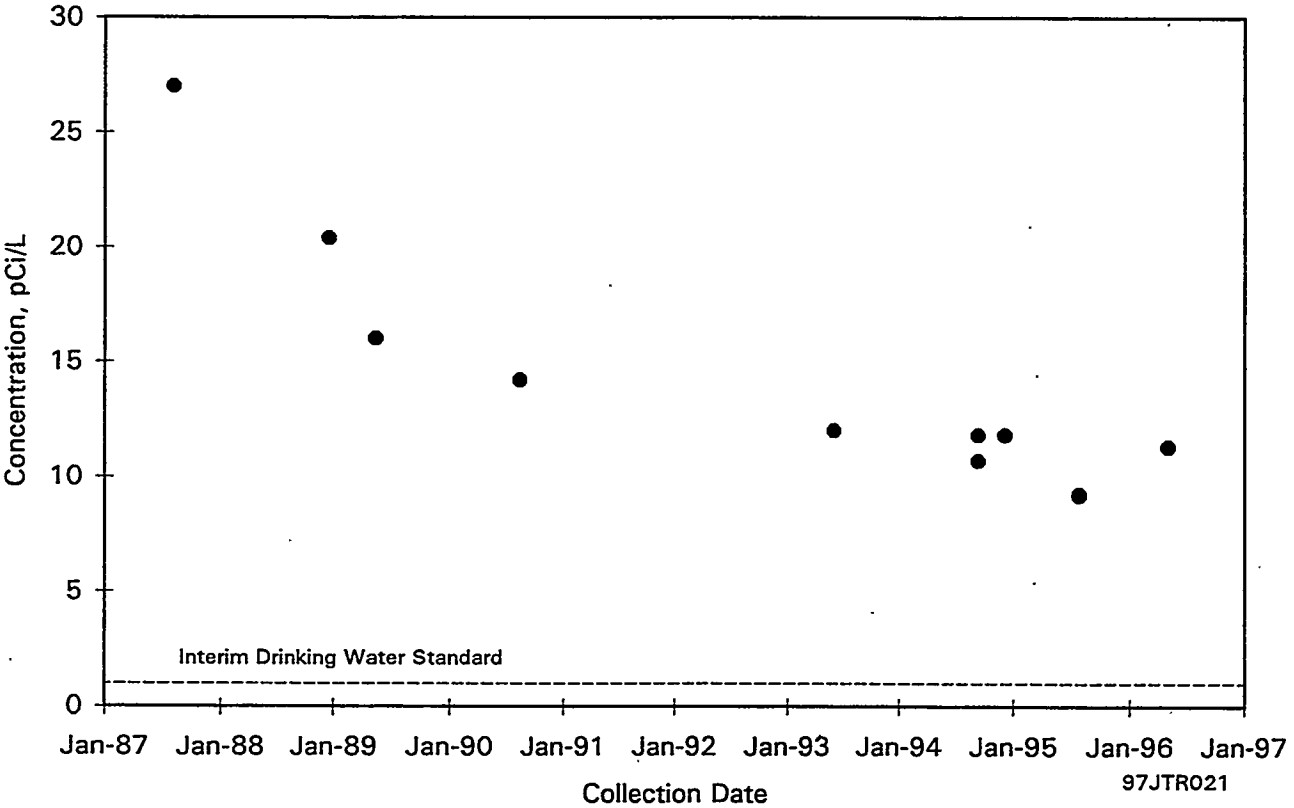


Figure 6.10-16. Iodine-129 Concentrations in Well 299-E17-9

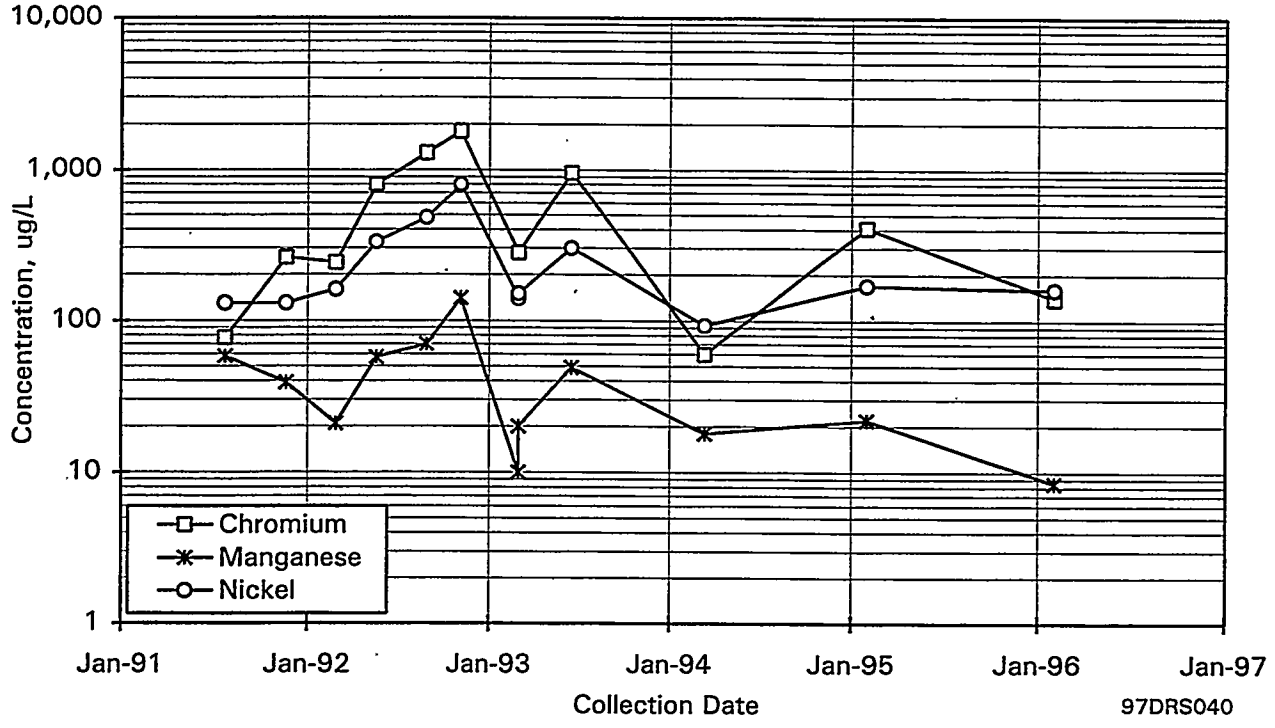


Figure 6.10-17. Chromium, Manganese, and Nickel Results from Well 299-E24-19

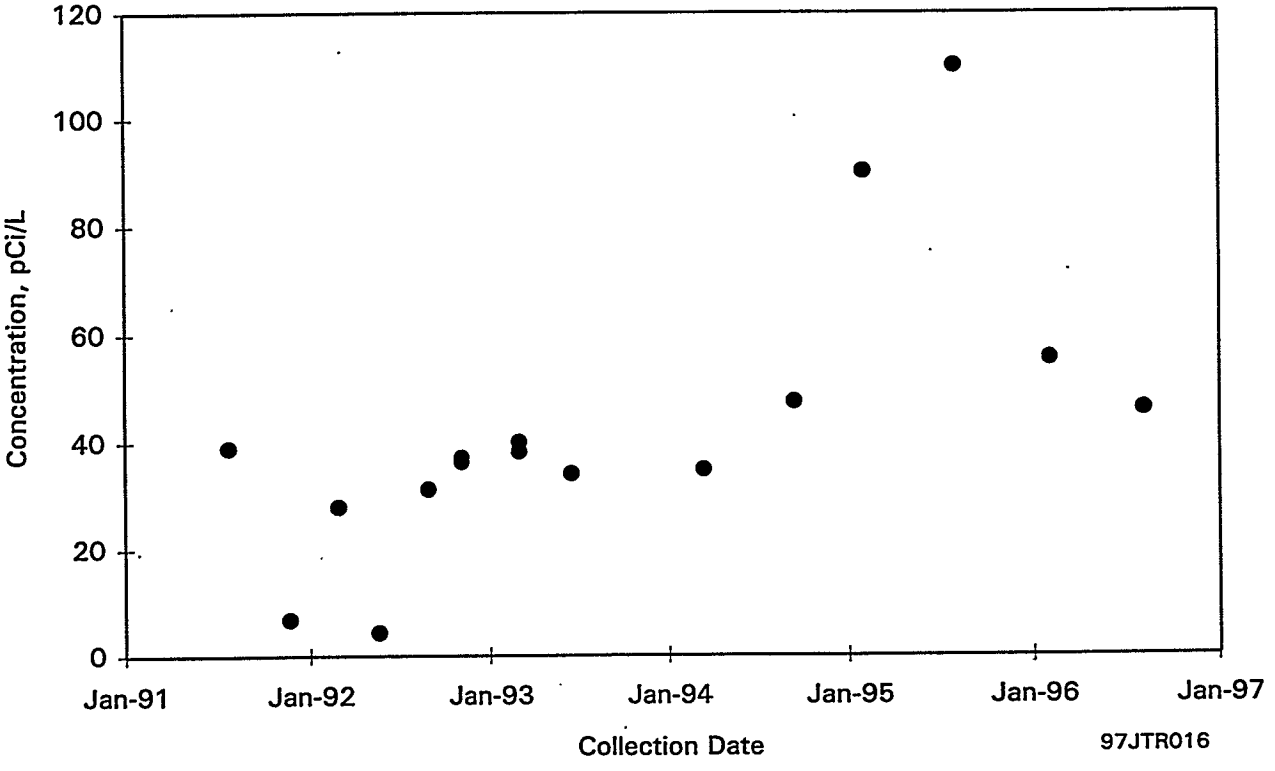


Figure 6.10-18. Technetium-99 Concentrations in Well 299-E24-19

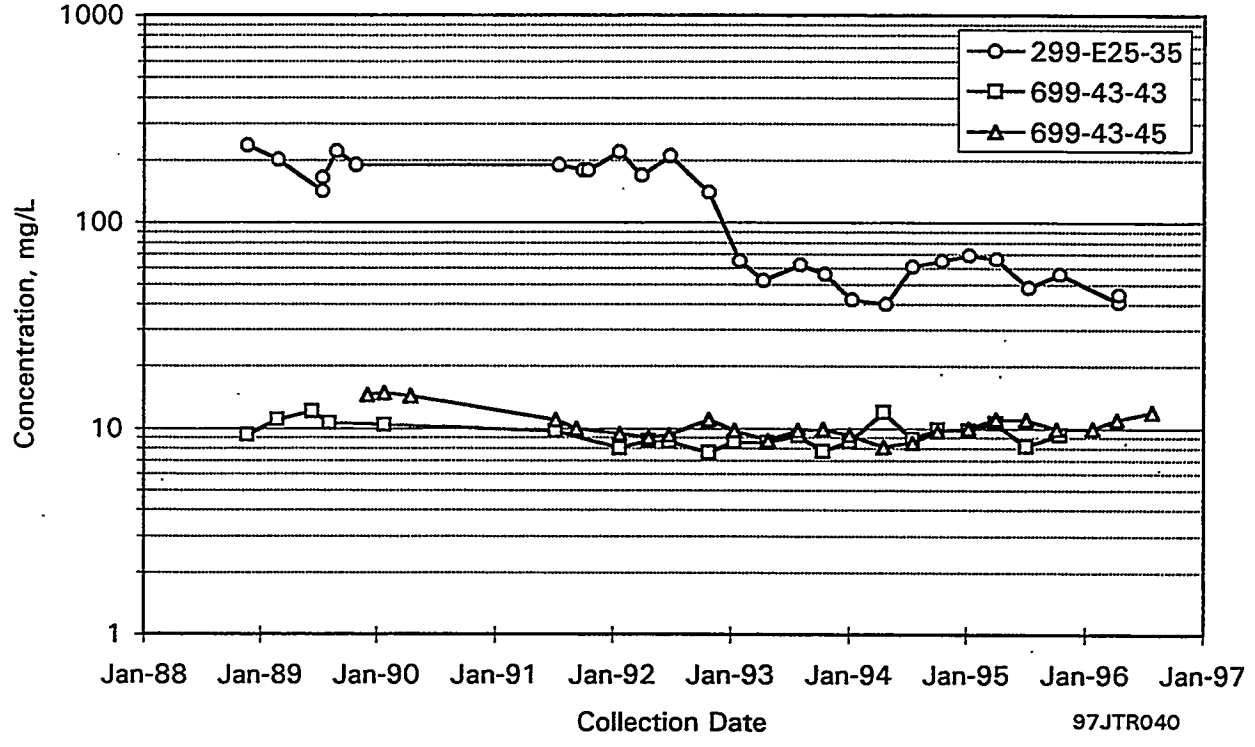


Figure 6.10-19. Sulfate Concentrations in 200-East Area Wells

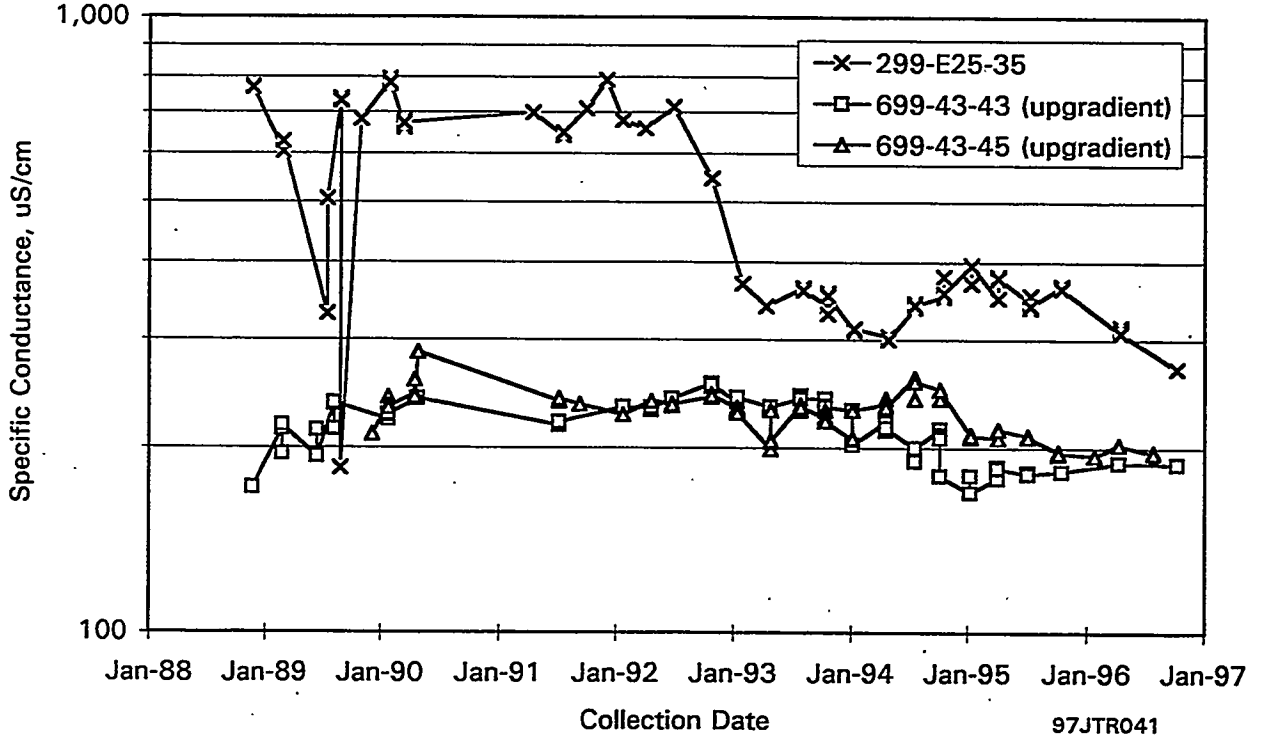


Figure 6.10-20. Specific Conductance in 200-East Area Wells

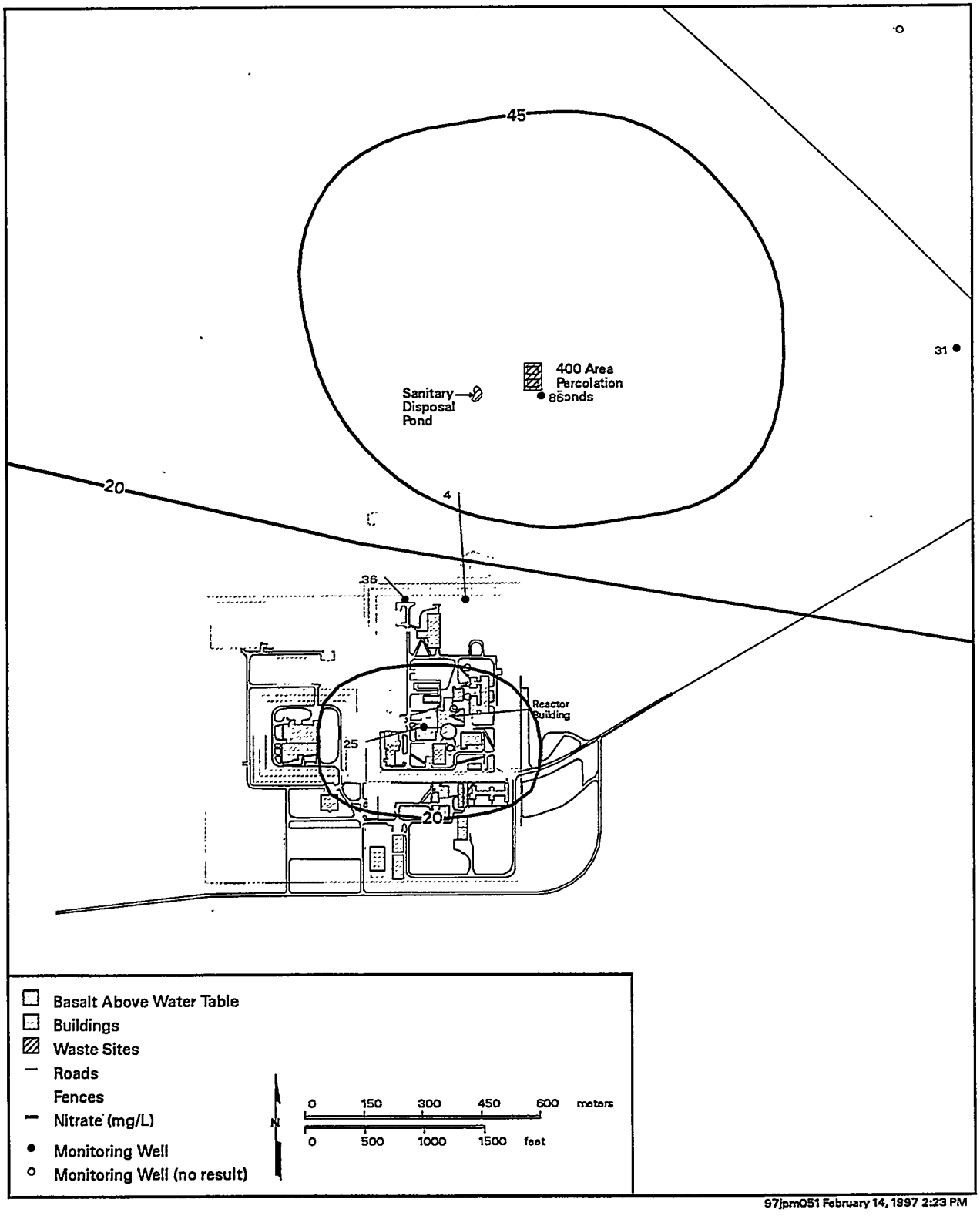


Figure 6.11-1. Average FY 1996 Nitrate Concentrations in 400 Area Wells

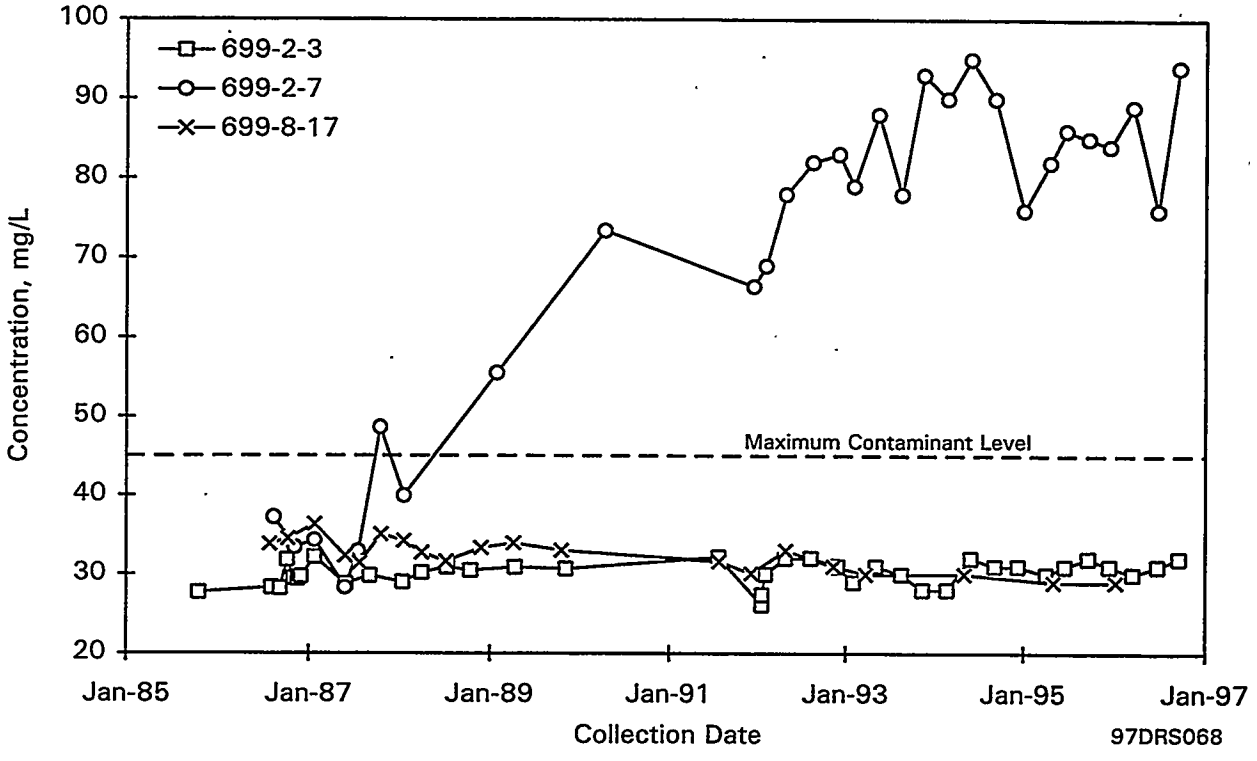


Figure 6.11-2. Nitrate Concentrations in 600 Area Wells Near the 400 Area

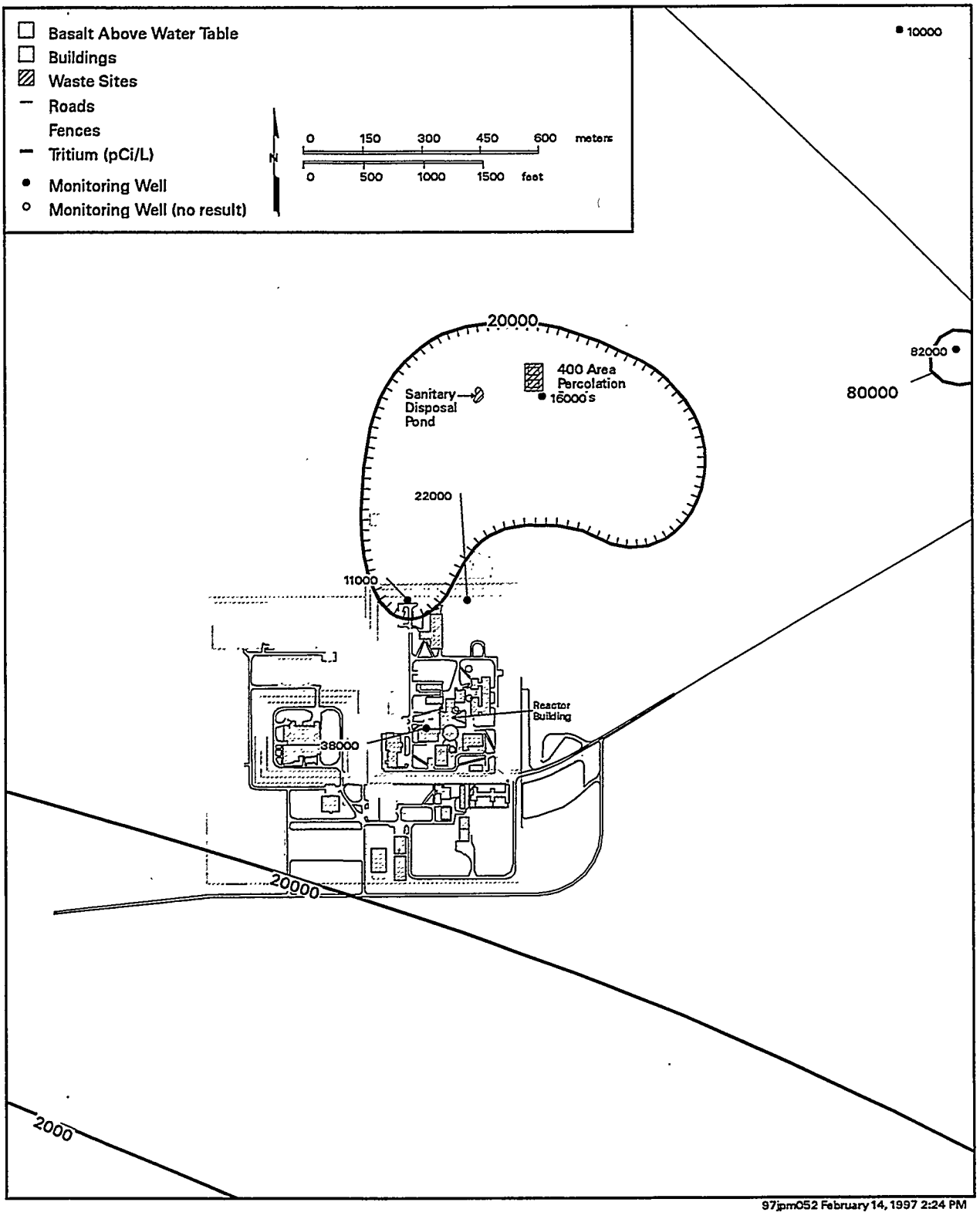


Figure 6.11-3. Average FY 1996 Tritium Concentrations in 400 Area Wells

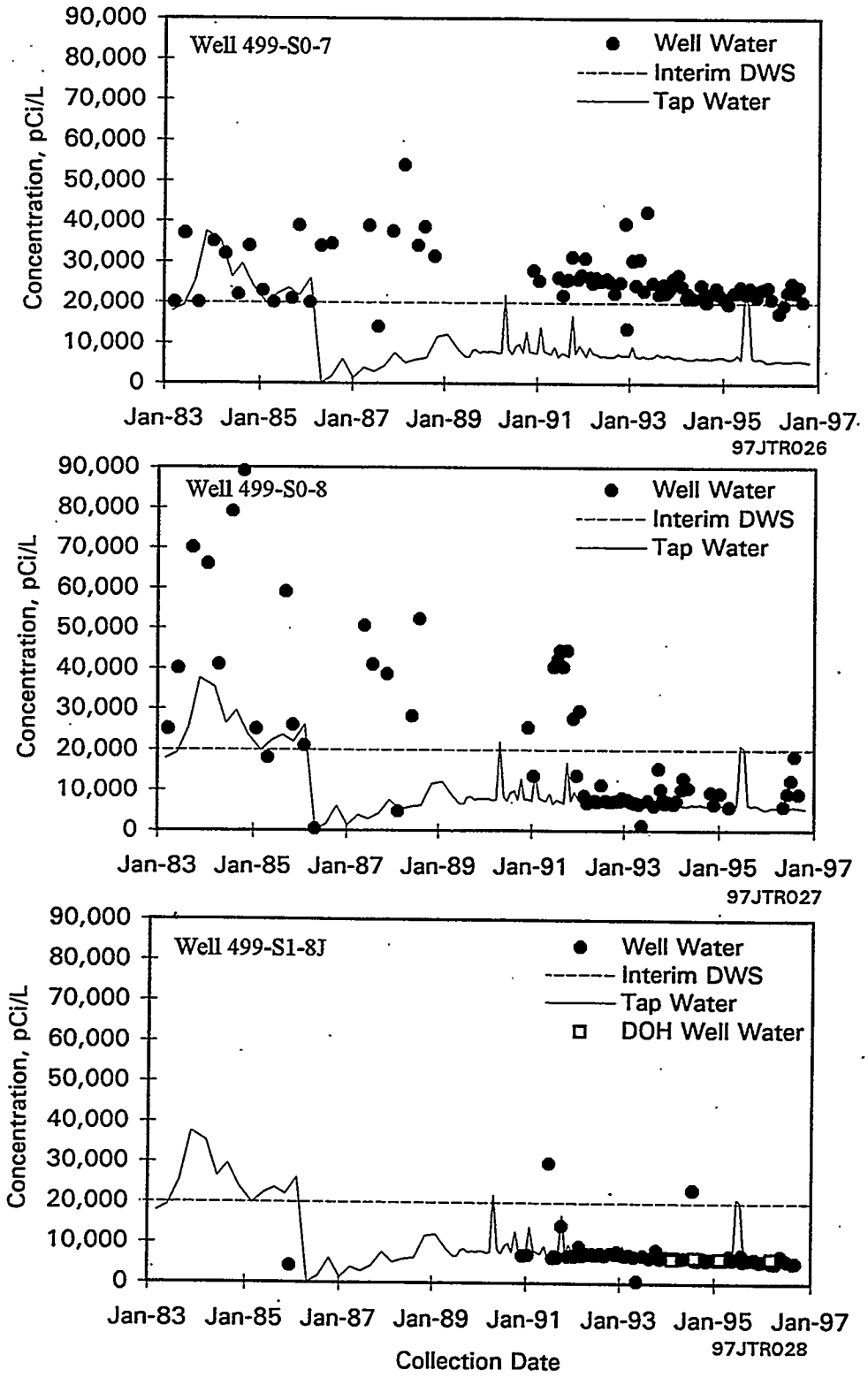


Figure 6.11-4. Comparison of Tritium Trends in 400 Area Drinking Water System (DOH = State of Washington Department of Health)

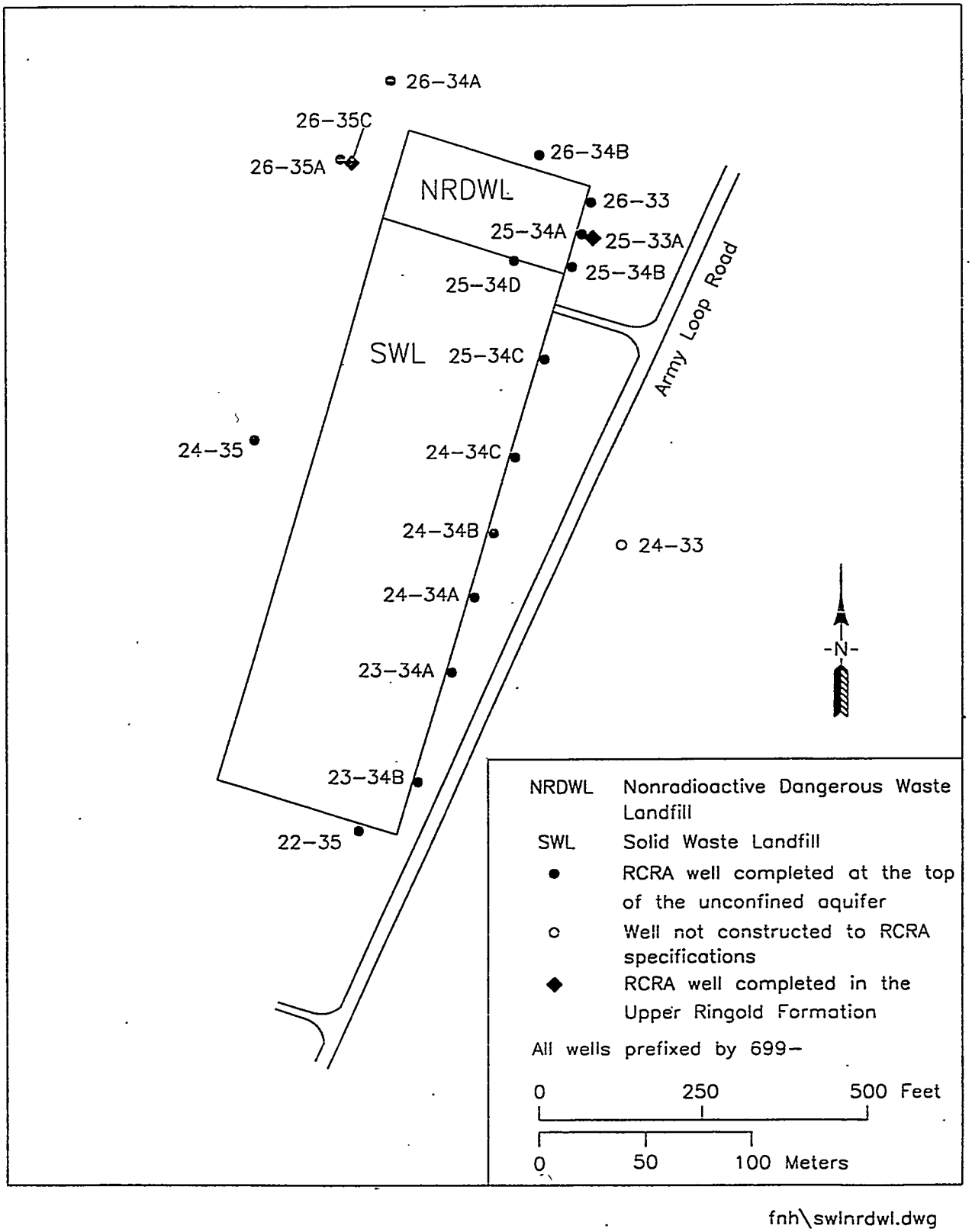


Figure 6.12-1. Solid Waste Landfill and Nonradioactive Dangerous Waste Landfill Monitoring Well Network

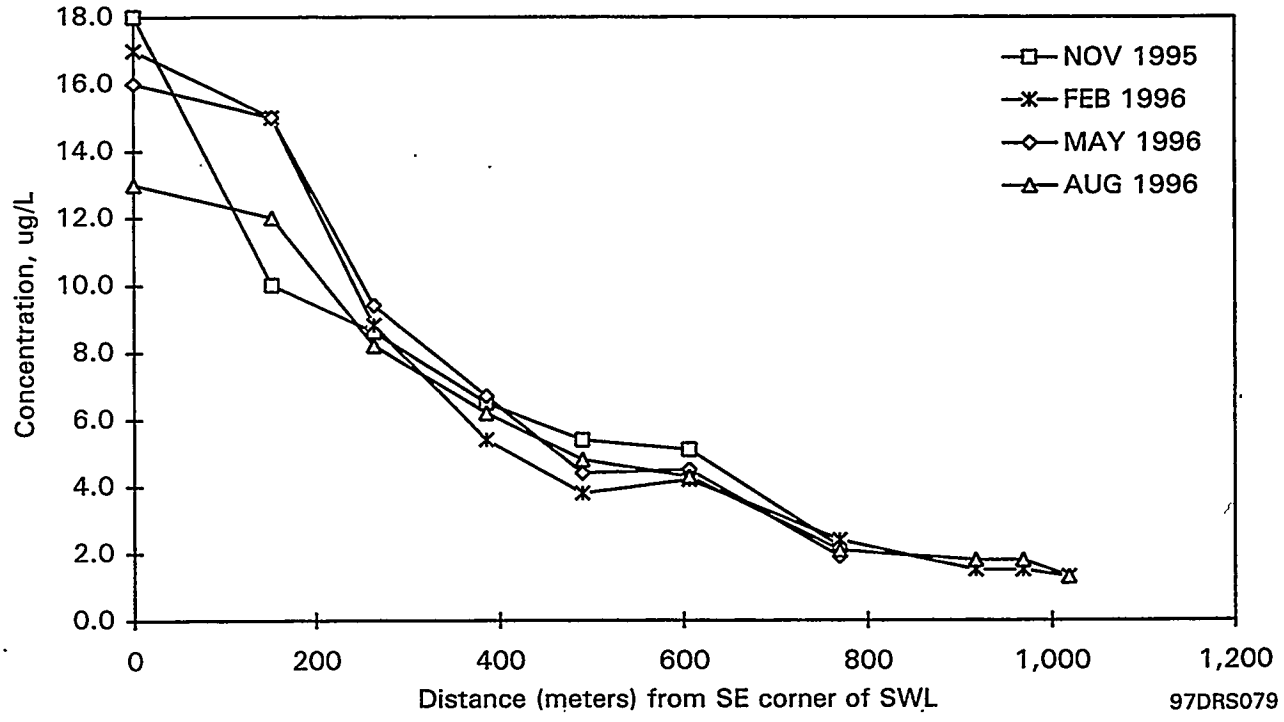


Figure 6.12-2. 1,1,1-Trichloroethane Concentrations in Wells Monitoring Solid Waste Landfill

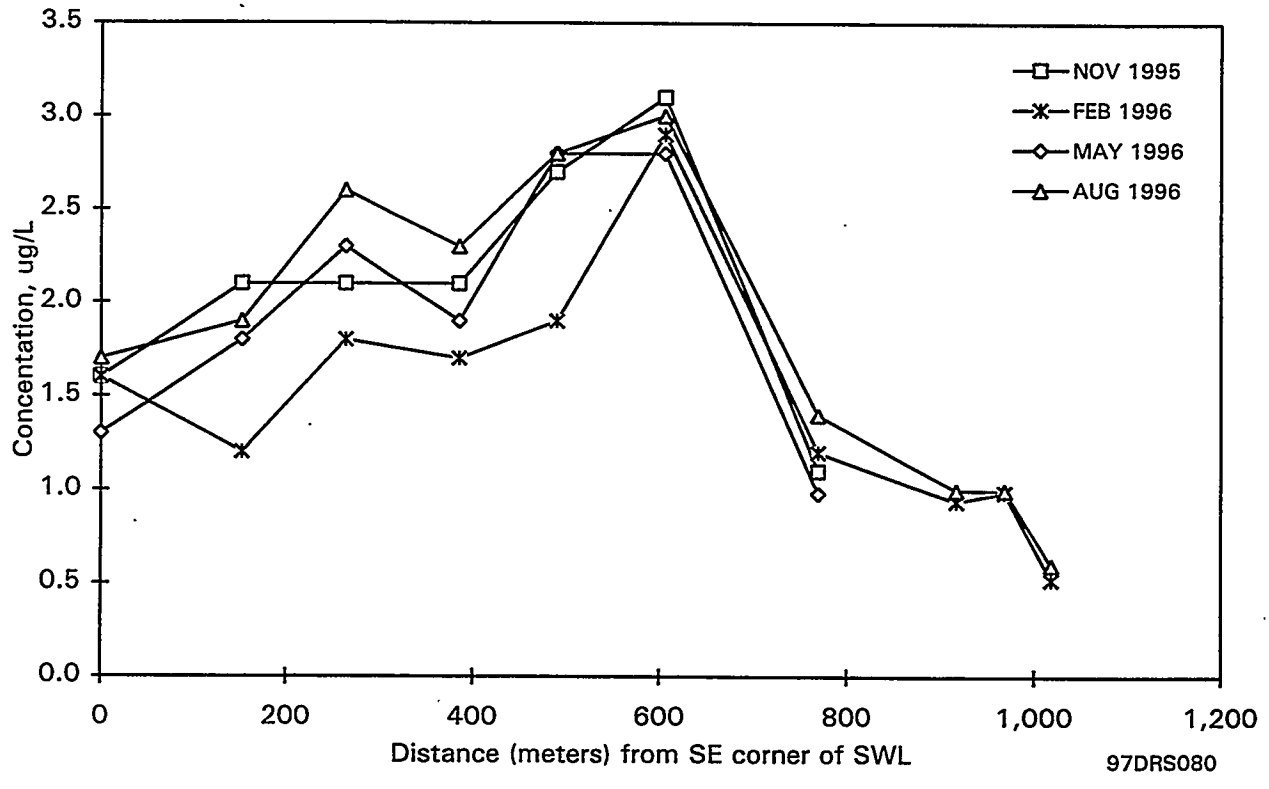


Figure 6.12-3. Tetrachloroethylene Concentrations in Wells Monitoring Solid Waste Landfill

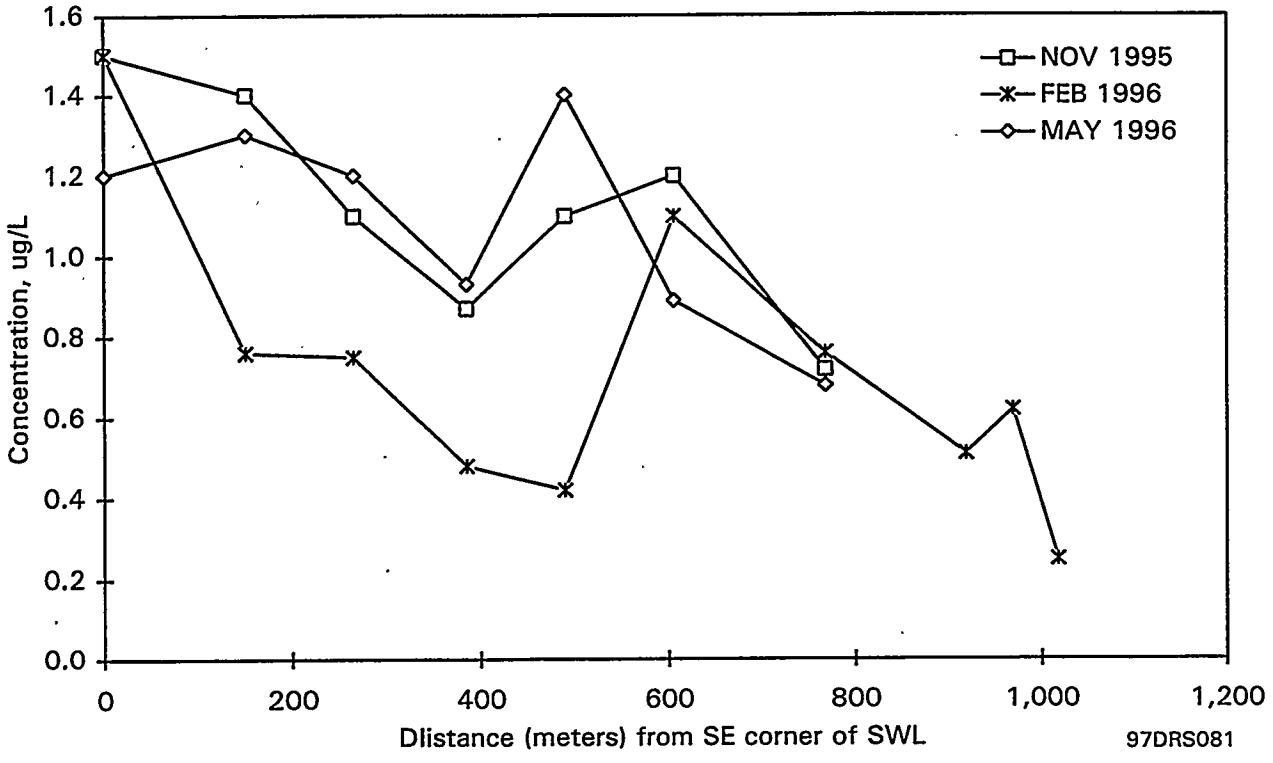


Figure 6.12-4. Trichloroethylene Concentrations in Wells Monitoring Solid Waste Landfill

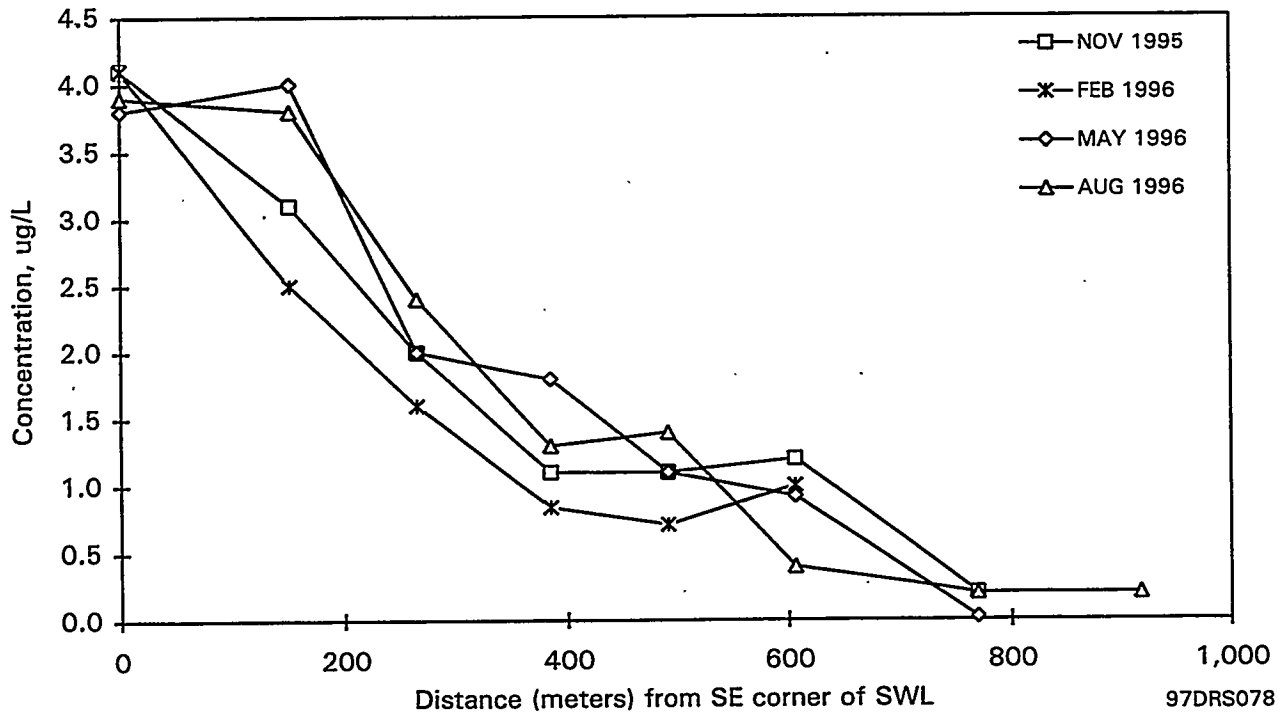


Figure 6.12-5. 1,1-Dichloroethane Concentrations in Wells Monitoring Solid Waste Landfill

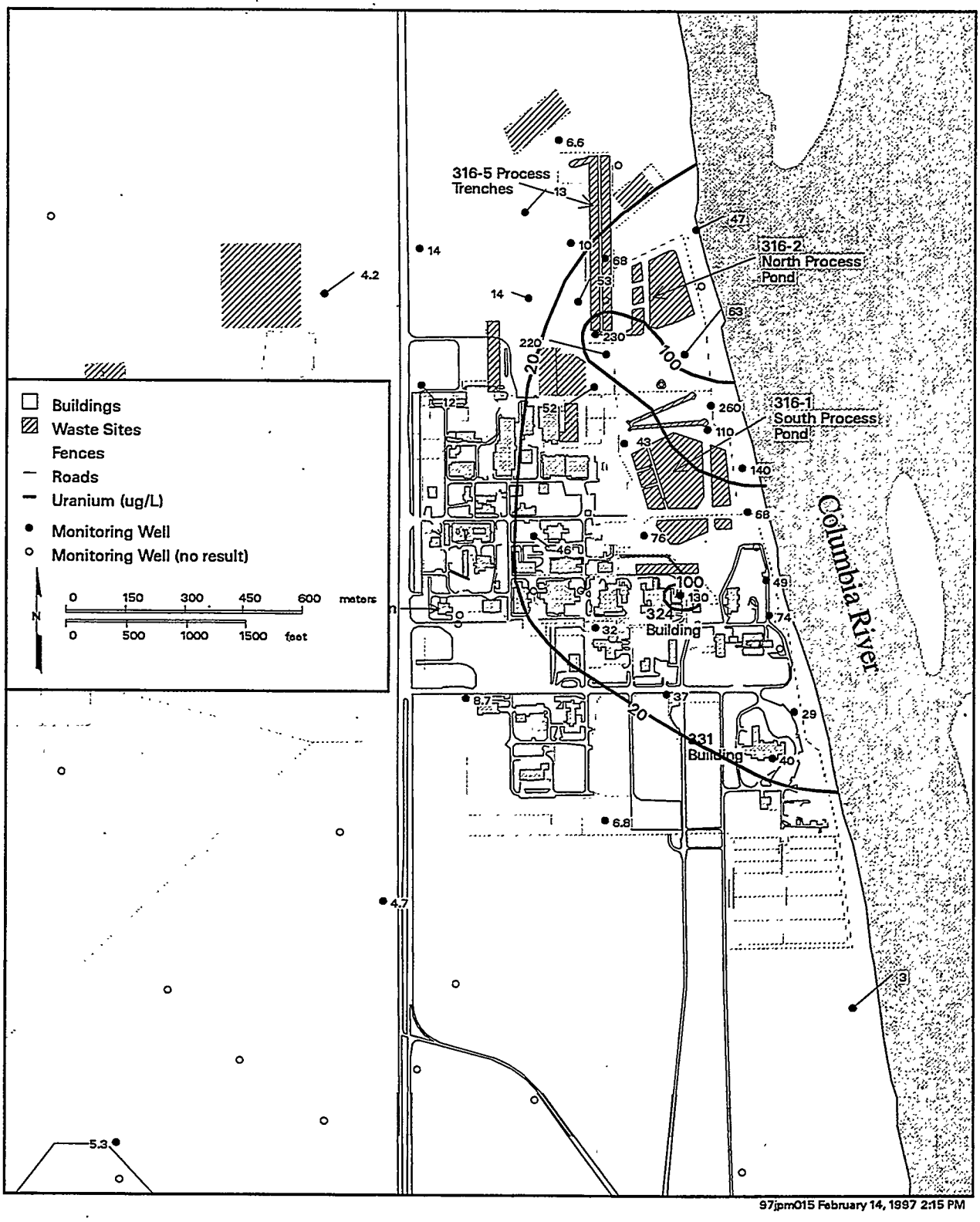


Figure 6.13-1. Average FY 1996 Uranium Concentrations in 300 Area

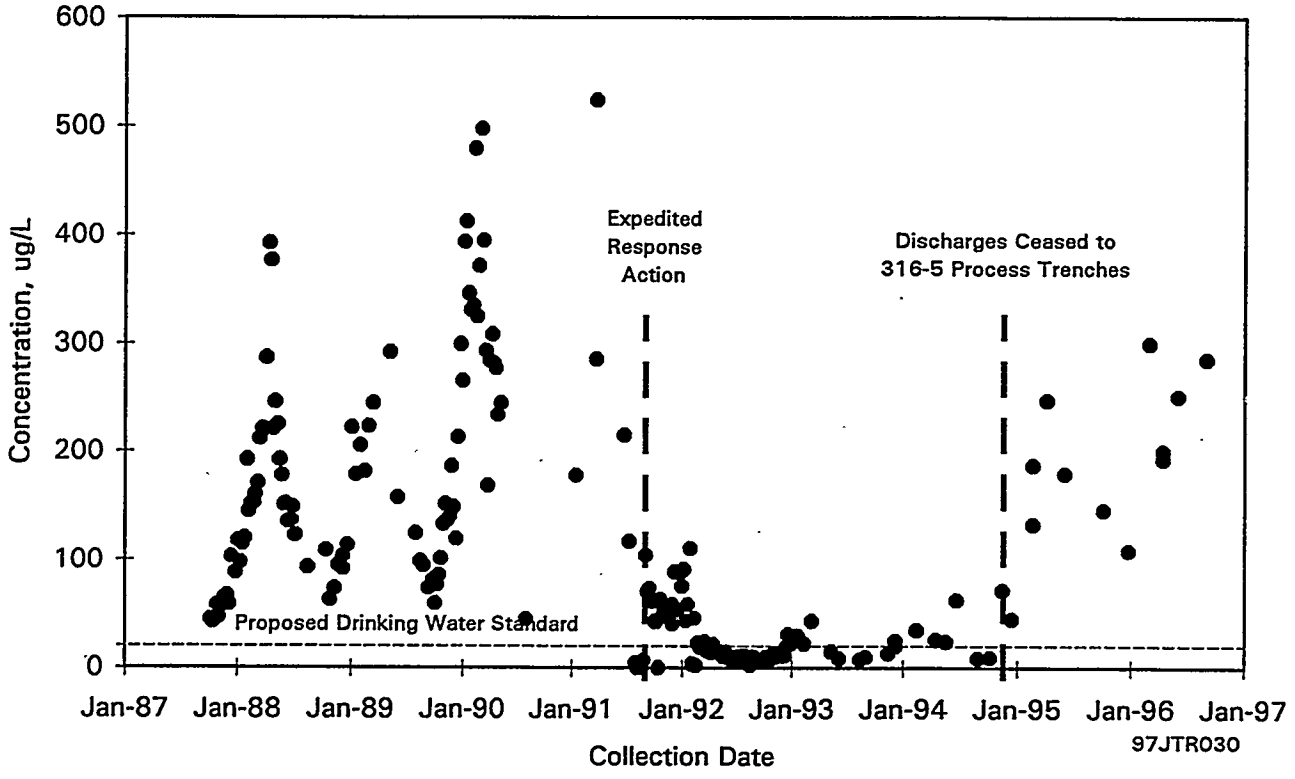


Figure 6.13-2. Uranium Concentrations in Well 399-1-17A

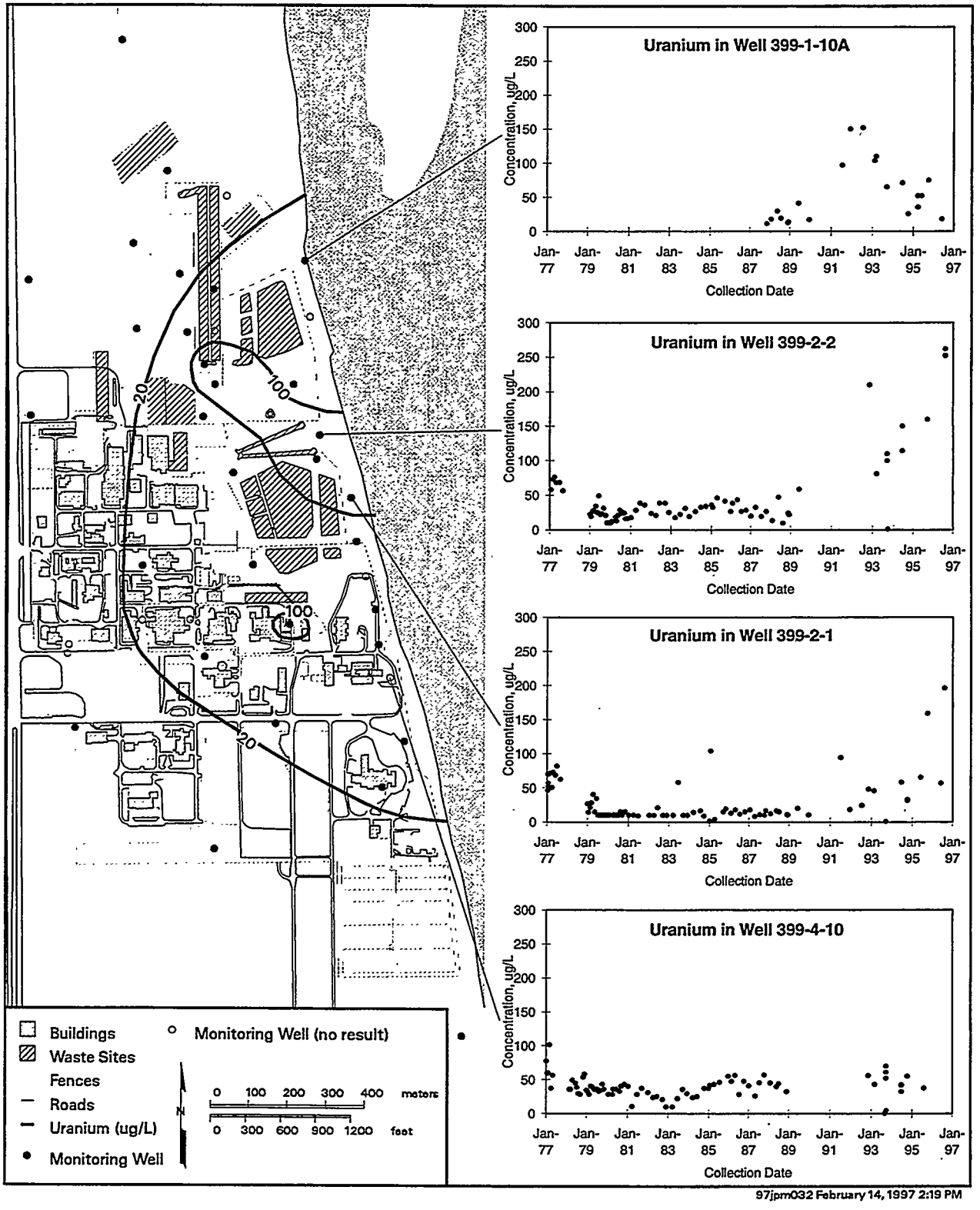


Figure 6.13-3. Uranium Concentrations in Unconfined Aquifer-Monitoring Wells in 300 Area

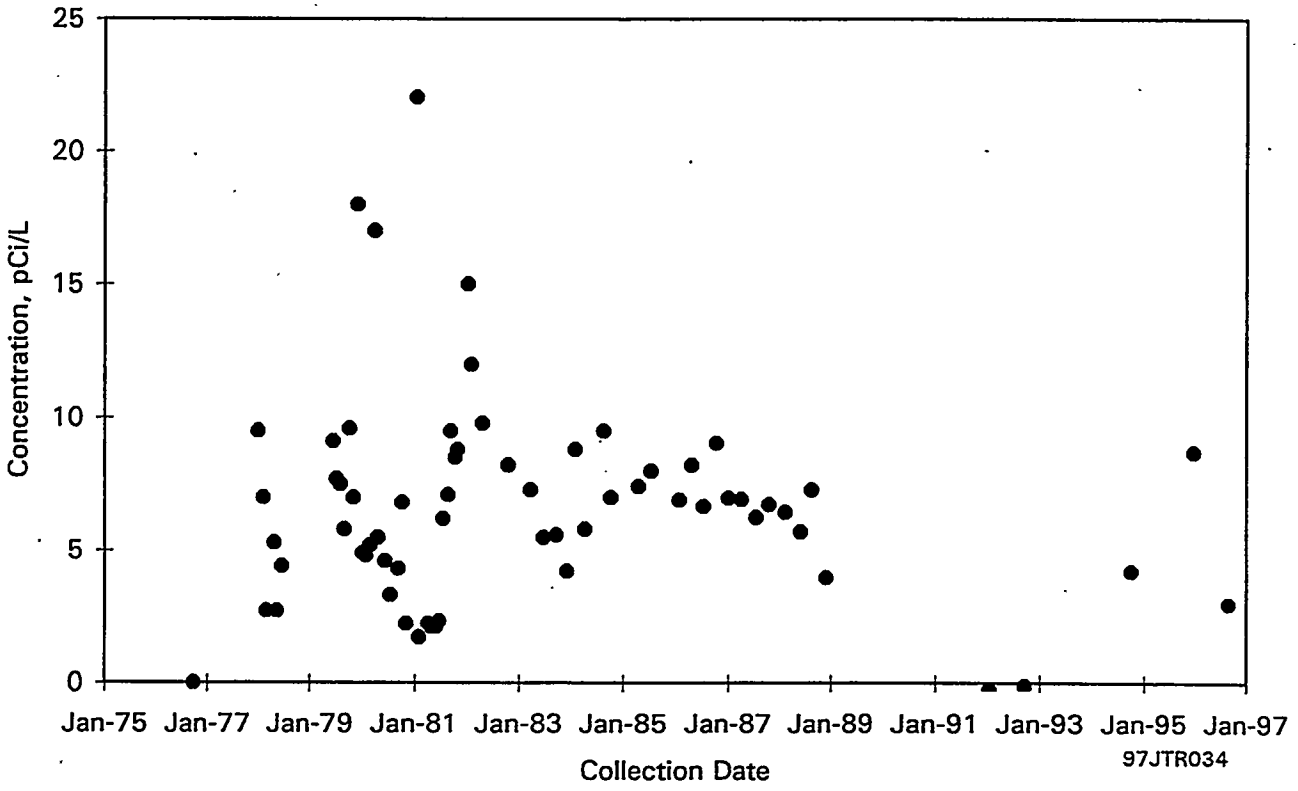


Figure 6.13-4. Strontium-90 Concentrations in Well 399-3-11

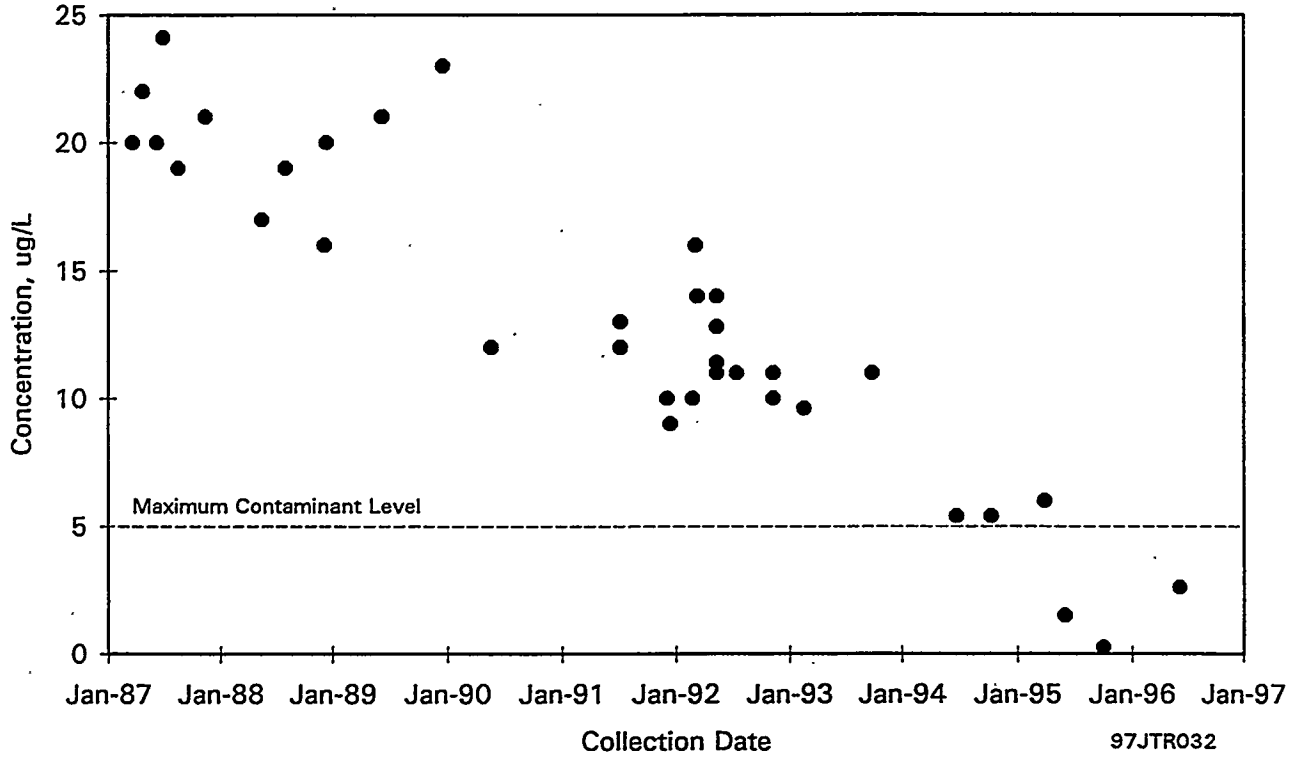


Figure 6.13-5. Trichloroethylene Concentrations in Well 399-1-16B

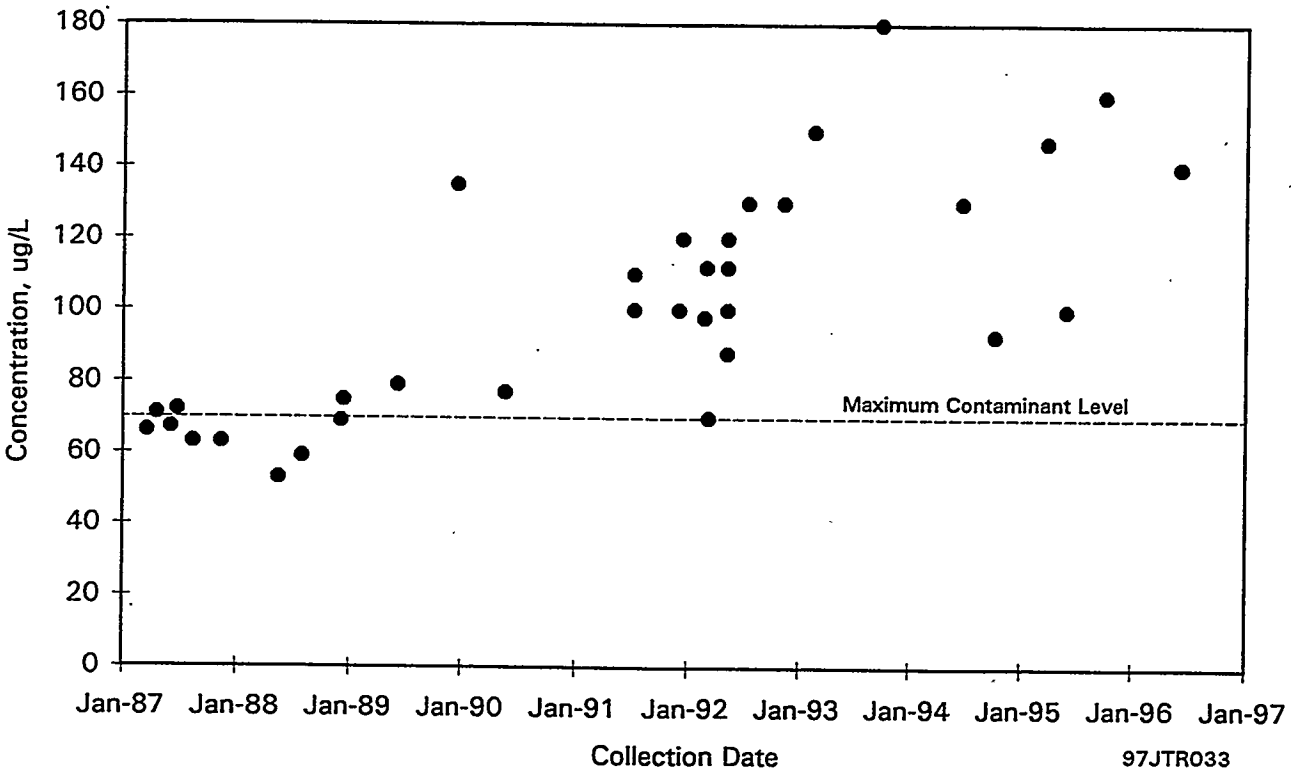


Figure 6.13-6. cis-1,2-Dichloroethylene Concentrations in Well 399-1-16B

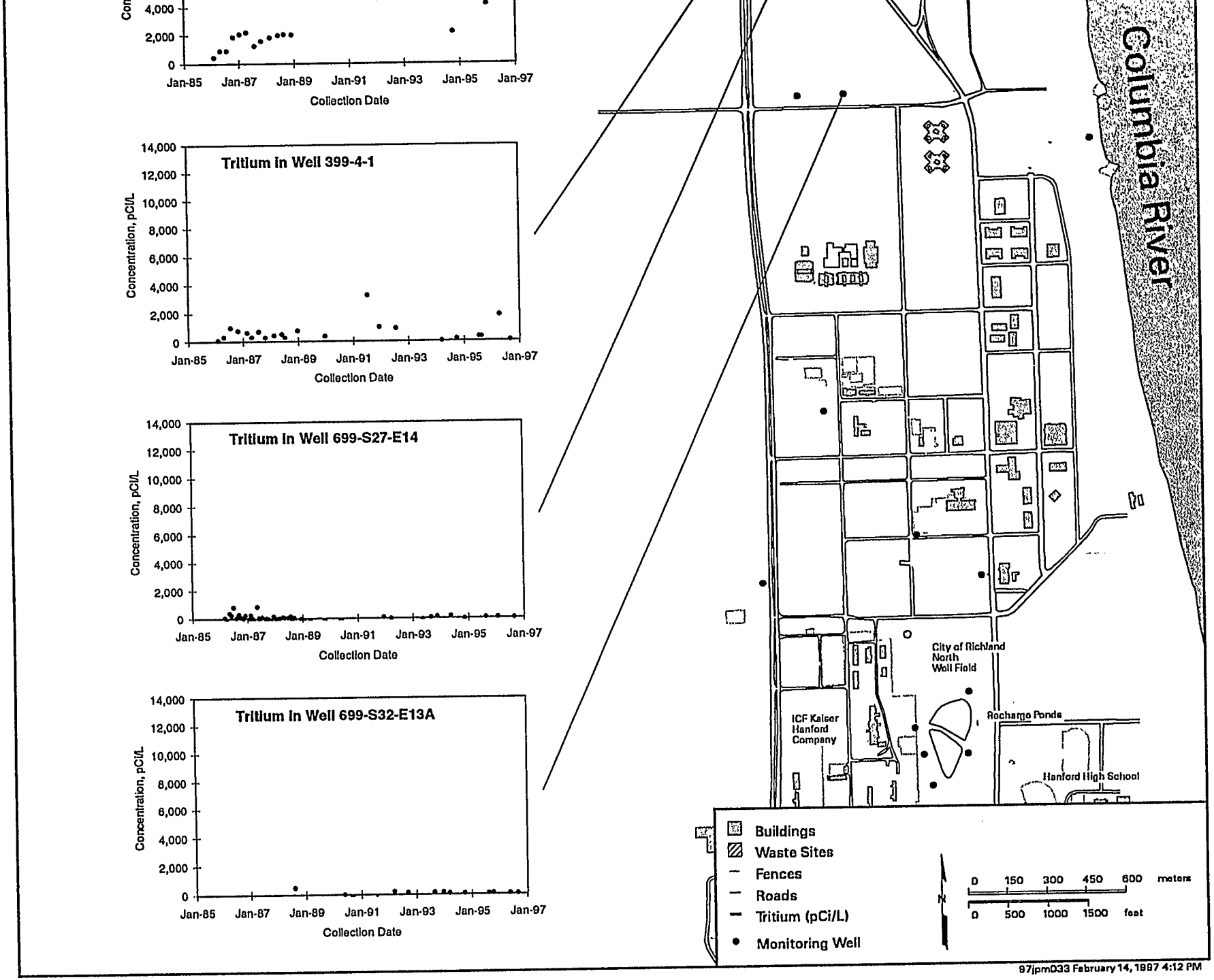
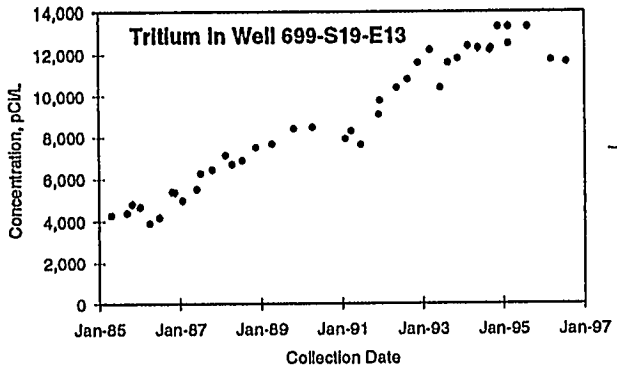
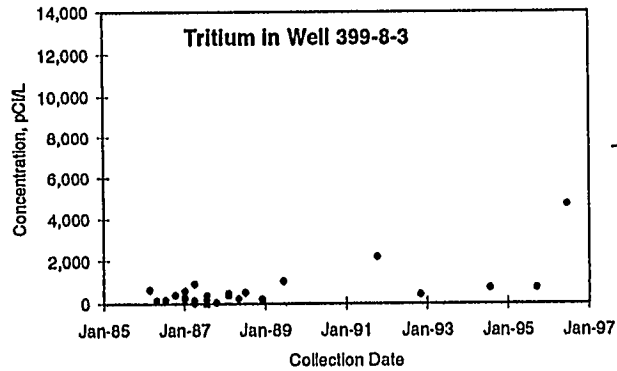
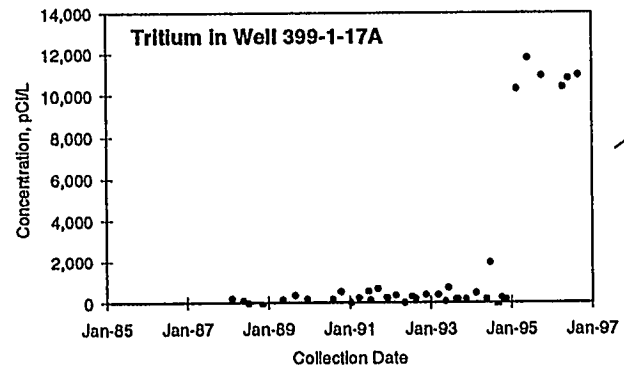


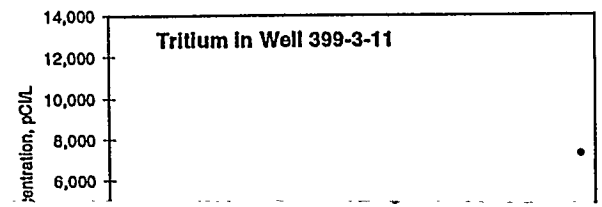
Figure 6.14-1. Tritium Concentrations in Unconfined Aquifer-Monitoring Wells in 300 and Richland North Areas

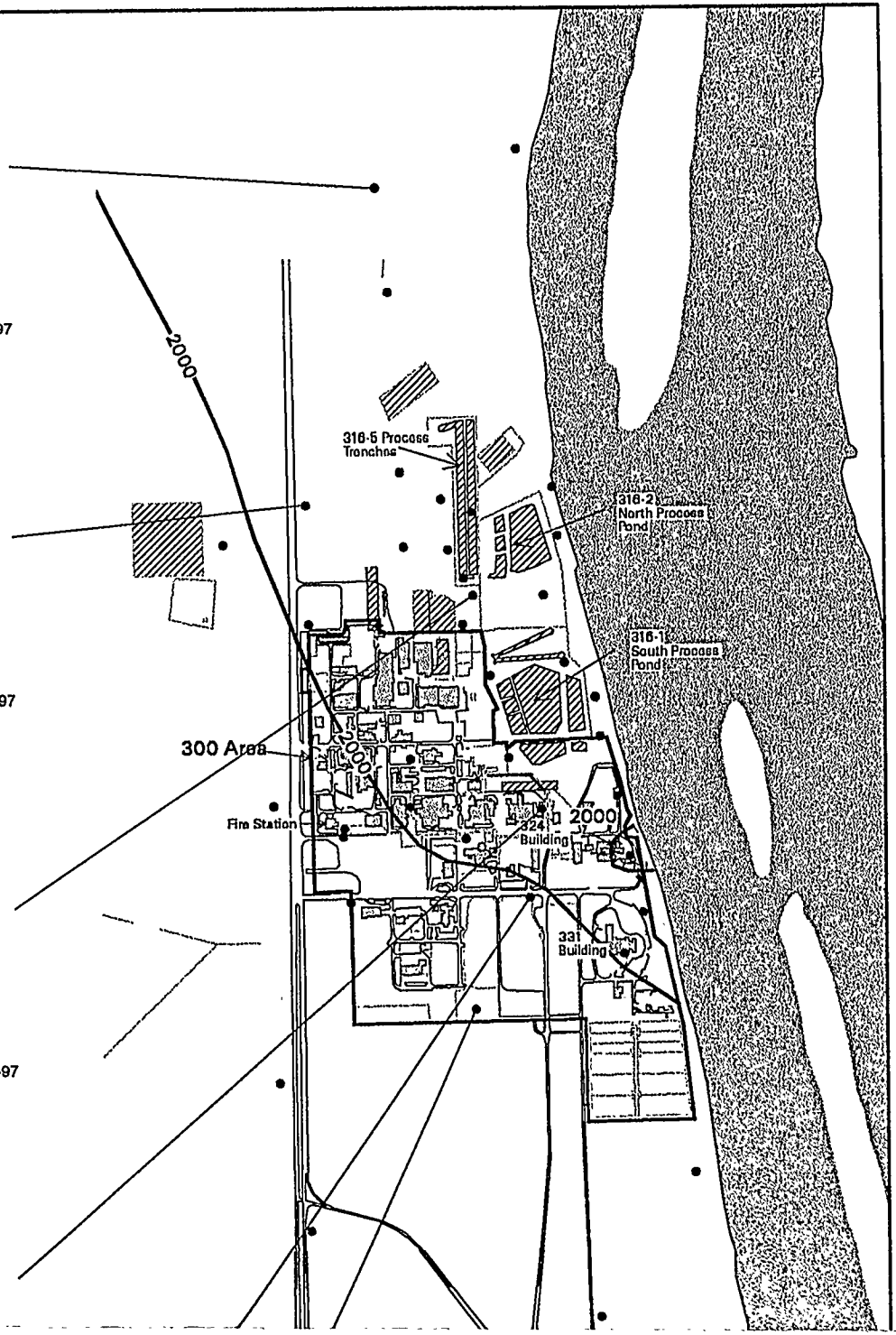
nd

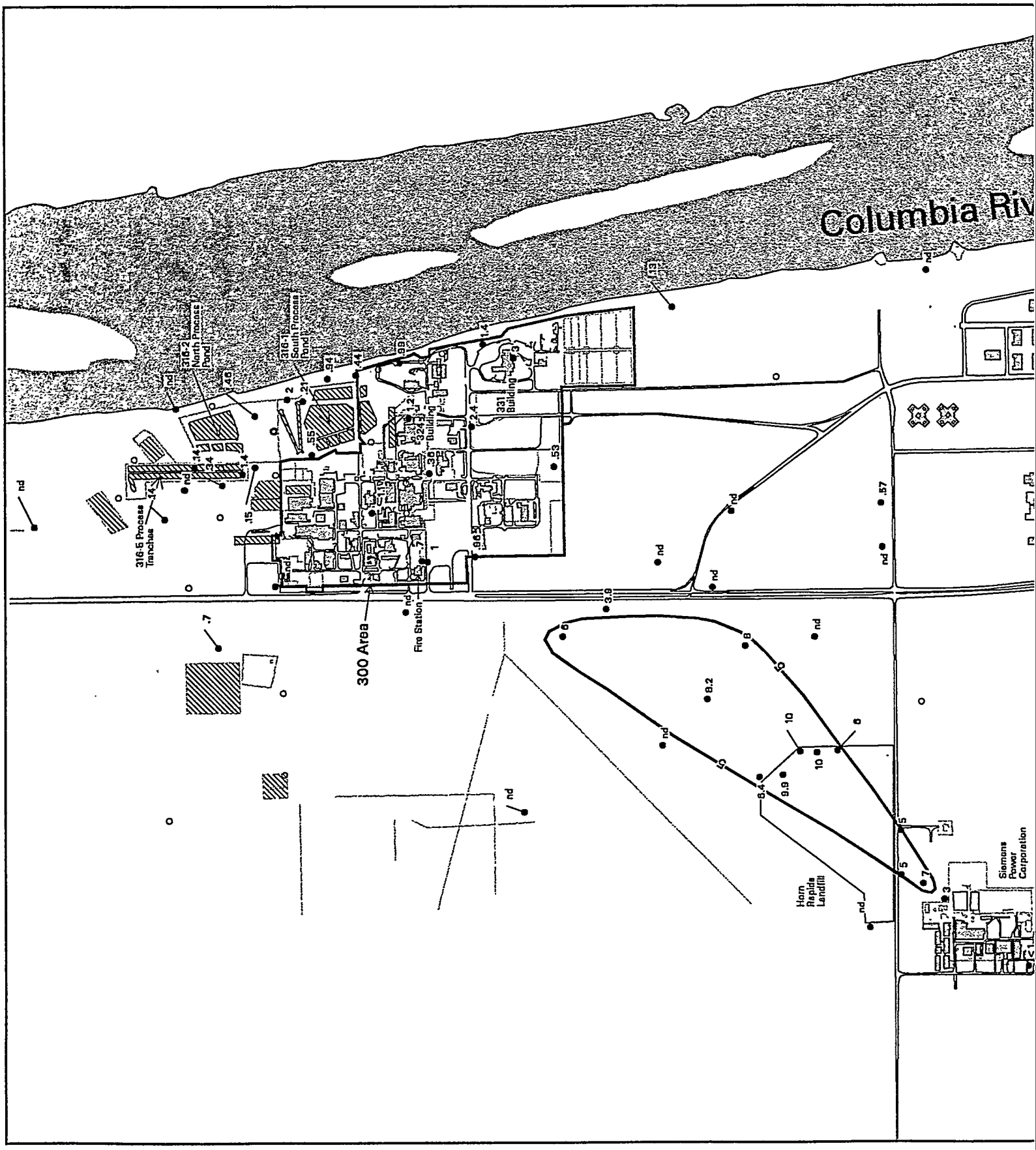

Tritium in Well 699-S19-E13
Concentration, pCi/L
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Collection Date


Tritium in Well 399-8-3
Concentration, pCi/L
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Collection Date


Tritium in Well 399-1-17A
Concentration, pCi/L
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan-85
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Collection Date


Tritium in Well 399-3-11
14,000
12,000
10,000
8,000
6,000


2000
316-5 Process Trenches
316-2 North Process Pond
316-1 South Process Pond
300 Area
2000
Fire Station
324 Building
2000
331 Building


Columbia Riv
316-2 North Process Pond
316-1 South Process Pond
316-5 Process Trenches
331 Building
324 Building
300 Area
Fire Station
Siemens Power Corporation
Horn Rapids Landfill
nd

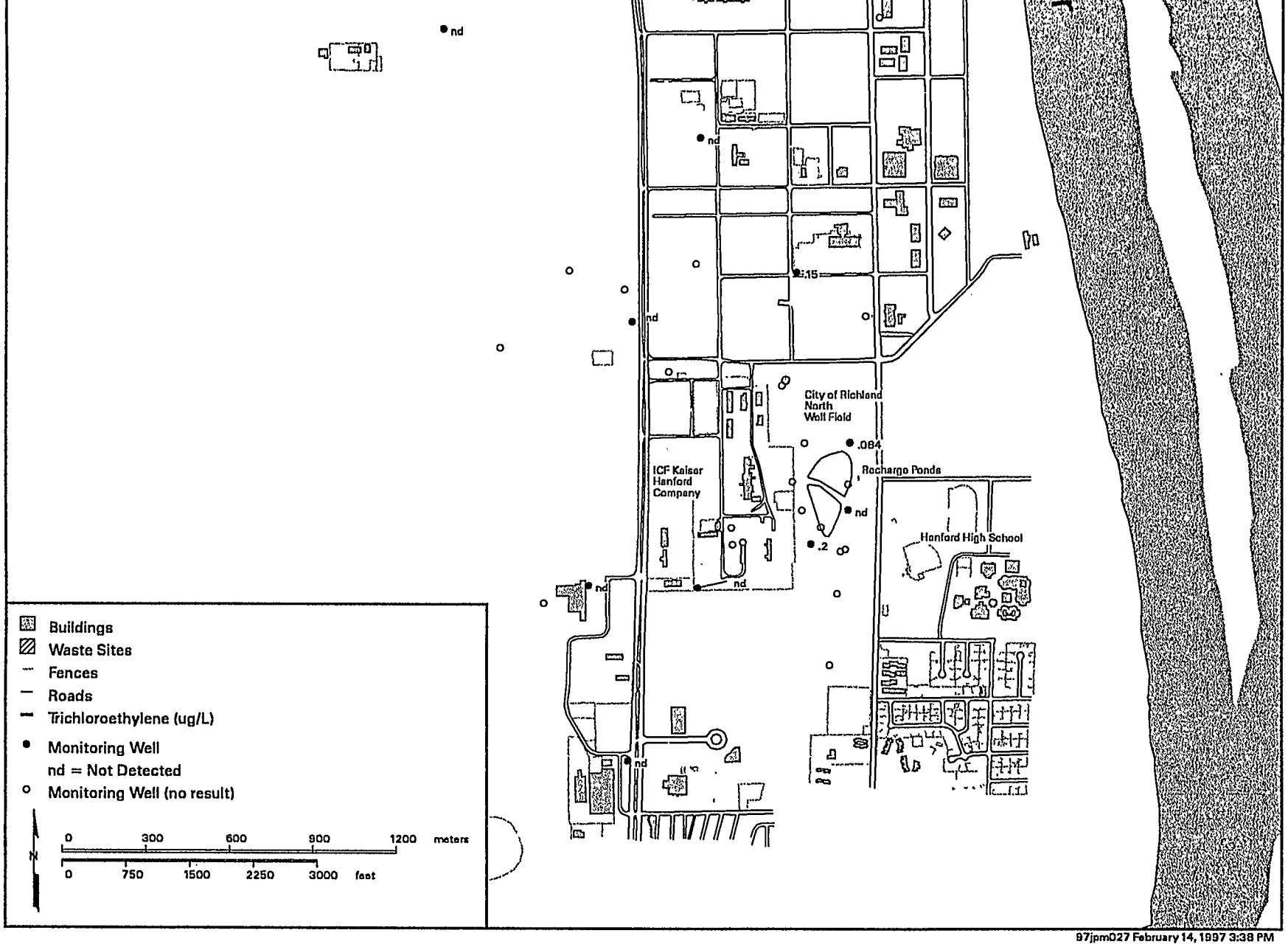


Figure 6.14-2. Average FY 1996 Trichloroethylene Concentrations in 300 and Richland North Areas

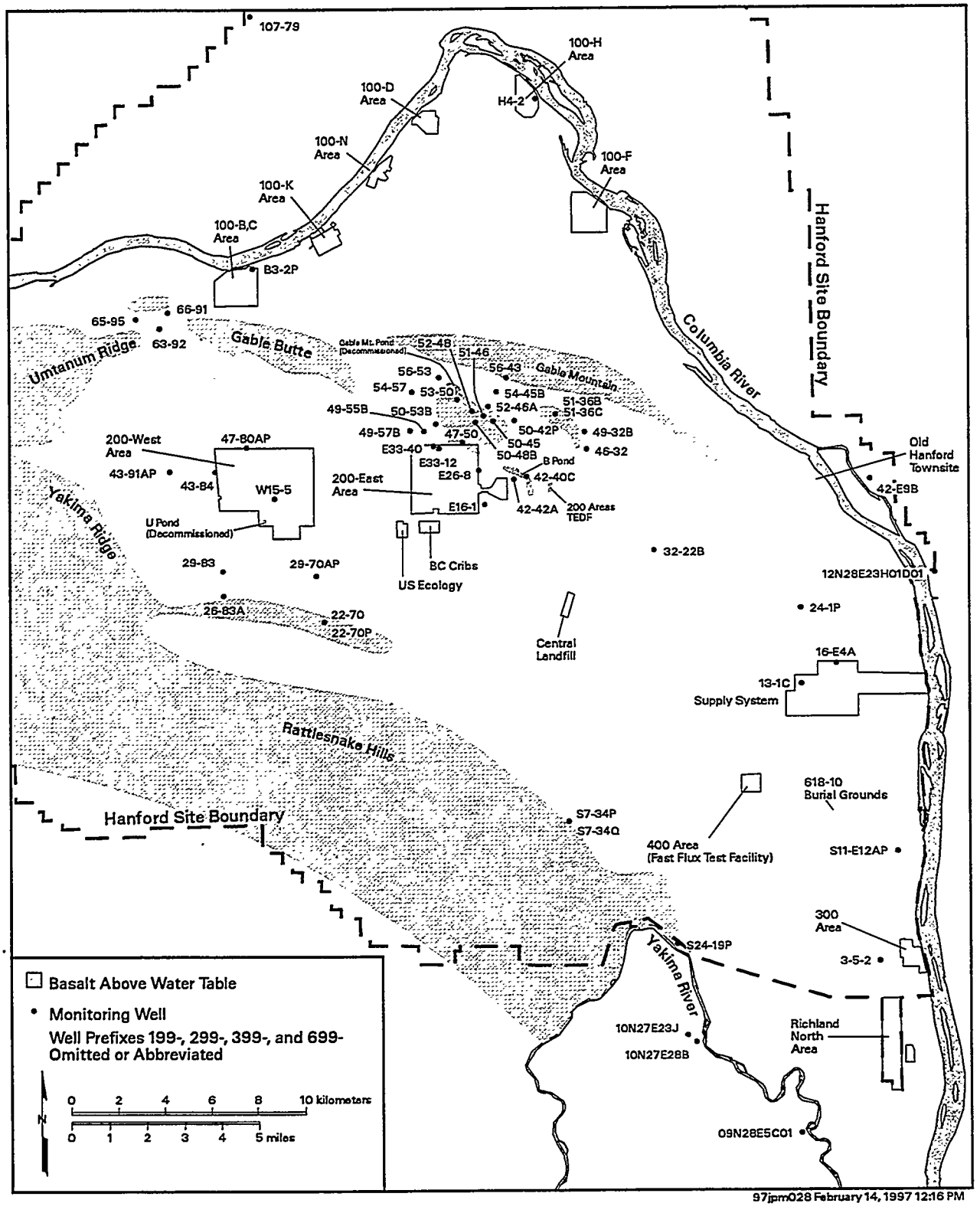


Figure 6.15-1. Hanford Site Map Showing Upper Basalt-Confined Aquifer Monitoring Wells

7.0 Groundwater Modeling

Modeling of groundwater flow and contaminant transport at the Hanford Site is performed for several different purposes. The Ground-Water Surveillance Project, managed by Pacific Northwest National Laboratory, uses models to predict future groundwater-flow conditions and to assess the potential for contaminants to migrate from the Hanford Site through the groundwater pathway. Models have also been used by the Environmental Restoration Contractor, Bechtel Hanford, Inc. (BHI), to provide a basis for prioritizing and optimizing environmental restoration activities. These are complex, large-scale models capable of simulating sitewide groundwater flow and contaminant transport. Simpler, smaller-scale models were used by BHI to support the design of site-specific groundwater-treatment projects.

During the past several years, a three-dimensional flow and transport model has been under development by the Ground-Water Surveillance Project to improve the simulation of groundwater flow and contaminant transport within the unconfined aquifer system. The model is based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code (Gupta et al. 1987). The model includes nine layers above the top of basalt to represent the major hydrogeologic units within the unconfined aquifer system.

The separate BHI modeling effort, with the objective of prioritizing and optimizing environmental restoration activities, was completed during FY 1996. Migration of eight radionuclide and chemical contaminant plumes over the next 200 years was simulated using a two-layer model based on the Variably Saturated Analysis Model in 3 Dimensions with Preconditioned Conjugate Gradient Matrix Solvers (VAM3DCG) code (developed by HydroGeoLogic, Inc., Herndon, Virginia). This modeling effort was initiated ~5 years ago to support development of the Hanford Sitewide Groundwater Remediation Strategy, which was required by Milestone M-13-81 in the *Hanford Federal Facility Agreement and Consent Order* (commonly referred to as the Tri-Party Agreement; Ecology et al. 1989).

BHI applied models based on the Micro-FEM© code (Hemker-vanElburg, Amsterdam, The Netherlands) and the FLOWPATH code (developed by Waterloo Hydrogeologic Software, Waterloo, Ontario) to design pump-and-treat operations in the 100 Areas and the 200-West Area. These models were used to support the design of the operations and to assess performance under operating conditions. The models were also used to describe the capture and injection zones for the extraction and injection wells, respectively, and to estimate the area affected by the pump-and-treat operations at different times.

7.1 CFEST Three-Dimensional Sitewide Model

S. K. Wurstner and P. D. Thorne

Information on the initial development of the three-dimensional CFEST model is available in Wurstner et al. (1995). The first transport simulations using this new model were performed during

FY 1996. The model was applied to predict the migration of tritium from the 200 Areas Effluent Treatment Facility (ETF; also referred to as the C-018H facility), which is located north of the 200-West Area. The model was also used to predict the future movement of existing tritium and iodine-129 plumes originating in the southeastern part of the 200-East Area. Preliminary modeling results are presented in the following sections; however, calibration and testing of this model are continuing and may result in different predictions.

7.1.1 Hydrogeologic Framework

To support development of the three-dimensional model, the lithofacies defined by Lindsey (1991) were regrouped into nine hydrogeologic units based on similarity in expected groundwater-flow properties, which correlate to texture and degree of cementation. Other geologic factors such as depositional environment, lithologic composition, and time of deposition were not considered in the definition of the model units. As discussed in Section 3.1.2, this grouping is similar but not identical to that of Lindsey (1991). A comparison of the model units and Lindsey's stratigraphic column was shown in Figure 3.2. The lateral extent and thickness distribution of each hydrogeologic unit were defined based on information from well driller's logs, geophysical logs, and an understanding of the geologic environment. These interpreted areal distributions and thicknesses were then integrated into EarthVision™ (Dynamic Graphics, Inc., Alameda, California), a three-dimensional visualization software package that was used to construct a database of the three-dimensional hydrogeologic framework.

7.1.2 Recharge and Flow-System Boundaries

Both natural and artificial recharge to the aquifer were incorporated in the model. Natural recharge to the unconfined aquifer system occurs from infiltration of: 1) runoff from elevated regions along the western boundary of the Hanford Site, 2) spring discharges originating from the basalt-confined aquifer system, and 3) precipitation falling across the site. Some recharge also occurs along the Yakima River in the southern portion of the site. Natural recharge from runoff and irrigation in Cold Creek Valley, upgradient of the site, also provides a source of groundwater inflow. As discussed in Section 3.2.1, areal recharge from precipitation on the site is highly variable, both spatially and temporally, and depends on local climate, soil type, and vegetation. The recharge map developed by Fayer and Walters (1995) (see Figure 3.5) was applied in the model.

The large volume of artificial recharge from wastewater discharged to disposal facilities on the Hanford Site over the past 50 years has significantly impacted groundwater flow and contaminant transport in the unconfined aquifer system. The volume of artificial recharge decreased significantly during the past 10 years and is continuing to decrease, as shown in Figure 5.3-2. Artificial recharge sources considered in the model are summarized in Table 7.1 for 1979, the time used for steady-state model calibration.

Flow-system and model boundaries are formed by the Columbia River on the north and east and by the Yakima River and basalt ridges on the south and west. Flow boundaries defined for the three-dimensional model are illustrated in Figure 7.1. The Columbia River represents a point of regional discharge for the unconfined aquifer system. The amount of groundwater discharging to the river is a

function of local hydraulic gradient between groundwater elevation along side and beneath the river. This hydraulic gradient is highly variable at any given time because the river stage is affected by seasonal variations in river flow and releases from upstream dams. To approximate the long-term effect of the Columbia River on the unconfined aquifer system in the three-dimensional model, the Columbia River was represented as a constant-head boundary over the entire thickness of the aquifer. The CHARIMA river-simulation model (Walters et al. 1994) was used to generate long-term average river-stage elevations for the Columbia River based on 1979 conditions. To represent its impact as a line of recharge to the modeled region, the Yakima River was also represented as a constant-head boundary over the entire thickness of the aquifer.

At Cold Creek and Dry Creek Valleys, the unconfined aquifer system extends westward beyond the boundary of the model. To approximate the groundwater flux entering the modeled area from these valleys, both constant-head and constant-flux boundary conditions were defined. A constant-head boundary condition was specified for Cold Creek Valley for the steady-state model calibration runs. Once calibrated, the steady-state model was used to calculate the flux condition that was then used in the transient simulations. The constant-flux boundary was used because it better represents the response of the boundary to a declining water table than a constant-head boundary. Discharges from Dry Creek Valley in the model area, resulting from infiltration of precipitation and spring discharges, are approximated with a prescribed-flux boundary condition.

The uppermost units of basalt underlying the unconfined aquifer system represent a lower boundary to the unconfined aquifer system. The potential for interflow (recharge and discharge) between the basalt-confined aquifer system and the unconfined aquifer system is largely unquantified but is postulated to be small relative to the other flow components estimated for the unconfined aquifer system. Therefore, interflow with underlying basalt units was not included in the current three-dimensional model.

7.1.3 Steady-State Three-Dimensional Flow Model

The three-dimensional flow model was developed and calibrated based on the transmissivity distribution from the updated two-dimensional inverse-model calibration. This transmissivity distribution was shown in Figure 3.6. Information on hydraulic conductivities and thicknesses of the nine individual layers in the model was used to divide transmissivity between the layers. Hydrogeologic units below the unit containing the 1979 water table were assigned a constant hydraulic conductivity, while the hydrogeologic unit containing the 1979 water table was assigned a variable hydraulic conductivity that would preserve the total transmissivity from the inverse calibration. As illustrated in Figure 3.4, the water table is found in either Unit 1 or Unit 5 over most of the Hanford Site.

As in Wurstner et al. (1995), the database of geologic and hydrologic information was developed to be independent of the model grid. Thus, modifications to the finite-element grid (see Figure 7.1) could be easily made. Additional horizontal discretization of the model elements and vertical discretization of the hydrogeologic units were required for transport modeling to: 1) allow for appropriate specification of vertical distribution of initial contaminant distributions (initial conditions), 2) more accurately

represent flow-path curvature, and 3) minimize numerical dispersion. However, the extent of the vertical discretization had to be constrained to minimize the number of nodes and, thus, model run times.

7.1.4 Three-Dimensional Transient Flow Model

After a reasonable steady-state solution based on 1979 flow conditions was generated for the three-dimensional model, calibration of the response of the model to transient flux input was performed. Transient simulations with the two- and three-dimensional flow models required data on changes in artificial recharge. Artificial recharge sources were stored in ARC/INFO™ (Environmental Systems Research Institute, Inc., Redlands, California) format as volumes associated with the locations of effluent discharge sites. Calibration simulations were performed to evaluate the appropriate specific yield value to achieve the best overall match with observed water-table changes. The transient simulations were conducted for the 1980 to 1995 time frame, using a specific yield of 0.10 and 0.35. In most areas, the specific yield of 0.10 gave better results.

Transient simulations were then performed using a specific yield of 0.10 for the 1980 through 2050 time frame. The heads for the year 2050 predicted with the three-dimensional model are illustrated in Figure 7.2. The difference between the predicted water table in 2050 and in 1995 is shown in Figure 7.3. The maximum change in head over that time is a decrease of just over 6 m.

7.1.5 Transport Modeling

Simulation of contaminant transport for the selected applications summarized here made use of both the two-dimensional and three-dimensional flow and transport models. The two-dimensional flow and transport model was used to examine various transport issues and the effects of different transport properties. These simulations provided insight into the adequacy of the grid spacing for the transport simulations as well as the appropriateness of subregions selected. These simulations were conducted both with the refined grids nested in the regional CFEST model and as separate subregion models. Simulations were conducted for both the 200 Areas ETF and the existing 200-East Area tritium and iodine-129 plumes. The two-dimensional model results were then used to design the grid-refinement and transport parameters used in the application of the three-dimensional model. Sample results of the three-dimensional transport model are summarized below.

7.1.5.1 Tritium Transport from Effluent Treatment Facility

The subregion grid for the three-dimensional transport of tritium from the 200 Areas ETF (C-018H facility) is illustrated in Figure 7.4. The subregion encompasses most of the 200-West Area and extends to Gable Butte. This subregion was modeled with a feature of CFEST that allows definition of subregion models and transfer of boundary conditions to the subregion from the regional model. Thus, the flow conditions determined with the regional model were transferred as boundary conditions over time to the subregion model.

No initial tritium concentrations were included in the ETF subregion transport model. The only source of tritium in the subregion model was from the ETF. Disposal at the ETF began in 1995 and is projected to cease in 2015. Predicted concentration contours for 2015, when maximum plume concentrations occur, are illustrated in Figure 7.5. Figure 7.6 shows the predicted tritium plume contours in 2050, the end of the simulation period. Initial results also indicate that the tritium plume is expected to reach the bottom of the aquifer in the vicinity of the ETF. However, this initial model result is dependent on assumptions made in the model and is currently being evaluated through a sensitivity analysis to understand how the predicted vertical depth of the plume is influenced by dispersivity and vertical discretization.

7.1.5.2 Transport of the 200-East Area Tritium Plume

The subregion for three-dimensional transport modeling of the tritium plume located east and southeast of the 200-East Area is illustrated in Figure 7.7. The subregion extends to the Columbia River.

Initial 1995 tritium concentrations were assigned only to the uppermost layer of the subregion model to approximate the current understanding that the bulk of contamination is found in the uppermost 5 to 10 m in the aquifer. However, vertical movement of tritium over time through the model layers could occur in the simulations. The source terms for tritium input to the model were generated from discharge records available for the site. As with the discharge volumes, the source terms were assigned as yearly averages for each of the facilities.

Figures 7.8 and 7.9 show model-predicted concentration contours for the 200-East Area tritium plume for 1995 and 2050, respectively. The three-dimensional model of tritium transport from the 200-East Area demonstrates that the plume is transported to and discharges into the Columbia River in much the same way as discussed for the two-dimensional model. Radioactive decay decreases the size of the plume with time. The prediction for 1995 with the three-dimensional subregion model (see Figure 7.8) compares well with observed conditions. The observed 200,000-pCi/L contour encompasses a smaller area, but review of the monitoring well data (Dresel et al. 1996) shows that some of the wells outside that contour have measured concentrations close to 200,000 pCi/L.

7.1.5.3 Transport of the 200-East Area Iodine-129 Plume

The subregion used for three-dimensional iodine-129 transport was the same as that used for the three-dimensional 200-East Area tritium plume. The iodine-129 transport simulation was conducted as an initial value problem, starting with observed 1995 concentrations with no additional sources of iodine-129 release. Iodine-129 was assumed to move as a conservative constituent (i.e., a distribution coefficient of zero was assumed). The predicted 2050 distribution of iodine-129 coming from the southeastern part of the 200-East Area is shown in Figure 7.10.

7.2 VAM3DCG Sitewide Model

L. C. Swanson

The *Hanford Site Groundwater Remediation Strategy* (DOE 1995a) establishes overall goals for groundwater remediation. To support development of this strategy and aid in environmental remediation planning, a modeling study was conducted to predict the movement of eight Hanford Site contaminant plumes over the next 200 years. This activity was completed in FY 1996. The following discussion is a summary of this modeling effort. A more detailed description is available in Law et al. (1996) and Chiaramonte et al. (1996).

Under the auspices of two Tri-Party Agreement milestones (DOE 1991e, 1991f) and through a cooperative effort by the U.S. Department of Energy (DOE), onsite contractors, and a regulator committee, the VAM3DCG code was selected for this analysis. The code is a three-dimensional, finite-element model and was selected for the following reasons:

- The solution algorithms are robust, and the original developer, an internationally recognized expert, was available.
- The code efficiently simulates a fluctuating free-water surface, which makes it especially attractive for Hanford Site applications.
- The code is able to deal with transitional elements, which permit the grid to be refined in regions of interest or steep gradient.

7.2.1 Model Description

The modeled region covered ~971 km^2, including the Hanford Site, and was bounded by Rattlesnake Mountain to the southwest, Cold and Dry Creeks to the west, and Columbia River to the north and east. The model domain consisted of the unconfined aquifer system, with the Ringold Formation as the lower unit and the pre-Missoula/Hanford formation as the upper unit (where it exists). The model accounted for artificial recharge. Communication between the modeled unconfined aquifer and the underlying confined aquifer systems was assumed to be negligible, as was areal recharge over the site because of precipitation. Additional details on the geologic and hydrogeologic conceptual model of the flow system are available in Law et al. (1996).

7.2.2 Model Calibration

The groundwater-flow portion of the model was calibrated to both steady-state and transient groundwater-flow conditions. The steady-state flow was calibrated to 1979 conditions, and the transient period was run for 14 years (from 1980 through 1993). Calibration of groundwater flow was confirmed by simulating tritium transport, with several flow simulations used to calibrate the model to where it reasonably emulated observed water levels. Over the period of simulation, the model was in reasonable agreement with measured values.

7.2.3 Selected Model Results

A hydraulic simulation was performed to evaluate changing wastewater-disposal trends and declining water levels at the Hanford Site. Simulations were made for a time period of 200 years and showed that the groundwater-flow system required 100 to 125 years to reach steady-state flow, where heads were not changing. At steady state, the flow direction was predominantly from the west to the east across the Hanford Site. Figure 7.11 shows the predicted water-table elevation for 2195, and Figure 7.12 shows the change in water-table elevation from 1995 to 2195. As shown in Figure 7.12, the largest predicted head changes occur in the vicinity of the 200-East and 200-West Areas. Water-table declines were predicted to be as high as 7 m in some areas.

Contaminant transport was also modeled to predict concentrations for eight sitewide plumes over a period of 200 years. Transport predictions for each contaminant incorporated identical groundwater-flow-system behavior. For a detailed discussion of the transport model results, refer to Chiaramonte et al. (1996). One transport prediction was performed for the areally extensive carbon tetrachloride plume in the 200-West Area. Figure 7.13 shows the extent of this plume under current conditions, and Figure 7.14 shows the predicted contaminant distribution in the year 2195 without any remediation. Two notable features are 1) the plume does not move northward through Gable Gap and 2) the plume does not move significantly eastward beyond the boundary defined by the Future Site Uses Working Group, as documented in DOE (1996i). Based on this result, the simulation provides a basis for deciding how to proceed with remediation and monitoring of this contaminant plume, meeting one of the primary modeling objectives.

7.3 Modeling of 200-West Area Pump-and-Treat Operations

L. C. Swanson

Numerical models for the 200-UP-1 and 200-ZP-1 Operable Units in the 200-West Area were developed to assess the performance of groundwater pump-and-treat systems operating at these sites and to predict system performance under different configurations of extraction and injection wells. The models were also used to describe the capture zones and zones of hydraulic influence for the extraction and injection wells, respectively. A description of the pump-and-treat systems is provided in Section 6.9.

The modeling was conducted using the Micro-FEM© finite-element code. Included in the modeling package are mesh-generating programs, a calculation module, and a postprocessing program. The mesh-generating programs allow the user to construct irregularly shaped and variably spaced triangular finite-element meshes. This feature allows for high resolution of the finite-element mesh near pumping or injection centers. The calculation module supports either a transient or steady-state solution. The postprocessing program enables the user to export the results of the simulations for presentation. The Micro-FEM© package was chosen because the finite-element mesh-generating and output capabilities make it easy to change the configuration of pumping and injection wells and quickly examine the results. For specific details of model setup, refer to Freeman-Pollard et al. (1996) for 200-ZP-1. The 200-UP-1 pump-and-treat modeling is not yet published.

The modeling results for the 200-UP-1 Operable Unit uranium/technetium plume and the 200-ZP-1 Operable Unit carbon tetrachloride plume are consistent with the results of groundwater data collected at each site. The model indicates that the 200-UP-1 plume is being contained while removing contaminant mass relatively efficiently. The ratio of the capture zone intersecting the high-concentration portion of the plume to the total capture zone area is 0.86 based on the modeling results. At 200-ZP-1, both model simulations and measured groundwater elevations indicate that a hydraulic sink is forming around the three operating extraction wells Freeman-Pollard et al. (1996). For a more detailed discussion of groundwater remediation at these sites, see Sections 6.9.4.1 and 6.9.4.2.

7.4 Groundwater Modeling to Support 100 Areas Pump-and-Treat Operations

M. P. Connelly

Groundwater models were used to develop a pump-and-treat expedited response action at the 100-N Area (DOE 1996d). The goal of this action was to reduce the flux of strontium-90 to the Columbia River. Modeling was also performed to support the interim remedial action design process at the 100-D, 100-H, and 100-K Areas for the capture and treatment of chromium. The groundwater models were used to help with placement of new wells and to determine which existing wells could support the interim remedial action. They were also used to estimate extraction and injection rates for the pump-and-treat operations.

At the 100-N Area, the numerical model used to perform this work was FLOWPATH v.5 (developed by Waterloo Hydrogeologic Software, Waterloo, Ontario). FLOWPATH v.5 solves two-dimensional groundwater-flow equations for the unconfined aquifer system using the finite-difference method. This code was chosen to simulate the 100-N Area pump-and-treat operations as a result of meetings with regulators in 1994. However, Micro-FEM© is now available and has advantages, in that it simulates transient flow conditions and provides a preprocessor that allows the user to quickly create high-resolution finite-element meshes. Micro-FEM© was used at other sites in the 100 Areas because the high-resolution meshes allow very tight node spacing close to the pumping and injection centers and coarse node spacing away from the pumping and injection centers.

7.4.1 Strontium-90 Flux Reduction in 100-N Area

In 1996, groundwater modeling was used to evaluate the existing pump-and-treat system at the 100-N Area and make recommendations on how it could be modified to more effectively reduce the flux of strontium-90 to the Columbia River (DOE 1996d). The pump-and-treat system in the 100-N Area reduces the regional flow of groundwater through the strontium-90-contaminated sediments to the Columbia River. By reducing the flow of water through these sediments, the flux of strontium-90 released to the Columbia River is reduced. This work was a carryover from 1994 and 1995, which is described in DOE (1994e). A complete description of the modeling conducted for the 100-N Area pump-and-treat operation is provided in DOE (1996d). Additional information on the pump-and-treat system is provided in Section 6.5.

The modeling described in DOE (1996d) examined six design cases. The first was a no-action design case against which all other design cases were compared to determine the relative effectiveness of that design. These design cases considered different pumping and injection well combinations, using various discharge and injection rates. In one instance, a barrier was considered. The remaining design cases are:

- existing pump and treat: wells 199-N-75 and 199-N-105A pumping at ~57 L/min each, well 199-N-106A pumping at ~76 L/min, and inject at well 199-N-29 at ~190 L/min (see Plate 1 for well locations)

- modified existing pump and treat: wells 199-N-75 and 199-N-103A pumping at ~57 L/min each, well 199-N-106A pumping at ~114 L/min, and inject at well 199-N-29 at ~228 L/min

- existing pump and treat and barrier: wells 199-N-75 and 199-N-105A pumping at ~57 L/min each, well 199-N-106A pumping at ~76 L/min, and inject at well 199-N-29 at ~190 L/min, plus a 460-m-long impermeable barrier

- alternate pump and treat: pump from wells 199-N-75, 199-N-103A, and 199-N-106A at ~57 L/min; add an additional well between wells 199-N-75 and 199-N-106A, also pumping at ~57 L/min; and inject at well 199-N-29 at ~228 L/min

- alternate pump and treat: pump from wells 199-N-75 and 199-N-103A at ~57 L/min, add an additional well between wells 199-N-75 and 199-N-106A, pump from the new well and well 199-N-106A at ~95 L/min, and inject at wells 199-N-29 and 199-N-104A at ~152 L/min.

The strontium-90 flux was then calculated over the next 200 years using a steady-state stream-tube analysis, which also accounted for radioactive decay (DOE 1996d). The yearly annual average strontium-90 flux to the Columbia River is given in the upper plot in Figure 7.15 and the total cumulative loading is given in the lower plot. Table 7.2 gives the percentage reduction compared to the no-action design case for strontium-90 annual release. This table takes into account radioactive decay. The percentages presented in the table were calculated by normalizing to the calculated no-action release (0.09 Ci/yr) observed at time zero.

As seen from this table, the pump-and-treat operation does provide hydraulic control of strontium-90 discharging into the Columbia River. However, it should be noted that once the pumps are turned off and natural conditions reestablish themselves, the release of strontium-90 will return to the levels indicated by Figure 7.15 for the no-action design case minus the radioactive decay that took place during the pump-and-treat period.

7.4.2 100 Areas Interim Remedial Action Design

For the 100-D, 100-H, and 100-K Areas, a number of modeling scenarios were developed for simulation. The scenarios were successively modified based on the results of iterative model simulation to conceptually optimize pump-and-treat performance (McKinley 1996). Because of the highly

variable saturated thickness in the 100-H Area model, simulations for that area were performed under transient conditions. Performing transient simulations allowed the model to account for and include changes in the transmissivity. Considering that the thickness of the aquifer thins to <1 m in certain places, small changes in aquifer thickness result in significant changes in transmissivity. Drawdown and buildup of the water table caused by different pump-and-treat operations were simulated for a 5-year time span. The model simulations for the 100-D and 100-K Areas were performed to steady state. The initial aquifer thickness for both models was uniform, and changes in aquifer thickness were not considered significant compared to the original thickness.

Stream paths and capture zones for the 100-H Area were based on the resulting 5-year hydraulic velocity field, while stream paths and capture zones for the 100-D and 100-K Areas were based on the resulting steady-state velocity fields. Capture zones show the area of the aquifer from which the individual extraction wells draw water. Groundwater contained within or crossing a contour closed around by two or more extraction wells becomes trapped. Trapped groundwater is either captured or becomes stagnant. Stream paths crossing the river boundary at that line are assumed to represent paths of river recharge.

7.4.2.1 100-D Area

Modeling of the 100-D Area resulted in an interim remedial action design that includes extraction from two wells (199-D8-53 and 199-D8-54) with injection of the treated water taking place in the 100-H Area. The capture zone created by pumping these two wells at 151 L/min extends laterally across the entire plume area. The cone of depression caused by pumping at this rate will eventually intersect the Columbia River, thereby inducing recharge into the aquifer from the river. After ~ 2 years, 33% of the influent is expected to come from the river.

7.4.2.2 100-H Area

Ten modeling scenarios using five different extraction and injection well networks were simulated for the 100-H Area (McKinley 1996). Examining the results of these 10 simulations resulted in a recommendation for the interim remedial action design that wells 199-H4-11, 199-H4-12A, and 199-H4-15A be pumped at 38 L/min; well 199-H4-7 be pumped at 76 L/min; well 199-H3-2A be pumped at 151 L/min; and that 2 new injection wells be installed that can inject water at 322 L/min. See Plate 1 for well locations.

Recirculation between wells 199-H4-11 and 199-H4-12A occurs in ~ 4 years. Recirculation between well 199-H4-15A and the injection wells does not occur for 11 years and is not considered to be a factor during the life span of this interim action. Wells 199-H4-7 and 199-H3-2A both establish recirculation cells with the injection wells. This design captures chromium at the 100-H Area, where it is thought to be entering the Columbia River.

7.4.2.3 100-K Area

Five scenarios were simulated for the interim remedial design. On examining the results from the simulation, it was recommended that 6 new extraction wells be placed between the Columbia River and the 116-K-2 trench and 3 injection wells be placed ~600 m inland of the 116-K-2 trench. All of these extraction wells would be pumped at 95 L/min. The 3 injection wells would operate at 190 L/min. This design is expected to prevent or reduce the quantity of chromium reaching the Columbia River in this area.

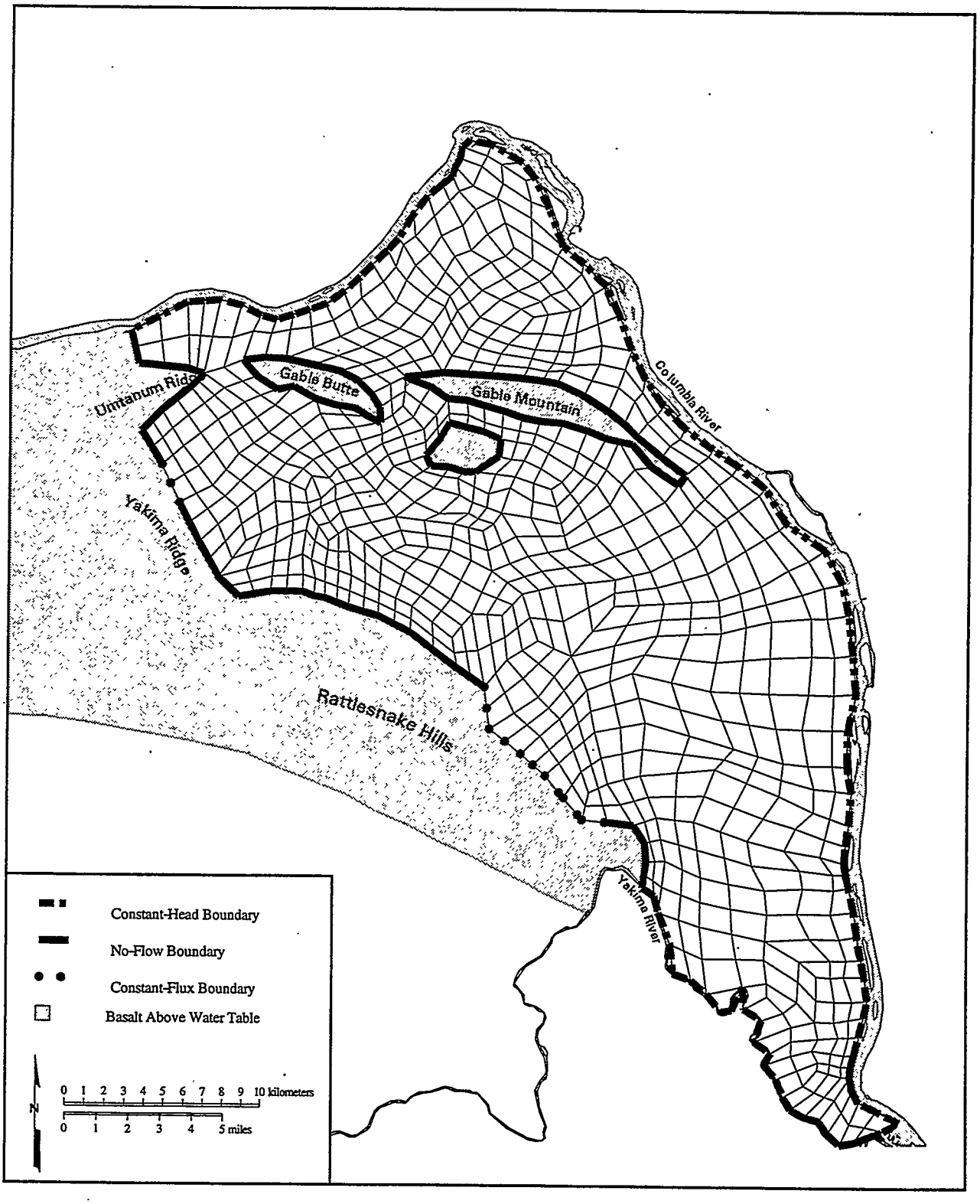
Table 7.1. Summary of Artificial Recharge Sources Used in CFEST Model for 1979 (Wurstner et al. 1995)

Facility	Discharge, m^3/d
124-N-10 Lagoon	65
1301-N Crib	13,042
100-K Septic Tanks	4
100-D Septic Tanks	9
100-F Septic Tanks	2
2101-M Pond	14
216-S-10 Pond and Ditch	543
216-S-19 Pond	162
216-T-1 Trench	32
216-T-4-2 Pond	52
216-U-10 Pond	4,390
216-A-25 (Gable Mountain) Pond	33,100
216A-30, 216-A-37-1 Cribs	536
216-B-55, 216-B-62 Cribs	604
216-B-3 Pond	11,500
216-B-63 Trench	719
316-5 Process Trenches	12,000
300 Area Ash-Disposal Pits	153
400 Area Well/Septic System	-120
North Richland Well Field	14,800

Table 7.2. Strontium-90 Annual Flux Reduced to Columbia River for Each Design Case[a]

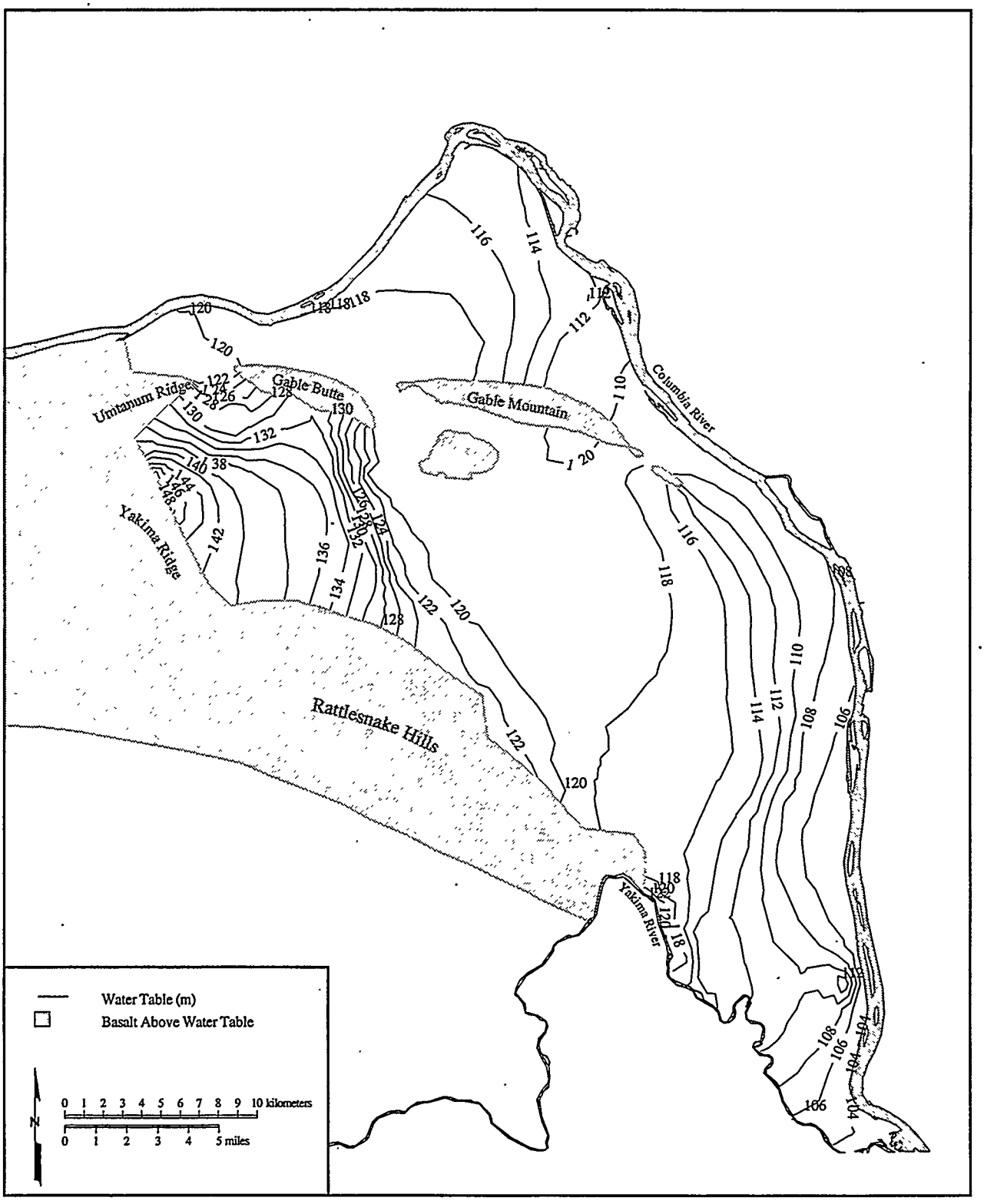
	Years							
	0	5	10	20	30	50	100	200
Case 1 - No action	0%	11%	21%	38%	51%	70%	91%	99%
Case 2 - Existing 189.3 L/min (199-N-75, 199-N-105A, 199-N-106A pumping; 199-N-29 injecting)	73%	76%	79%	83%	86%	91%	97%	99%
Case 3 - Modified 227.2 L/min (199-N-75, 199-N-103A, 199-N-106A pumping; 199-N-29 injecting)	97%	97%	97%	98%	98%	98%	99%	100%
Case 4 - Existing 189.3 L/min (199-N-75, 199-N-105A, 199-N-106A pumping; 199-N-29 injecting +460-m vertical barrier)	98%	98%	98%	98%	99%	99%	99%	100%
Case 5 - Modified design 227.2 L/min (199-N-75, 199-N-103A, 199-N-106A, 199-N-107A pumping; 199-N-29 injecting)	98%	98%	98%	99%	99%	99%	99%	100%
Case 6 - Modified design 302.8 L/min (199-N-75, 199-N-103A, 199-N-106A, 199-N-107A pumping; 199-N-29, 199-N-104A injecting)	99%	99%	99%	99%	100%	100%	100%	100%

(a) Radioactive decay accounted for.



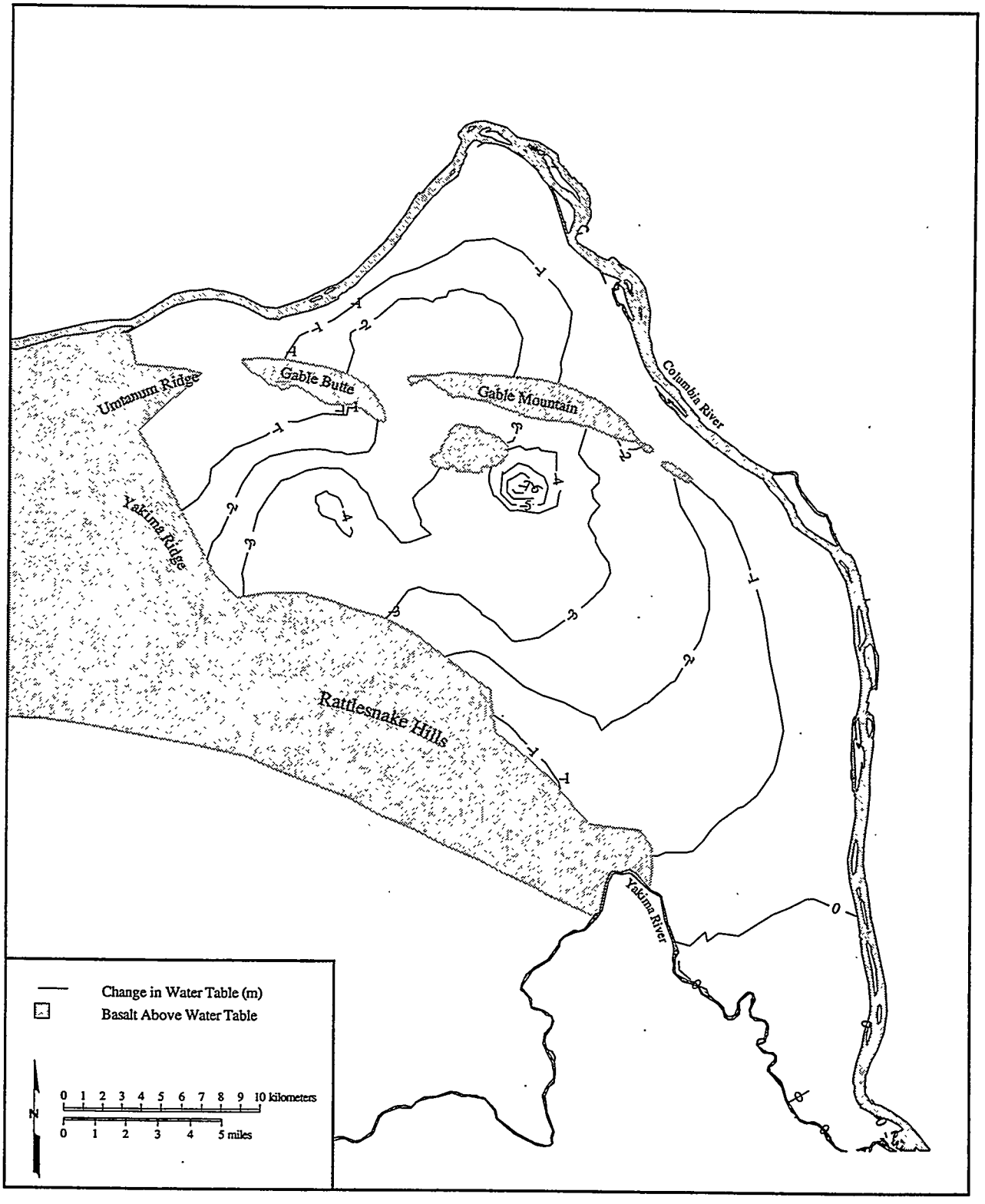
97skw002.eps February 12, 1997

Figure 7.1. CFEST Sitewide Numerical Model Grid and Boundary Conditions



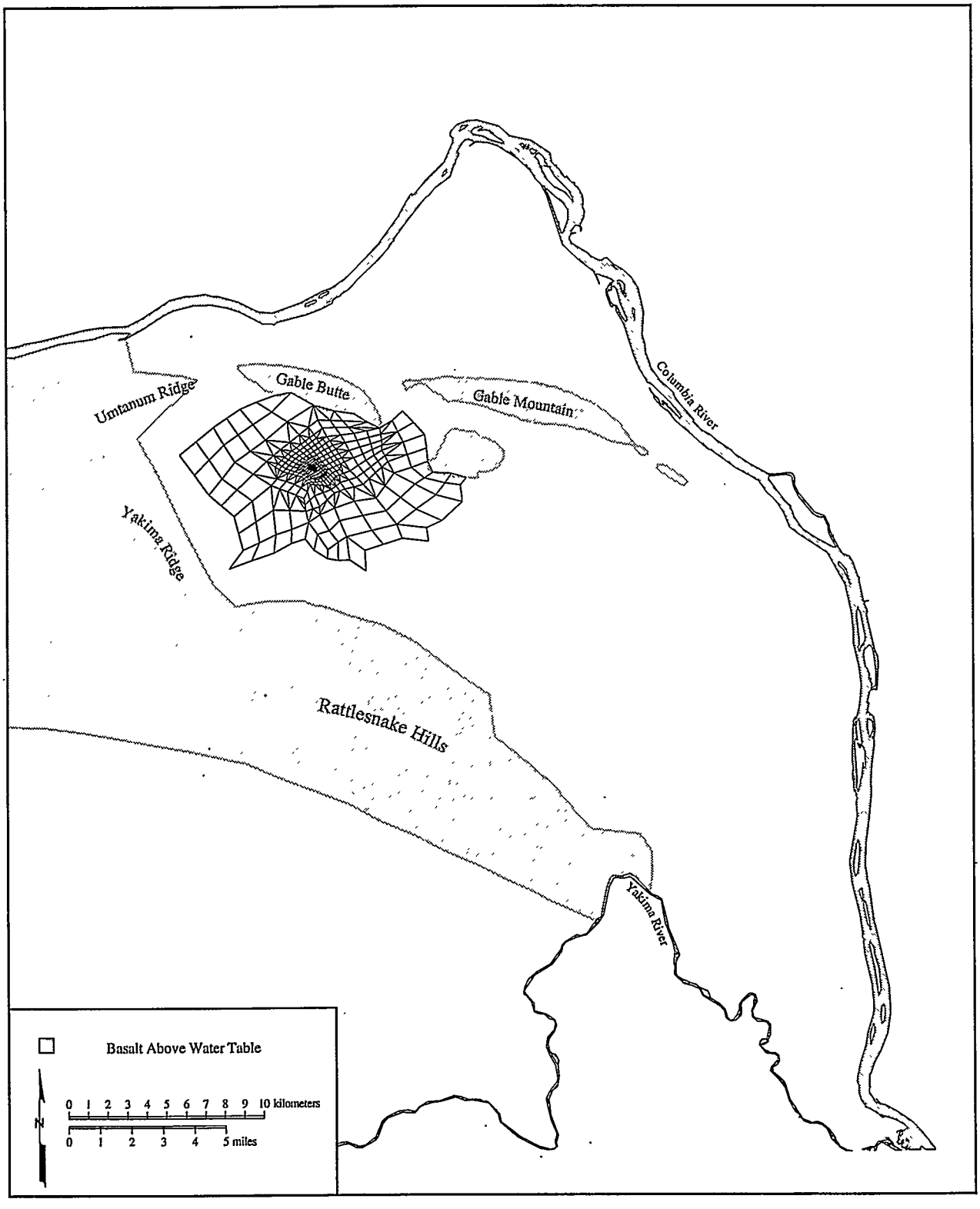
97skw003.eps January 15, 1997

Figure 7.2. Heads Predicted for 2050 with CFEST Three-Dimensional Model



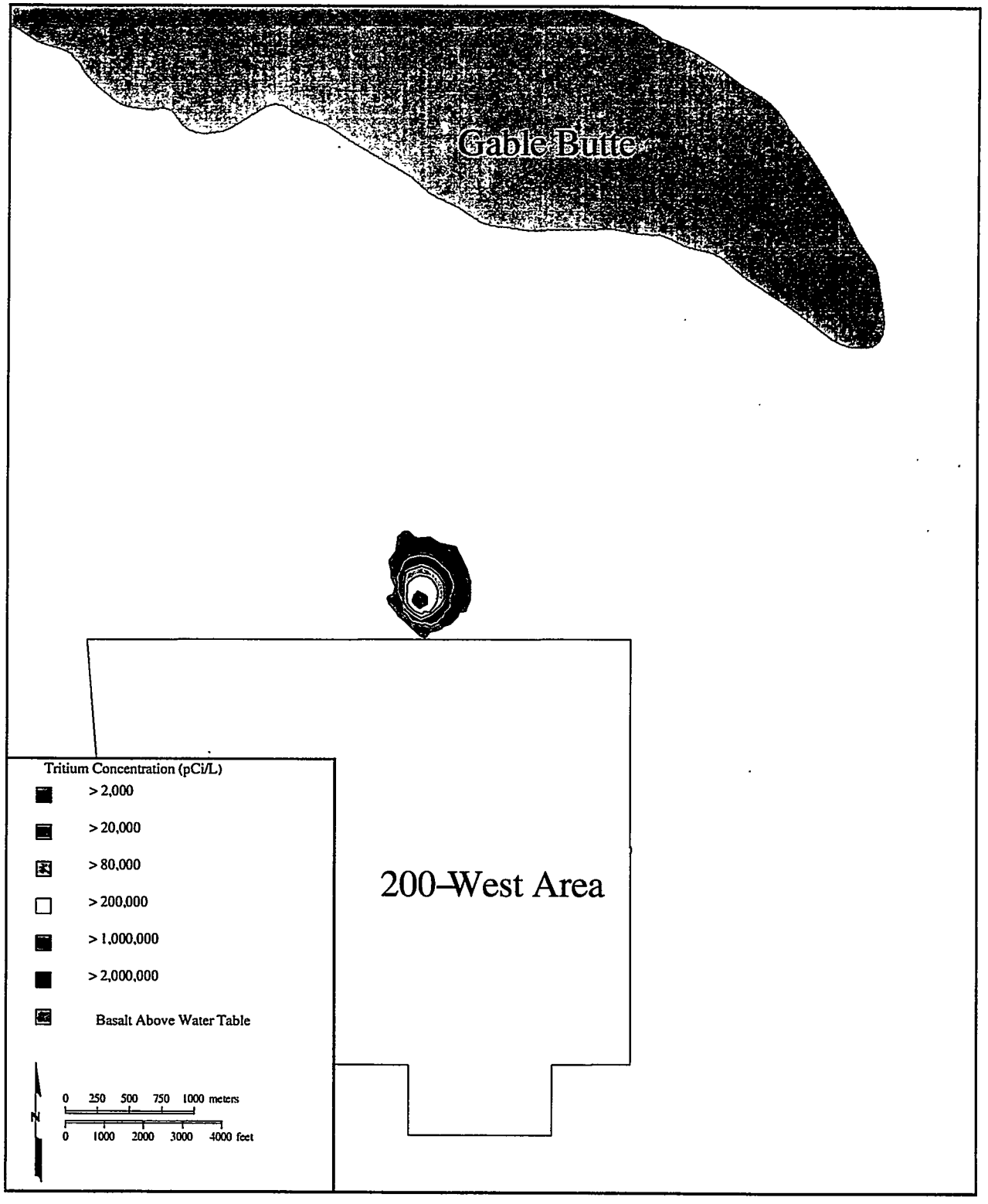
97skw011.eps February 07, 1997

Figure 7.3. Change in Water Table Between 1995 and 2050 Predicted with CFEST Model



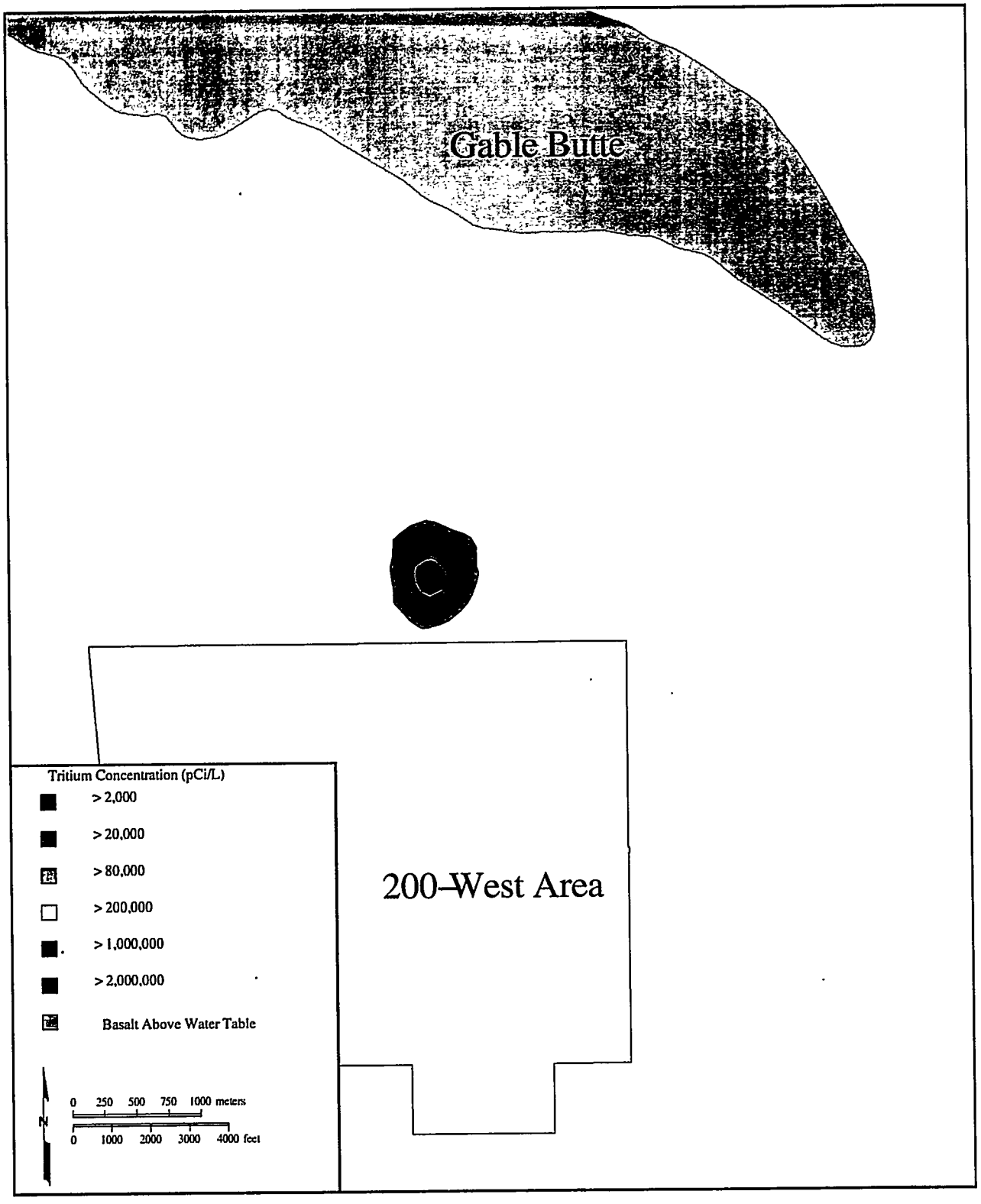
97skw004.eps January 15, 1997

Figure 7.4. Subregion Grid for CFEST Three-Dimensional Tritium Plume Transport from 200 Areas Effluent Treatment Facility



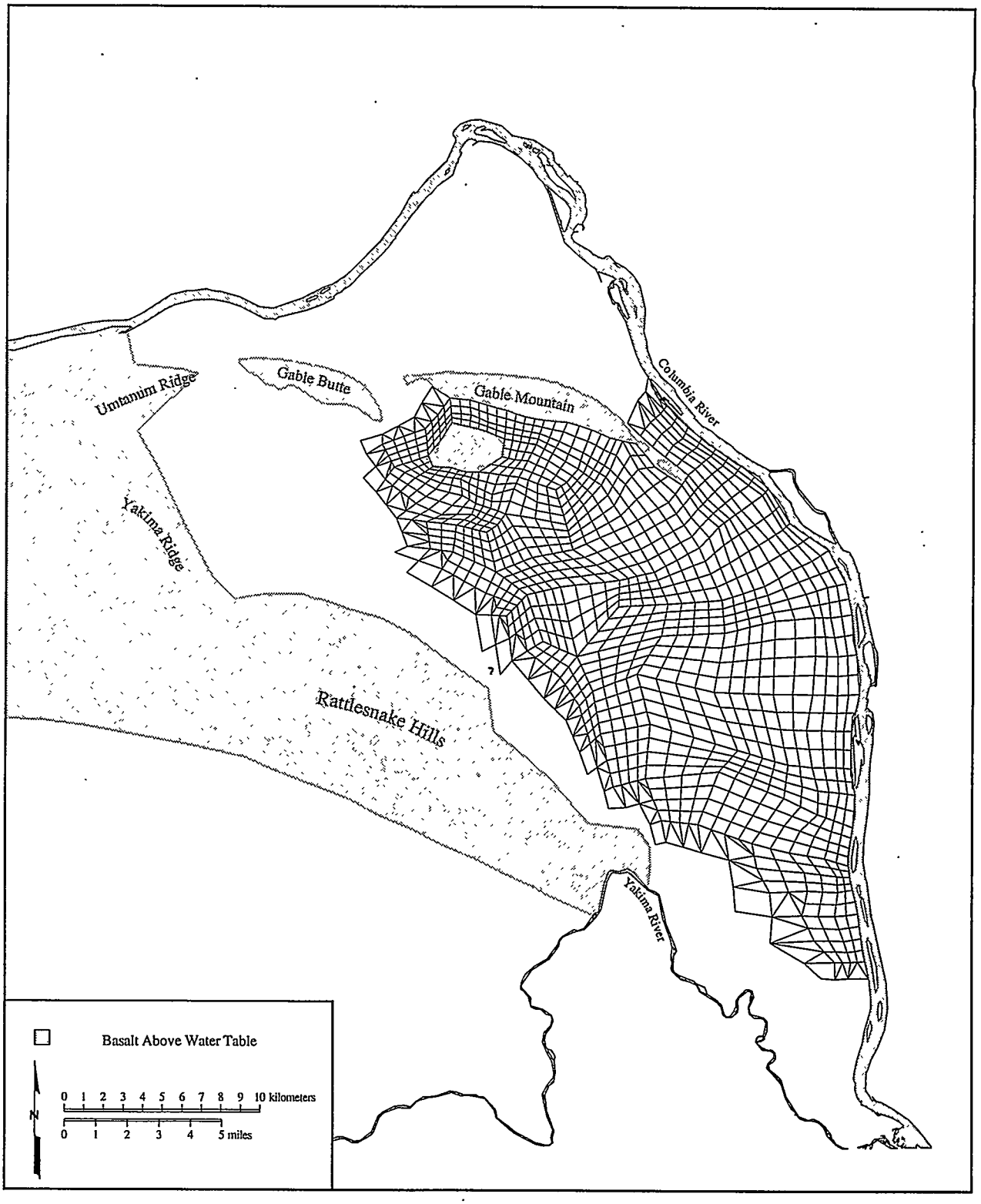
97skw009.eps January 16, 1997

Figure 7.5. Predicted 2015 Tritium Plume Concentrations from CFEST Three-Dimensional Subregion Model for 200 Areas Effluent Treatment Facility



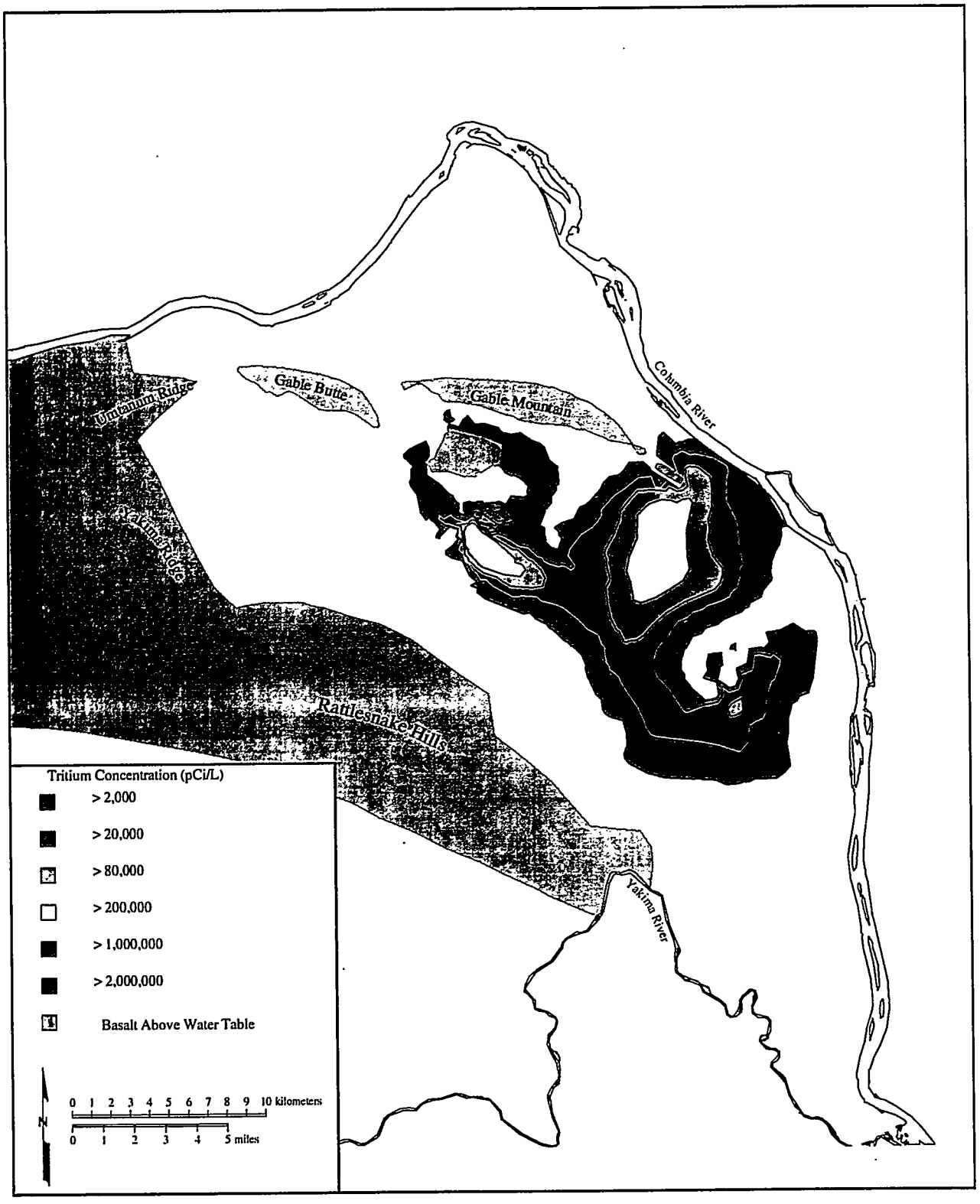
97skw010.eps January 16, 1997

Figure 7.6. Predicted Tritium Plume Concentrations in 2050 from CFEST Three-Dimensional Subregion Model for 200 Areas Effluent Treatment Facility



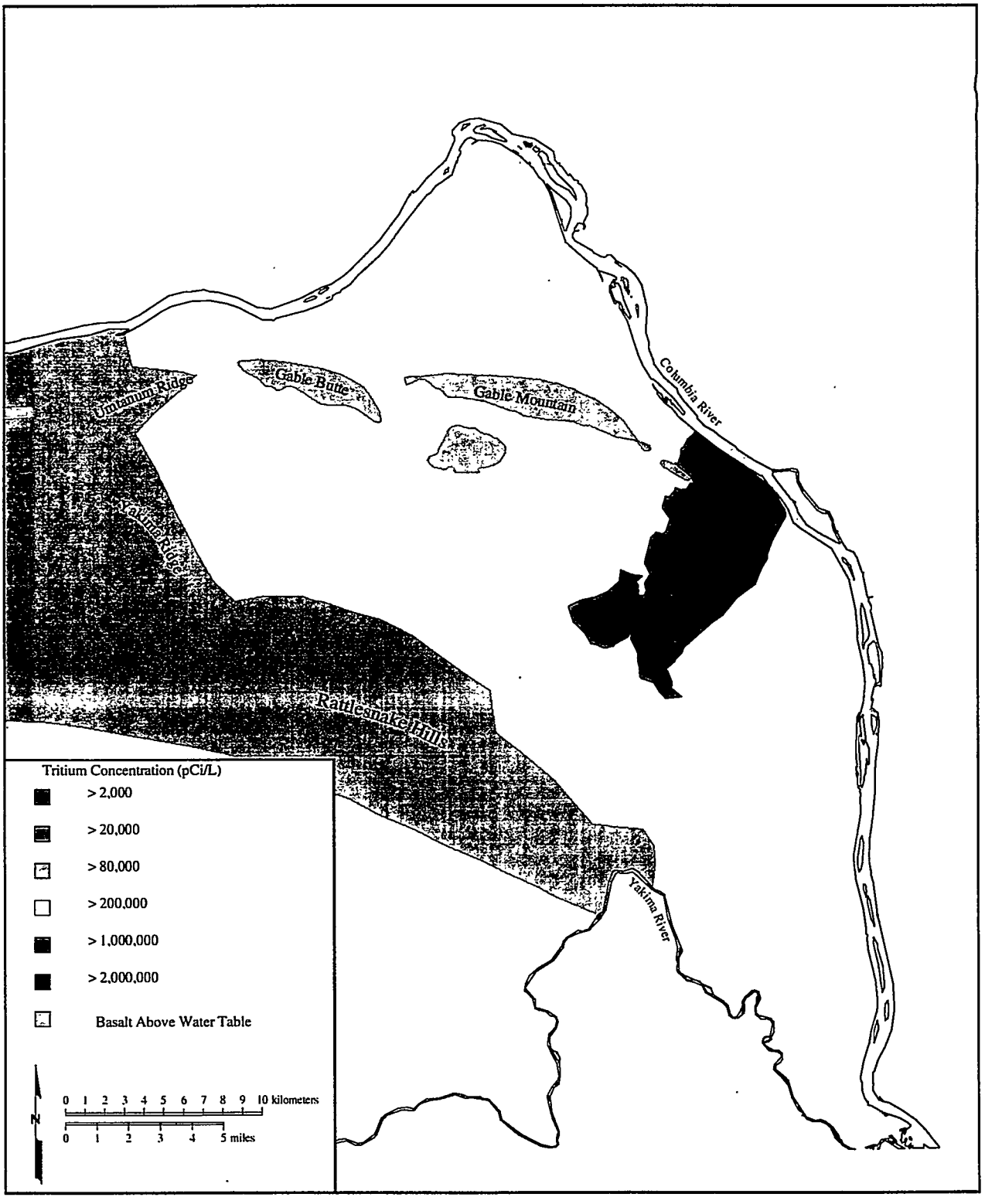
97skw005.eps January 15, 1997

Figure 7.7. Subregion Grid for CFEST Three-Dimensional Tritium Plume Transport from 200-East Area



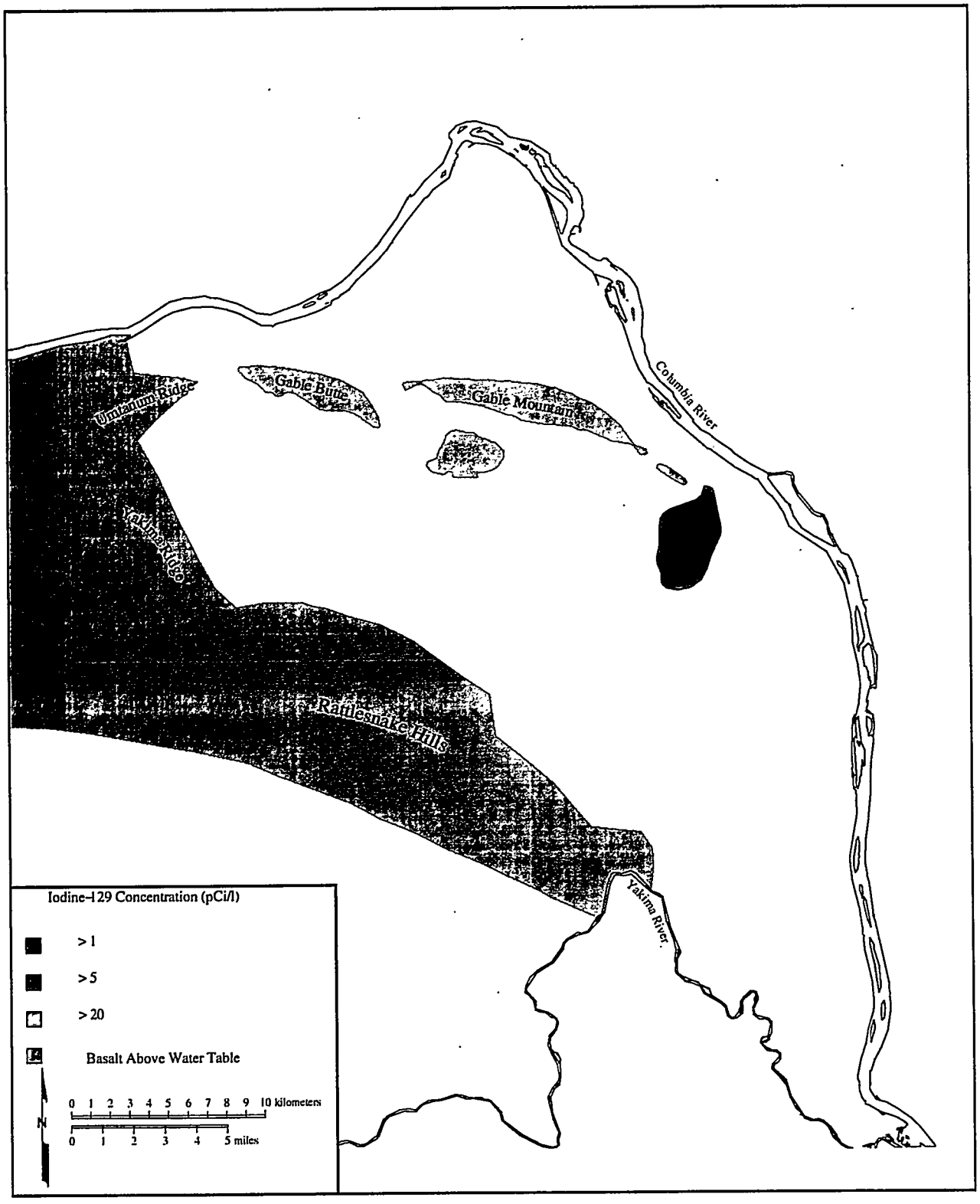
97skw006.eps January 16, 1997

Figure 7.8. Predicted 1995 Tritium Plume from CFEST Three-Dimensional Subregion Model for 200-East Area



97skw007.eps January 16, 1997

Figure 7.9. Predicted 2050 Tritium Plume from CFEST Three-Dimensional Subregion Model for 200-East Area



97skw008.eps January 16, 1997

Figure 7.10. Predicted 2050 Iodine-129 Plume from CFEST Three-Dimensional Model for 200-East Area

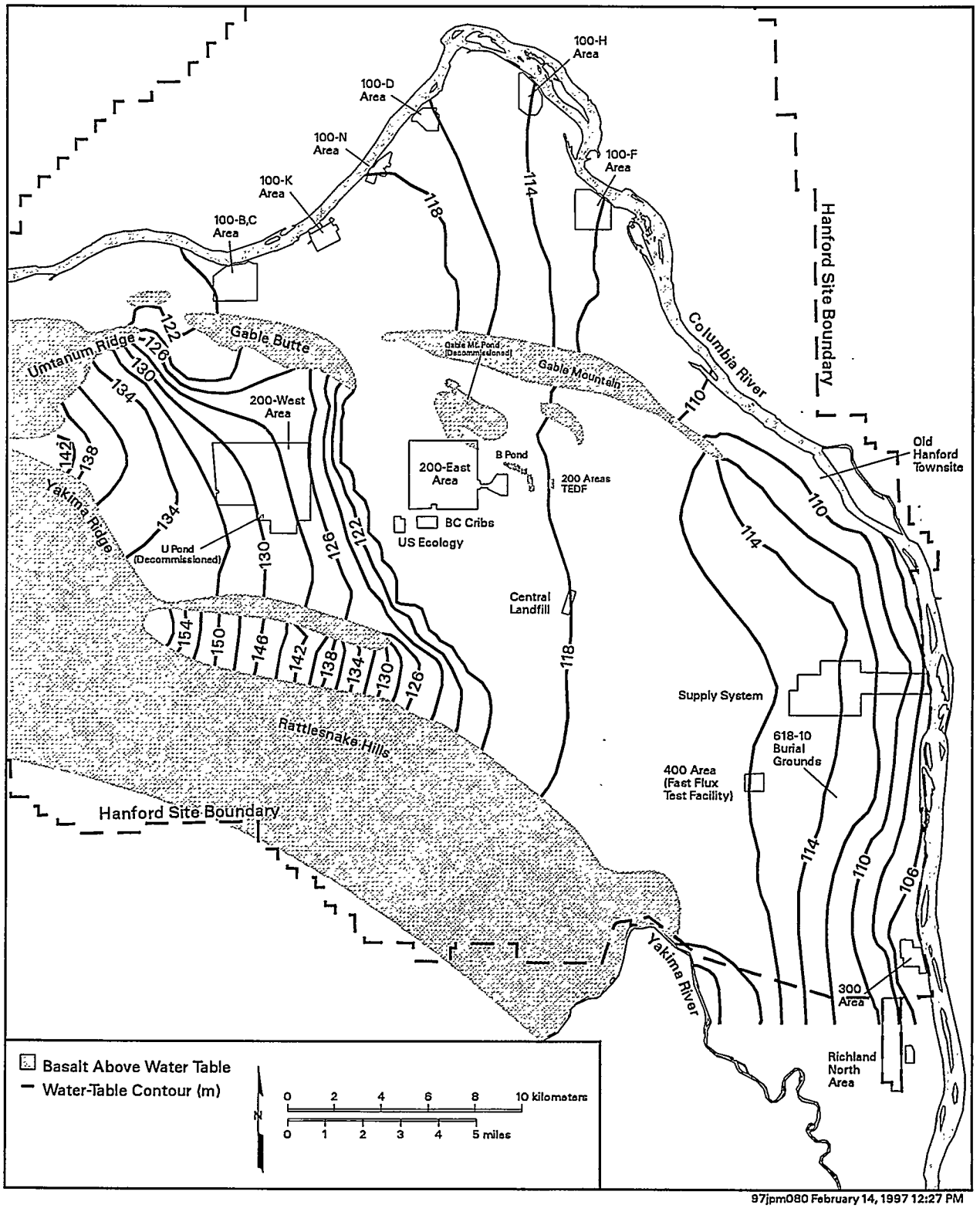


Figure 7.11. 2195 Water-Table Elevations Predicted by VAM3DCG Sitewide Model (after Chiaramonte et al. 1996)

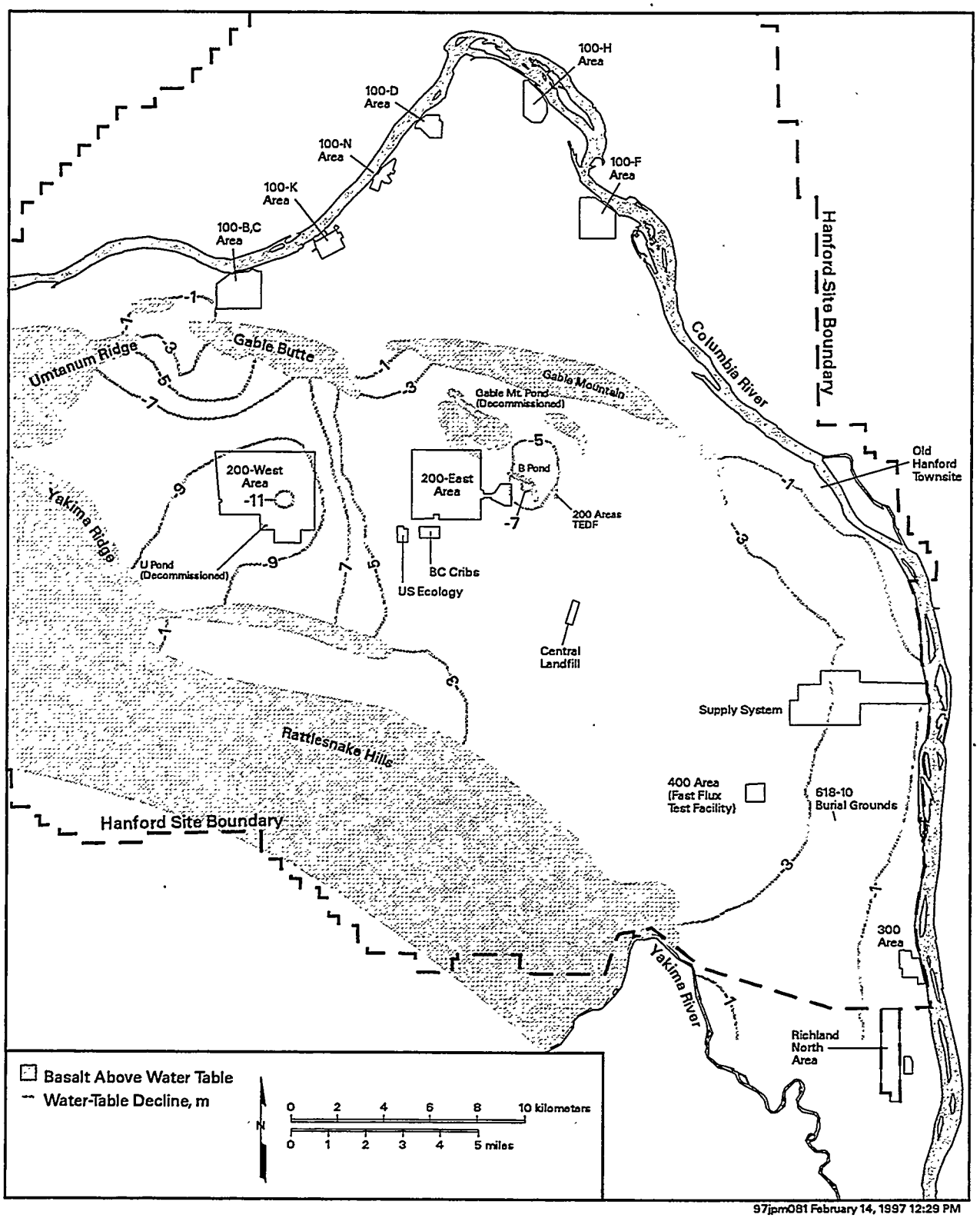


Figure 7.12. Change in Water Table Between 1995 and 2195 Predicted with VAM3DCG Model (after Chiaramonte et al. 1996)

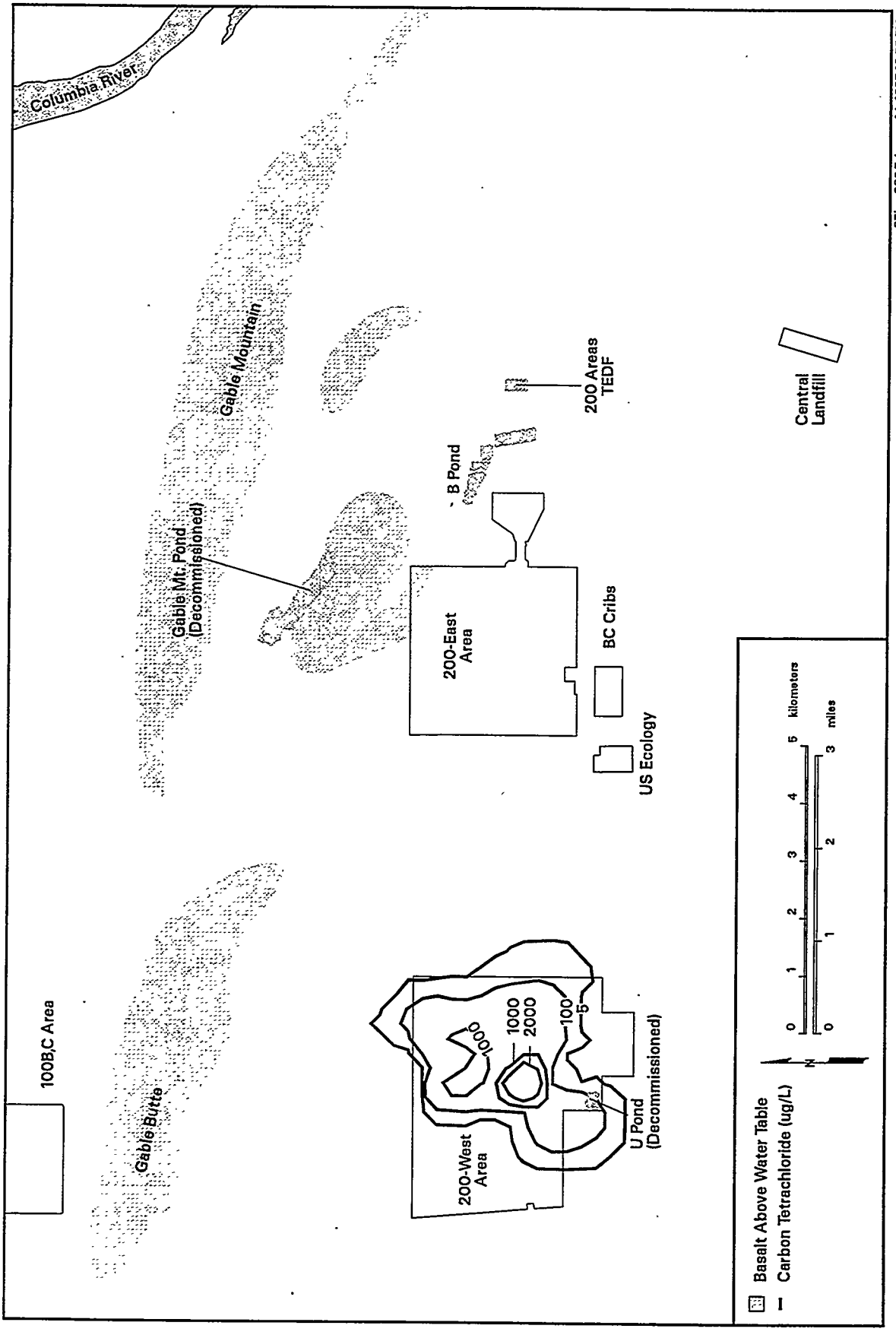


Figure 7.13. Initial Carbon Tetrachloride Distribution Near 200-West Area in 1995 (after Chiaramonte et al. 1996)

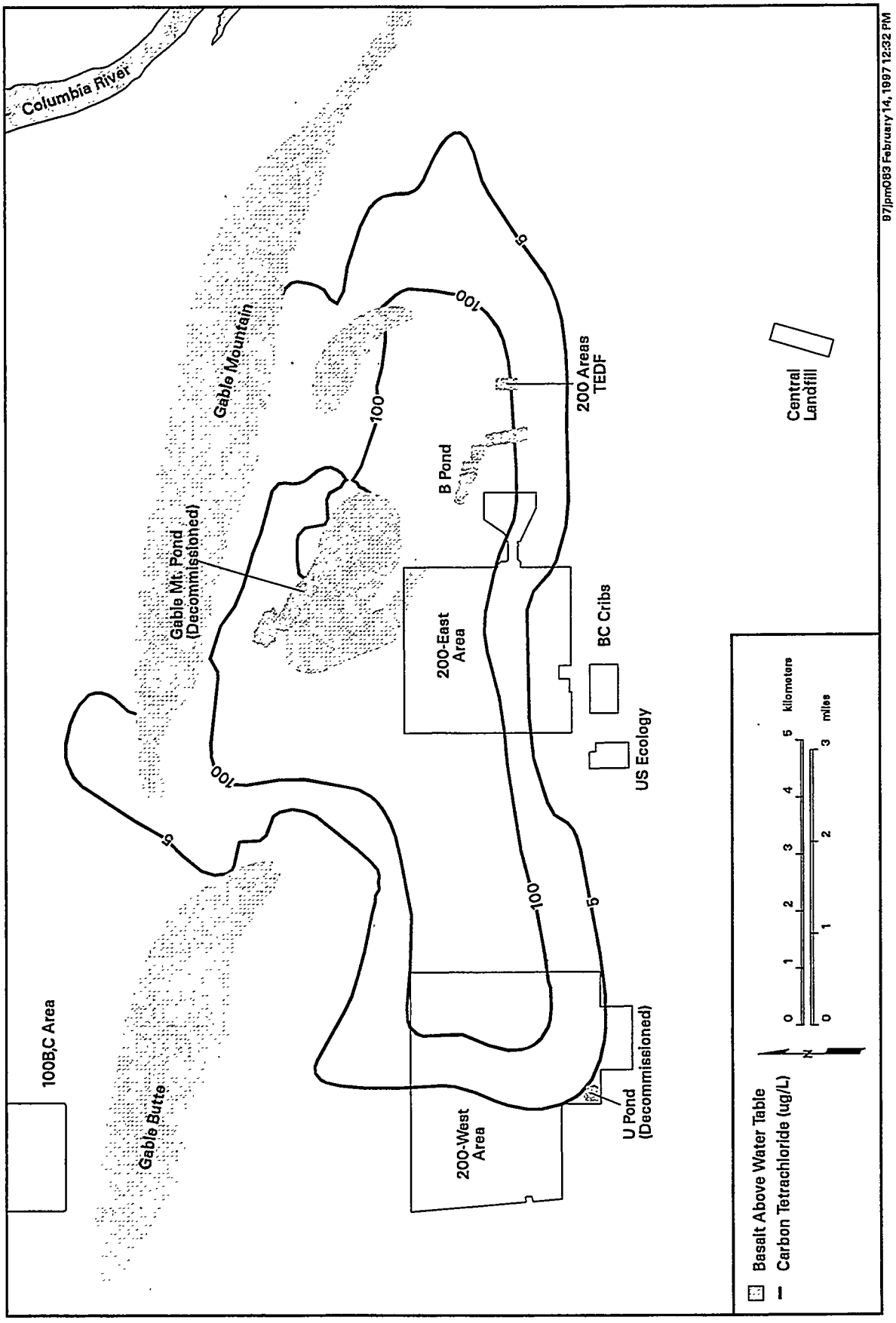
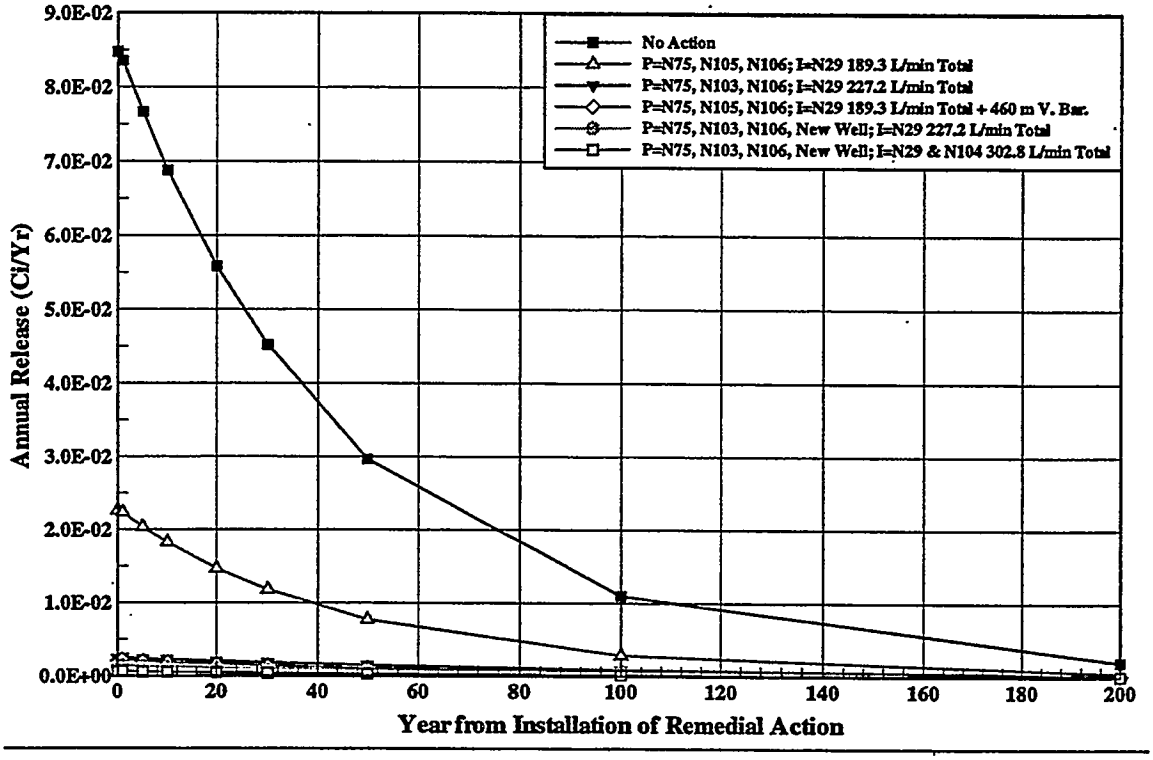


Figure 7.14. Carbon Tetrachloride Distribution Predicted in 2195 by VAM3DCG Model (after Chiaramonte et al. 1996)



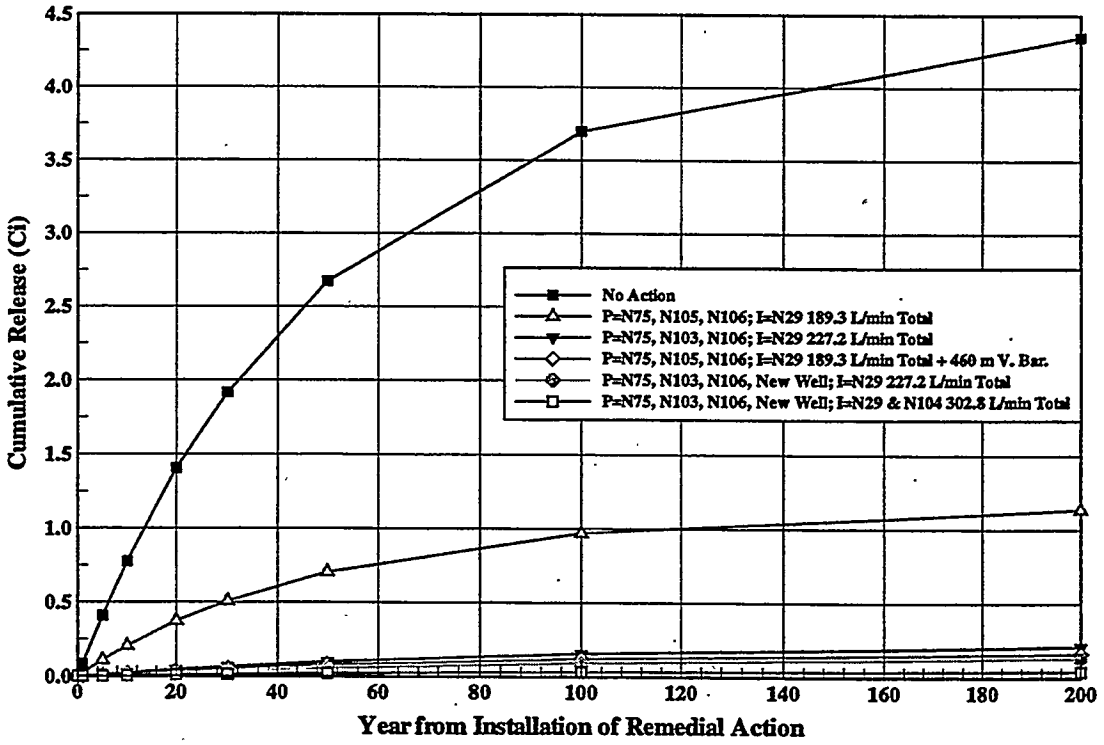


Figure 7.15. Strontium-90 Flux to Columbia River (DOE 1996c)

8.0 Well Maintenance, Reconfiguration, and Decommissioning

V. R. Vermeul

This chapter describes well maintenance, reconfiguration, and decommissioning activities conducted on the Hanford Site during fiscal year (FY) 1996.

8.1 Well and Pump Maintenance

Routine well and pump maintenance can be divided into two general activities: 1) surface tasks, which include conducting field inspections, well labeling, maintenance and replacement of locking well caps, casing repairs, diagnosis and repair of surface electrical and pump-discharge deficiencies, etc. and 2) well tasks, which include downhole work such as repairing and replacing sampling pumps, performing camera surveys, brushing casing perforations, and developing wells to improve yield and sample quality, removal of sediment accumulation, etc.

During FY 1996, the Ground-Water Surveillance Project, managed by Pacific Northwest National Laboratory (PNNL), requested that Westinghouse Hanford Company (WHC) perform a total of 67 well-maintenance-related activities. Of these, 38 were surface tasks and 29 were well tasks. During this same time, the *Resource Conservation and Recovery Act of 1976* (RCRA) and Operational Monitoring Program, managed by WHC, requested 689 well-maintenance-related tasks be performed. Of these, 477 were surface tasks and 212 were well tasks. All work was completed on an as-needed basis and was successfully scheduled to meet the needs of groundwater sample-collection activities.

All work was conducted in accordance with the *Environmental Investigations and Site Characterization Manual* (WHC 1989), including documentation through the use of Well Service Request, Well Services Planning Report, and Field Activity Report forms. All well- and pump-maintenance activities are tracked in the Hanford Well Services Database, which is maintained by Rust Federal Services Northwest, formerly WHC's Technical Services Group.

In addition to well maintenance in support of the groundwater-monitoring programs, the Environmental Restoration Contractor, Bechtel Hanford, Inc. (BHI), performed maintenance on ~85 wells. These well-maintenance activities included ~50 routine pump repairs or replacements, 25 downhole camera surveys, and well cleaning at a limited number of locations (~10 wells). All work was conducted in accordance with *Environmental Investigations Procedures* (Price 1994).

One nonroutine pump-maintenance activity was conducted during FY 1996. PNNL requested that WHC support the disposal of 116 Peabody-Barnes® electric submersible pumps contaminated with polychlorinated biphenyls (PCBs) and a single pump with both PCB and radiological contamination. The work was agreed to and conducted by WHC personnel, following standard procedures for PCB disposal. The pumps were disassembled, drained of their PCB-contaminated oil, packaged in drums, and shipped to an appropriate offsite PCB-disposal facility.

8.1.1 Cyclic Well Rehabilitation

Cyclic well rehabilitation is a preventive maintenance program developed for Hanford Site wells. This cyclic well-cleaning program involves, as needed, brushing the carbon steel casing and casing perforations, developing the wells to improve yield and sample quality, and removing the sediment accumulation. Wells are rehabilitated once every 5 years; this 5-year well-rehabilitation cycle is based on prior field experience, which was used to develop a best management practice for maintaining wells on the site.

During FY 1996, PNNL requested that WHC perform cyclic well rehabilitation on 21 Hanford Site wells. Emphasis was placed on those wells included in the *Environmental Surveillance Master Sampling Schedule* (Bisping 1996) that have not historically been rehabilitated. Most of these wells are located in surface radiation zones and/or require containment of generated purgewater. Rehabilitation of these wells brings all PNNL-maintained wells currently scheduled for sampling in compliance with the 5-year rehabilitation rotation, with one exception. A well located in the 100-N Area was removed from the rehabilitation list (199-N-5, which is located within a surface contamination zone) because of access problems and the cost associated with regulating a pump-setting rig. Well 199-N-5 will be evaluated during FY 1997 as a candidate for rehabilitation.

During this same time, WHC performed cyclic well rehabilitation on 20 Hanford Site wells. Cyclic well rehabilitation includes, as needed, the following activities:

- perform field inspection and complete a field inspection report
- remove sample pumps and downhole equipment
- conduct downhole television camera survey
- brush and clean well casing
- remove debris and fill material with a sand pump and/or core barrel to restore well to original depth or to depth necessary to support sampling activities
- develop well using a bailer and/or an electric submersible pump
- install groundwater-sampling pump and/or downhole equipment
- track field activities through the use of the Well Service Request, Well Services Planning Report, and Field Activity Report forms, and input resulting data into the Hanford Well Services Database.

All work was conducted in accordance with WHC (1989). Wells rehabilitated during FY 1996, in addition to the historical record of wells rehabilitated, are tracked in the Hanford Well Services Database.

8.2 Well Reconfiguration

Two wells (699-S24-19 and 699-S6-E4C) were reconfigured to provide additional contaminant-distribution information for the lower unconfined aquifer system and upper confined aquifer beneath the Hanford Site. Well-reconfiguration work was performed under a contract with WHC. PNNL staff took the lead on reconfiguration design and worked closely with WHC staff during the design process. All work was done in accordance with WHC (1989) and meets Washington Administrative Code (WAC) 173-160 for well construction.

In addition to these PNNL well-reconfiguration activities, BHI reconfigured well 699-S6-E4A in support of a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) limited field investigation for the 300-FF-2 Operable Unit. In FY 1995, uranium and hydrocarbon contamination were detected in well 699-S6-E4A, which is adjacent to both the 618-10 burial ground and the 316-4 crib. The investigative activities in calendar year 1996 included renovating well 699-S6-E4A and collecting samples from this well and two cone penetrometer borings at the site. All work was conducted in accordance with Price (1994) and meets WAC 173-160 for well construction.

8.2.1 Well 699-S24-19

This well is located on the southwestern boundary of the Hanford Site near the Yakima River, just downstream of Horn Rapids Dam. Because this well is one of the few that monitors this boundary, it is an important well for inclusion in PNNL's contaminant transport assessment task. This well, which was originally drilled into the upper confined aquifer and perforated across both the unconfined and upper confined aquifer systems, historically provided a conduit for aquifer intercommunication. Remediation of this well, which involved installing a cement grout seal between the two monitoring intervals, was designed to prevent vertical flow within the borehole. Once properly sealed, a determination can be made whether the historical intercommunication between the two aquifer systems could be fully attributed to the poor design of the original well completion. Intercommunication may also be attributed to naturally occurring leakage through fractures in the basalt flow top that separates the unconfined and the upper confined aquifers at this location. Well-construction and completion-summary diagram, detailed design, permitting, and field activity documentation are filed in the PNNL-maintained well logs and are tracked in the Hanford Well Services Database.

Originally, well 699-S24-19 was drilled to a total depth of 26 m (89 ft); a 23-cm (9-in.) nominal borehole and a 20-cm (8-in.) carbon steel casing were advanced to 13 m (44 ft) followed by an 18-cm (7-in.) nominal borehole and a 15-cm (6-in.) carbon steel casing to 20.5 m (67.5 ft); the 15-cm (6-in.) casing extended from ground surface. There were no documented perforations in the 20-cm (8-in.) carbon steel casing. The 15-cm (6-in.) carbon steel casing was perforated over the following intervals: 6 to 8, 11 to 13, and 18 to 20.5 m (20 to 27, 35 to 42, and 60 to 67.5 ft). The well-reconfiguration design consisted of installing two 5-cm (2-in.) piezometers: one across the unconfined aquifer (7 to 13 m [24 to 44 ft] below ground surface) and one across a sand/sand and gravel interflow zone just below the basalt flow top (19.1 to 20.5 m [62.5 to 67.5 ft] below ground surface) with a cement grout seal separating the intervals. Postreconfiguration hydraulic testing indicated the installed seal was not

effective in hydraulically isolating the two monitoring zones, indicating that leakage between the unconfined and confined aquifers at this location is most likely associated with naturally occurring and/or drilling-induced fracturing of the basalt flow top. The seal design incorporated in the current well completion should have ended any intercommunication within the borehole. Samples from both monitoring intervals were collected during FY 1996 using micropurge techniques to minimize sampling-induced intercommunication between the two aquifers; the samples were submitted for analysis. Because of time and funding constraints, an interpretation of analysis results was not completed for inclusion in this report. Water-level data from the upper piezometer in well 699-S24-19 was included in the data set used to construct a map of the water-table surface beneath the Hanford Site (see Plate 2).

8.2.2 Well 699-S6-E4C

This well, which is located southeast of the 400 Area and on the south edge of the tritium plume, penetrates the entire thickness of the unconfined aquifer system. Well 699-18-21, located ~10 km (~6 mi) northwest (upgradient) of well 699-S6-E4C, was reconfigured in 1993 to provide a monitoring interval between 16 and 28 m (53 and 93 ft) below the water table. The tritium concentration from this well is ~150,000 pCi/L, which is comparable to tritium concentrations from nearby wells completed at the water table. These results indicate the vertical extent of tritium contamination in the unconfined aquifer system may not be accounted for by the current well network and point to the importance of monitoring deep in the unconfined aquifer system. Well 699-S6-E4C was reconfigured to provide two deep, depth-discrete monitoring intervals that, in conjunction with currently sampled shallow wells (699-S6-E4B and 699-S6-E4D), will provide information on the vertical distribution of contaminants at this location. Well-construction and completion-summary diagram, detailed design, permitting, and field activity documentation are filed in the PNNL-maintained well logs and are tracked in the Hanford Well Services Database.

Originally, well 699-S6-E4C was drilled to a total depth of 140 m (461 ft); a 23-cm (9-in.) nominal borehole and a 20-cm (8-in.) carbon steel casing were advanced to 98 m (322 ft) followed by a 20-cm (8-in.) nominal borehole (open hole) to 140 m (461 ft). The 20-cm (8-in.) carbon steel casing was perforated over the following intervals: 14 to 30, 53 to 59, and 75 to 81 m (45 to 100, 175 to 195, and 245 to 265 ft). Driller's logs indicate the 20-cm (8-in.) carbon steel casing parted at the 85-m (279-ft) depth. The well-reconfiguration design consisted of installing two 5-cm (2-in.) piezometers over depth intervals of 44 to 46 and 69 to 71 m (145 to 150 and 227 to 232 ft) below ground surface (26 and 50 m [85 and 165 ft] below the static water table, respectively) with a cement grout seal above, below, and separating the intervals. Postreconfiguration hydraulic testing indicated the installed seal was effective in hydraulically isolating the two monitoring zones. Samples from both monitoring intervals were collected during FY 1996 and submitted for analysis (see Section 6.12.2.4).

8.2.3 Well 699-S6-E4A

This well was reconfigured in support of a CERCLA limited field investigation for the 300-FF-2 Operable Unit. Detailed information regarding this well reconfiguration is available in the Hanford Well Services Database.

Originally, well 699-S6-E4A was drilled to a total depth of 36 m (117 ft). A 23-cm (9-in.) nominal borehole and a 20-cm (8-in.) carbon steel casing were advanced to 36 m (117 ft) with no documented perforations in the 20-cm (8-in.) carbon steel casing; a camera survey was conducted. The well-reconfiguration work was initiated in FY 1995 and completed during FY 1996. The well-reconfiguration design consisted of perforating the 20-cm (8-in.) carbon steel casing and installing a 10-cm (4-in.) stainless steel screen and liner with both an annular filter pack and annular seal material above and below the monitoring interval. The screen was installed over a depth interval of 22 to 28 m (71 to 91 ft) below ground surface (approximately the top 6 m [20 ft] of the unconfined aquifer system).

8.3 Well Decommissioning

The decommissioning of wells is also part of the overall well-maintenance strategy that supports groundwater- and vadose-zone-monitoring and characterization programs conducted on the Hanford Site. These activities are conducted in response to regulatory drivers and, in some cases, to facilitate programmatic or project-specific goals. A well-remediation and -decommissioning program was implemented in FY 1993 under WHC's RCRA and Operational Monitoring Program. During FY 1996, 33 Hanford Site wells (Table 8.1), 47 characterization borings (decommissioned immediately following drilling), and 5 old farm wells identified as safety hazards were decommissioned under this program. All work was conducted in accordance with WHC (1989). Wells decommissioned during FY 1996, in addition to the historical record of wells decommissioned, are tracked in the Hanford Well Services Database.

Table 8.1. Wells Decommissioned During FY 1996

Well Name	Effective Date	Location
199-F2-1	01/12/96	100-F Area
199-F2-2	01/12/96	
B2767	03/19/96	200-West Area (Central Waste Wrap Site)
B2768	03/19/96	
B2769	03/19/96	
299-W15-97	09/13/96	200-West Area
299-W15-98	09/13/96	
299-W15-99	09/13/96	
299-W15-100	09/13/96	
299-W15-759	09/13/96	
299-W15-760	09/13/96	
299-W15-761	09/13/96	
B2835	10/01/95	600 Area (Near River north of 100-H Area)
B2836	10/01/95	
699-83-36F	11/22/95	600 Area
699-S24-E19	12/07/95	
699-81-47	11/22/95	
699-39-7N	02/13/96	14 m north of 699-39-7M
699-39-7O	02/13/96	14 m north of 699-39-7N
699-82-47	03/01/96	
699-81-46	03/01/96	
699-39-7M	03/18/96	10 m north of 699-39-7L
699-39-7L	03/19/96	4 m north of 699-39-7K
699-39-7B	03/28/96	
699-42-12B	04/16/96	
699-31-65	06/20/96	
699-42-12C	06/26/96	
699-39-7K	07/29/96	8 m north of 699-39-7J
699-39-7J	07/30/96	3 m east of 699-39-7H
699-39-7H	08/05/96	15 m north of 699-39-7G
699-39-7G	08/06/96	24 m north of 699-39-7A
699-39-7F	09/04/96	12 m north and 12 m west of 699-39-7A
699-39-7A	09/25/96	

9.0 References

Public Laws

Atomic Energy Act of 1954, as amended, Ch. 1073, 68 Stat. 919, 42 USC 2011 et seq.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, Public Law 96-510, 94 Stat. 2767, 42 USC 9601 et seq.

Hazardous and Solid Waste Amendments of 1984, as amended, Public Law 98-616, 98 Stat. 3221, 42 USC 6901 et seq.

Resource Conservation and Recovery Act of 1976, as amended, Public Law 94-580, 90 Stat. 2795, 42 USC 6901 et seq.

Safe Drinking Water Act of 1974, as amended, Public Law 93-523, 88 Stat. 1660, 42 USC 300f et seq.

Superfund Amendments and Reauthorization Act of 1986, as amended, Public Law 99-499, 100 Stat. 1613, 42 USC 11001 et seq.

Code of Federal Regulations

40 CFR 141, Code of Federal Regulations, Title 40, Part 141. *National Primary Drinking Water Standards*.

40 CFR 142, Code of Federal Regulations, Title 40, Part 142. *National Primary Drinking Water Regulations Implementation.*

40 CFR 143, Code of Federal Regulations, Title 40, Part 143. *National Secondary Drinking Water Regulations*.

40 CFR 257, Code of Federal Regulations, Title 40, Part 257. *Criteria for Classification of Solid Waste Disposal Facilities and Practices*.

40 CFR 264, Code of Federal Regulations, Title 40, Part 264. *Standards for Owners and Operators of Hazardous Water Treatment, Storage, and Disposal Facilities*.

40 CFR 265, Code of Federal Regulations, Title 40, Part 265. *Interim Status Standards for Owners and Operators of Hazardous Water Treatment, Storage, and Disposal Facilities*.

40 CFR 300, Code of Federal Regulations, Title 40, Part 300. *National Oil and Hazardous Substances Pollution Contingency Plan.*

40 CFR 300, Code of Federal Regulations, Title 40, Part 300, Appendix B. *National Priorities List.*

U.S. Department of Energy Orders

DOE Order 5400.1. *General Environmental Protection Program.* U.S. Department of Energy, Washington, D.C.

DOE Order 5400.5. *Radiation Protection of the Public and the Environment.* U.S. Department of Energy, Washington, D.C.

DOE Order 5820.2. *Radioactive Waste Management.* U.S. Department of Energy, Washington, D.C.

Revised Code of Washington

RCW 70.105, Revised Code of Washington, Title 70, Chapter 105. *Hazardous Waste Management Act.*

Washington Administrative Code

WAC 173-160, Washington Administrative Code. *Minimum Standards for Construction and Maintenance of Wells.* Olympia, Washington.

WAC 173-200, Washington Administrative Code. *Water Quality Standards for Ground Waters of the State of Washington.* Olympia, Washington.

WAC 173-216, Washington Administrative Code. *State Waste Discharge Program.* Olympia, Washington.

WAC 173-303, Washington Administrative Code. *Dangerous Waste Regulations.* Olympia, Washington.

WAC 173-303-400, Washington Administrative Code. *Interim Status Facility Standards.* Olympia, Washington.

WAC 173-303-600, Washington Administrative Code. *Final Status Standards.* Olympia, Washington.

WAC 173-303-610, Washington Administrative Code. *Closure and Postclosure.* Olympia, Washington.

WAC 173-303-645, Washington Administrative Code. *Releases from Regulated Units.* Olympia, Washington.

WAC 173-304, Washington Administrative Code. *Minimum Functional Standards for Solid Waste Handling.* Olympia, Washington.

WAC 173-304-490, Washington Administrative Code. *Ground Water Monitoring Requirements.* Olympia, Washington.

WAC 173-340-720, Washington Administrative Code. *Groundwater Cleanup Standards.* Olympia, Washington.

WAC 246-290, Washington Administrative Code. *Public Water Supplies*. Olympia, Washington.

WAC 246-290-310, Washington Administrative Code. *Maximum Contaminant Levels (MCLs)*. Olympia, Washington.

Agnew, S. F. 1995. *Hanford Defined Wastes: Chemical and Radionuclide Compositions*. LA-UR-94-2657, Rev. 2, prepared by Chemical Science and Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico.

Agnew, S. F., J. Boyer, R. A. Corbin, T. B. Duran, J. R. FitzPatrick, K. A. Jurgensen, T. P. Ortiz, and B. L. Young. 1996. *Hanford Tank Chemical and Radionuclide Inventories: HDW Model Rev. 3*. LA-UR-96-858, Los Alamos National Laboratory, Los Alamos, New Mexico.

Airhart, S. P. 1990. *Borehole Completion Data Package for the 216-S-10 Ditch and Pond*. WHC-MR-0206, Westinghouse Hanford Company, Richland, Washington.

Airhart, S. P., J. V. Borghese, and S. Dudziak. 1990. *Interim-Status Ground Water Monitoring Plan for the 216-S-10 Pond and Ditch*. WHC-SD-EN-AP-018, Rev. 0, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Aldrich, R. C. 1987. *Radioactive Liquid Wastes Discharged to Ground in the 200 Areas During 1986*. RHO-HS-SR-86-3-4Q LIQ P, Rockwell Hanford Operations, Richland, Washington.

Alexander, D. J. 1993. *Groundwater Impact Assessment Report for the 100-D Ponds*. WHC-EP-0666, Westinghouse Hanford Company, Richland, Washington.

Alexander, D. J., S. D. Evelo, V. G. Johnson, and M. D. Sweeney. 1995. *Groundwater Impact Assessment Report for the 216-T-4-2 Ditch*. WHC-EP-0815, Westinghouse Hanford Company, Richland, Washington.

Allison, I. S. 1933. "New Version of the Spokane Flood." *Geological Society of America Bulletin* 44:675-722.

American Public Health Association. 1989. *Standard Methods for the Examination of Water and Wastewater, 17th Edition*. New York.

American Society for Testing and Materials (ASTM). 1986. *Annual Book of ASTM Standards*. Philadelphia, Pennsylvania.

American Society for Testing and Materials (ASTM). 1988. "D 4750-87, Standard Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)." *Annual Book of ASTM Standards*. Philadelphia, Pennsylvania.

Anderson, J. D. 1990. *A History of the 200 Area Tank Farms*. WHC-MR-0132, Westinghouse Hanford Company, Richland, Washington.

Baker, S. M., J. L. Devary, R. P. Elmore, R. L. Lorang, A. J. Rossi, and M. D. Freshley. 1988. *U1/U2 Uranium Plume Characterization, Remedial Action Review and Recommendation for Future Action*. WHC-EP-0133, Westinghouse Hanford Company, Richland, Washington.

Baker, V., B. N. Bjornstad, A. J. Busacca, K. R. Fecht, E. P. Kiver, U. L. Moody, J. G. Rigby, D. F. Stradling, and A. M. Tallman. 1991. "Quaternary Geology of the Columbia Plateau." In Morrison, R. B. (ed.), *Quaternary Nonglacial Geology; Conterminous U.S.* The Geological Society of America, v. K-2, p. 215-250.

Barnett D. B., J. S. Schmid, S. S. Lowe, W. L. Allen, N. A. Ballantyne, C. H. Dohrer, M. J. Hartman, F. N. Hodges, D. G. Horton, V. G. Johnson, K. J. Lueck, D. J. Ortiz, A. J. Knepp, B. H. Ford, S. P. Hope, D. K. Tyler, R. D. Hildebrand, D. E. Olson, R. E. Peterson, G. L. Kasza, D. A. Myers, S. P. Luttrell, P. D. Thorne, and K. R. Moser. 1995a. *Hanford Site Ground-Water Protection Management Plan.* DOE/RL-89-12, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Barnett, D. B., J. D. Davis, C. J. Chou, L. C. Collard, and P. B. Freeman. 1995b. *Ground-Water Screening Evaluation/Monitoring Plan -- 200 Area Treated Effluent Disposal Facility (Project W-049H).* WHC-SD-EN-WP-012, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Bauer, H. H., J. J. Vaccaro, and R. C. Lane. 1985. *Maps Showing Ground-Water Levels in the Columbia River Basalt and Overlying Materials, Spring 1983, Southeastern Washington.* Water-Resources Investigations Report 84-4360, U.S. Geological Survey, Tacoma, Washington.

Bierschenk, W. H. 1959. *Aquifer Characteristics and Groundwater Movement at Hanford.* HW-60601, Hanford Atomic Products Operations, Richland, Washington.

Bisping, L. E. 1996. *Environmental Surveillance Master Sampling Schedule.* PNNL-10950, Pacific Northwest National Laboratory, Richland, Washington.

Bjornstad, B. N. 1984. *Suprabasalt Stratigraphy Within and Adjacent to the Reference Repository Location.* SD-BWI-DP-039, Rockwell Hanford Operations, Richland, Washington.

Bjornstad, B. N., and S. Dudziak. 1989. *40 CFR 265 Interim Status Indicator-Evaluation Ground Water Monitoring Plan for the 216-B-63 Trench.* PNL-6862, Pacific Northwest Laboratory, Richland, Washington.

Borghese, J. V., J. N. Winters, S. W. Petersen, J. T. Hadley, J. M. Shorey, and R. W. Ovink. 1996a. *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units.* DOE/RL-96-090, prepared by Bechtel Hanford, Inc. for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Borghese, J. V., M. J. Hartman, S. P. Luttrell, C. J. Perkins, J. P. Zoric, and S. C. Tindall. 1996b. *100-N Pilot Project: Proposed Consolidated Groundwater Monitoring Program.* BHI-00725, Bechtel Hanford, Inc., Richland, Washington.

Brown, D. J. 1963. *Status of Groundwater Beneath Hanford Reactor Areas: January 1962 to January 1963.* HW-77170, General Electric Company, Hanford Atomic Products Division, Richland, Washington.

Brown, R. E. 1979. *A Review of Water-Well Data From the Unconfined Aquifer in the Eastern and Southern Parts of the Pasco Basin.* RHO-BWI-C-56, Rockwell Hanford Operations, Richland, Washington.

Buelt, J. L., W. Conbere, M. D. Freshley, R. J. Hicks, W. L. Kuhn, D. A. Lamar, R. J. Serne, and J. L. Smoot. 1988. *The Predicted Impacts to the Ground Water and Columbia River from Ammoniated Water Discharged to the 216-A-36B Crib*. PNL-6463, Pacific Northwest Laboratory, Richland, Washington.

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

Caggiano, J. A. 1996b. "4.11 Single-Shell Tanks." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995*. DOE/RL-96-01, Rev. 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Caggiano, J. A. 1996c. *Assessment Groundwater Monitoring Plan for SST Waste Management Area B-BX-BY*. WHC-SD-ENV-AP-002, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A., and C. J. Chou. 1993. *Interim-Status Groundwater Quality Assessment Plan for the Single-Shell Tanks*. WHC-SD-EN-DP-042, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A., and S. M. Goodwin. 1991. *Interim-Status Groundwater Monitoring Plan for the Single-Shell Tanks*. WHC-SD-EN-AP-012, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Campbell, M. D., W. J. McMahon, and K. R. Simpson. 1993. *Water Level Measurements for Modeling Hydraulic Properties in the 300-FF-5 and 100 Aggregate Area Operable Units*. PNL-8580, Pacific Northwest Laboratory, Richland, Washington.

Carpenter, R. W. 1993. *100-D Technical Baseline Report*. WHC-SD-EN-TI-181, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Carpenter, R. W., and S. L. Cote. 1994. *100-K Area Technical Baseline Report*. WHC-SD-EN-TI-239, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Chiaramonte, G. R., C. W. Denslow, A. J. Knepp, R. D. Landon, and S. Panday. 1996. *Hanford Sitewide Groundwater Remediation Strategy - Groundwater Contaminant Predictions*. BHI-00469, Bechtel Hanford, Inc., Richland, Washington.

Chou, C. J., and V. G. Johnson. 1996. *Effluent Variability Study Results for the 200 Area Effluent Disposal Facility (W-049H)*. WHC-SD-LEF-EV-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., B. H. Ford, J. W. Lindberg, S. J. Trent, C. D. Delaney, and J. V. Borghese. 1992a. *Hydrogeologic Model for the 200 East Groundwater Aggregate Area*. WHC-SD-EN-TI-019, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Connelly, M. P., B. H. Ford, and J. V. Borghese. 1992b. *Hydrogeologic Model for the 200 West Groundwater Aggregate Area*. WHC-SD-EN-TI-014, Westinghouse Hanford Company, Richland, Washington.

Daily, W., and E. Owen. 1991. "Cross-Borehole Resistivity Tomography." *Geophysics* 56:1228-1235.

Daily, W., and A. Ramirez. 1993. "Electrical Resistance Tomography During In Situ Remediation of a TCE Plume at the U.S. Department of Energy Savannah River Site." In *Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems*, vol. 1, pp 51-52.

Daily, W., and A. Ramirez. 1995. "Electrical Resistance Tomography During In-Situ Trichloroethylene Remediation at the Savannah River Site." *Journal of Applied Geophysics* 33:239-249.

Daily, W., A. Ramirez, D. LaBrecque, and J. Nitao. 1992. "Electrical Resistivity Tomography of Vadose Water Movement." *Water Resources Research* 28:1429-1442.

Davis, J. D., D. B. Barnett, C. J. Chou, and P. B. Freeman. 1996. *Ground-Water Screening Evaluation/Monitoring Plan -- 200 Area Effluent Treatment Facility (Project C-018H)*. WHC-SD-C018H-PLN-004, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Deford, D., and M. W. Einan. 1995. *100-H Area Technical Baseline Report*. BHI-00127, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Delaney, C. D., K. A. Lindsey, and S. P. Reidel. 1991. *Geology and Hydrology of the Hanford Site: A Standardized Text for Use in Westinghouse Hanford Company Documents and Reports*. WHC-SD-ER-TI-003, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Dirkes, R. L., and R. W. Hanf (eds.). 1996. *Hanford Site Environmental Report for Calendar Year 1995*. PNNL-11139, Pacific Northwest National Laboratory, Richland, Washington.

DOE (see U.S. Department of Energy)

Dresel, P. E., J. T. Rieger, W. D. Webber, P. D. Thorne, B. M. Gillespie, S. P. Luttrell, S. K. Wurstner, and T. L. Liikala. 1996. *Hanford Site Ground-Water Monitoring for 1995*. PNNL-11141, Pacific Northwest National Laboratory, Richland, Washington.

Drost, B. W., K. M. Schurr, and W. E. Lum II. 1989. *Selected Ground-Water Information for the Pasco Basin and Adjacent Areas, Washington, 1986-1989*. Open-File Report 89-228, U.S. Geological Survey, Tacoma, Washington.

Drost, B. W., J. C. Ebbert, and S. E. Cox. 1993. *Long-Term Effects of Irrigation With Imported Water on Water Levels and Water Quality*. Water-Resources Investigations Report 93-4060, U.S. Geological Survey, Tacoma, Washington.

Drummond, M. E. 1992. *The Future for Hanford: Uses and Cleanup. A Final Report of the Hanford Future Site Uses Working Group*. Eastern Washington University, Ellensburg, Washington.

Ebbert, J. C., S. E. Cox, and B. W. Drost. 1991. "The Effects of Lining Irrigation Canals on Nitrate Concentrations in Ground Water." In *Proceedings of the Conference on Nonpoint Source Pollution: The Unfinished Agenda for the Protection of Our Water Quality*. Tacoma, Washington.

Ebbert, J. C., S. E. Cox, B. W. Drost, and K. M. Shurr. 1995. *Distribution and Sources of Nitrate and Presence of Fluoride and Pesticides in Parts of the Pasco Basin, Washington, 1986-1988*. Water-Resources Investigations Report 93-4197, U.S. Geological Survey, Washington, D.C., p. 173.

Ecology (see State of Washington Department of Ecology)

Engelman, R. E., R. E. Lewis, and D. C. Stromswold. 1995. *Calibration Models for Measuring Moisture in Unsaturated Formations by Neutron Logging*. PNL-10801, Pacific Northwest Laboratory, Richland, Washington.

EPA (see U.S. Environmental Protection Agency)

Evans, J. C., R. W. Bryce, and D. R. Sherwood. 1989. *Hanford Site Ground-Water Monitoring for January Through June 1988*. PNL-6886, Pacific Northwest Laboratory, Richland, Washington.

Fancher, J. D. 1994. *Carbon Tetrachloride ERA Soil-Gas Baseline Monitoring*. WHC-SD-EN-TI-265, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Fayer, M. J., and T. B. Walters. 1995. *Estimated Recharge Rates at the Hanford Site*. PNL-10285, Pacific Northwest Laboratory, Richland, Washington.

Fecht, K. R., and D. C. Weekes. 1996. *Geologic Field Inspection of the Sedimentary Sequence at the Environmental Restoration Disposal Facility*. BHI-00230, Bechtel Hanford, Inc., Richland, Washington.

Fecht, K. R., S. P. Reidel, and A. M. Tallman. 1987. "Paleodrainage of the Columbia River system on the Columbia Plateau of Washington State - A Summary." In Schuster, J. E., (ed.), *Selected Papers on the Geology of Washington*. Washington State Division of Geology and Earth Resources, Bulletin 77, p. 219-248.

Fecht, K. R., D. B. Barnett, A. G. Law, K. A. Lindsey, and V. J. Rohay. 1994. "Pleistocene Clastic Dikes and Their Influence on Moisture Flow in the Vadose Zone of South-Central Washington State." *Geological Society of America, Abstracts with Programs* 26(7):A204.

Ford, B. H. 1995. *200-UP-1 Vertical Profiling Activity Summary Report*. BHI-00149, Rev. 00, Bechtel Hanford, Inc., Richland, Washington.

Ford, B. H., and S. J. Trent. 1994. "4.1 Hydrogeologic Setting of the 200 Areas." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1993*. DOE/RL-93-88, Rev. 0, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Frain, J. M., and G. J. Jackson. 1994. *N Springs Groundwater Pump-and-Treat System Functional and Operational Requirements*. BHI-00030, Rev. 00, Bechtel Hanford, Inc., Richland, Washington.

Freeman-Pollard, J. R., I. D. Jacques, W. J. McMahon, K. M. Singleton, S. A. Strope, L. C. Swanson, and C. R. Windmueller. 1996. *200-ZP-1 Phase II Interim Remedial Measure Quarterly Report, August - October 1996*. BHI-00952-01, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Freshley, M. D., and M. J. Graham. 1988. *Estimation of Ground-Water Travel Time at the Hanford Site: Description, Past Work, and Future Needs*. PNL-6328, Pacific Northwest Laboratory, Richland, Washington.

Freshley, M. D., and P. D. Thorne. 1992. *Ground-Water Contribution to Dose from Past Hanford Operations*. PNWD-1974 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Fruland, R. M., and R. E. Lundgren (eds.). 1989. *RCRA Ground-Water Monitoring Projects for Hanford Facilities: Annual Progress Report for 1988*. PNL-6852, Pacific Northwest Laboratory, Richland, Washington.

Garber, M. S., and F. C. Koopman. 1968. *Methods of Measuring Water Levels in Deep Wells: U.S. Geological Survey*. TRWI, Book 8, Chapter A-1. U.S. Government Printing Office, Washington, D.C.

Gee, G. W., M. J. Fayer, M. L. Rockhold, and M. D. Campbell. 1992. "Variations in Recharge at the Hanford Site." *Northwest Science* 66:237-250.

General Electric. 1963. "Volume 3: Description of the 100-B, 100-C, 100-D, 100-DR, 100-F, and 100-H Production Reactor Plants." In *Hazards Summary Report*. HW-74094, Hanford Atomic Products Division, Richland, Washington.

Gephart, R. E., R. C. Arnett, R. G. Baca, L. S. Leonhart, and F. A. Spane, Jr. 1979. *Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge*. RHO-BWI-ST-5, Rockwell Hanford Operations, Richland, Washington.

Gerber, M. S. 1993. *Manhattan Project Buildings and Facilities at the Hanford Site: A Construction History*. WHC-MR-0425, Westinghouse Hanford Company, Richland, Washington.

Gilmore, T. J, F. A. Spane, Jr., D. R. Newcomer, and C. R. Sherwood. 1992. *Applications of Three Aquifer Test Methods for Estimating Hydraulic Properties Within the 100-N Area*. PNL-8335, Pacific Northwest Laboratory, Richland, Washington.

Goodwin, S. M. 1990. *Borehole Completion Data Package for the 216-U-12 Crib*. WHC-MR-0208, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Graham, M. J., M. D. Hall, S. R. Strait, and W. R. Brown. 1981. *Hydrology of the Separations Area*. RHO-ST-42, Rockwell Hanford Operations, Richland, Washington.

Graham, M. J., G. V. Last, and K. R. Fecht. 1984. *An Assessment of Aquifer Intercommunication in the B Pond, Gable Mountain Pond Area*. RHO-RE-ST-12P, Rockwell Hanford Operations, Richland, Washington.

Gupta, S. K., C. R. Cole, C. T. Kincaid, and A. M. Monti. 1987. *Coupled Fluid, Energy, and Solute Transport (CFEST) Model: Formulation and User's Manual*. BMI/ONWI-660, Battelle Memorial Institute, Columbus, Ohio.

Gustafson, F. W., J. W. Green, and C. D. Wittreich. 1995. *Treatability Test Report for the 200-UP-1 Operable Unit, Hanford Site*. DOE/RL-95-02, Rev. 0, International Technology Hanford Corporation for the U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Haney, W. A. 1957. *Disposal of High Cobalt-60 Scavenged Wastes*. HW-48862, Hanford Atomic Products Operation, Richland, Washington.

Harris, S. F. 1990. *Ground Water Quality Assessment Plan for the 216-B-3 Pond System*. WHC-SD-EN-AP-030, Westinghouse Hanford Company, Richland, Washington.

Harris, S. F. 1991. "5.0 216-B-3 Pond System." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990*. DOE/RL-91-03, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hartman, M. J. 1991. *Groundwater Monitoring Plan for the 100-D Ponds*. WHC-SD-EN-AP-048, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1992a. *Borehole Completion Data Package 100-D Ponds Wells: CY 1992*. WHC-SD-EN-DP-043, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1992b. *Results of Ground Water Quality Assessment Monitoring at the 1301-N Liquid Waste Disposal Facility and 1324-N/NA Facilities*. WHC-SD-EN-EV-003, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1993a. *Groundwater Quality Assessment Plan for the 1324-N/NA Site*. WHC-SD-EN-AP-065, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1993b. *Groundwater Monitoring Plan for the 1301-N and 1325-N Liquid Waste Disposal Facilities*. WHC-SD-EN-AP-038, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1994. "3.0 100-D Ponds." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1993*. DOE/RL-93-88, Rev. 0, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hartman, M. J. 1995. "3.3 183-H Solar Evaporation Basins." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1994*. DOE/RL-94-136, Rev. 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hartman, M. J. 1996a. "3.3 183-H Solar Evaporation Basins." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995*. DOE/RL-96-01, Rev. 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hartman, M. J. 1996b. *RCRA Assessment Report: Total Organic Halogen at the 1324-N/NA Site.* WHC-SD-EN-EV-031, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1996c. *Groundwater Monitoring Plan for the 1301-N, 1325-N, and 1324-N/NA Sites.* WHC-SD-EN-AP-038, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J. 1996d. *100-D Ponds Groundwater Quality Assessment.* WHC-SD-EN-EV-033, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and C. J. Chou. 1995. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins.* WHC-SD-EN-AP-180, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and K. A. Lindsey. 1993. *Hydrogeology of the 100-N Area, Hanford Site, Washington.* WHC-SD-EN-EV-027, Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and R. E. Peterson. 1992. *Hydrologic Information Summary for the Northern Portion of the Hanford Site.* WHC-SD-EN-TI-023, Westinghouse Hanford Company, Richland, Washington.

Hausenbuiller, R. L. 1972. *Soil Science: Principles and Practices.* Wm. C. Brown Company Publishers, Dubuque, Iowa.

Hodges, F. N. 1991a. "18.0 Solid Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990.* DOE/RL-91-03, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hodges, F. N. 1991b. "17.0 Nonradioactive Dangerous Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990.* DOE/RL-91-03, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hodges, F. N. 1992a. "19.0 Solid Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1991.* DOE/RL-92-03, Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hodges, F. N. 1992b. *Interim Status Groundwater Monitoring Plan for the Nonradioactive Dangerous Waste Landfill, Hanford, Washington.* WHC-SD-EN-AP-026, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hodges, F. N. 1993a. "19.0 Solid Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1992.* DOE/RL-93-09, Rev. 0, Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland, Washington.

Hodges, F. N. 1993b. *Groundwater Monitoring Plan for the Solid Waste Landfill, Hanford, Washington.* WHC-SD-EN-AP-043, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Hodges, F. N. 1994a. "5.3 Solid Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1993*. DOE/RL-93-88, Rev. 0, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hodges, F. N. 1994b. "5.2 Nonradioactive Dangerous Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1993*. DOE/RL-93-88, Rev. 0, prepared by Geosciences Group, Westinghouse Hanford Company, Environmental Division for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hodges, F. N. 1994c. *Corrective Action Plan for the Hanford Site Solid Waste Landfill*. DOE/RL-94-143, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hodges, F. N. 1995. "5.2 Solid Waste Landfill." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1994*. DOE/RL-94-136, Rev. 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Hope, S. J., and R. A. Peterson. 1996. *Pore Water Chromium Concentration at 100-H Reactor Area Adjacent to Fall Chinook Salmon Spawning Habitat of the Hanford Reach, Columbia River*. BHI-00345, Rev. 1, Bechtel Hanford, Inc., Richland, Washington.

ICF Northwest. 1987. *Hydrogeologic Study of North Richland Well Field and Ground-Water Recharge Basins*. Prepared for the City of Richland, Richland, Washington.

Jacobson, E. A., and M. D. Freshley. 1990. *An Initial Inverse Calibration of the Ground-Water Flow Model for the Hanford Unconfined Aquifer*. PNL-7144, Pacific Northwest Laboratory, Richland, Washington.

Jacques, I. D., and R. B. Kerkow. 1993. *Nonradioactive Dangerous Waste Landfill Soil Gas Survey: Final Report*. WHC-SD-EN-TI-199, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Jenkins, O. P. 1922. *Undergroundwater Supply of the Region About White Bluffs and Hanford*. Bulletin No. 26, State of Washington Department of Conservation and Development, Division of Geology, Olympia, Washington.

Jensen, E. J. 1987. *An Evaluation of Aquifer Intercommunication Between the Unconfined and Rattlesnake Ridge Aquifers on the Hanford Site*. PNL-6313, Pacific Northwest Laboratory, Richland, Washington.

Jensen, E. J., S. P. Airhart, M. A. Chamness, T. J Gilmore, D. R. Newcomer, and K. R. Oster. 1989. *40 CFR 265 Interim-Status Ground-Water Monitoring Plan for the Single-Shell Tanks*. WHC-SD-EN-AP-012, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Jensen, E. J., M. A. Chamness, S. M. Goodwin, S. H. Hall, and D. R. Newcomer. 1990. *Interim-Status Ground-Water Monitoring Plan for the 216-U-12 Crib*. WHC-SD-EN-AP-019 Rev. 0, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G. 1993a. *Groundwater Impact Assessment Report for 216-Z-20 Crib, 200 West Area.* WHC-EP-0674, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G. 1993b. *Westinghouse Hanford Company Operational Groundwater Status Report 1990-1992.* WHC-EP-0595, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., and C. J. Chou. 1995. *Groundwater Monitoring Results for the 100 K Area Fuel Storage Basins: March to December 1994.* WHC-SD-EN-TI-280, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., and S. D. Evelo. 1995. *Groundwater Monitoring Results for the 100-K Area Nuclear Fuel Storage Basins: January through June 1995.* WHC-SD-EN-TI-280, Rev. 2, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., C. J. Chou, and F. N. Hodges. 1994. *Some Statistical Aspects of Background Based Groundwater Standards at Arid Hazardous Waste Sites.* WHC-SA-2358-FP, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. G., C. J. Chou, and J. W. Lindberg. 1995. *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins.* WHC-SD-EN-AP-174, Westinghouse Hanford Company, Richland, Washington.

Johnson, V. M., M. Mehlhorn, D. A. Myers, and L. D. Walker. 1996. *Well Summary Report: 100-HR-3 and 100-KR-4 Interim Remedial Action Wells.* BHI-00953, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Kasza, G. L. 1992. *Borehole Completion Data Package for the 216-A-29 RCRA Facility Monitoring Wells: Calendar Year 1991.* WHC-SD-EN-DP-047, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L. 1993. *Potential for Groundwater Contamination from High Density Wastes Disposed at the BY Cribs, 200-BP-1 CERCLA Operable Unit.* WHC-SD-EN-TA-003, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L. 1994. *Interim-Status Groundwater Monitoring Plan for the 216-A-10 and 216-A-36B Cribs.* WHC-SD-EN-AP-170, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

Kasza, G. L., and S. M. Goodwin. 1991. *Groundwater Monitoring Plan for the 216-A-29 Ditch.* WHC-SD-EN-AP-045, Rev. 0-A, Westinghouse Hanford Company, Richland, Washington.

Kemp, C. J., and B. H. Ford. 1996. *Fiscal Year 1996 Groundwater Sampling for the Horn Rapids Landfill.* BHI-00949, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Kipp, K. L., and R. D. Mudd. 1973. *Collection and Analysis of Pump Test Data for Transmissivity Values.* BNWL-1709, Battelle, Pacific Northwest Laboratory, Richland, Washington.

Krupka, K. M., and R. J. Serne. 1995. *Performance Assessment of Low-Level Radioactive Waste Disposal Facilities: Effects on Radionuclide Concentrations by Cement/Ground-Water Interactions*. NUREG/CR-6377, U.S. Nuclear Regulatory Commission, Washington, D.C.

Last, G. V., and B. N. Bjornstad. 1989. *Revised Ground-Water Monitoring Plan for the 200 Areas Low-Level Burial Grounds*. WHC-SD-EN-AP-015, Rev. 0, prepared by Pacific Northwest Laboratory for Westinghouse Hanford Company, Richland, Washington.

Last, G. V., and V. H. Rohay. 1993. *Refined Conceptual Model for the Volatile Organic Compounds - Arid Integrated Demonstration and 200 West Area Carbon Tetrachloride Expedited Response Action*. PNL-8597, Pacific Northwest Laboratory, Richland, Washington.

Last, G. V., B. N. Bjornstad, M. P. Bergeron, D. W. Wallace, D. R. Newcomer, J. A. Schramke, M. A. Chamness, C. S. Cline, S. P. Airhart, and J. S. Wilber. 1989. *Hydrogeology for the 200 Areas Low-Level Burial Grounds - An Interim Report*. PNL-6820, Pacific Northwest Laboratory, Richland, Washington.

Law, A., S. Panday, C. Denslow, K. Fecht, and A. Knepp. 1996. *Hanford Sitewide Groundwater Flow and Transport Model Calibration Report*. BHI-00608, Bechtel Hanford, Inc., Richland, Washington.

Liikala, T. L. 1994. *Hydrogeology Along the Southern Boundary of the Hanford Site Between the Yakima and Columbia Rivers, Washington*. PNL-10094, Pacific Northwest Laboratory, Richland, Washington.

Liikala T. L., R. L. Aaberg, N. J. Aimo, D. J. Bates, T. J Gilmore, E. J. Jensen, G. V. Last, P. L. Oberlander, K. B. Olsen, K. R. Oster, L. R. Roome, J. C. Simpson, S. S. Teel, and E. J. Westergard. 1988. *Geohydrologic Characterization of the Area Surrounding the 183-H Solar Evaporation Basins*. PNL-6728, Pacific Northwest Laboratory, Richland, Washington.

Lindberg, J. W. 1995. *Hydrogeology of the 100-K Area, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-294, Westinghouse Hanford Company, Richland, Washington.

Lindberg, J. W. 1996. "6.1 300 Area Process Trench." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995*. DOE/RL-96-01, Rev. 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Lindberg, J. W., and F. W. Bond. 1979. *Geohydrology and Ground-Water Quality Beneath the 300 Area, Hanford Site, Washington*. PNL-2949, Pacific Northwest Laboratory, Richland, Washington.

Lindberg, J. W., C. J. Chou, and V. G. Johnson. 1995. *Groundwater Monitoring Plan for the 300 Area Process Trenches*. WHC-SD-EN-AP-185, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1991. *Revised Stratigraphy for the Ringold Formation, Hanford Site, South-Central Washington*. WHC-SD-EN-EE-004, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1992. *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas*. WHC-SD-EN-TI-011, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A. 1995. *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*. BHI-00184, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Lindsey, K. A., and G. K. Jaeger. 1993. *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*. WHC-SD-EN-TI-132, Westinghouse Hanford Company, Richland, Washington.

Lindsey, K. A., B. N. Bjornstad, J. W. Lindberg, and K. M. Hoffman. 1992. *Geologic Setting of the 200 East Area: An Update*. WHC-SD-EN-TI-012, Westinghouse Hanford Company, Richland, Washington.

Lu, A. H., R. Khaleel, and D. L. Hams. 1992. "Vadose Zone Flow and Transport Modelling: C-018H Soil Column Disposal Siting Evaluation." In Reidel, S. P., and E. C. Thornton, *Characterization Report, C-018H Disposal Siting Evaluation*. WHC-SD-C018H-RPT-001, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Ludowise, J. D. 1978. *Report on Plutonium Mining Activities at 216-Z-9 Enclosed Trench*. RHO-ST-21, Rockwell Hanford Operations, Richland, Washington.

McKinley, W. S. 1996. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units Interim Action*. BHI-00765 Draft A, Bechtel Hanford, Inc., Richland, Washington.

Mercer, R. B. 1993a. *1991 Borehole Completion Data Package for the Low-Level Burial Grounds*. WHC-SD-EN-DP-044, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Mercer, R. B. 1993b. *1992 Borehole Completion Data Package for the Low-Level Burial Grounds*. WHC-SD-EN-DP-049, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Mercer, R. B. 1996. "4.10 200 Areas Low-Level Burial Grounds." In *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995*. DOE/RL-96-01, Rev. 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company for U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Myers, C. W./S. M. Price, J. A. Caggiano, M. P. Cochran, W. J. Czimer, N. J. Davidson, R. C. Edwards, K. R. Fecht, G. E. Holmes, M. G. Jones, J. R. Kunk, R. D. Landon, R. K. Ledgerwood, J. T. Lillie, P. E. Long, T. H. Mitchell, E. H. Price, S. M. Reidel, and A. M. Tallman. 1979. *Geologic Studies of the Columbia Plateau: A Status Report*. RHO-BWI-ST-4, Rockwell Hanford Operations, Richland, Washington.

Myers, D. A. 1978. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1977*. PNL-2624, Pacific Northwest Laboratory, Richland, Washington.

Myers, D. A., J. J. Fix, and J. R. Raymond. 1977. *Environmental Monitoring Report on Radiological Status of the Groundwater Beneath the Hanford Site, January-December 1976.* BNWL-2199, Battelle, Pacific Northwest Laboratory, Richland, Washington.

Myers, D. A., C. W. Denslow, D. B. Erb, F. W. Gustafson, J. W. Green, Jr., and W. J. McMahon. 1996. *200-UP-1 Groundwater Pump-and-Treat Phase I Annual Report, FY 1996.* BHI-00951, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Narbutovskih, S. M., D. F. Iwatate, M. D. Sweeney, A. L. Ramirez, W. Daily, R. M. Morey, and L. Christensen. 1996. *Feasibility of CPT-Deployed Vertical Electrode Array in Single Shell Tank Farms.* WHC-SD-EN-TA-004, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Natrella, M. G. 1966. *Experimental Statistics.* National Bureau of Standards Handbook 91, John Wiley and Sons, New York, Table A-7.

Newcomb, R. C. 1958. "Ringold Formation of the Pleistocene Age in the Type Locality, The White Bluffs, Washington." *American Journal of Science* 256:328-340.

Newcomb, R. C., J. R. Strand, and F. J. Frank. 1972. *Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington.* Professional Paper 717, U.S. Geological Survey, Washington, D.C.

Newcomer, D. R. 1990. *Evaluation of Hanford Site Water-Table Changes—1980 to 1990.* PNL-7498, Pacific Northwest Laboratory, Richland, Washington.

Newcomer, D. R., J. V. Borghese, and W. E. Cronin. 1990. *Hydrologic Testing at the Single-Shelled Tanks, 1989.* WHC-SD-EN-TI-147, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Newcomer, D. R., L. A. Doremus, S. H. Hall, M. J. Truex, V. R. Vermeul, and R. E. Engelman. 1995. *Geology, Hydrology, Chemistry, and Microbiology of the In Situ Bioremediation Demonstration Site.* PNL-10422, Pacific Northwest Laboratory, Richland, Washington.

PSPL (see Puget Sound Power and Light)

Peterson, R. E., and M. P. Connelly. 1992. *Characterization of a Chromium Plume in Groundwater Along the Columbia River Shoreline, Hanford Site, Washington.* WHC-SA-1674-VA, Westinghouse Hanford Company, Richland, Washington.

Peterson, R. E., and R. F. Raidl. 1996. *Groundwater Monitoring Implementation Plan for the 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units.* BHI 00916, Rev. 0, prepared by CH2M Hill Hanford, Inc. for Bechtel Hanford, Inc., Richland, Washington.

Peterson, R. E., R. F. Raidl, and C. W. Denslow. 1996. *Conceptual Site Models for Groundwater Contamination at 100-BC-5, 100-KR-4, 100-HR-3, and 100-FR-3 Operable Units.* BHI-00917, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Piepho, M. G. 1996. *Numerical Analysis of Carbon Tetrachloride Movement in the Saturated and Unsaturated Zones in the 200 West Area, Hanford Site*. BHI-00459, Rev. 0, Bechtel Hanford Inc., Richland, Washington.

Price, R. K. 1995. *Vadose Zone Monitoring Plan Using Geophysical Nuclear Logging for Radionuclides Discharged to Hanford Liquid Waste Disposal Facilities*. WHC-SD-EN-AP-087, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Price, R. K., J. E. Meisner, and R. R. Randall. 1996. *Radionuclide Logging System In Situ Vadose Zone Moisture Measurement Calibration*. WHC-SD-EN-TI-306, Westinghouse Hanford Company, Richland, Washington.

Price, S. M., R. B. Kasper, M. K. Additon, R. M. Smith, and G. V. Last. 1979. *Distribution of Plutonium and Americium Beneath the 216-Z-1A Crib: Status Report:* RHO-ST-17, Rockwell Hanford Operations, Richland, Washington.

Price, W. H. 1994. *Environmental Investigations Procedures*. BHI-EE-01, Vols. 1 and 2, Bechtel, Hanford, Inc., Richland, Washington.

Puget Sound Power and Light Company (PSPL). 1982. *Skagit/Hanford Nuclear Project, Preliminary Safety Analysis Report*. Appendix 20, Amendment 23, Puget Sound Power and Light Company, Bellevue, Washington.

Ramirez, A., W. Daily, D. LaBrecque, E. Owen, and D. Chesnut. 1993. "Monitoring an Underground Steam Injection Process Using Electrical Resistance Tomography." *Water Resources Research* 29:73-87.

Ramirez, A., W. Daily, and R. Newmark. 1995a. "Electrical Resistance Tomography for Steam Injection and Process Control." *Journal of Environmental and Eng. Geophysics* 0(1):39-51.

Ramirez, A., W. Daily, A. Binley, D. LaBrecque, and D. Roelant. 1995b. *Detection of Leaks in Underground Storage Tanks Using Electrical Resistance Methods*. UCRL-JC-122180, Lawrence Livermore National Laboratory, Livermore, California.

Randall, R. R. 1994. *Calibration of the Radionuclide Logging System Germanium Detector*. WHC-SD-EN-TI-292, Westinghouse Hanford Company, Richland, Washington.

Record of Decision (ROD). 1993. *Record of Decision, USDOE Hanford 1100 Area, Hanford Site, Richland Washington*. Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1995. *Declaration of the Record of Decision, USDOE Hanford 100 Area, 100-BC-1, 100-DR-1 and 100-HR-1 Operable Units, Hanford Site, Benton County, Washington*. Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1996a. *Declaration of the Record of Decision, USDOE Hanford 100 Area, 100-HR-3 and 100-KR-4 Operable Units, Hanford Site, Benton County, Washington, April 1996.* Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Record of Decision (ROD). 1996b. *Declaration of the Record of Decision for the 300-FF-1 and 300-FF-5 Operable Units*. Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Reidel, S. P., and K. R. Fecht. 1994a. *Geologic Map of the Richland 1:100,000 Quadrangle, Washington*. Open File Report 94-8, Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia, Washington.

Reidel, S. P., and K. R. Fecht. 1994b. *Geologic Map of the Priest Rapids 1:100,000 Quadrangle, Washington*. Open File Report 94-13, Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources, Olympia, Washington.

Reidel, S. P., K. A. Lindsey, and K. R. Fecht. 1992. *Field Trip Guide to the Hanford Site*. WHC-MR-0391, Westinghouse Hanford Company, Richland, Washington.

Reidel, S. P., K. R. Fecht, K. A. Lindsey, and N. P. Campbell. 1994. "Late Cenozoic Structure and Stratigraphy of South-Central Washington." In Lasmanis, R. and E. S. Cheney (eds.), *Washington Division of Geology and Earth Resources Bulletin 80*, p. 159-180.

Rohay, V. J. 1996. *Performance Evaluation Report for Soil Vapor Extraction System Operations at the Carbon Tetrachloride Site, February 1992 - June 1996*. BHI-00720, Rev. 1. Bechtel Hanford, Inc., Richland, Washington.

Rohay, V. J., and V. G. Johnson. 1991. "Site Evaluation." In *Expedited Response Action Proposal (EE/CA & EA) for 200 West Area Carbon Tetrachloride Plume, Appendix B*. DOE/RL-91-32, Draft B, U.S. Department of Energy, Richland Field Office, Richland, Washington.

Rohay, V. J., and R. K. Tranbarger. 1996. *Test Plan for the FY 1997 Rebound Study at the Carbon Tetrachloride Soil Vapor Extraction Site*. BHI-00947, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Rohay, V.J., K. J. Swett, and G. V. Last. 1994. *1994 Conceptual Model of the Carbon Tetrachloride Contamination in the 200 West Area at the Hanford Site*. WHC-SD-EN-TI-248, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Schalla, R., R. W. Wallace, R. L. Aaberg, S. P. Airhart, D. J. Bates, J. V. M. Carlile, C. S. Cline, D. I. Dennison, M. D. Freshley, P. R. Heller, E. J. Jensen, K. B. Olsen, R. G. Parkhurst, J. T. Rieger, and E. J. Westergard. 1988a. *Interim Characterization Report for the 300 Area Process Trenches*. PNL-6716, Pacific Northwest Laboratory, Richland, Washington.

Schalla, R., R. L. Aaberg, D. J. Bates, J. V. M. Carlile, M. D. Freshley, T. L. Liikala, P. J. Mitchell, K. B. Olsen, and J. T. Rieger. 1988b. *Revised Ground-Water Monitoring Compliance Plan for the 300 Area Process Trenches*. PNL-6671, Pacific Northwest Laboratory, Richland, Washington.

Schmid, J. S. 1990. *Interim Status Groundwater Monitoring Plan for the 200 East Area Liquid Effluent Retention Facility.* WHC-SD-EN-AP-024, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Schmidt, J. W., J. W. Fasset, V. G. Johnson, R. M. Mitchell, B. M. Markes, S. M. McKinney, K. J. Moss, and C. J. Perkins. 1996.. *Westinghouse Hanford Company Operational Environmental Monitoring Annual Report, Calendar Year 1995.* WHC-EP-0573-4, Westinghouse Hanford Company, Richland, Washington.

Serkowski, J. A., M. J. Hartman, and M. D. Sweeney. 1996. *Groundwater Maps of the Hanford Site, December 1995.* WHC-EP-0394-12, Westinghouse Hanford Company, Richland, Washington.

Serne, R. J., and V. L. LeGore. 1996. *Strontium-90 Adsorption-Desorption Properties and Sediment Characterization at the 100-N Area.* PNL-10899, Pacific Northwest Laboratory, Richland, Washington.

Serne, R. J., A. R. Felmy, K. J. Cantrell, K. M. Krupka, J. A. Campbell, H. Bolton, Jr., and J. K. Fredrickson. 1996. *Characterization of Radionuclide-Chelating Agent Complexes Found in Low-Level Radioactive Decontamination Waste.* NUREG/CR-6124, U.S. Nuclear Regulatory Commission, Washington, D.C.

Siemens Power Corporation. 1996. *Quarterly Groundwater Monitoring Summary, Second Quarter 1996.* EMF-1865, Addendum 5, Siemens Power Corporation, Richland, Washington.

Singleton, K. M., and K. A. Lindsey. 1994. *Groundwater Impact Assessment Report for the 216-U-14 Ditch.* WHC-EP-0698, Westinghouse Hanford Company, Richland, Washington.

Smith, R. M. 1980. *216-B-5 Reverse Well Characterization Study.* RHO-ST-37, Rockwell Hanford Operations, Richland, Washington.

Smith, R. M., and R. B. Kasper. 1983. *Serviceability of Cribs Affected by PUREX Startup.* RHO-HS-EV-18, Rockwell Hanford Operations, Richland, Washington.

Spane, F. A. Jr. 1993. *Selected Hydraulic Test Analysis Techniques for Constant-Rate Discharge Tests.* PNL-8539, Pacific Northwest Laboratory, Richland, Washington.

Spane, F. A. Jr. 1996. "Applicability of Slug Interference Tests for Hydraulic Characterization of Unconfined Aquifers:(1) Analytical Assessment." *Ground Water* 34(1):66-74.

Spane, F. A. Jr., and R. G. Raymond. 1993. *Preliminary Potentiometric Map and Flow Dynamic Characteristics for the Upper-Basalt Confined Aquifer System.* PNL-8869, Pacific Northwest Laboratory, Richland, Washington.

Spane, F. A. Jr., and V. R. Vermeul. 1994. *Summary and Evaluation of Hydraulic Property Data Available for the Hanford Site Upper Basalt Confined Aquifer System.* PNL-10158, Pacific Northwest Laboratory, Richland, Washington.

Spane, F. A. Jr., and P. D. Thorne. 1995. *Comparison of Constant-Rate Pumping Test and Slug Interference Test Results at the B-Pond Multi-Level Test Facility, Hanford Site*. PNL-10835. Pacific Northwest Laboratory, Richland, Washington.

Spane, F. A. Jr., and W. D. Webber. 1995. *Hydrochemistry and Hydrogeologic Conditions Within the Hanford Upper Basalt Confined Aquifer System*. PNL-10817, Pacific Northwest Laboratory, Richland, Washington.

State of Washington Department of Ecology (Ecology). 1994. *Hanford Facility RCRA Permit*. Permit WA7890008967, effective September 28, 1994, Olympia, Washington.

State of Washington Department of Ecology (Ecology). 1995a. *State Waste Discharge Permit (216 Permit) for the 200 Area Treated Effluent Disposal Facility (TEDF)*. Permit No. ST 4502, issued in compliance with the provisions of Chapter 90.48 RCW, as amended, and Chapter 173-216 WAC, as amended, Olympia, Washington.

State of Washington Department of Ecology (Ecology). 1995b. *State Waste Discharge Permit (216 Permit) for the 200 Area Effluent Treatment Facility (ETF)*. Permit No. ST 4500, issued in compliance with the provisions of Chapter 90.48 RCW, as amended, and Chapter 173-216 WAC, as amended, Olympia, Washington.

State of Washington Department of Ecology (Ecology). 1996. *Modification B to the Hanford Facility Dangerous Waste Permit*. As amended December 26, 1996, Olympia, Washington.

State of Washington Department of Ecology (Ecology) and U.S. Environmental Protection Agency (EPA). 1986. *Consent Agreement and Compliance Order*. Ecology No. DE 86-133, Olympia and Seattle, Washington.

State of Washington Department of Ecology (Ecology) and U.S. Environmental Protection Agency (EPA). 1994. *Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy Hanford Site, Richland, WA*. Olympia and Seattle, Washington.

State of Washington Department of Ecology (Ecology) and U.S. Environmental Protection Agency (EPA). 1996. *Memorandum of Understanding Between Washington State Department of Ecology and U.S. Environmental Protection Agency Region 10 Concerning Hanford Federal Facility Agreement and Consent Order*. Approved August 27, 1996, Olympia and Seattle, Washington.

State of Washington Department of Ecology (Ecology), U.S. Environmental Protection Agency (EPA), and U.S. Department of Energy (DOE). 1989. *Hanford Federal Facility Agreement and Consent Order Between the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the State of Washington Department of Ecology, May 15, 1989*, as amended. Olympia, Seattle, and Richland, Washington.

Stenner, R. D., K. H. Cramer, K. A. Higley, S. J. Jette, D. A. Lamar, T. J. McLaughlin, D. R. Sherwood, and N. C. VanHouten. 1988. *Hazard Ranking System Evaluation of CERCLA Inactive Waste Sites at Hanford. Volume I, Evaluation Method and Results*. PNL-6456, Pacific Northwest Laboratory, Richland, Washington.

Stordeur, R. T., and D. L. Flyckt. 1988. *1988 Annual Status Report of the Plan and Schedule to Discontinue Disposal of Contaminated Liquids into the Soil Column at the Hanford Site.* WHC-EP-0196-1, Westinghouse Hanford Company, Richland, Washington.

Strait, S. R., and B. A. Moore. 1982. *Geohydrology of the Rattlesnake Ridge Interbed in the Gable Mountain Pond Area.* RHO-ST-38, Rockwell Hanford Operations, Richland, Washington.

Stromswold, D. C. 1994a. *Calibration Facilities at Hanford for Gamma-Ray and Fission-Neutron Well Logging.* PNL-9958, Pacific Northwest Laboratory, Richland, Washington.

Stromswold, D. C. 1994b. *Technical Evaluation of Software for Gamma-Ray Logging System.* PNL-9807, Pacific Northwest Laboratory, Richland, Washington.

Swanson, L. C. 1992. *Phase I Hydrogeologic Summary of the 300-FF-5 Operable Unit, 300 Area.* WHC-SD-EN-TI-052, Westinghouse Hanford Company, Richland, Washington.

Swanson, L. C. 1994. *1994 Characterization Report for the State Approved Land Disposal Site.* WHC-SD-C018H-RPT-003, Westinghouse Hanford Company, Richland, Washington.

Swanson, D. A., J. L. Anderson, R. D. Bentley, V. E. Camp, J. N. Gardner, and T. L. Wright. 1979. *Reconnaissance Geologic Map of the Columbia River Basalt Group in Washington and Adjacent Idaho.* Open-File Report 79-1363, U.S. Geological Survey, Washington, D.C.

Sweeney, M. D. 1995. *Interim-Status Groundwater Monitoring Plan for the 216-B-3 Pond System.* WHC-SD-EN-AP-013, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Tallman, A. M., K. R. Fecht, M. C. Marratt, and G. V. Last. 1979. *Geology of the Separations Areas, Hanford Site, South-Central Washington.* RHO-ST-23, Rockwell Hanford Operations, Richland, Washington.

Tallman, A. M., J. T. Lillie, and K. R. Fecht. 1981. "Suprabasalt Sediments of the Cold Creek Syncline Area." In Myers, C. W. and S. M. Price (eds.), *Subsurface Geology of the Cold Creek Syncline.* RHO-BWI-ST-14, Rockwell Hanford Operations, Richland, Washington.

Thompson, K. M. 1991. *Hanford Past-Practices Strategy.* DOE/RL-91-40, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

Thorne, P. D., and M. A. Chamness. 1992. *Status Report on the Development of a Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System.* PNL-8332, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., and D. R. Newcomer. 1992. *Summary and Evaluation of Available Hydraulic Property Data for the Hanford Site Unconfined Aquifer System.* PNL-8337, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, F. A. Spane, Jr., V. R. Vermeul, and W. D. Webber. 1993. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System, FY 93 Status Report.* PNL-8971, Pacific Northwest Laboratory, Richland, Washington.

Thorne, P. D., M. A. Chamness, V. R. Vermeul, Q. C. MacDonald, and S. E. Schubert. 1994. *Three-Dimensional Conceptual Model for the Hanford Site Unconfined Aquifer System: FY 1994 Status Report*. PNL-10195, Pacific Northwest Laboratory, Richland, Washington.

Tyler, D. K. 1992. *Groundwater Impact Assessment Report for the 400 Area Ponds*. WHC-EP-0587, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy (DOE). 1985. *Closure/Post-Closure Plan for the 300 Areas Process Trenches*. TRAC-0098, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1988. *Consultation Draft, Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*. DOE/RW-0164, Vols. 1 and 2, Richland, Washington.

U.S. Department of Energy (DOE). 1990a. *Phase 1 Remedial Investigation Report for the Hanford Site 1100-EM-1 Operable Unit*. DOE/RL-90-18, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1990b. *Nonradioactive Dangerous Waste Landfill Closure/ Postclosure Plan*. DOE/RL-90-17, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1991a. *Hanford Site Solid Waste Landfill Permit Application*. DOE/RL-90-38, Rev. 0., Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1991b. *Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance*. DOE/EH-0173T, Assistant Secretary for the Environment, Safety, and Health, Washington, D.C.

U.S. Department of Energy (DOE). 1991c. *Hanford Site Waste Minimization and Pollution Awareness Program Plan*. DOE/RL-91-31, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1991d. *183-H Solar Evaporation Basins Closure/Post-Closure Plan*. DOE/RL-88-04, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1991e. *Description of Codes and Models to be Used in Risk Assessment*. DOE/RL-91-44, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1991f. *Ground-Water Model Development Plan in Support of Risk Assessment*. DOE/RL-91-62, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992a. *200 West Area Groundwater Aggregate Area Management Study Report*. DOE/RL-92-16, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992b. *Remedial Investigation/Feasibility Study Work Plan for the 100-BC-5 Operable Unit, Hanford Site, Richland, Washington*. DOE/RL-90-08, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992c. *Final Remedial Investigation Study-Environmental Assessment Report for the 1100-EM-1 Operable Unit, Hanford.* DOE/RL-92-67, Draft B, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1993a. *Hanford Site Solid Waste Landfill Permit Application.* DOE/RL-90-38, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy. 1993b. *100-D Ponds Closure Plan.* DOE/RL-92-71, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1994a. *Hanford Site Environmental Monitoring Plan.* DOE/RL-91-50, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1994b. *Vadose Zone Characterization Project at the Hanford Tank Farms, Training Integration Plan.* P-GJPO-1778, Rev. 0, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1994c. *Limited Field Investigation Report for the 100-KR-4 Operable Unit.* DOE/RL-93-79, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1994d. *Limited Field Investigation Report for the 100-HR-3 Operable Unit.* DOE/RL-93-43, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1994e. *216-B-3 Expansion Ponds Closure Plan.* DOE/RL-89-28, Rev. 2, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1994f. *300 Area Process Trenches Closure Plan.* DOE/RL-93-73, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1994g. *Modeling Evaluation of N-Springs Barrier and Pump-and-Treat System.* DOE/RL-94-132, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995a. *Hanford Site Groundwater Remediation Strategy.* DOE/RL-94-95, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995b. *Vadose Zone Characterization Project at the Hanford Tank Farms, Spectral Gamma-Ray Borehole Geophysical Logging Characterization and Baseline Monitoring Plan for the Hanford Single-Shell Tanks.* P-GJPO-1786, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1995c. *Vadose Zone Characterization Project at the Hanford Tank Farms, Calibration of Two Spectral Gamma-Ray Logging Systems for Baseline Characterization Measurements in the Hanford Tank Farms.* GJPO-HAN-1, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1995d. *Vadose Zone Characterization at the Hanford Tank Farms, High-Resolution Passive Spectral Gamma-Ray Logging Procedures.* P-GJPO-1783, Rev. 1, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1995e. *Vadose Zone Characterization Project at the Hanford Tank Farms, Records Management Plan.* P-GJPO-1782, Rev. 1, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE) 1995f. *Vadose Zone Characterization Project at the Hanford Tank Farms, Project Management Plan.* P-GJPO-1780, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1995g. *Vadose Zone Characterization at the Hanford Tank Farms, Health and Safety Plan.* P-GJPO-1776, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1995h. *Proposed Plan for Interim Remedial Measures at the 100-BC-1 Operable Unit.* DOE/RL-94-99, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995i. *Proposed Plan for Interim Remedial Measures at the 100-BC-2 Operable Unit.* DOE/RL-95-66, Draft A, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995j. *Proposed Plan for Interim Remedial Measures at the 100-KR-1 Operable Unit.* DOE/RL-94-119, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995k. *Proposed Plan for Interim Remedial Measures at the 100-KR-2 Operable Unit.* DOE/RL-95-96, Decisional Draft, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995l. *The Pilot-Scale Treatability Test Summary for the 100-HR-3 Operable Unit.* DOE/RL-95-83, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995m. *Proposed Plan for Interim Remedial Measures at the 100-DR-1 Operable Unit.* DOE/RL-94-100, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995n. *Proposed Plan for Interim Remedial Measures at the 100-DR-2 Operable Unit.* DOE/RL-95-67, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995o. *RCRA Facility Investigation Report for the 200-PO-1 Operable Unit.* DOE/RL-95-100, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995p. *Proposed Plan for Interim Remedial Measures at the 100-HR-1 Operable Unit.* DOE/RL-94-101, Rev. 1, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995q. *Proposed Plan for Interim Remedial Measures at the 100-HR-2 Operable Unit.* DOE/RL-94-135, Draft A, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995r. *100-HR-3 Operable Unit Focused Feasibility Study.* DOE/RL-94-67, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995s. *Proposed Plan for Interim Remedial Measures at the 100-FR-1 Operable Unit.* DOE/RL-95-54, Draft B, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995t. *Proposed Plan for Interim Remedial Measures at the 100-FR-2 Operable Unit.* DOE/RL-95-92, Decisional Draft, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995u. *200-ZP-1 Operable Unit Treatability Test Report.* DOE/RL-95-30, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1995v. *100-KR-4 Operable Unit Focused Feasibility Study.* DOE/RL-94-48, Rev. 0, Richland Operations Office, Richland, Washington.

U.S.Department of Energy (DOE). 1996a. *Vadose Zone Characterization Project at the Hanford Tank Farms, Biannual Recalibration of Two Spectral Gamma-Ray Logging Systems Used for Baseline Characterization Measurements in the Hanford Tank Farms.* GJPO-HAN-3, prepared by Rust Geotech for the Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of Energy (DOE). 1996b. *Vadose Zone Characterization Project at the Hanford Tank Farms: SX Tank Farm Report.* DOE/ID/12584-268, GJPO-HAN-4, prepared by U.S. Department of Energy, Albuquerque Operations Office, Grand Junction Projects Office for Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996c. *Remedial Design Report and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action.* DOE/RL-96-84, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996d. *The N-Springs Expedited Response Action Performance Evaluation Report.* DOE/RL-95-110, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996e. *100-FR-3 Groundwater/Soil Gas Supplemental Limited Field Investigation Report.* DOE/RL-95-99, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996f. *RCRA Corrective Measure Study for the 200-PO-1 Operable Unit.* DOE/RL-96-66, Rev. 0, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996g. *Limited Field Investigation Report for the 300-FF-2 Operable Unit.* DOE/RL-96-42, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996h. *Operation and Maintenance Plan for the 300-FF-5 Operable Unit*. DOE/RL-95-73, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996i. *Hanford Remedial Action Environmental Impact Assessment and Comprehensive Land Use Plan*. DOE/EIS-0222D, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE) and State of Washington Department of Ecology (Ecology). 1992. *100-NR-2 Operable Unit Groundwater Monitoring Network*. 100-NPL Agreement/Change Control Form #33, Richland and Olympia, Washington.

U.S. Department of Energy (DOE) and State of Washington Department of Ecology (Ecology). 1996. *Modifications to the Groundwater Sampling and Analysis Schedules for the 100-NR-2 Operable Unit Groundwater Sampling Project and 100-N Area RCRA Monitoring Program*. Federal Facility Agreement and Consent Order Change Control Form M-15-95-08, signed October 9, 1996, Richland and Olympia, Washington.

U.S. Environmental Protection Agency (EPA). 1982. *Methods for Chemical Analysis of Water and Wastes*. EPA-600/4-82-055, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986a. *Resource Conservation and Recovery Act (RCRA) Groundwater Monitoring Technical Enforcement Guidance Document*. OWSER-9950.1, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986b. *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods, 3rd ed.* SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986c. *Quality Criteria for Water, 1986*. EPA/440/5-86-001, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1996. *Drinking Water Regulations and Health Advisories*. EPA 822-R-96-001, Office of Water, Washington, D.C.

U.S. Geological Survey (USGS). 1977. *National Handbook of Recommended Methods for Water Data Acquisition*. Office of Water Data Coordination, Reston, Virginia.

Van Vleet, R. J. 1993. *Radionuclide and Chemical Inventories for the Single-Shell Tanks*. WHC-SD-WM-TI-565, Rev. 1, prepared by WASTREN, Inc. for Westinghouse Hanford Company, Westinghouse Hanford Company, Richland, Washington.

Vermeul, V. R., S. S. Teel, J. E. Amonette, C. R. Cole, J. S. Fruchter, Y. A. Gorby, F. A. Spane, Jr., J. E. Szecsody, M. D. Williams, and S. B. Yabusaki. 1995. *Geologic, Geochemical, Microbiologic, and Hydrologic Characterization at the In Situ Redox Manipulation Test Site*. PNL-10633, Pacific Northwest Laboratory, Richland, Washington.

Votava, J. M. 1995. *Results of Groundwater Quality Assessment Program at the 216-A-29 Ditch RCRA Facility*. WHC-SD-EN-EV-032, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Waite, J. L. 1991. *Tank Wastes Discharged Directly to the Soil at the Hanford Site.* WHC-MR-0027, Westinghouse Hanford Company, Richland, Washington.

Walters, W. H., M. C. Richmond, and B. G. Gilmore. 1994. *Reconstruction of Radionuclide Concentrations in the Columbia River from Hanford, Washington to Portland, Oregon January 1950-January 1971*. PNWD-2225 HEDR, Pacific Northwest Laboratory, Richland, Washington.

Weekes, D. C., S. P. Luttrell, and M. R. Fuchs. 1987. *Interim Hydrogeologic Characterization Report and Groundwater Monitoring System for the Nonradioactive Dangerous Waste Landfill, Hanford Site, Washington*. WHC-EP-0021, Westinghouse Hanford Company, Richland, Washington.

Weekes D. C., G. K. Jaeger, W. J. McMahon, and B. H. Ford. 1996. *Groundwater Protection Plan or the Environmental Restoration Disposal Facility*. BHI-00070, Rev. 0, Bechtel Hanford, Inc., Richland, Washington.

Westinghouse Hanford Company (WHC). 1989. *Environmental Investigations and Site Characterization Manual*. WHC-CM-7-7, Vol. 1, Richland, Washington.

Westinghouse Hanford Company (WHC). 1990a. *Interim Hydrogeologic Characterization Report for the 216-B-3 Pond*. WHC-SD-EV-002, Rev. 0, Richland, Washington.

Westinghouse Hanford Company (WHC). 1990b. *Liquid Effluent Study Final Project Report*. WHC-EP-0367, Richland, Washington.

Westinghouse Hanford Company (WHC). 1995. *Environmental Releases for Calendar Year 1994*. WHC-EP-0527-4, Richland, Washington.

WHC (see Westinghouse Hanford Company)

Wilber, J. S. , M. J. Graham, and A. H. Lu. 1983. *Results of the Separations Area Ground-Water Monitoring Network for 1982*. RHO-RE-SR-83-24 P, Rockwell Hanford Operations, Richland, Washington.

Williams, B. A., and D. B. Barnett. 1993. *Borehole Completion Data Package for the 216-S-10 Facility, CY-1992*. WHC-SD-EN-DP-052, Westinghouse Hanford Company, Richland, Washington.

Williams, B. A. and C. J. Chou. 1993. *Interim-Status Groundwater Quality Assessment Plan for the 216-U-12 Crib*. WHC-SD-EN-AP-103, Rev. 0, Westinghouse Hanford Company, Richland, Washington.

Wilson, C. R., C. M. Einberger, R. L. Jackson, and R. B. Mercer. 1992. Design of Ground-Water Monitoring Networks using the Monitoring Efficiency Model (MEMO). *Groundwater* (30)6:965-970.

Wurstner, S. K., P. D. Thorne, M. A. Chamness, M. D. Freshley, and M. D. Williams. 1995. *Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report*. PNL-10886, Pacific Northwest Laboratory, Richland, Washington.

Zimmerman, D. A., A. E. Reisenauer, G. D. Black, and M. A. Young. 1986. *Hanford Site Water Table Changes 1950 Through 1980—Data Observations and Evaluation*. PNL-5506, Pacific Northwest Laboratory, Richland, Washington.

Appendix A

Historical Bibliography

Appendix A

Historical Bibliography

R. B. Mercer

This appendix, Historical Bibliography, is on the 3-1/2-in. computer disk included with this report. The material is formatted in WordPerfect® 5.1 for personal computer.

Appendix B

Statistics

Appendix B

Statistics

C. J. Chou

Statistics gathered in support of groundwater monitoring at the Hanford Site are used to evaluate the changes noted in groundwater quality from those conditions existing upgradient of the various operations facilities. The methods used for the statistical evaluations are described in this appendix. The facilities included in this evaluation are the 1) *Resource Conservation and Recovery Act of 1976* (RCRA) liquid and solid waste treatment, storage, and/or disposal units; 2) Solid Waste Landfill; and 3) liquid effluent-receiving facilities.

The RCRA units with a potential to contaminate groundwater require monitoring as prescribed in 40 CFR 265 and WAC 173-303-400 (interim status) and 40 CFR 264 and WAC 173-303-645 (final status). Groundwater-monitoring activities at most of the RCRA units will continue to be governed under interim status regulations, except for the 183-H solar evaporation basins and the 316-5 process trenches. During fiscal year (FY) 1996, only the 183-H basins were monitored under the final status regulations.

Because the Solid Waste Landfill is not a RCRA hazardous waste site, its operations fall under the regulations of WAC 173-304. A permit application for the Solid Waste Landfill under this regulation has been prepared (DOE 1993).

Operations at the 200 Areas Treated Effluent Disposal Facility (TEDF) and the 200 Areas Effluent Treatment Facility (ETF) began during 1995. These facilities are regulated under WAC 173-200 and WAC 173-216 and are administered by the Project Hanford Management Contractor. Because these are discharge permit disposal facilities, both require effluent and groundwater monitoring.

B.1 Statistical Methods

B.1.1 RCRA Interim Status Facilities

The primary objectives of RCRA groundwater monitoring are to comply with the intent of applicable interim and final status state and federal regulations and to assess potential impacts on groundwater quality. In accordance with WAC 173-303-400, RCRA projects are monitored under one of

three levels of efforts: 1) background monitoring, 2) indicator parameter evaluation, or 3) groundwater quality assessment. All of the RCRA facilities at the Hanford Site have completed their initial background monitoring programs.

Statistical evaluations for interim status RCRA facilities during FY 1996 consisted of reestablishing background levels to reflect changing conditions and evaluating the facility's impact on groundwater quality. A general description of the applicable statistical methods that are appropriate for these interim status facilities is provided in this section.

The statistical method used to summarize background data is the averaged replicate t-test method as described in Appendix B of EPA (1986) and Chou (1991). The averaged replicate t-test method for each contamination indicator parameter is calculated as:

$$t = (\bar{x}_i - \bar{x}_b)/S_b * \sqrt{1+1/n_b} \qquad \text{(B.1)}$$

where t = test statistic

$\bar{x}_i$ = average of replicates from the i^{th} monitoring well
$\bar{x}_b$ = background average
S_b = background standard deviation
n_b = number of background replicate averages.

The guiding documentation (EPA 1986) states that a test statistic larger than the Bonferroni critical value, t_c, (i.e., $t > t_c$) indicates a statistically significant probability of contamination. These Bonferroni critical values depend on the overall false-positive rate required for each sampling period (i.e., 1% for interim status), the total number of wells in the monitoring network, and the number of degrees of freedom (n_b - 1) associated with the background standard deviation. Because of the nature of the test statistic in Equation (B.1), results to be compared to background do not contribute to the estimate of the variance. The test can be reformulated, without prior knowledge of the results of the sample to be compared to background (i.e., $\bar{x}_i$), in such a way that a critical mean, CM, can be obtained:

$$CM = \bar{x}_b + t_c * S_b * \sqrt{(1+1/n_b)} \quad \text{(one tailed)} \qquad \text{(B.2)}$$

$$CM = \bar{x}_b \pm t_c * S_b * \sqrt{(1+1/n_b)} \quad \text{(two tailed)} \qquad \text{(B.3)}$$

For pH, a two-tailed CM (or critical range) is calculated and a one-tailed CM is calculated for specific conductance, total organic carbon, and total organic halogen. The CM (or range for pH) is the value above which (or above/below in the case of pH) a compared value is determined to be statistically different from background.

The measured values for total organic carbon from upgradient (background) wells during the initial background periods for most of the RCRA facilities were less than the contractually required quantitation limit of 1,000 μg/L for DataChem Laboratories, Inc., Salt Lake City, Utah. These values were reported with the contractually required quantitation limit value followed by a U qualifier. Estimates of the background standard deviations cannot be obtained. In addition, laboratory-reporting practices changed since April 1993. Results below the contractually required quantitation limit but above the method detection limit are reported with the measured value followed by an L qualifier. Results below the method detection limit are reported with the measured value followed by a U qualifier. The lack of estimates of background variability precludes the determination of total organic carbon critical means for various RCRA facilities. In this case, a limit of quantitation is to be used as the threshold value for upgradient/downgradient comparisons. For FY 1996, a limit of quantitation of 976 μg/L, calculated using FY 1995 field blanks data, was used for total organic carbon (Appendix C in DOE 1996). For comparisons to be performed in FY 1997, the limit of quantitation for total organic carbon is calculated to be 525 μg/L using FY 1996 field blanks data (Appendix D in DOE 1996).

Because of concerns over the laboratory's procedure for total organic halogen, samples were analyzed by another laboratory from November 1993 to May 1995. The change of laboratories did not provide the needed background values from which critical means could be derived. However, the total organic halogen data were evaluated using the following steps: 1) screening total organic halogen values from upgradient wells; 2) if results from upgradient wells indicated a history of nondetections, a limit of quantitation was used as the upgradient/downgradient comparison value; and 3) if total organic halogen were historically detected, a limit of quantitation could not be used as a surrogate background value. In this case, the background value must be derived based on four quarters of monitoring data and used in the statistical evaluation (e.g., Waste Management Area [WMA] U single-shell tank farm).

Finally, if the calculated critical ranges for pH were too large to be meaningful because of the requirement to use four quarters of data to establish background (e.g., 120-D-1 ponds, Liquid Effluent Retention Facility), the upgradient/downgradient comparison value would be the revised to the critical range by using all available data. The expansion of the background data set to include more than 1 year's data provides a better estimate of background mean and background standard deviation. More important, it increases the number of degrees of freedom associated with the background standard deviation. Other things being equal, a smaller t_c value and a narrower critical range for pH would result. This approach is preferred because it complies with both the requirements and the spirit of the regulations.

B.1.2 RCRA Final Status Facility

Three levels of groundwater-monitoring programs are required under final status regulations (40 CFR 264 Subpart F and WAC 173-303-645): detection monitoring, compliance monitoring, and corrective action. During FY 1996, only the 183-H solar evaporation basins were monitored under RCRA final status regulations. Starting in December 1996, the 316-5 Area process trenches will be in final status compliance-level monitoring.

B.1.2.1 Detection-Level Monitoring

In a detection-level groundwater-monitoring program, groundwater parameter data (pH, specific conductance, total organic carbon, total organic halogen, heavy metals, waste constituents, or reaction products) from downgradient compliance-point wells will be compared semiannually with data on area background wells to determine whether there is a statistically significant increase (or decrease for pH) over background concentrations. Statistical methods appropriate for a final status detection-level monitoring program will include analysis of variance, tolerance intervals, prediction intervals, control charts, test of proportions, or other statistical methods approved by the State of Washington Department of Ecology (Ecology). The important factors to consider when selecting appropriate statistical methods are the distribution(s) of monitoring parameters; the nature of the data; and the proportions of nondetections, seasonal, temporal, and spatial variations. The statistical evaluation procedures chosen will be based on guidance given in EPA (1989, 1992). Specific statistical methods are to be addressed in the unit-specific permit applications and/or in the groundwater-monitoring plans.

B.1.2.2 Compliance-Level Monitoring

A compliance-level groundwater-monitoring program will be established for a unit if groundwater sampling during detection-level monitoring reveals a statistically significant increase (or pH decrease) over area background concentrations for groundwater. In compliance-level monitoring, the monitoring objective is to determine whether groundwater-protection standards have been exceeded. This is accomplished by comparing the concentration of a constituent of concern to groundwater-protection standards, such as a risk-based maximum concentration limit; alternative concentration limit; area or natural background; or applicable, relevant, and appropriate requirements. The parameters monitored and the concentration limits are specified in the permit.

Maximum concentration limits will be identified for each groundwater-monitoring parameter listed in Table 1 of WAC 173-303-645. Alternative concentration limits will be proposed after considering the observed concentrations of chemical constituents in the groundwater that might have originated from the regulated unit in question. The area background, natural background, and other standards that are applicable, relevant, and appropriate requirements will be evaluated when proposing an alternative concentration limit.

The Hanford Facility RCRA Permit became effective on September 28, 1994 (Ecology 1994). The 183-H solar evaporation basins are one of five units included in this RCRA permit and are subject to final status groundwater-monitoring regulations. During 1995, a groundwater-monitoring plan was prepared (Hartman and Chou 1995) to reflect final status compliance-level requirements and to describe the updated well list, constituent list, and sampling frequency. Detailed statistical methods can be found in Hartman and Chou (1995). This unit will be closed under the final status requirements of WAC 173-303-610.

B.1.2.3 Corrective Action

If, during compliance-level monitoring at the point of compliance, dangerous constituents are measured in the groundwater at concentrations that exceed acceptable groundwater-protection standards, sufficient data, supporting information, and analyses will be provided to establish a corrective-action program. Details for the corrective-action program will be specified in the unit-specific permit applications. In addition, a groundwater-monitoring plan, which will be used to assess the effectiveness of the corrective-action measures, will be submitted. This monitoring plan will be similar in scope to the compliance-level groundwater-monitoring program and will include all relevant information pertaining to the location and description of monitoring wells, monitoring network, well construction and development, sampling and analysis plans, statistical methods, and quality assurance and quality control procedures.

B.1.3 Solid Waste Landfill

Groundwater-monitoring activities for the Solid Waste Landfill are regulated under WAC 173-304-490, requiring no replicate analyses. Thus, the tolerance interval approach, suitable for individual sample comparisons, was used for performing the required comparisons between upgradient and downgradient wells for determining whether a significant change over background occurred for constituents specified in WAC 173-304-490. The statistical evaluations are described as follows.

B.1.3.1 Calculating Background Summary Statistics

Summary statistics were calculated using background samples for the site (Table B-11 in DOE 1991). The results are presented in Table B.1. Some of the background data are below the contractual detection limits required of the contracting laboratory or below the contractually required quantitation limit. In cases where measured values are available (e.g., most of the total organic carbon values), they were used in calculating the summary statistics. In cases where the proportion of nondetections is between 15% and 50%, less-than values were replaced by half of their contractual detection limits and/or contractually required quantitation limits, and the usual calculations were performed (e.g., filtered iron). In cases where the proportion of nondetections is greater than 50%, summary statistics are not calculated (e.g., nitrite, ammonium, filtered zinc, filtered manganese, coliform, and chemical oxygen demand).

B.1.3.2 Testing Assumption of Normality of Data

The tolerance interval defines a concentration range (from background well data) that contains at least a specified proportion (coverage) of the population with a specified probability (confidence level). There are two types of tolerance intervals: parametric and nonparametric. Parametric tolerance interval techniques are sensitive to the assumption that the data are drawn from a normal population. The statistical tests used for evaluating whether the data follow a specified distribution are called goodness-of-fit tests. The Lilliefors test is used to evaluate the fit of a hypothesized normal or log-normal distribution. STATGRAPHICS™, Version 6.0 (Statistical Graphics Corporation, Rockville, Maryland) was used to calculate the Lilliefors test statistics. Test procedures are described by Conover

(1980). If the data are not normal, the Lilliefors test was applied to the natural logarithm of the data to see if the transformed data are approximately normal. This is equivalent to testing the hypothesis that the concentration measurements follow a lognormal distribution. If the proportion of nondetections is more than 15%, a goodness-of-fit test is not performed and a nonparametric tolerance interval will be calculated to the extent possible.

Results of the Lilliefors test are presented in Table B.2. Temperature, field pH, and chloride concentration measurements from background wells are approximately normally distributed. Specific conductance, total organic carbon, nitrate, and sulfate concentrations are neither normal nor lognormal.

B.1.3.3 Establishing Background Levels

Tolerance intervals are constructed from the data on background wells. Both the upper and lower bounds of the interval (two sided) were calculated for field pH. For other constituents of concern, only the upper bounds of the intervals (one sided) were calculated.

If a normal (or a lognormal) distribution is a reasonable approximation of the background concentrations, a parametric tolerance interval, TI, of the following form is calculated:

$$TI = \bar{x}_b \pm KS_b \text{ (two sided) or } TI = \bar{x}_b + KS_b \text{ (one sided)} \qquad \text{(B.4)}$$

where K = a normal tolerance factor, which depends on the number of background samples (n), coverage (P%), and confidence level (Y). A coverage of 95% and a confidence level of 95% are recommended (EPA 1989). With n = 16, P = 95%, and Y = 95%, K is 2.523 (K is 2.566 if n = 15) for a one-sided normal tolerance interval (Natrella 1966).

If background concentrations do not follow a normal or a lognormal distribution, a nonparametric tolerance interval can be constructed (Conover 1980). A two-sided nonparametric tolerance interval is just the range of the observed data. An upper one-sided nonparametric tolerance limit is the largest observation. The number of background samples determines the coverage (P%) and the confidence level (Y) associated with that proportion. For a one-sided 95% (P = 95%) nonparametric tolerance interval with 95% (Y = 95%) probability, the number of background samples required is 59 (Conover 1980). With only 15 background samples (nitrate, filtered iron, and filtered zinc), the coverage is 85% and the confidence level is 90% (i.e., the upper one-sided tolerance limit defined by the largest background concentration contains at least 85% of the background population with 90% confidence). More background samples are needed if a larger coverage and/or a larger confidence level are desired.

In cases where all of the background values are below the contractually established detection limits or where the proportion of nondetections is more than 15%, a limit of quantitation was used (e.g., total organic carbon). In cases where a limit of quantitation is not available (e.g., coliform and chemical oxygen demand), the contractually required quantitation limits were used as the background threshold values. The resulting tolerance limits, limit of quantitations, and background threshold values are also presented in Table B.2.

B.1.3.4 Comparisons with Background Levels

Once the background threshold values are established, data from compliance-point wells were compared individually with these background concentration levels. If the background levels are exceeded, it is interpreted as providing evidence of statistically significant contamination.

B.1.4 Liquid Effluent Receiving Facilities

Operation of the 200 Areas TEDF and ETF began during 1995. These facilities are regulated under WAC 173-200 and WAC 173-216, both requiring effluent and groundwater monitoring. The principal groundwater quality regulations (WAC 173-200) emphasize the nondegradation of current groundwater quality. These regulations require "Establishment of an enforcement limit as near the natural ground water quality as practical," and establishment of the point of compliance in the groundwater "...as near the source as technically, hydrogeologically, and geographically feasible."

B.1.4.1 Preoperational Monitoring

Groundwater quality data from the preoperational phase were used to establish the background (baseline) values for the potential constituents of concern. In essence, background values were calculated using the parametric tolerance interval approach discussed above because background water quality is statistically defined as the 95% upper tolerance interval with a 95% confidence (Ecology 1996, p. 65). The baseline values were provided to Ecology to allow the determination of enforcement limits for specific constituents in groundwater.

B.1.4.2 Operational Monitoring

The objectives of collecting and evaluating the groundwater quality data from operational monitoring are 1) to determine if groundwater quality has changed from the baseline, preoperational conditions; 2) to evaluate the impacts, if any, that operation of the facility have on the quality of groundwater in the uppermost aquifer; and 3) to demonstrate compliance with the groundwater enforcement limits set forth in the permit.

Statistical approaches used for preoperational and operational monitoring were described in detail in the groundwater-monitoring plans for the 200 Areas TEDF and ETF (WHC 1995, 1996).

B.2 Results of Evaluation

B.2.1 RCRA Interim Status Facilities

During FY 1996, exceedances of critical means for the contamination indicator parameters were confirmed for two RCRA interim status facilities (120-D-1 ponds and WMA-B-BX-BY single-shell tank farms), triggering an assessment of groundwater contamination required by 40 CFR 265 (Section 93). Sequences of events for these sites and others are provided below.

B.2.1.1 120-D-1 Ponds

Field pH measured on February 28, 1996 from downgradient well 199-D8-6 averaged 9.22, exceeding the upper range of 9.15. Verification sampling conducted on March 11, 1996 confirmed the initial exceedance. An assessment report was prepared and submitted to Ecology in April 1996 (Hartman 1996). A similar assessment of groundwater in the 120-D-1 ponds was conducted for another program in 1993 (Alexander 1993). Results of that assessment showed that the elevated pH was caused by the presence of alkaline ash sediments beneath the ponds, which are not part of the RCRA unit. As a result of the assessment report (Hartman 1996), the 120-D-1 ponds will remain in indicator parameter evaluation status.

B.2.1.2 Single-Shell Tank Farms

On May 24, 1996, Ecology ordered the U.S. Department of Energy (DOE) to monitor the WMA-S-SX single-shell tank farms under a groundwater quality assessment program. Ecology concluded, after analyzing the available data, that there is evidence that these tank farms have contaminated the groundwater with technetium-99. Although the same unequivocal conclusion has not been drawn from the available data, DOE concurred that there is a reasonable presumption that some of the groundwater contamination came from sources within the tank farms and that they could be impacting groundwater quality. An assessment monitoring plan was prepared to address this issue (Caggiano et al. 1996a).

Downgradient well 299-E33-32 monitoring the WMA-B-BX-BY single-shell tank farms, exceeded the 365.7-μS/cm critical mean for specific conductance in February 1996 (average measured values = 369 μS/cm). Verification sampling performed in June 1996 (average measured values = 427 μS/cm) confirmed the initial exceedance. Ecology was notified of the exceedance in July 1996. An assessment monitoring plan was prepared and submitted in October 1996 (Caggiano et al. 1996b).

A statistically significant increase in total organic halogen concentrations was observed in August 1996 in one downgradient well (299-W18-30) monitored for the WMA-U tank farm. The elevated total organic halogen is believed to be caused by an upgradient source of contamination (carbon tetrachloride). This well is in the process of verification sampling. Anomalous technetium-99 and nitrate trends observed in another downgradient well (299-W19-31) may be due to WMA-related sources.

B.2.1.3 216-S-10 Pond and Ditch

The background concentrations for total organic halogen at upgradient wells 299-W26-7 and 299-W26-8 historically have been below the analytical detection limits. The limit of quantitation for total organic halogen has been used as the surrogate background value for statistical evaluations; however, an upward trend is noted in one of the upgradient wells (299-W26-8). During the June 1996 sampling event, observed values from this well exceeded the limit of quantitation for this parameter.

These changing conditions upgradient of the facility render the surrogate background value irrelevant for statistical evaluations. The upgradient wells will be sampled on a quarterly basis so that a critical mean for total organic halogen can be established.

B.2.2 RCRA Final Status Facility

B.2.2.1 183-H Solar Evaporation Basins

This facility has been monitored under a final status program (WAC 173-303-645) since September 1995. Four independent samples were collected in September, October, November, and December 1995. The constituents of concern are chromium, nitrate, technetium-99, and uranium. Concentration limits for each of these constituents were exceeded in at least one downgradient well (point of compliance). Verification sampling was conducted in conjunction with the regularly scheduled spring 1996 sampling event. Verification results confirmed that concentration limits were exceeded. Table B.3 summarizes the results of the initial and verification sampling for this facility.

The DOE was notified of the exceedances and subsequently notified Ecology, as required by the regulations. Additionally, within 90 days, the owner/operator must submit an application for a permit modification to establish a corrective-action program. DOE requested Ecology's concurrence that a permit revision already planned for 1997 (Modification C) would be used to establish a corrective action program to satisfy the requirements of WAC 173-303-645.

B.2.3 Solid Waste Landfill

The sampling results from FY 1996 were compared to the background levels (see Table B.2). The sampling and comparison results are presented in Table B.4. Values for specific conductance exceeded the background level in downgradient wells 699-22-35, 699-23-34A, 699-23-34B, 699-24-34A, 699-24-34B, and 699-24-34C for all sampling events during this reporting period and in downgradient well 699-25-35C in three sampling events. This pattern of exceedances is similar to that observed from 1990 through 1995. Detailed discussions are presented in Section 6.12.2.2 of the main text.

B.2.4 200 Areas TEDF and ETF

Groundwater samples are collected quarterly and analyzed for the permit constituents. Groundwater monitoring at the TEDF has not detected any changes in groundwater quality caused by operation during the past year. Results of groundwater data analyzed for the ETF indicate that tritium-rich effluent began affecting groundwater during July 1996.

B.3 Background Tables

This section provides critical means tables (Tables B.5 through B.34) for RCRA facilities that are/have been in indicator parameter evaluation monitoring status during FY 1996. In addition, tables showing the raw input data, replicate averages, and background summary statistics are also provided

for the 120-D-1 ponds, the 1324-N/NA pond, and the WMA-U single-shell tank farm because the critical means were revised during FY 1996. The revisions were necessary to reflect 1) the change in monitoring status (1324-N/NA ponds), 2) a change in upgradient groundwater chemistry (120-D-1 ponds), or 3) the change in groundwater flow direction (WMA-U single-shell tank farm). Note that the number of digits presented in these tables do not reflect the precision of the analytical methods. These digits are for formatting purposes only.

E.4 References

40 CFR 264, Code of Federal Regulations, Title 40, Part 264. *Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*.

40 CFR 265, Code of Federal Regulations, Title 40, Part 265. *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities*.

WAC 173-200, Washington Administrative Code. *Water Quality Standards for Ground Waters of the State of Washington*. Olympia, Washington.

WAC 173-216, Washington Administrative Code. *State Waste Discharge Permit Program*. Olympia, Washington.

WAC 173-303-400, Washington Administrative Code. *Dangerous Waste Regulations, Interim Status Facility Standards*. Olympia, Washington.

WAC 173-303-610, Washington Administrative Code. *Dangerous Waste Regulations, Closure and Postclosure*. Olympia, Washington.

WAC 173-303-645, Washington Administrative Code. *Dangerous Waste Regulations, Releases from Regulated Units*. Olympia, Washington.

WAC-173-304, Washington Administrative Code. *Minimum Functional Standards for Solid Waste Handling*. Olympia, Washington.

WAC 173-304-490, Washington Administrative Code. *Minimum Functional Standards for Solid Waste Handling, Groundwater Monitoring Requirements*. Olympia, Washington.

Alexander, D. J. 1993. *Groundwater Impact Assessment Report for the 100-D Ponds*. WHC-EP-0666, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A., V. G. Johnson, and C. J. Chou. 1996a. *Groundwater Quality Assessment Monitoring Plan for Single-Shell Tank Waste Management Area S-SX*. WHC-SD-EN-AP-191, Revision 0, Westinghouse Hanford Company, Richland, Washington.

Caggiano, J. A., C. J. Chou, and V. G. Johnson. 1996b. *Groundwater Quality Assessment Monitoring Plan for the Single-Shell Tank System Waste Management Area B-BX-BY.* WHC-SD-ENV-AP-002, Revision 0, Westinghouse Hanford Company, Richland, Washington.

Chou, C. J. 1991. *Statistical Approach on RCRA Groundwater Monitoring Projects at the Hanford Site.* WHC-SA-1124-FP, Westinghouse Hanford Company, Richland, Washington.

Conover, W. J. 1980. *Practical Nonparametric Statistics, Second Edition.* John Wiley and Sons, Inc., New York, pp. 118-121, 346-363.

DOE (see U.S. Department of Energy).

Ecology (see State of Washington Department of Ecology).

EPA (see U.S. Environmental Protection Agency)

Hartman, M. J. 1996. *100-D Ponds Groundwater Quality Assessment.* WHC-SD-EN-EV-003, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

Hartman, M. J., and C. J. Chou. 1995. *Groundwater Monitoring Plan for the 183-H Solar Evaporation Basins.* WHC-SD-EN-AP-180, Rev. 0., Westinghouse Hanford Company, Richland, Washington.

Natrella, M. G. 1966. *Experimental Statistics.* National Bureau of Standards Handbook 91, John Wiley and Sons, New York, Table A-7.

Resource Conservation and Recovery Act of 1976, as amended, Public Law 94-580, 90 Stat. 2795, 42 USC 6901 et seq.

State of Washington Department of Ecology (Ecology). 1994. *Dangerous Waste Portion of the Resource Conservation and Recovery Act Permit for the Treatment, Storage, and Disposal of Dangerous Waste.* Permit Number WA7890008967, Revision 0, Olympia, Washington.

State of Washington Department of Ecology (Ecology). 1996. *Implementation Guidance for the Ground Water Quality Standards.* Olympia, Washington.

U.S. Department of Energy (DOE). 1991. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990.* DOE/RL 91-03, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1993. *Hanford Site Solid Waste Landfill Permit Application.* DOE/RL-90-38, Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1995*. DOE/RL-96-01, Revision 0, prepared by Earth and Environmental Technical Services, Westinghouse Hanford Company, Richland, Washington.

U.S. Environmental Protection Agency (EPA). 1986. *Resource Conservation and Recovery Act (RCRA) Groundwater Monitoring Technical Enforcement Guidance Document (TEGD)*. OWSER-9950.1, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1989. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities--Interim Final Guidance*. PB89-151047, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1992. *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities, Draft Addendum to Interim Final Guidance*. EPA/530-R-93-003, Washington, D.C.

Westinghouse Hanford Company (WHC). 1995. *Groundwater Monitoring Plan -- 200 Area Treated Effluent Disposal Facility (Project W-049H)*. WHC-SD-EN-WP-012, Rev. 1, Richland, Washington.

Westinghouse Hanford Company (WHC). 1996. *Groundwater Monitoring Plan -- 200 Area Effluent Treatment Facility (Project C-018H)*. WHC-SD-EN-WP-012, Rev. 1, Richland, Washington.

Table B.1. Summary Statistics for Background Monitoring Constituent Parameter Data for Solid Waste Landfill

Constituent	Number of Samples	GT	LT	Mean	Median	Standard Deviation	CV (%)	Minimum	Maximum
Temperature, °C	22	22	0	18.7	18.8	1.00	5.4	16	20.4
Specific conductance, μS/cm	38	38	0	385.3	397	68.9	17.9	206	550
Field pH[a]	36	36	0	7.33	7.31	0.46	6.3	6.08	8.45
Total organic carbon, μg/L[b,c]	38	0	38	421.6	468	142.9	33.9	32	750
Chloride, μg/L[b,c]	36	36	0	7,341	7,280	798.4	10.9	6,000	8,660
Nitrate, μg/L[b,c]	36	36	0	25,929	27,725	5,139.2	19.8	16,000	33,800
Nitrite, μg/L[b,c]	24	0	24	BDL	BDL	NC	NC	BDL	BDL
Ammonium, μg/L[b,c]	24	4	20	BDL	BDL	NC	NC	BDL	100
Sulfate, μg/L[b,c]	36	36	0	44,169	46,000	4,695.0	10.6	34,000	51,500
Iron[c], filtered, μg/L	29	16	13	33.3	28	19.3	58.0	BDL	78
Zinc, filtered, μg/L[b,c]	29	14	15	BDL	BDL	NC	NC	BDL	34
Manganese, filtered, μg/L[b,c]	29	1	28	BDL	BDL	NC	NC	BDL	11
Coliform bacteria, colonies/ 100 m/L	29	2	27	BDL	BDL	NC	NC	BDL	16
Chemical oxygen demand, mg/L[b,c]	8	0	8	BDL	BDL	NC	NC	BDL	BDL

(a) Inconsistent pH values of 5.4 and 5.5 were excluded.
(b) Statistics were calculated from values reported below contractually required detection limit.
(c) Less-than-detection values were replaced by one-half of the contractually required detection limit in the calculation of summary statistics.

BDL = below contractually required detection limit.
CV = coefficient of variation.
GT = number of samples that are greater than the contractually required quantitation limit.
LT = number of samples that are less than the contractually required quantitation limit.
NC = not calculated; insufficient measured values.

Table B.2. Results of Lilliefors Test for Normality and Background Threshold Values for Solid Waste Landfill

Constituent	Test Statistic, Raw Data	Test Statistic, Log Value	Upper Tolerance Limit	Background Threshold Value[a]
Temperature, °C	0.115 ns	NA	21.0[b]	21.0
Specific conductance, (μS/cm)	0.162 s	0.207 s	550[c]	550
Field pH	0.089 ns	NA	[6.2, 8.46][b]	[6.2, 8.46]
Total organic carbon, μg/L	0.191 s	0.181 s	750[c] 525[d]	750
Chloride, μg/L	0.104 ns	NA	9,045[b]	9,045
Nitrate, μg/L	0.168 s	0.195 s	33,800[c]	33,800
Nitrite, μg/L	NC	NC	356[d]	356
Ammonium, μg/L	NC	NC	100[c] 72[d]	100
Sulfate, μg/L	0.179 s	0.190 s	51,500[c]	51,500
Iron, filtered, μg/L	NC	NC	78[c] 59[d]	78
Zinc, filtered, μg/L	NC	NC	34[c] 35[d]	35
Manganese, filtered, μg/L	NC	NC	11[c] 1.3[d]	11
Coliform, most probable number	NC	NC	16[c] 1[e]	16
Chemical oxygen demand, mg/L	NC	NC	3[e] 13[d]	13

(a) Background threshold value for each constituent is the larger of the upper tolerance limit or the applicable limit of quantitation.
(b) Based on normal distribution.
(c) Maximum value reported; for pH range reported.
(d) Based on limit of quantitation (see Appendix F).
(e) Based on contractually required detection limit.

NA = not applicable.
NC = not calculated; insufficient measured values.
ns = not significant at 0.05 level of significance.
s = significant at 0.05 level of significance.

Table B.3. Results of Initial and Verification Sampling for 183-H Solar Evaporation Basins

Constituent of Concern	Concentration Limit[a]	Wells Exceeding Limit During Initial Sampling Event	Well Exceeding Limit During Verification Sampling Event	Maximum Concentrations, pCi/L
Chromium	122 μg/L	199-H3-2A 199-H4-3 199-H4-12C	199-H4-12C	240
Nitrate	45,000 μg/L	199-H4-3 199-H4-4 199-H4-9 199-H4-18	199-H4-18 199-H4-3	580,000 446,800
Technetium-99	900 pCi/L	199-H4-3 199-H4-4	199-H4-3	1,923.3
Uranium	20 pCi/L	199-H4-3 199-H4-4	199-H4-3	138.2

(a) Chromium concentration limit is based on local area background.

Table B.4. Sampling Results for Required Constituents (WAC 173-304) at Solid Waste Landfill, November 1995 through August 1996

Constituent	Tolerance Interval[a]	Date	Well 699-22-35	Well 699-23-34A	Well 699-23-34B	Well 699-24-34A	Well 699-24-34B	Well 699-24-34C	Well 699-24-35	Well 699-25-34C	Well 699-26-35A
Temperature, °C	21.0	Nov 1995	18.3	18.1	25.0[E]	18.1	17.5	18.2	17.8	25.0[E]	19.3
		Feb 1996	16.5	17.1	17.0	17.6	18.0	18.1	17.6	18.3	19.7
		May 1996	18.5	19.2	18.0	17.1	17.7	17.9	18.2	18.6	20.5
		Aug 1996	18.3	18.6	18.2	19.3	19.1	19.8	18.4	19.4	20.4
Specific conductance, µS/cm	550	Nov 1995	762[E]	646[E]	740[E]	680[E]	624[E]	695[E]	593[E]	564[E]	538
		Feb 1996	773[E]	638[E]	737[E]	612[E]	620[E]	687[E]	519	547	453
		May 1996	772[E]	635[E]	741[E]	637[E]	617[E]	680[E]	508	545	456
		Aug 1996	775[E]	634[E]	741[E]	596[E]	606[E]	687[E]	510	454	450
Field pH	[6.2, 8.46]	Nov 1995	7.1	6.7	7.2	6.9	7.0	6.9	7.2	7.4	7.4
		Feb 1996	7.1	6.7	6.9	6.7	6.8	7.1	7.1	7.2	7.6
		May 1996	7.0	6.7	6.9	6.7	6.7	6.9	7.2	7.3	7.5
		Aug 1996	6.9	6.6	6.9	6.7	6.7	6.9	7.1	7.2	7.4
Total organic carbon, µg/L	750	Nov 1995	350	113	170	163	184	150	240	285	120
		Feb 1996	88	180	181	173	203	154	178	153	206
		May 1996	203	191	193	<300	199	197	<300	227	194
		Aug 1996	<532	<532	<532	<532	<532	<532	<532	<532	<532
Chloride, µg/L	9,045	Nov 1995	6,700	6,200	6,500	6,400	6,900	7,300	6,100	7,500	7,000
		Feb 1996	6,700	6,800	6,700	6,700	7,300	7,500	6,200	7,500	7,200
		May 1996	6,200	6,900	6,100	6,000	6,600	7,100	5,900	7,200	7,000
		Aug 1996	5,910	6,120	5,940	5,980	6,710	7,660	5,590	7,620	6,840
Nitrate, µg/L	33,800	Nov 1995	13,000	12,000	12,000	14,000	15,500	20,000	11,000	23,000	22,000
		Mar 1996	13,000	12,000	12,000	13,000	16,000	20,000	11,000	22,500	21,000
		May 1996	13,000	12,000	12,000	11,000	16,000	20,000	12,000	23,000	24,000
		Aug 1996	14,600	13,200	12,500	14,300	17,100	21,500	12,500	23,700	21,900
Nitrite, µg/L	356	Nov 1995	<140	<140	<140	<140	<140	<140	<140	<140	<140
		Feb 1996	<140	<140	<140	<140	<140	<140	<140	<140	<140
		May 1996	<11	<11	<11	<11	<11	<11	<11	<11	<11
		Aug 1996	<2	<2	<2	<2	<2	<2	<2	<2	<2
Ammonium, µg/L	100	Nov 1995	<27	<27	<27	<27	<27	<27	<27	<27	<27
		Feb 1996	<27	<27	<27	36	<27	<27	39	<27	<27
		May 1996	<16	<16	<16	<16	<16	<16	<16	<16	<16
		Aug 1996									

Table B.4. (contd)

Constituent	Tolerance Interval[a]	Date	Well 699-22-35	Well 699-23-34A	Well 699-23-34B	Well 699-24-34A	Well 699-24-34B	Well 699-24-34C	Well 699-24-35	Well 699-25-34C	Well 699-26-35A
Sulfate, μg/L	51,500	Nov 1995	50,000	43,000	51,000	43,000	43,000	41,000	40,000	44,000	37,000
		Feb 1996	53,000[E]	44,000	52,000	42,500	43,000	40,000	42,000	39,500	37,000
		May 1996	51,000	46,000	51,000	43,000	43,000	42,000	42,000	40,000	37,000
		Aug 1996	56,800[E]	46,300	51,900	44,500	42,700	42,200	43,300	39,900	35,900
Iron (filtered), μg/L	78	Nov 1995	33	23	43	25	28	23	22	24	<8.9
		Feb 1996	16	32	50	32	29	41	25	20	<8.9
		May 1996	14	15	34	18	48	34	34	80[E]	13
		Aug 1996	56.4	37.3	60.1	55.4	37.7	44.1	60.3	51	49
Zinc (filtered) μg/L	35	Nov 1995	<3.7	<3.7	<3.7	<3.7	<3.7	6.8	<3.7	6.7	<3.7
		Feb 1996	<3.7	<3.7	<3.7	<3.7	4.1	12	<3.7	<3.7	<3.7
		May 1996	<7.7	<7.7	<7.7	<7.7	<7.7	<7.7	<7.7	<3.7	<7.7
		Aug 1996	8.7	5.9	6.9	7.0	8.5	24.7	9.3	22	12.3
Manganese (filtered), μg/L	11	Nov 1995	2.7	<0.55	3.2	<0.55	<0.55	1.1	0.78	<0.55	<0.55
		Feb 1996	0.81	0.68	2.7	2.0	1.5	1.8	0.58	0.53	<0.55
		May 1996	0.50	<0.29	0.67	<0.29	1.5	1.0	0.71	0.39	0.71
		Aug 1996	4.9	4.3	5.3	4.5	4.5	4.5	2.9	4.1	4.7
Chemical oxygen demand, μg/L	13,000	Nov 1995	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900
		Feb 1996	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900	<2,900
		May 1996	<2,800	<2,800	<2,800	<2,800	<2,800	<2,800	<2,800	<2,800	<2,800
		Aug 1996	<3,000	<3,000	<3,000	<3,000	<3,000	5,000	<3,000	<3,000	<3,000
Coliform bacteria, most probable number	16	Nov 1995	<1	<1	<1	<1	<1	<1	<1	<1	<1
		Feb 1996	<1	<1	<1	<1	<1	<1	<1	<1	<1
		May 1996	<1	<1	<1	<1	<1	<1	<1	<1	<1
		Aug 1996	<1	<1	<1	<1	<1	<1	<1	<1	<1

(a) Numbers are obtained from Table E3.2 (Background threshold value column).
E = Exceeds background threshold values.
< = Data values less than the contractually required quantitation limit; the number given is the respective contractually required quantitation limit.
NA = Not available.

Table B.5. Critical Means for 16 Comparisons--Background Contamination Indicator Parameter Data for the 120-D-1 Ponds[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	5	4	8.122	519.40	15.265	655.2	655.2
Field pH	4[b]	3	15.145	8.223	0.151	[5.66, 10.78]	[7.06, 9.31][c]
Total organic carbon, μg/L	5	4	8.122	853.65	70.751	1,483.1	1,483.1
Total organic halogen, μg/L	5	4	8.122	8.752	3.239	37.6	37.6

(a) Data collected from March 1995 to February 1996 for upgradient well 199-D5-13.
(b) Excluding invalid pH data collected on March 14, 1995.
(c) Values calculated using data collected from May 1995 to August 1996 because the critical range calculated using only four quarters of data is too large to be meaningful.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 16 comparisons.

Table B.6. Background Contamination Indicator Parameter Data for 120-D-1 Ponds

Well	Sample Date	Duplicate Sample Number	Specific Conductance, μS/cm	Field pH	Total Organic Carbon, μg/L	Total Organic Halogen, μg/L
199-D5-13	03/14/95	1	502	7.62[R]	800[L,Q]	10.8
		2	502	7.63[R]	900[L,Q]	6.5
		3	501	7.64[R]	900[L,Q]	12.2
		4	502	7.65[R]	900[L,Q]	7.6
199-D5-13	05/02/95	1	534	8.02	800[L]	9.3[L]
		2	533	8.03	800[L]	9.5[L]
		3	533	8.03	900[L]	10.0
		4	532	8.03	800[L]	10.0
199-D5-13	08/16/95	1	504	8.16	1,000	6.9[U]
		2	500	8.16	800	6.9[U]
		3	508	8.21	800	6.9[U]
		4	506	8.24	800	6.9[U]
199-D5-13	11/14/95	1	525	8.31	720	12.0
		2	524	8.30	840	9.7[L]
		3	525	8.28	780	11.0
		4	525	8.28	710	6.9[U]
199-D5-13	02/27/96	1	532	8.37	913	9.1[L]
		2	533	8.38	1,030	13.2
		3	533	8.38	961	13.8
		4	534	8.39	919	13.1

L = Analyte concentration below contractually required quantitation limit but above method detection limit.
Q = Result associated with suspect quality control data.
R = Reviewed data that were rejected as a result of the request for analytical data evaluations process.
U = Analyte concentration below method detection limit; reported values were analytical laboratories' method detection limit.

Table B.7. Average Replicate Statistics--Background Indicator Parameter Data for 120-D-1 Ponds

Constituent	Well Name	Sample Date	Number of Samples	Average	Standard Deviation	Coefficient of Variation, %
Specific conductance, μS/cm	199-D5-13	03/14/95	4	501.75	0.500	0.10
	199-D5-13	05/02/95	4	533.00	0.816	0.15
	199-D5-13	08/16/95	4	504.50	3.416	0.68
	199-D5-13	11/14/95	4	524.75	0.500	0.10
	199-D5-13	02/07/96	4	533.00	0.816	0.15
Field pH	199-D5-13	03/14/95	4	7.635[R]	0.013[R]	0.17[R]
	199-D5-13	05/02/95	4	8.028	0.005	0.06
	199-D5-13	08/16/95	4	8.192	0.040	0.48
	199-D5-13	11/14/95	4	8.292	0.015	0.18
	199-D5-13	02/07/96	4	8.380	0.008	0.10
Total organic carbon, μg/L	199-D5-13	03/14/95	4	875[L,Q]	50.000[L,Q]	5.71[L,Q]
	199-D5-13	05/02/95	4	825[L]	50.000[L]	6.06[L]
	199-D5-13	08/16/95	4	850	100.000	11.76
	199-D5-13	11/14/95	4	762.5	60.208	7.90
	199-D5-13	02/07/96	4	955.75	53.910	5.64
Total organic halogen,[(a)] μg/L	199-D5-13	03/14/95	4	9.275	2.670	28.79
	199-D5-13	05/02/95	4	9.700	0.356	3.67
	199-D5-13	08/16/95	4	6.90[U]	NC	NC
	199-D5-13	11/14/95	4	9.038	3.842	42.51
	199-D5-13	02/07/96	4	12.30	2.156	17.53

(a) Statistics were calculated by replacing nondetected values with half of the respective method detection limit.

L = Calculated using values below contractually required quantitation limit but above method detection limit; actual reported values were used.
NC = Not calculated.
Q = Result associated with suspect quality control data.
R = Reviewed data were rejected as a result of the request for analytical data evaluation process.
U = Calculated values are below method detection limit.

Table B.8. Background Statistics--Contamination Indicator Parameter Data for 120-D-1 Ponds

Constituent	Number of Samples	Background Average	Background Standard Deviation	Background Coefficient of Variation, %
Specific conductance, μS/cm	5	519.40	15.265	2.94
Field pH	4[a]	8.223	0.151	1.84
Total organic carbon, μg/L	5	853.65	70.751	8.29
Total organic halogen,[b] μg/L	5	8.752	3.239	37.00

(a) Excluding invalid pH data collected on March 14, 1995.
(b) Background summary statistics calculated using values below method detection limit.

Table B.9. Critical Means Table for 32 Comparisons--Background Contamination Indicator Parameter Data for 1301-N Liquid Waste-Disposal Facility[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	10	9	5.1241	592.70	272.527	2,057.3	2,057.3
Field pH[b]	9	8	6.0313	7.855	0.248	[6.28, 9.43]	[6.28, 9.43]
Total organic carbon, μg/L	10	9	5.1241	377	205.037	1,478.9	1,478.9
Total organic halogen, μg/L	10	9	5.1241	10.742	5.087	38.1	38.1

(a) Data collected from February 1994 to February 1995 for upgradient wells 199-N-57 and 199-N-34. Values calculated based on 32 comparisons.
(b) Excluding suspect pH data collected on September 6, 1994 from well 199-N-57.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 32 comparisons.

Table B.10. Critical Means Table for 16 Comparisons--Background Contamination Indicator Parameter Data for 1324-N/NA Liquid Waste-Disposal Facilities[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	4[b]	3	11.984	260.812	26.709	618.7	618.7
Field pH	4[b]	3	15.145	8.198	0.115	[6.26, 10.14]	[7.59, 8.87][c]
Total organic carbon, μg/L	4[d]	3	11.984	291.875	80.710	1,373.2	1,373.2
Total organic halogen, μg/L	5	4	8.122	6.470	2.385	27.7	27.7

(a) Data collected from May 1994 to May 1995 for upgradient well 199-N-71.
(b) Excluding outliers specific conductance and pH collected on March 1, 1995 and August 26, 1994, respectively.
(c) Values calculated using data collected from May 1994 to September 1996 because the critical range calculated using only four quarters of data is too large to be meaningful.
(d) Excluding invalid data collected on November 4, 1994; blank contamination.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 16 comparisons.

Table B.11. Background Contamination Indicator Parameter Data for 1324-N/NA Liquid Waste-Disposal Facilities

Well	Sample Date	Duplicate Sample Number	Specific Conductance, μS/cm	Field pH	Total Organic Carbon, μg/L	Total Organic Halogen, μg/L
199-N-71	05/12/94	1	253	8.06	400[L]	8.1
		2	252	8.07	400[L]	ND
		3	252	8.07	350[L]	ND
		4	253	8.07	400[L]	ND
199-N-71	08/26/94	1	256	7.47[F]	320[U]	8.0
		2	254	7.48[F]	320[U]	7.6
		3	255	7.48[F]	320[U]	8.4
		4	255	7.49[F]	340[L]	8.9
199-N-71	11/04/94	1	238	8.16	300[L,B]	6.2
		2	237	8.17	200[L,B]	6.9
		3	236	8.16	200[L,B]	8.5
		4	236	8.17	200[L,B]	8.4
199-N-71	03/01/95	1	183[F]	8.35	300[L]	10.1
		2	182[F]	8.35	300[L]	9.0
		3	186[F]	8.33	400[L]	5.0[U]
		4	185[F]	8.34	300[L]	5.0[U]
199-N-71	05/02/95	1	299	8.22	200[L]	5.0[U]
		2	299	8.21	300[L]	5.0[U]
		3	299	8.22	200[L]	5.0[U]
		4	299	8.22	300[L]	5.0[U]

B = Blank associated with analyte is elevated.
F = Suspect data; currently under review.
L = Analyte concentration below contractually required quantitation limit but above method detection limit.
U = Analyte concentration below method detection limit; reported values were analytical laboratories' method detection limit.
ND = No data.

Table B.12. Average Replicate Statistics--Background Indicator Parameter Data for 1324-N/NA Liquid Waste-Disposal Facilities

Constituent	Well Name	Sample Date	Number of Samples	Average	Standard Deviation	Coefficient of Variation, %
Specific conductance, μS/cm	199-N-71	05/12/94	4	252.50	0.577	0.23
	199-N-71	08/06/94	4	255.00	0.816	0.32
	199-N-71	11/04/94	4	236.75	0.957	0.40
	199-N-71	03/01/95	4	184.00[F]	1.826[F]	0.99[F]
	199-N-71	05/02/95	4	299.00	0	0
Field pH	199-N-71	05/12/94	4	8.068	0.005	0.06
	199-N-71	08/26/94	4	7.480[F]	0.008[F]	0.11[F]
	199-N-71	11/04/94	4	8.165	0.006	0.07
	199-N-71	03/01/95	4	8.342	0.010	0.11
	199-N-71	05/02/95	4	8.218	0.005	0.06
Total organic carbon[(a)], μg/L	199-N-71	05/12/94	4	387.5[L]	25.000[L]	6.45[L]
	199-N-71	08/26/94	4	205.0[L]	90.000[L]	43.90[L]
	199-N-71	11/04/94	4	225.0[L,B]	50.000[L,B]	22.2[L,B]
	199-N-71	03/01/95	4	325.0[L]	50.000[L]	15.38[L]
	199-N-71	05/02/95	4	250.0[L]	57.735[L]	23.09[L]
Total organic halogen[(a)], μg/L	199-N-71	05/12/94	1	8.100	NC	NC
	199-N-71	08/26/94	4	8.225	0.556	6.76
	199-N-71	11/04/94	4	7.500	1.134	15.12
	199-N-71	03/01/95	4	6.025	4.095	67.97
	199-N-71	05/02/95	4	2.500[U]	0	0

(a) Statistics were calculated by replacing nondetected values with half of the respective method detection limit.

B = Blank associated with analyte is elevated.
F = Suspect data; currently under review.
L = Calculated using values below contractually required quantitation limit but above method detection limit; actual reported values were used.
NC = Not calculated.
U = Calculated values are below method detection limit.

Table B.13. Background Statistics--Contamination Indicator Parameter Data for 1324-N/NA Liquid Waste-Disposal Facilities

Constituent	Number of Samples	Background Average	Background Standard Deviation	Background Coefficient of Variation, %
Specific conductance, μS/cm	4[a]	260.812	26.709	10.24
Field pH	4[a]	8.198	0.115	1.40
Total organic carbon[b], μg/L	4[c]	291.875	80.710	27.65
Total organic halogen[b], μg/L	5	6.470	2.385	36.87

(a) Outliers excluded; collected on March 1, 1995 and August 26, 1994, respectively.
(b) Background summary statistics calculated using values below method detection limit.
(c) Excludes invalid data collected on November 4, 1994; blank contamination.

Table B.14. Critical Means Table for 24 Comparisons--Background Contamination Indicator Parameter Data for 1325-N Liquid Waste-Disposal Facility[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	4	3	13.745	501.75	14.046	717.6	717.6
Field pH	4	3	17.358	7.991	0.129	[5.49, 10.49]	[6.50, 9.12][b]
Total organic carbon[c], μg/L	4	3	13.745	500	NC	NC	525
Total organic halogen, μg/L	4	3	13.745	11.185	2.952	56.6	56.6

(a) Data collected from May 1992 to March 1993 for upgradient well 199-N-74, except for total organic halogen that was collected from June 1994 to March 1995 (well 199-N-29 not sampled in 1995).
(b) Values calculated using data collected from May 1992 to November 1994 (well 199-N-74) because the critical range calculated using only four quarters of data is too large to be meaningful.
(c) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 24 comparisons.

Table B.15. Critical Means Table for 36 Comparisons--Background Contamination Indicator Parameter Data for 216-A-29-Ditch[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.976	217.75	28.382	397.6	397.6
Field pH	8	7	6.699	7.792	0.308	[5.60, 9.98]	[6.16, 9.71][b]
Total organic carbon, μg/L	8	7	5.976	499.375	98.758	1,125.3	1,125.3
Total organic halogen, μg/L	8	7	5.976	5.964	2.509	21.9	21.9

(a) Data collected from April 1994 to January 1995 for upgradient wells 699-43-43 and 699-43-45.
(b) Values calculated using data collected from April 1994 to July 1995 (wells 699-43-43 and 699-43-45) because the critical range calculated using only four quarters of data is too large to be meaningful.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 36 comparisons.

Table B.16. Critical Means Table for 28 Comparisons--Background Contamination Indicator Parameter Data for 216-A-36B Crib[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	12	11	4.6425	281.646	68.595	613.1	613.1
Field pH	12	11	5.0765	7.953	0.290	[6.42, 9.48]	[6.42, 9.48]
Total organic carbon[b,c], μg/L	12	11	4.6425	598.708	125.606	1,205.6	1,205.6
Total organic halogen[b,c], μg/L	12	11	4.6425	4.075	2.176	14.6	16.2[d]

(a) Data collected from September 1988 to June 1989 for upgradient wells 299-E17-17, 299-E24-18, and 299-E25-36.
(b) Critical means were calculated from values reported below the contractually required detection limit (DOE 1991).
(c) Critical means were calculated using data analyzed by United States Testing Company, Inc., Richland, Washington.
(d) Value is limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 36 comparisons.

Table B.17. Critical Means Table for 24 Comparisons--Background Contamination Indicator Parameter Data for 216-A-10 Crib[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.5799	273.31	77.643	732.8	732.8
Field pH	8	7	6.2684	8.024	0.319	[5.90, 10.14]	[6.76, 9.26][b]
Total organic carbon[c,d], μg/L	8	7	5.5799	618.75	117.83	1,316.1	1,316.1
Total organic halogen[c,d], μg/L	8	7	5.5799	4.47	1.544	13.6	13.6

(a) Data collected from November 1988 to August 1989 for upgradient wells 299-E24-18 and 299-E25-36.
(b) Values calculated using data collected from November 1988 to August 1992 (wells 299-E24-18 and 299-E25-36) because the critical range calculated using only four quarters of data is too large to be meaningful.
(c) Critical means calculated from values reported below the contractually required detection limit (DOE 1991).
(d) Critical means calculated using data analyzed by United States Testing Company, Inc., Richland, Washington.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 24 comparisons.

Table B.18. Critical Means Table for 48 Comparisons--Background Contamination Indicator Parameter Data for 216-B-63 Trench[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	21	20	4.224	369.393	60.192	629.6	629.6
Field pH	20	19	4.572	7.975	0.190	[7.08, 8.87]	[7.08, 8.87]
Total organic carbon[b], μg/L	20	19	4.267	500	NC	NC	525
Total organic halogen[c], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from July 1992 to April 1993 for upgradient wells 299-E27-8, 299-E27-9, 299-E34-10, and 299-E27-17. Data collected from July 1992 to July 1993 for upgradient well 299-E27-11.
(b) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(c) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 48 comparisons.

Table B.19. Critical Means Table for 20 Comparisons--Background Contamination Indicator Parameter Data for 216-S-10 Pond and Ditch[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.4079	248.375	9.186	301.1	301.1
Field pH	8	7	6.0818	7.888	0.178	[6.74, 9.04]	[6.74, 9.04]
Total organic carbon[b], μg/L	7[c]	6	5.9588	500	NC	NC	525
Total organic halogen[d], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from August 1991 to June 1992 for upgradient wells 299-W26-7 and 299-W26-8.
(b) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(c) Excluding values collected on February 11, 1992 from well 299-W26-7 because of Nonconformance Report.
(d) Critical means not calculated because problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 20 comparisons.

Table B.20. Critical Means Table for 16 Comparisons--Background Contamination Indicator Parameter Data for Liquid Effluent Retention Facility[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	4	3	11.984	332.125	11.736	489.4	489.4
Field pH	4	3	15.145	7.742	0.311	[2.48, 13.01]	[6.25, 9.42][b]
Total organic carbon[c], μg/L	4	3	11.984	718.75	295.364	4,676	4,676
Total organic halogen[d], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from June 1991 to April 1992 for upgradient well 299-E26-11.
(b) Values calculated using data from June 1991 to October 1993 (well 299-E26-11) because the critical range calculated using four quarters of data is too large to be meaningful.
(c) Critical means calculated from values reported below the contractually required quantitation limit.
(d) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 16 comparisons.

Table B.21. Critical Means Table for 68 Comparisons--Background Contamination Indicator Parameter Data for Low-Level WMA-1[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	26[b]	25	4.2027	373.721	74.637	693.4	693.4
Field pH	27	26	4.4409	7.896	0.330	[6.40, 9.39]	[6.40, 9.39]
Total organic carbon[c], μg/L	26	25	4.2027	500	NC	NC	525
Total organic halogen[d], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from July 1992 to April 1993 for upgradient wells 299-E28-26, 299-E28-27, 299-E28-28, 299-E33-28, 299-E33-29, and from July 1992 to January 1993 for 299-E33-35, and from September 1991 to July 1992 for 299-E32-4.
(b) Excluding outlier collected on July 2, 1992 from well 299-E33-28.
(c) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(d) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 68 comparisons.

Table B.22. Critical Means Table for 52 Comparisons--Background Contamination Indicator Parameter Data for Low-Level WMA-2[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	12	11	5.0293	385.875	116.987	998.3	998.3
Field pH	12	11	5.4790	8.077	0.174	[7.08, 9.07]	[7.08, 9.07]
Total organic carbon[b], μg/L	12	11	5.0293	445.833	94.648	941.3	941.3
Total organic halogen[c], μg/L	12	11	5.0293	4.833	2.861	19.8	19.8

(a) Data collected from September 1988 to July 1989 for upgradient wells 299-E27-10 and 299-E34-5.
(b) Critical means calculated from values reported below contractually required detection limit.
(c) Critical means calculated using data analyzed by United States Testing Company, Inc., Richland, Washington.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 52 comparisons.

Table B.23. Critical Means Table for 32 Comparisons--Background Contamination Indicator Parameter Data for Low-Level WMA-3[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	12	11	4.7248	439.812	26.865	579.1	579.1
Field pH	12	11	5.1621	8.120	0.294	[6.54, 9.70]	[6.54, 9.70]
Total organic carbon[b], μg/L	10	9	5.1241	195.75	42.296	423.1	525
Total organic halogen, μg/L	9	8	5.4284	8.731	7.183	49.8	49.8

(a) Data collected from February 1994 to March 1995 for upgradient wells 299-W10-13 and 299-W9-1. Critical means calculated for area not impacted by upgradient source of contamination.
(b) Critical means calculated from values reported below contractually required detection limit. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 32 comparisons.

Table B.24. Critical Means Table for 40 Comparisons--Background Contamination Indicator Parameter Data for Low-Level WMA-3[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	17	16	4.3467	580.941	32.230	725.1	725.1
Field pH	17	16	4.6820	7.838	0.3867	[5.97, 9.70]	[5.97, 9.70]
Total organic carbon[b], μg/L	15	14	4.4995	367.833	107.483	867.3	867.3
Total organic halogen, μg/L	14	13	4.5978	797.923	319.605	2,319.0	2.319.0

(a) Data collected from February 1994 to March 1995 for upgradient wells 299-W10-19, 299-W10-20, and 299-W10-21. Critical means calculated for area impacted by upgradient source of contamination.
(b) Critical means calculated from values reported below contractually required detection limit.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 40 comparisons.

Table B.25. Critical Means Table for 56 Comparisons--Background Contamination Indicator Parameter Data for Low-Level WMA-4[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	16	15	4.586	328.594	133.345	958.9	958.9
Field pH	16	15	4.938	7.779	0.261	[6.45, 9.11]	[6.45, 9.11]
Total organic carbon[b], μg/L	15	14	4.676	470.0	142.428	1,157.8	1,157.8
Total organic halogen[b], μg/L	11	10	5.2814	2,029.796	2,002.864	13,078	13,078

(a) Data collected from October 1988 to July 1989 for upgradient wells 299-W15-16, 299-W15-18, and 299-W18-24 and from October 1992 to August 1993 for the newly installed upgradient well 299-W18-32.
(b) Critical means calculated using data analyzed by United States Testing Company, Inc., Richland, Washington.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 56 comparisons.

Table B.26. Critical Means Table for 20 Comparisons--Background Contamination Indicator Parameter Data for WMA-A-AX Single-Shell Tank Farms[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.4079	396.563	59.671	738.8	738.8
Field pH	8	7	6.0818	7.798	0.194	[6.55, 9.05]	[6.55, 9.05]
Total organic carbon[b], μg/L	6[c]	5	5.4079	500	NC	NC	525
Total organic halogen[d], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from July 1991 to May 1992 for upgradient wells 299-E25-40 and 299-E25-41.
(b) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(c) Excluding values collected on February 28, 1992 from wells 299-E25-40 and 299-E25-41 because of Nonconformance Report.
(d) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 20 comparisons.

Table B.27. Critical Means Table for 28 Comparisons--Background Contamination Indicator Parameter Data for WMA-B-BX-BY Single-Shell Tank Farms[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.7282	262.656	16.958	365.7	365.7
Field pH	7[b]	6	7.2227	8.126	0.344	[5.47, 10.78][b]	[6.91, 9.28][c]
Total organic carbon[d], μg/L	8	7	5.7282	500	NC	NC	525
Total organic halogen[e], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from July 1991 to June 1992 for upgradient wells 299-E33-33 and 299-E33-36.
(b) Excluding inconsistent pH replicate average 6.335 of samples collected on January 3, 1992 from well 299-E33-36.
(c) Values calculated using data collected from July 1991 to June 1993 (wells 299-E33-33 and 299-E33-36) because the critical range calculated using only four quarters of data is too large to be meaningful.
(d) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(e) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 28 comparisons.

Table B.28. Critical Means Table for 16 Comparisons--Background Contamination Indicator Parameter Data for WMA-C Single-Shell Tank Farm[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	4	3	11.9838	353.063	14.244	543.9	543.9
Field pH	4	3	15.1451	8.038	0.109	[6.19, 9.88]	[6.19, 9.88]
Total organic carbon[b], μg/L	4	3	11.9838	500	NC	NC	525
Total organic halogen[c], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from July 1991 to August 1992 for upgradient well 299-E27-14.
(b) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(c) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 16 comparisons.

Table B.29. Critical Means Table for 28 Comparisons--Background Contamination Indicator Parameter Data for WMA-S-SX Single-Shell Tank Farms[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.3168	246.3125	42.666	486.9	486.9
Field pH	7	6[b]	6.4295	7.918	0.307	[5.81, 10.03]	[6.68, 9.18][c]
Total organic carbon[d], μg/L	8	7	5.3168	500	NC	NC	525
Total organic halogen[e], μg/L	NC	NC	NC	NC	NC	NC	16.2

(a) Data collected from October 1991 to July 1992 for upgradient wells 299-W23-13 and 299-W23-14.
(b) Excluding inconsistent pH replicate average 5.868 of samples collected on October 9, 1991 from well 299-W23-14.
(c) Values calculated using data collected from October 1991 to June 1993 (wells 299-W23-13 and 299-W23-14) because the critical range calculated using four quarters of data is too large to be meaningful.
(d) Critical means not calculated because of lack of estimate of background standard deviation. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).
(e) Critical means not calculated because of problems associated with data quality for samples analyzed by DataChem Laboratories, Inc., Salt Lake City, Utah. The upgradient/downgradient comparison value is the limit of quantitation (see Appendix F).

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
NC = Not calculated.
t_c = Bonferroni critical t-value for appropriate df and 28 comparisons.

Table B.30. Critical Means Table for 20 Comparisons--Background Contamination Indicator Parameter Data for WMA-U Single-Shell Tank Farm[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.4079	308.875	39.032	532.8	532.8
Field pH	8	7	6.0818	8.008	0.091	[7.42, 8.59]	[7.42, 8.59]
Total organic carbon, μg/L	8	7	5.4079	275.031	82.580	748.7	748.7
Total organic halogen, μg/L	8	7	5.4079	102.994	24.120	241.3	241.3

(a) Data collected based on semiannual sampling events from February 1995 to August 1996 for upgradient wells 299-W18-25 and 299-W18-31.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 20 comparisons.

Table B.31. Background Contamination Indicator Parameter Data for WMA-U Single-Shell Tank Farm

Well	Sample Date	Duplicate Sample Number	Specific Conductance, μS/cm	Field pH	Total Organic Carbon, μg/L	Total Organic Halogen, μg/L
299-W18-25	02/13/95	1	311	7.97	200[L]	110.0
		2	311	7.97	200[L]	108.0
		3	311	7.97	200[L]	107.0
		4	311	7.97	200[L]	107.0
299-W18-25	07/31/95	1	302	7.97	300[L]	60.0
		2	303	7.97	200[L]	80.0
		3	303	7.97	300[L]	80.0
		4	303	7.96	200[L]	80.0
		5	ND	ND	200[L]	70.0
		6	ND	ND	300[L]	80.0
		7	ND	ND	200[L]	80.0
		8	ND	ND	200[L]	90.0
299-W18-25	02/20/96	1	271	8.01	229[L]	114.0
		2	271	8.01	200[L]	108.0
		3	271	8.02	218[L]	114.0
		4	271	8.02	244[L]	97.5
299-W18-25	08/19/96	1	290	7.86	300[U]	126.0
		2	290	7.87	300[U]	148.0
		3	290	7.87	300[U]	148.0
		4	290	7.87	300[U]	149.0
299-W18-31	02/13/95	1	351	8.16	300[L]	125.0
		2	348	8.14	300[L]	115.0
		3	346	8.14	400[L]	137.0
		4	345	8.11	300[L]	143.0
299-W18-31	08/01/95	1	377	7.97	400[L]	90.0
		2	371	8.00	300[L]	100.0
		3	370	8.00	300[L]	100.0
		4	369	8.00	500[L]	80.0
299-W18-31	02/20/96	1	323	8.13	306[L]	85.6
		2	324	8.14	420[L]	73.1
		3	324	8.14	312[L]	66.6
		4	326	8.14	362[L]	75.9
299-W18-31	08/19/96	1	260	7.95	305[L]	83.3
		2	251	7.98	815[F]	80.0
		3	251	7.99	401[L]	96.6
		4	249	7.99	314[L]	98.2

F = Suspect data; currently under review.
L = Analyte concentration below contractually required quantitation limit but above method detection limit.
ND = No data.
U = Analyte concentration below method detection limit; reported values were analytical laboratories' method detection limit.

Table B.32. Average Replicate Statistics--Background Indicator Parameter Data for the WMA-U Single-Shell Tank Farm

Constituent	Well Name	Sample Date	Number of Samples	Average	Standard Deviation	Coefficient of Variation, %
Specific conductance, μS/cm	299-W18-25	02/13/95	4	311.00	0	0
	299-W18-25	07/31/95	4	302.75	0.500	0.17
	299-W18-25	02/20/96	4	271.00	0	0
	299-W18-25	08/19/96	4	290.00	0	0
Field pH	299-W18-25	02/13/95	4	7.970	0	0
	299-W18-25	07/31/95	4	7.968	0.005	0.06
	299-W18-25	02/20/96	4	8.015	0.006	0.07
	299-W18-25	08/19/96	4	7.868	0.005	0.06
Total organic carbon[a], μg/L	299-W18-25	02/13/95	4	200.00[L]	0	0
	299-W18-25	07/31/95	8	237.50[L]	51.755	21.79
	299-W18-25	02/20/96	4	222.75[L]	18.536	8.32
	299-W18-25	08/19/96	4	150.00[U]	NC	NC
Total organic halogen, μg/L	299-W18-25	02/13/95	4	108.00	1.414	1.31
	299-W18-25	07/31/95	8	77.50	8.864	11.44
	299-W18-25	02/20/96	4	108.375	7.782	7.18
	299-W18-25	08/19/96	4	142.75	11.177	7.83
Specific conductance, μS/cm	299-W18-31	02/13/95	4	347.50	2.646	0.76
	299-W18-31	08/01/95	4	371.75	3.594	0.97
	299-W18-31	02/20/96	4	324.25	1.258	0.39
	299-W18-31	08/19/96	4	252.75	4.924	1.95
Field pH	299-W18-31	02/13/95	4	8.138	0.021	0.25
	299-W18-31	08/01/95	4	7.992	0.015	0.19
	299-W18-31	02/20/96	4	8.138	0.005	0.06
	299-W18-31	08/19/96	4	7.978	0.019	0.24
Total organic carbon[a], μg/L	299-W18-31	02/13/95	4	325[L]	50.000	15.38
	299-W18-31	08/01/95	4	375[L]	95.743	25.53
	299-W18-31	02/20/96	4	350[L]	52.991	15.14
	299-W18-31	08/19/96	3[b]	340[L]	53.019	15.59
Total organic halogen, μg/L	299-W18-31	02/13/95	4	130.00	12.490	9.61
	299-W18-31	08/01/95	4	92.50	9.574	10.35
	299-W18-31	02/20/96	4	75.30	7.895	10.48
	299-W18-31	08/19/96	4	89.525	9.216	10.29

(a) Statistics were calculated by replacing nondetected values with half of the respective method detection limit.
(b) Outlier not used in calculation.

L = Calculated using values below contractually required quantitation limit but above method detection limit; actual reported values were used.
NC = Not calculated.
U = Calculated values are below method detection limit.

Table B.33. Background Statistics--Contamination Indicator Parameter Data for WMA-U Single-Shell Tank Farm

Constituent	Number of Samples	Background Average	Background Standard Deviation	Background Coefficient of Variation, %
Specific conductance, μS/cm	8	308.875	39.032	12.64
Field pH	8	8.008	0.091	1.13
Total organic carbon[a], μg/L	8	275.031	82.580	30.03
Total organic halogen, μg/L	8	102.994	24.120	23.42

(a) Background summary statistics calculated using values below method detection limit.

Table B.34. Critical Means Table for 28 Comparisons--Background Contamination Indicator Parameter Data for Nonradioactive Dangerous Waste Landfill[a]

Constituent	n	df	t_c	Average Background	Standard Deviation	Critical Mean	Upgradient/ Downgradient Comparison Value
Specific conductance, μS/cm	8	7	5.7282	335.31	80.088	821.9	821.9
Field pH	7	6	7.2227	7.546	0.685	[2.26, 12.84]	[5.16, 9.87][b]
Total organic carbon[c,d], μg/L	8	7	5.7282	424.65	89.98	971.3	971.3
Total organic halogen[d], μg/L	8	7	5.7282	5.15	1.83	16.3	16.3

(a) Data collected from November 1987 to July 1988 for upgradient wells 699-26-34A and 699-26-35A.
(b) Values calculated using data collected from November 1987 to June 1992 (wells 699-26-34A and 699-25-35A) because the critical range calculated using four quarters of data is too large to be meaningful.
(c) Critical means calculated from values reported below the contractually required detection limit.
(d) Critical means calculated using data analyzed by United States Testing Company, Inc., Richland, Washington.

df = Degrees of freedom (n-1).
n = Number of background replicate averages.
t_c = Bonferroni critical t-value for appropriate df and 28 comparisons.

Appendix C

Borehole Spectral Gamma Logs

Appendix C

Borehole Spectral Gamma Logs

This appendix lists the spectral-gamma and moisture logs obtained at various soil-column-disposal sites and at special study sites. The logs are listed by file name (first column), site designator (second column), type of sensor or probe used (third column), and the date of the log (fourth column). Data are stored electronically by file name (contact R. K. Price, Rust Federal Services, Inc., Richland, Washington for access to the original logs). More information about the waste site can be found in the Waste Information Data System (WIDS).

Well or Borehole Name	Site	Probe	Log Date
299-E17-003	A-27 Crib	HPGe	06/27/95
299-E24-059	A-10 Crib	HPGe	07/10/95
299-E24-060	A-10 Crib	HPGe	07/12/95
299-E24-078	A-38 Crib	MOIST	05/30/95
299-E24-079	A-38 Crib	MOIST	05/30/95
299-E24-084	A-38 Crib	HPGe	03/17/95
299-E24-092	A-38 Crib	HPGe	02/24/95
299-E24-100	A-38 Crib	HPGe	03/17/95
299-E24-160	A-10 Crib	HPGe	06/12/95
299-E25-004	A-8 Crib	HPGe	10/31/95
299-E25-005	A-8 Crib	HPGe	11/28/95
299-E25-005	A-8 Crib	MOIST	12/04/95
299-E25-007	A-8 Crib	HPGe	11/08/95
299-E25-007	A-8 Crib	MOIST	11/29/95
299-E26-051	A-24 Crib	HPGe	09/26/95
299-E26-052	A-24 Crib	HPGe	09/27/95
299-E26-053	A-24 Crib	HPGe	10/11/95
299-E26-056	A-24 Crib	HPGe	09/26/95
299-E26-057	A-24 Crib	HPGe	11/01/95
299-E26-060	A-24 Crib	HPGe	09/27/95
299-E26-064	A-24 Crib	HPGe	10/27/95

Well or Borehole Name	Site	Probe	Log Date
299-E26-071	A-24 Crib	HPGe	10/12/95
299-E26-074	A-24 Crib	HPGe	10/11/95
299-E26-076	A-24 Crib	HPGe	10/04/95
299-E27-001	C-9 Crib	MOIST	05/18/95
299-E32-002	E-10 Burial	HPGe	06/30/95
299-E32-002	E-10 Burial	NA(I)	06/30/95
299-E33-005	B43-50 Crib	MOIST	05/03/95
299-E33-020	B-11 Crib	HPGe	05/25/95
299-E33-020	B-11 Crib	MOIST	05/24/95
299-E33-020	B-11 Crib	NA(I)	05/25/95
299-E33-038	B43-50 Crib	HPGe	07/05/95
299-E33-038	B43-50 Crib	MOIST	07/07/95
299-E33-038	B43-50 Crib	NA(I)	07/05/95
299-W11-001	T-6 Crib	HPGe	05/03/95
299-W11-007	T-3 Crib	HPGe	10/25/95
299-W11-007	T-3 Crib	MOIST	11/09/95
299-W11-018	T-35 Crib	HPGe	10/23/95
299-W11-052	T-224 Bldg	HPGe	05/16/95
299-W11-054	T-6 Crib	HPGe	05/17/95
299-W11-055	T-6 Crib	HPGe	05/13/95
299-W11-057	T-6 Crib	HPGe	05/11/95
299-W11-058	T-6 Crib	HPGe	04/18/95
299-W11-058	T-6 Crib	MOIST	05/22/95
299-W11-059	T-6 Crib	HPGe	04/17/95
299-W11-060	T-6 Crib	HPGe	03/27/95
299-W11-060	T-6 Crib	MOIST	05/23/95
299-W11-061	T-6 Crib	HPGe	03/23/95
299-W11-061	T-6 Crib	MOIST	05/22/95
299-W11-062	T-6 Crib	NA(I)	10/18/95
299-W11-063	T-6 Crib	HPGe	03/27/95
299-W11-064	T-6 Crib	HPGe	04/18/95
299-W11-065	T-6 Crib	HPGe	04/19/95
299-W11-067	T-6 Crib	HPGe	04/18/95
299-W11-067	T-6 Crib	NA(I)	10/18/95

Well or Borehole Name	Site	Probe	Log Date
299-W11-070	T-26 Crib	HPGe	06/28/95
299-W14-004	T-28 Crib	HPGe	05/23/95
299-W15-004	T-19 Crib	HPGe	11/15/95
299-W15-007	Z-7 Crib	HPGe	04/13/95
299-W15-007	Z-7 Crib	MOIST	04/21/95
299-W15-007	Z-7 Crib	MOIST	04/25/95
299-W15-009	Z-9 Crib	HPGe	04/11/95
299-W15-062	Z-5 Crib	HPGe	04/05/95
299-W15-062	Z-5 Crib	MOIST	06/07/95
299-W15-063	Z-5 Crib	HPGe	04/04/95
299-W15-063	Z-5 Crib	MOIST	03/30/95
299-W15-064	Z-5 Crib	HPGe	04/07/95
299-W15-076	Z-7 Crib	HPGe	04/06/95
299-W15-076	Z-7 Crib	MOIST	06/08/95
299-W15-077	Z-7 Crib	HPGe	04/10/95
299-W15-077	Z-7 Crib	MOIST	06/08/95
299-W15-078	Z-7 Crib	HPGe	04/10/95
299-W15-078	Z-7 Crib	MOIST	06/06/95
299-W15-198	Z-8	HPGe	04/12/95
299-W15-213	Z-8	HPGe	04/12/95
299-W15-214	Z-8	HPGe	04/12/95
299-W18-250	U-14 Ditch	MOIST	06/12/95
299-W22-023	U-12 Crib	HPGe	08/08/95
299-W22-028	U-12 : S-9	HPGe	09/06/95
299-W23-004	S-21 Crib	HPGe	06/28/95
299-W23-004	S-21 Crib	MOIST	06/27/95
299-W23-004	S-21 Crib	NA(I)	06/28/95
699-059-058	600 Area VZM	HPGe	07/10/95
699-059-058	600 Area VZM	MOIST	07/10/95
699-059-058	600 Area VZM	NA(I)	07/10/95
699-060-057	600 Area VZM	HPGe	07/11/95
699-060-057	600 Area VZM	MOIST	07/11/95
699-060-057	600 Area VZM	NA(I)	07/11/95
199-F02-001	Decon	MOIST	12/06/95

Well or Borehole Name	Site	Probe	Log Date
199-F02-001	Decon	NA(I)	12/06/95
199-F02-002	Decon	MOIST	12/14/95
199-F02-002	Decon	NA(I)	12/12/95
199-K-025	Decon	MOIST	05/02/95
199-K-025	Decon	NA(I)	05/07/95
699-040-012A	Decon	NA(I)	03/20/95
699-049-012A	Decon	MOIST	04/27/95
699-049-012A	Decon	NA(I)	04/27/95
699-049-012B	Decon	MOIST	04/26/95
699-049-012B	Decon	NA(I)	04/26/95
699-052-018A	Decon	NA(I)	03/09/95
699-052-018C	Decon	NA(I)	03/17/95
699-054-018E	Decon	NA(I)	02/08/95
699-056-026B	Decon	NA(I)	03/09/95
699-057-025B	Decon	NA(I)	02/01/95
699-059-101	Decon	NA(I)	01/11/95
699-062-043B	Decon	NA(I)	01/26/95
699-065-059B	Decon	NA(I)	01/30/95
699-065-059C	Decon	NA(I)	01/26/95
699-080-062	Decon	NA(I)	05/01/95
699-097-051B	Decon	NA(I)	05/02/95
116-B4-01	116-B-4	CPT	08/08/95
116-B4-02	116-B-4	CPT	08/08/95
116-B4-03	116-B-4	CPT	08/08/95
116-B4-04	116-B-4	CPT	08/08/95
116-B4-05	116-B-4	CPT	08/08/95
116-B4-06	116-B-4	CPT	08/09/95
116-B4-07	116-B-4	CPT	08/09/95
116-B4-08	116-B-4	CPT	08/09/95
116-B4-09	116-B-4	CPT	08/09/95
116-B4-10	116-B-4	CPT	08/09/95
116-C1-01	116-C-1	CPT	08/11/95
116-C1-02	116-C-1	CPT	08/11/95
116-C1-03	116-C-1	CPT	08/11/95

Well or Borehole Name	Site	Probe	Log Date
116-C1-04	116-C-1	CPT	08/11/95
116-C1-05	116-C-1	CPT	08/14/95
116-C1-06	116-C-1	CPT	08/14/95
116-C1-07	116-C-1	CPT	08/14/95
116-C1-08	116-C-1	CPT	08/14/95
116-C1-09	116-C-1	CPT	08/14/95
116-C1-10	116-C-1	CPT	08/14/95
116-C1-11	116-C-1	CPT	08/15/95
116-C1-12	116-C-1	CPT	08/15/95
116-C1-13	116-C-1	CPT	08/15/95
116-C1-14	116-C-1	CPT	08/15/95
116-C1-15	116-C-1	CPT	08/15/95
116-C1-16	116-C-1	CPT	08/16/95
116-C1-17	116-C-1	CPT	08/16/95
116-C1-18	116-C-1	CPT	08/16/95
116-C1-19	116-C-1	CPT	08/16/95
116-C1-20	116-C-1	CPT	08/17/95
116-C1-21	116-C-1	CPT	08/17/95
116-C1-22	116-C-1	CPT	08/17/95
116-C1-23	116-C-1	CPT	08/17/95
116-C1-24	116-C-1	CPT	08/23/95
116-C1-25	116-C-1	CPT	08/23/95
116-C5-01	116-B-11	CPT	12/12/95
116-C5-02	116-B-11	CPT	12/12/95
116-C5-03	116-B-11	CPT	12/12/95
116-C5-04	116-B-11	CPT	12/12/95
116-C5-05	116-B-11	CPT	12/13/95
116-C5-06	116-B-11	CPT	12/13/95
116-C5-07	116-B-11	CPT	12/13/95
116-C5-08	116-B-11	CPT	12/15/95
116-C5-09	116-B-11	CPT	12/15/95
116-C5-10	116-B-11	CPT	12/15/95
116-C5-11	116-B-11	CPT	12/15/95
116-C5-12	116-B-11	CPT	12/20/95

Well or Borehole Name	Site	Probe	Log Date
199-N-014	N Springs	HPGe	04/19/95
199-N-035	N Springs	HPGe	06/21/95
199-N-035	N Springs	MOIST	06/21/95
199-N-103A	N Springs	HPGe	03/07/95
199-N-104A	N Springs	HPGe	03/20/95
199-N-105A	N Springs	HPGe	04/19/95
199-N-106A	N Springs	HPGe	08/29/95
199-N-045	1301-N	HPGe	07/14/95
199-N-045	1301-N	MOIST	07/18/95
199-N-067	1301-N	HPGe	07/20/95
199-N-067	1301-N	MOIST	07/20/95
B2470	1301-N	NA(I)	07/20/95
B2536	1301-N	HPGe	12/21/95
B2536	1301-N	MOIST	12/21/95
B2537	1301-N	HPGe	12/04/95
B2539	1325-N	HPGe	12/20/95
299-W15-031	200-ZP-2	HPGe	05/17/95
299-W15-031	200-ZP-2	MOIST	05/17/95
299-W15-031	200-ZP-2	NA(I)	05/17/95
299-W15-031A	200-ZP-2	MOIST	08/17/95
ERT-1	ERT	MOIST	03/28/95
ERT-1	ERT	MOIST	07/18/95
ERT-1	ERT	NA(I)	07/18/95
ERT-2	ERT	MOIST	07/21/95
ERT-4	ERT	MOIST	03/28/95

CPT = Cone penetrometer.
Decon = Decontamination.
ERT = Electrical resistivity tomography.
HPGe = High purity germanium gamma-ray detector.
NA(I) = Sodium iodide gamma-ray detector.
MOIST = Moisture detector (neutron source).
VZM = Vadose-zone monitoring.

Appendix D

Selected Water-Level Measurements from Unconfined Aquifer System Wells on the Hanford Site and Outlying Areas used for June 1996 Water-Table-Contour Map

Appendix D

Selected Water-Level Measurements from Unconfined Aquifer System Wells on the Hanford Site and Outlying Areas used for June 1996 Water-Table-Contour Map

J. T. Rieger and W. D. Webber

This appendix is on the 3-1/2-in. computer diskette included with this report.

Appendix E

Analytical Methods

Appendix E

Analytical Methods

B. M. Gillespie and T. X. Washington

The methodology for analysis of chemical constituents in groundwater at the Hanford Site for fiscal year 1996 conforms to the U.S. Environmental Protection Agency's (EPA's) *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods* (EPA 1986); *Methods for Chemical Analysis of Water and Wastes* (EPA 1982) or other EPA methods; and the *Annual Book of ASTM Standards* (ASTM 1986). The methodologies used for analysis of radiochemical constituents were developed by the analyzing laboratory and are recognized as acceptable within the technical radiochemical industry. The methodologies used to obtain routine data results are presented in Table E.1. During fiscal year 1996, samples were analyzed for chemical constituents by four primary laboratories and for radiochemical analytes by three primary laboratories. Brief descriptions of each methodology for each test ordered follow. Some tests were performed by slightly different methodologies, dependent on the laboratory. A section on field measurement methodology is also included.

E.1 Chemical Analyses

E.1.1 Volatile Organic Compounds

Volatile organic compounds were analyzed by gas chromatography per Methods 8010/8020, 8240, or 8260 (EPA 1986). Volatile organic compounds were extracted from the water sample through a purge-and-trap system (e.g., Method 5030 [EPA 1986]). Purged sample components were trapped in a tube containing suitable sorbent materials. When purging was complete, the sorbent tube was heated and backflushed with helium to desorb trapped sample components onto a gas chromatography column. The column separated the analytes, which were then detected with a photoionization detector and a halogen-specific detector placed in series for Methods 8010/8020. For Methods 8240 and 8260, the compounds were identified and quantified using a mass spectrometer.

E.1.2 Semivolatile Organic Compounds

Semivolatile organic compounds were analyzed by Method 8270 (EPA 1986) after extraction into methylene chloride, using a fused-silica capillary column. Polynuclear aromatic hydrocarbons, chlorinated hydrocarbons and pesticides, phthalate esters, organophosphate esters, nitrosamines, haloethers, aldehydes, ethers, ketones, anilines, pyridines, quinolines, aromatic nitro compounds, and phenols (including nitrophenols) could be analyzed using this methodology.

E.1.3 Polychlorinated Biphenyls and Pesticides

Organochloride pesticide and polychlorinated biphenyl compounds were determined by Method 8080 (EPA 1986). This method specifies gas chromatographic conditions for detection. Prior to analysis, appropriate sample-extraction techniques must be used. Both neat and diluted organic liquids may be analyzed by direct injection. A 2- to 5-μL sample is injected into a gas chromatograph, using the solvent flush technique, and compounds in the gas chromatograph effluent are detected by an electron capture detector or an electrolytic conductivity detector.

Organophosphorus pesticides were determined by Method 8140 (EPA 1986), which specifies gas chromatographic conditions for the detection of microgram-per-liter levels. Prior to analysis, appropriate sample-extraction techniques must be used. Both neat and diluted organic liquids may be analyzed by direct injection. A 2- to 5-μL aliquot of the extract is injected into a gas chromatograph, and compounds in the gas chromatograph effluent are detected with a flame photometric or thermionic detector.

E.1.4 Dioxins and Dibenzofurans

Dioxins and dibenzofurans were determined by Method 8280 (EPA 1986). Dioxins and dibenzofurans are determined by matrix-specific extraction, analyte-specific cleanup, and high-resolution capillary column gas chromatography/low resolution mass spectrometry techniques.

E.1.5 Chlorinated Herbicides

Herbicides were determined by Method 8150 (EPA 1986), which specifies extraction, esterification, and gas chromatographic conditions. Spiked samples are used to verify the applicability of the chosen extraction technique to each new sample type. The esters are hydrolyzed with potassium hydroxide, and extraneous organic material is removed by a solvent wash. After acidification, the acids are extracted with solvent and converted to their methyl esters using diazomethane as the derivation agent. After the excess reagent is removed, the esters are determined by gas chromatography, employing electron capture, microcoulometric, or electrolytic conductivity detectors. The results are reported as the acid equivalents.

E.1.6 Phenols

Phenolic compounds were determined by Method 8040A (EPA 1986), which specifies gas chromatographic conditions for the detection of phenolic compounds. A sample is extracted using methylene chloride and is then injected into the gas chromatograph using the solvent flush technique. The compounds in the gas chromatograph effluent are detected by a flame ionization detector. This method also provides for the preparation of pentafluorobenzyl-bromide derivatives, with additional cleanup procedures for electron capture gas chromatography.

E.1.7 Cyanide

Cyanide was determined by Method 335.2 (EPA 1979), Method 9010, or Method 9012 (EPA 1986). The sample was acidified, converting any cyanide to hydrocyanic acid. The sample was then distilled, and the hydrocyanic acid was trapped in an absorber scrubber of sodium hydroxide solution. The cyanide ion was converted to cyanogen chloride with Chloramine-T, and color formation was achieved through the addition of pyridine barbituric acid. The cyanide concentration was then determined by volumetric titration, colorimetry, or automated ultraviolet colorimetry.

E.1.8 Inductively Coupled Plasma Metals Analysis

Samples were acid digested before analysis by Methods 3010A or 3015 (EPA 1986) then injected into a plasma per Method 6010 (EPA 1986). Metal concentrations were determined by inductively coupled atomic emission spectrometry.

E.1.9 Alkalinity

One of two methods was used to determine alkalinity, depending on the laboratory. The sample is titrated electrometrically to an end point of pH 4.5 using Method 310.1 (EPA 1979, 1982) or by colorimetric titration, using methyl orange indicator; Method 310.2 (EPA 1982).

E.1.10 Anions

Nitrate, nitrite, bromide, chloride, fluoride, phosphate, and sulfate were determined using ASTM D 4327-88 (ASTM 1986) or Method 300.0 (O'Dell et al. 1984). The sample was introduced into an ion chromatograph where the anions of interest were separated and measured with a conductivity detector. Specific methods for the detection of individual anions used in some instances are given below.

- Fluoride was determined by Method 340.2 (EPA 1979). This method determines fluoride by potentiometrically using a fluoride electrode in conjunction with a standard single-junction sleeve-type reference electrode and a pH meter having an expanded millivolt scale or a selective ion meter having a direct concentration scale for fluoride.

- Total nitrate plus nitrite were determined by Methods 353.1 and 353.2 (EPA 1979), which are colorimetric methods that first reduce the nitrate to nitrite with either hydrazine or cadmium. Total nitrite was determined colorimetrically by using sulfanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly colored azo dye. The results were expressed as nitrogen in nitrate plus nitrite.

- Phosphorus was determined by Method 365.1 (EPA 1979), which uses ammonium molybdate and antimony potassium tartrate reacting in an acid medium with a dilute solution of

phosphorus to form an antimony-phospho-molybdate complex. This complex was reduced to an intensely blue-colored complex by ascorbic acid. The color was proportional to the phosphorus concentration.

- Sulfate was determined by Method 375.4 (EPA 1979). The sulfate ion is converted to a barium sulfate suspension under controlled conditions. The resulting turbidity was determined by a nephelometer, filter photometer, or spectrophotometer and compared to a curve prepared from standard sulfate solutions.

E.1.11 Graphite Furnace Atomic Absorption Metals

Lead, arsenic, antimony, thallium, and selenium were analyzed by graphite furnace atomic absorption analysis. Methods (EPA 1986) used were 7421 (lead), 7060 (arsenic), 7041 (antimony), 7841 (thallium), and 7740 (selenium) after acid digestion. Samples were introduced into the pyrolitic graphite chamber and atomized. Background subtraction techniques were used to correct for absorbance or scatter of light.

E.1.12 Mercury

Method 7470 (EPA 1986), a cold-vapor atomic absorption technique, is based on the absorption of radiation at 253.7-nm by mercury vapor. The mercury is reduced to the elemental state and aerated from solution in a closed system. The mercury vapor passes through a cell positioned in the light path of an atomic absorption spectrophotometer. Absorbance (peak height) is measured as a function of mercury concentration.

E.1.13 Sulfides

Method 9030A (EPA 1986) was used to measure the concentration of total and dissolved sulfides. The sample was treated with zinc acetate to produce zinc sulfide. Excess iodine was added to oxidize the sulfide to sulfur under acid conditions. The excess iodine is backtitrated with sodium thiosulfate or phenylarsine oxide.

E.1.14 Total Dissolved Solids

Total dissolved solids were determined by Method 160.1 (EPA 1982) or Standard Method #209B (APHA 1985). These methods dry the sample to 180°C and determine the total dissolved solids content by the gravimetric technique.

E.1.15 Total Organic Halides

Method 9020B (EPA 1986) was used to determine total organic halides. The sample is passed through an activated carbon column. The column is washed to remove any trapped inorganic halides. The sample is then combusted to convert the adsorbed organohalides to hydrogen halide, which is trapped and titrated electrolytically using a microcoulometric detector.

E.1.16 Total Organic Carbon

Method 9060 (EPA 1986) was used to determine total organic carbon. This method uses an instrument, a carbonaceous analyzer, to convert the organic carbon in the sample to carbon dioxide by either catalytic combustion or wet chemical oxidation. The carbon dioxide is then directly measured by an infrared detector or converted to methane and measured by a flame ionization detector. The amount of carbon dioxide or methane measured is directly proportional to the concentration of carbonaceous material in the sample.

E.1.17 Total Carbon

Total carbon was determined by Method 415.1 (EPA 1982). Carbon in a sample is converted to carbon dioxide by catalytic combustion or wet chemical oxidation. The carbon dioxide formed can be measured directly by an infrared detector or converted to methane and measured by a flame ionization detector. The amount of carbon dioxide or methane is directly proportional to the concentration of carbonaceous material in the sample.

E.1.18 Conductivity

Method 120.1 (EPA 1982), Method 9050 (EPA 1986), or ASTM D 1125A (ASTM 1986) was used to determine the electrical conductivity of a sample. The conductivity of a sample is measured by use of a self-contained conductivity meter, Wheatstone bridge-type, or equivalent.

E.1.19 Ammonia

One of two colorimetric methods was used to determine ammonia, depending on the laboratory: ASTM D 1426-C (ASTM 1986) or by Method 350.1 (EPA 1979, 1986). Both methods use alkaline phenol and hypochlorite to react with ammonia to form indenophenol blue that is proportional to the ammonia concentration. The blue color formed is intensified with sodium nitroprusside. The concentration is measured by use of a calibrated colorimeter.

E.1.20 pH

The determination of pH was by Method 9040 (EPA 1986) or ASTM D 1293 (ASTM 1986). The pH of a sample was determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode. The measuring device was calibrated using a series of standard solutions of known pH.

E.1.21 Turbidity

Standard Method #214A (APHA 1985) or Method 180.1 (EPA 1979), the nephelometric method, was used to determine turbidity of samples. Under defined conditions, the methods are based on a comparison of the intensity of light scattered by the sample with the intensity of light scattered by a

standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. Readings are given in nephelometric turbidity units.

E.1.22 Coliform

One of two methods was used to determine coliform, depending on the laboratory:

- Method 9132 (EPA 1986) to determine coliforms by the filter technique - The coliform group analyzed by this method includes all of the organisms that produce a colony of golden-green metallic sheen within 24 hours of inoculation. The sample is filtered through a membrane filter that retains the bacteria. The filters then undergo a two-step enrichment procedure. The sheen colonies are then counted under magnification.

- Standard Method 9222B (APHA 1989) to determine total coliform - The method requires the water sample to pass through a membrane filter. All coliform present in the sample will be retained directly on the filter's surface. The membrane filter is then placed on an absorbent pad, saturated with nutrients, incubated, and transferred to agar medium for incubation. The coliform on the filter will form sheen colonies that are counted under magnification and reported per 100 mL of original sample.

E.1.23 Chemical Oxygen Demand

Method 410.1 (EPA 1979, 1982) was used to determine chemical oxygen demand. Organic and oxidizable inorganic substances in the sample are oxidized by potassium dichromate in 50% sulfuric acid solution at reflux temperature. Silver sulfate is used as a catalyst and mercuric sulfate is added to remove chloride interference. The excess dichromate is titrated with standard ferrous ammonium sulfate, using orthophenanthroline ferrous complex as an indicator.

E.1.24 Nonhalogenated Volatile Organics

Nonhalogenated volatile organic compounds were determined by Method 8015A (EPA 1986). Samples are introduced into the gas chromatograph using the purge-and-trap system (Method 5030 [EPA 1986]). Detection is achieved by a flame ionization detector.

E.1.25 Total Petroleum Hydrocarbons

Three methods were used to determine total petroleum hydrocarbons, the first of which was Method 418.1 (EPA 1979). This method determines the mineral oils through acidifying the sample to pH<2 and serially extracting with fluorocarbon-113 in a separatory funnel. Interferences are removed with silica gel absorbent. Infrared analysis of the extract is performed by direct comparison with standards.

Total petroleum hydrocarbon, gasoline range, was determined using the method in State of Washington Department of Ecology (Ecology 1992), which adapts Method 5030 and/or 8020 (EPA

1986) to perform the analysis (see Section C.1.1). The method involves purging an aliquot of sample via a purge/trap concentrator into a gas chromatograph equipped with a flame ionization detector.

Total petroleum hydrocarbon, diesel range, was determined using the method in Ecology (1992), which adapted Methods 3510 and 8000 (EPA 1986). The method involves extracting the samples with methylene chloride and injecting a portion of the extract into a gas chromatograph equipped with a flame ionization detector. Quantitation is accomplished by integrating to baseline, as a group, the area of components after dodecane through tetracosane.

E.1.26 Oil and Grease

Method 413.1 (EPA 1979) is used to determine oil and grease in groundwater samples. In this method, the sample is acidified to a low pH (<2) and serially extracted with fluorocarbon-113 in a separatory funnel. The solvent is evaporated from the extract and the residue weighed. The definition of oil and grease is based on the procedure used. The nature of the oil and/or grease and the presence of extractable nonoily matter will influence the material measured and interpretation of results. Oil and grease are measures of biodegradable animal greases and vegetable oils along with the relative nonbiodegradable mineral oils.

E.2 Radiological Analyses

E.2.1 Gross Alpha and Gross Beta

Gross alpha and gross beta were determined by Method 9310 (EPA 1986) or Method 900.0 (EPA 1980). An aliquot of water was evaporated onto a stainless steel counting planchet. The residue was dried to constant weight and counted for alpha and beta radioactivity. Activity was determined using a standardized counting efficiency versus sample solids curve for the detector system. Efficiencies were determined by using strontium/yttrium-90 and americium-241 certified standards.

E.2.2 Gamma Spectrometry

Gamma scans provided a quantitative assay for a large number of gamma-emitting isotopes with a range of half-lives. Because these assays were performed by high-resolution counting techniques, it was possible to identify isotopes of interest with a high degree of confidence. In addition, a software library search could be used to identify unknowns. Isotopes routinely reported included cobalt-60, ruthenium-106, antimony-125, and cesium-137; numerous other isotopes are reported when detected. Laboratory-specific methods or Method 901.1 (EPA 1980) were used.

Samples were counted directly, using an intrinsic (hyperpure) germanium or lithium-drifted germanium detector. Isotopes with gamma-ray energies from 60 to 2,000 KeV were detected. Activity concentrations were determined using a Nuclear Data, Inc., Shaumberg, Illinois, computer system supplied with a library of isotopes.

E.2.3 Total Uranium

Total uranium analyses were generally performed by fluorophotometry or by laser kenetic phosphorimetry but may also be performed by alpha-counting determinations of individual isotopes for activity.

In the fluorophotometry method, the sample was evaporated and fused with sodium and lithium fluoride flux. The yellow-green uranium fluorescence was then measured using a fluorophotometer. A uranium-232 tracer is used to determine recovery from the purification process, and a natural uranium standard addition is used to adjust for interferences and to quantify sample reading.

The laser kinetic phosphorimetry method pretreats the water samples for organic and halide-quenching interferents (if necessary) and particulates are filtered out. The uranium is complexed with a substance such as phosphoric acid for it to phosphoresce. The concentration is calculated based on the phosphorescence of the sample in a laser phosphorimeter.

E.2.4 Uranium Isotopes

Uranium was separated from lead, radium, and thorium on a hydrochloric acid anion-exchange resin column; iron was removed by passing the sample through a nitric acid anion-exchange resin column. The uranium fraction was eluted and electrodeposited on a disk for alpha spectrometry counting.

E.2.5 Tritium

Sodium hydroxide was added to the tritium sample. The alkaline sample was then distilled and a fraction (5 mL) was mixed with scintillation cocktail, allowed to sit while the chemiluminescence decayed, and then counted by liquid-scintillation instrumentation. Laboratory-specific methods or Method 906.0 (EPA 1980) were used.

E.2.6 Low-Level Tritium

The sample was distilled in the presence of potassium permanganate to eliminate solids and organic material that may cause quenching. The sample was then enriched in a basic medium by electrolysis to a small volume. The enriched volume was transferred to a liquid-scintillation vial with scintillation cocktail and allowed to sit for 24 hours while the chemiluminescence decays and temperature equilibrium was reached. It was then counted by liquid-scintillation instrumentation.

E.2.7 Technetium-99

The technetium-99 samples were wet ashed with nitric acid and hydrogen peroxide to destroy organic material in the sample. Actinides, lanthinides, alkaline earths, transition metals, and lead were removed through precipitation as hydroxides and carbonates. Technetium, as the pertechnetate ion,

was adsorbed from a weak nitric acid solution on a strongly basic anion-exchange resin column. The technetium was then eluted with a stronger nitric acid solution and counted by liquid-scintillation beta counting.

E.2.8 Americium-241

Americium and curium were concentrated in the sample by coprecipitation on ferric hydroxide. Thorium and plutonium were separated from the americium and curium as the sample passed through an anion-exchange resin column conditioned with dilute nitric acid. The iron was then separated from the americium and curium by coprecipitation on calcium oxalate. The americium and curium were then extracted into a bidentate organophosphorus solvent (DDCP) from a nitric acid solution and then backextracted with weak nitric acid. Traces of iron, thorium, and any organic residue were removed by passing the solution through a cation-exchange resin column. The americium and curium were eluted from the cation-exchange resin column with dilute hydrochloric acid, electrodeposited or precipitated on a counting disk, and counted by alpha spectrometry.

E.2.9 Plutonium Isotopes

The sample was acidified with nitric acid, the plutonium oxidation state was adjusted to +4 with sodium nitrite, and the solution was loaded onto an anion-exchange resin column. The plutonium was eluted with hydrochloric acid and ammonium iodide. The sample was electrodeposited or coprecipitated on a counting disk and the activity counted by alpha spectrometry.

E.2.10 Strontium-90

Samples of strontium-90 were precipitated first as a nitrate and then as a carbonate. Calcium, barium, lead, and radium were removed by coprecipitation on barium chromate. Iron and other fission products were removed through hydroxide scavenging. The gravimetric yield of carrier (or strontium-85 tracer yield) was determined along with the strontium-89 and -90 activities by beta counting, following final carbonate precipitation. Yttrium-90 was then separated from the strontium by hydroxide and oxalate precipitations. The yttrium oxalate was converted to yttrium oxide, weighed for chemical recovery, and counted by beta-proportional counting for activity.

E.2.11 Iodine-129

Iodine-129 analyses presented a particular challenge because of the need for specially sensitive measurement. The iodine-129 interim drinking water standard is 1 pCi/L -- the lowest for any radionuclide. The contractual detection limit (referred to as the minimum detectable concentration) is currently 1 pCi/L for the most-sensitive method used by the primary radiological laboratory.

Iodine isotopes were first separated from interfering radioactive isotopes by oxidation to iodine (I_2) with sodium nitrite and then extracted into carbon tetrachloride from dilute acid media. The iodine was

next reduced to iodide with sodium bisulfite. It was then backextracted into water, precipitated as silver iodide, and counted on a low-energy photon detector. Chemical yield is determined gravimetrically.

E.2.12 Total Alpha - Radium

The total radium alpha activity is determined by Method 9315 (EPA 1986). Radium is coprecipitated in water samples with mixed barium and lead sulfates. The carriers are added to an alkaline solution containing citrate, which prevents precipitation during carrier exchange with radium isotopes in the sample. Ammonium sulfate is then used to precipitate the sulfates, which are purified by nitric acid washes. The precipitate is dissolved in an alkaline solution containing EDTA, and the barium and radium sulfates are precipitated by addition of acetic acid, thus separating radium from lead and other radionuclides. The precipitate is dried on a plate, weighed to determine chemical yield, and alpha counted to determine the activity concentration of the radium isotopes.

E.3 Field Measurements

Several tests were performed in the field by the sampling staff or by trained personnel in a mobile laboratory. The tests used are listed below and are also presented in Table E.1.

E.3.1 Volatile Organic Compounds

Field-screening methods for volatile organic compounds are based on Method 8010 (EPA 1986) by gas chromatography.

E.3.2 Alkalinity

The field-screening method used to determine alkalinity is based on Standard Method 2320 (APHA 1989). This method is an electrochemical titration method.

E.3.3 Conductivity

Conductivity is measured in the field using company-specific procedures based on Method 9050 (EPA 1986), electrical conductivity.

E.3.4 pH

The pH of groundwater samples is determined by electrometric measurement using company-specific procedures based on EPA methodology and instrument manuals.

E.3.5 Turbidity

Turbidity measurements performed in the field are nephelometric measurements based on Method 180.1 (EPA 1979) or Standard Method 2130B (APHA 1989).

E.3.6 Dissolved Oxygen

Field measurements for dissolved oxygen are based on the membrane electrode Method 360.1 (EPA 1979).

E.3.7 Temperature

The temperature of field samples is based on company-specific and instrument manual methodology using electronic digital thermometers.

E.3.8 Total Uranium

Laser kinetic phosphorimetry is used to determine total uranium in field samples using instrument manufacturer's and company-specific methods.

E.4 References

American Society for Testing and Materials (ASTM). 1986. *Annual Book of ASTM Standards*. Philadelphia, Pennsylvania.

American Public Health Association (APHA). 1985. *Standard Methods for the Examination of Water and Wastewater*, 16th Edition, New York, New York.

American Public Health Association (APHA). 1989. *Standard Methods for the Examination of Water and Wastewater*, 17th Edition, New York, New York.

O'Dell, J. W., J. D. Pfaff, M. E. Gales, and G. D. McKee. 1984. *Test Method: The Determination of Inorganic Anions in Water by Ion Chromatography - Method 300.0*. EPA-600/4-84-017, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

State of Washington Department of Ecology (Ecology). 1992. *Total Petroleum Hydrocarbons Analytical Methods*. Prepared by J. Barreca, April 8, 1992, Olympia, Washington.

U.S. Environmental Protection Agency (EPA). 1979. *Methods for Chemical Analysis of Water and Wastes*. EPA-600/4-79-020, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1980. *Prescribed Procedures for Measurement of Radioactivity in Drinking Water*. EPA-600/4-80-032, Cincinnati, Ohio.

U.S. Environmental Protection Agency (EPA). 1982. *Methods for Chemical Analysis of Water and Wastes*. EPA-600/4-82-055, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, 3rd ed.* SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

Table E.1. Methodologies Used to Obtain Routine Data Results for Project Samples

Analytical Test	User[a]	Reference	Analytical Methodology
Chemical Analyses			
Volatile organic compounds	G, R, E, F, E	Method 8010/8020 (EPA 1986) Method 8240 (EPA 1986) Method 8260 (EPA 1986)	Gas chromatography Gas chromatography/mass spectroscopy
	G, R		
Semivolatile organic compounds	G, R, E	Method 8270 (EPA 1986)	Gas chromatography/mass spectroscopy
Polychlorinated biphenyls and pesticides	G, R, E	Method 8080 (EPA 1986)	Gas chromatography
Organophosphorus pesticides	G, R, E	Method 8140 (EPA 1986)	Gas chromatography
Dioxins and dibenzofurans	G, R, E	Method 8280 (EPA 1986)	High-resolution gas chromatography/low-resolution mass spectrometry
Chlorinated herbicides	G, R, E	Method 8150 (EPA 1986)	Gas chromatography
Phenols	G, R	Method 8040A (EPA 1986)	Gas chromatography
Cyanide	G, R	Method 9012 (EPA 1986)	Colorimetry
	E	Method 335.2 (EPA 1979)	Titration or spectrophotometric
	E	Method 9010 (EPA 1986)	Automated ultraviolet colorimetry
Inductively coupled plasma metals	G, R, E	Method 6010 (EPA 1986)	Inductively coupled plasma, atomic emission spectroscopy
Alkalinity	G, R	Method 310.1 (EPA 1982) Method 310.2 (EPA 1982)	Electrochemical titration Colorimetric titration
	E	Method 310.1 (EPA 1979)	Electrochemical titration
	F	Standard 2320 (APHA 1989)	
Fluoride[b]	E	Method 340.2 (EPA 1979)	Potentiometric fluoride electrode
Nitrogen, nitrate-nitrite[b]	E	Method 353.1 (EPA 1979)	Colorimetric, hydrazine reduction
	E	Method 353.2 (EPA 1979)	Colorimetric, cadmium reduction

Table E.1. (contd)

Analytical Test	User[a]	Reference	Analytical Methodology
Phosphorus[b]	E	Method 365.1 (EPA 1979)	Colorimetric, automated, ascorbic acid
Sulfate[b]	E	Method 375.4 (EPA 1979)	Turbidimetric
Anions	G, R G, R, E	D 4327-88 (ASTM 1986) or Method 300.0 (O'Dell et al. 1984)	Ion chromatography
Lead	G, R, E	Method 7421 (EPA 1986)	Graphite furnace atomic absorption
Arsenic	G, R, E	Method 7060 (EPA 1986)	Graphite furnace atomic absorption
Antimony	E	Method 7041 (EPA 1986)	Graphite furnace atomic absorption
Thallium	E	Method 7841 (EPA 1986)	Graphite furnace atomic absorption
Selenium	G, R, E	Method 7740 (EPA 1986)	Graphite furnace atomic absorption
Mercury	G, R, E	Method 7470 (EPA 1986)	Cold vapor furnace atomic absorption
Sulfides	G, R, E	Method 9030A (EPA 1986)	Titration
Total dissolved solids	G, R G, R E	Standard #209B (APHA 1985) Method 160.1 (EPA 1982) Method 160.1 (EPA 1979, 1982)	Dried to 180°C and gravimetric technique
Total organic halides	G, R, E	Method 9020B (EPA 1986)	Electrolytic titration
Total organic carbon	G, R E	Method 9060 (EPA 1986) Method 415.1 (EPA 1979)	Carbon analyzer
Total carbon	G, R	Method 415.1 (EPA 1982)	Carbon analyzer
Conductivity	G, R G, R E, F	Method 120.1 (EPA 1982) D 1125A (ASTM 1986) Method 9050 (EPA 1986)	Electrical conductivity

Table E.1 (contd)

Analytical Test	User[a]	Reference	Analytical Methodology
Ammonium ion	G, R	D 1426-C (ASTM 1986)	Colorimetric
	G, R	Method 350.1 (EPA 1982)	
	E	Method 350.1 (EPA 1979)	
pH	G, R	D 1293 (ASTM 1986)	Electrometric measurement
	E	Method 9040 (EPA 1986)	
	F	Company specific	
Turbidity	G, R	Method #214A (APHA 1985)	Nephelometric
	E	Method 180.1 (EPA 1979)	
	F	Method 180.1 (EPA 1979) or Standard 2130B (APHA 1989)	
Coliform	G, R	Method 9132 (EPA 1986)	Filter technique
	G, R	Standard 9222B (APHA 1989)	
Chemical oxygen demand	G, R, E	Method 410.1 (EPA 1979, 1982)	Titration
Dissolved oxygen	F	Method 360.1 (EPA 1979)	Membrane electrode
Temperature	F	Company specific	Electronic digital thermometer
Nonhalogenated volatile organics	G, R	Method 8015 (EPA 1986)	Purge and trap/gas chromatography/flame ionization detector
Total petroleum hydrocarbons	G, R	WTPH-Gasoline and Diesel (Ecology 1992)	Gas chromatography/flame ionization detector
	E	Method 418.1 (EPA 1979) or WTPH-Gasoline (Ecology 1992)	Spectrophotometric, infrared or gas chromatography/flame ionization detector
Oil/grease	E	Method 413.1 (EPA 1979)	Gravimetric/separatory funnel extraction
Radiological Analyses			
Gross alpha and gross beta	G, R	Method 9310 (EPA 1986)	Gas-flow proportional counting
	E	Method 900.0 (EPA 1980)	
Gamma spectrometry	G, R	Laboratory specific	Intrinsic germanium counting
	E	Method 901.1 (EPA 1980)	

Table E.1. (contd)

Analytical Test	User[a]	Reference	Analytical Methodology
Total uranium	G, R	Laboratory specific	Fluorophotometry
	E	Laboratory specific	Laser kinetic phosphorimetry or fluorophotometry
	F	Company specific	Laser kinetic phosphorimetry
Isotopic uranium	G, R, E	Laboratory specific	Anion-exchange resin separation with alpha energy analysis
Tritium	G, R	Laboratory specific	Distillation and liquid scintillation counting
	E	Method 906.0 (EPA 1980)	
Low-level tritium	G, R	Laboratory specific	Electrolysis to enriched volume and liquid scintillation counted
Technetium-99	G, R, E	Laboratory specific	Anion-exchange resin column separation with liquid scintillation counting
Americium-241	G, R, E	Laboratory specific	Anion- and cation-exchange resin separation with alpha energy analysis
Isotopic plutonium	G, R, E	Laboratory specific	Anion-exchange resin separation with alpha energy analysis
Strontium-90	G, R, E	Laboratory specific	Nitrate and carbonate coprecipitation, gravimetric yield, and beta gas-flow-proportional counting
Iodine-129	G, R	Laboratory specific	Chemical separation, coprecipitated, and counted on low-energy photon detector
Total alpha radium	G, R	Method 9315 (EPA 1986)	Coprecipitation and alpha counting
	E	Laboratory specific	

(a) G = Ground-Water Surveillance Project, Pacific Northwest National Laboratory.
R = RCRA and Operational Monitoring Program, Westinghouse Hanford Company.
E = Environmental Restoration Contractor, Bechtel Hanford, Inc.
F = Field (all contractors).
(b) Also analyzed by anion methods.

Appendix F

Quality Assurance and Quality Control for Groundwater Chemistry

Appendix F

Quality Assurance and Quality Control for Groundwater Chemistry

F.1 Introduction

H. Hampt

The groundwater chemistry quality assurance/quality control (QA/QC) information for fiscal year (FY) 1996 for the *Resource Conservation and Recovery Act of 1976* (RCRA) and Operational Monitoring (ROM) Program, managed by Westinghouse Hanford Company (WHC), and the Ground-Water Surveillance Project (GWSP), managed by Pacific Northwest National Laboratory (PNNL), is presented in this appendix. Portions of the QA/QC information for the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) projects, managed by Bechtel Hanford, Inc., are also provided in this appendix; however the majority of the QA/QC information for the CERCLA projects is available in project-specific documents (e.g., DOE 1991a, 1992a, 1992b, 1992c, 1992d, 1992e, 1996a, 1996b).

The QA/QC practices used by ROM and GWSP ensure the reliability and validity of field and laboratory measurements conducted to support these programs. The primary components used to assess data quality are accuracy, precision, and detection (Mitchell et al. 1985). Representativeness, completeness, and comparability may also be used. These parameters are evaluated through laboratory QC checks (e.g., matrix spikes, laboratory blanks), replicate sampling and analysis, analysis of blind samples and blanks, and interlaboratory comparisons. Acceptance criteria have been established for each of these parameters. When a parameter is outside the criteria, corrective actions are taken to prevent a future occurrence.

The QC practices for ROM samples are based on guidance from the U.S. Environmental Protection Agency (EPA 1986a, 1986b). The controlling procedures used for ROM samples in FY 1996 are described in WHC (1992) and the QA program plan is outlined in WHC (1995).

U.S. Department of Energy (DOE) orders and internal requirements provide the guidance for the collection and analysis of samples for the GWSP. QC practices for GWSP samples are described in the surveillance QC task plan.

A glossary of QA/QC terms is given below.

- accuracy - The closeness of agreement between an observed value and a true value. Accuracy is assessed by means of reference samples and percent recoveries. For ROM and GWSP,

accuracy is evaluated using data from laboratory matrix spikes; laboratory control samples; EPA water pollution, water supply, and interlaboratory comparison programs; and blind samples.

- blind sample - A sample that contains a concentration of analyte that is known to the supplier but unknown to the analyzing laboratory. The analyzing laboratory is informed that the sample is a QC sample and not a field sample. The blind, the double blind, and the matrix-matched double blind samples are used to assess accuracy and monitor the performance of the analytical laboratory(ies).

- comparability - The confidence with which one set of data can be compared to another. Ideally, it should be evaluated using replicates to ensure that samples analyzed by different laboratories or by the same laboratory over different time periods are comparable.

- completeness - The percentage of measurements judged to be valid. ROM determines completeness by calculating the number of data unflagged during the validation process, divided by the total number of data evaluated, and multiplying by 100. The calculated percentages used in reporting completeness are conservative because all data flagged with H, Q, R, B, and Y are used in calculating the percentage complete; however, flagged data may still be used. The B flag is a qualifier added by the laboratory to indicate contamination in the blank associated with the sample.

- contractually required quantitation limit - A value intended to be the lowest analyte concentration in a given matrix that the laboratory can be expected to achieve consistently; agreed on under the contract statement of work.

- flags - Data flags are assigned by onsite working personnel. Flags alert data users to limitations on reported data values. The flags that are used include the following:

  - F - suspect data currently under review
  - H - laboratory holding time exceeded
  - G - reviewed data considered valid
  - P - potential problem (with the sample or well that may have affected the data)
  - Q - result associated with suspect QC data
  - R - reviewed data rejected
  - Y - reviewed data continue to be suspect.

- double blind sample - A sample that contains a concentration of analyte that is known to the supplier but is unknown to the analyzing laboratory. The analyzing laboratory is not informed that the sample is a QC sample. All attempts are made to make this sample appear like a field sample. For example, the double blind sample should be submitted to the laboratory within the same time period and with a sample identification number similar to that of the field samples. The double blind sample does not include matrix matching.

- equipment blank - A sample that contains Type II reagent water and preservative. An equipment blank is filled by pumping or washing Type II reagent water through a nondedicated pump or manifold. The equipment blank is analyzed for all constituents scheduled for the sampling event.

- field duplicate sample - A sample used to determine repeatability of an analytical measurement on identical samples collected as closely as possible to the same time at the same location. These samples are stored in separate containers and are analyzed independently by the same laboratory.

- field trip blank - A sample that contains only Type II reagent water. At the time of sample collection, the field trip blank is filled at the sampling site by pouring Type II reagent water from a cleaned container into vials. After collection, the field trip blank is treated in the same manner as the other samples collected during the sampling event. Field trip blanks are collected only on days when samples are collected for volatile organics analysis and are analyzed for volatile organic constitutents only.

- full trip blank - A sample that contains only Type II reagent water and preservative, as required. A full trip blank is used to check for contamination in sample bottles and sample preparation. The full trip blank is analyzed for all constituents of interest on all types of sample bottles used during that sampling period. The frequency of collection for a full trip blank is 1 per 20 samples, or 1 per sampling batch. A full trip blank is filled in the analytical laboratory using the sample-preparation procedures. The full trip blank is <u>not</u> opened in the field.

- limit of detection - The lowest concentration level that is statistically different from a blank. This is calculated by the average blank signal plus three standard deviations for the blank analyses.

- limit of quantitation - The level above which quantitative results may be obtained with a specified degree of confidence. This is calculated as the blank mean plus 10 standard deviations of the blank.

- matrix-matched double blind sample - A matrix-matched double blind sample contains a concentration of analyte that is known to the supplier but unknown to the analyzing laboratory. The sample matrix has been altered to closely match that of the field samples. The laboratory is unaware that the sample has been spiked.

- method detection limit - The minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero, and is determined from analysis of a sample in a given matrix type containing the analyte.

- minimum detectable activity - The level of activity that is practically achievable by a measurement system.

- precision - The agreement among a set of individual measurements of the same property, usually under prescribed similar conditions. Precision is calculated by using relative percent difference of the duplicate/replicate analyses. These samples should contain concentrations of analyte above the method detection limit and may involve the use of matrix spikes. For ROM and GWSP samples, results from laboratory duplicates, matrix spike duplicates, blind samples, and field duplicates are used to evaluate precision.

- relative percent difference - The relative percent difference is calculated as follows:

$$RPD = \frac{|D_1 - D_2|}{(D_1 + D_2)z} \times 100$$

where D_1 = original sample value
D_2 = duplicate sample value.

- reliable detection level - A detection limit set at two times the concentration of the method detection limit so the risk of both false-positives and false-negatives falls below 1%.

- representativeness - An expression of the degree to which samples represent the actual composition of the groundwater in the aquifer. Representativeness is addressed qualitatively by the specification of well construction, sampling locations, sampling intervals, and sampling and analysis techniques addressed in monitoring plans.

- Type II reagent water - Distilled or deionized water that is free of contaminants that may interfere with the analytical test.

F.2 Sample Collection and Field Quality Control

H. Hampt and B. M. Gillespie

F.2.1 ROM Program

Groundwater-monitoring samples are collected by trained staff according to approved procedures (WHC 1988).

The precision and accuracy of field measurements are gauged through the use of field duplicates and several types of field blanks. Field QC samples can reveal problems with the entire measurement process, from sample collection to laboratory analysis.

The analytical results of field QC samples are considered acceptable if the following evaluation criteria are met.

- field duplicates - Results of field duplicates must have precision within 20%, as measured by the relative percent difference. Only results that can be quantified are evaluated.

- blanks - Three kinds of blanks are used to check for contamination resulting from field activities and/or bottle preparation: full trip, field trip, and equipment blanks. For chemical analyses, results above two times the method detection limit (MDL) are identified as suspected contamination. For common laboratory contaminants such as acetone, methylene chloride, 2-butanone, toluene, and phthalate esters, the limit is set at five times the MDL. For radiochemistry data, blank results are flagged if they are greater than two times the total propagated analytical uncertainty (TPU).

- blind samples - Blind samples are periodically forwarded to the laboratories to evaluate their performance.

If a field QC sample does not meet the established criteria, it is assumed that there are potential problems with the data associated with that sample. Those data are flagged with a Q, as being associated with a QC sample that was out of limits.

Table F.1 provides a summary of the field duplicate and field blank results evaluated for FY 1996 for the ROM Program. The percentages of acceptable field blank and duplicate results in FY 1996 were very high.

Tables F.2 and F.3 summarize the total number of field blanks and field duplicates outside QC limits per method for the ROM Program. Methods not listed in Tables F.2 or F.3 were 100% acceptable for field blanks or field duplicates. Blank results were flagged for volatile organics, inductively coupled-plasma (ICP) metals, total organic halogen (TOX), gross alpha, gross beta, tritium, technetium-99, and total dissolved solids (TDS). The number of flagged ICP metal field blank results increased this fiscal year. The cause of this increase is under investigation. Work is ongoing with the field sampling team to determine if the problem is arising from their water system.

For both methods used for volatile organic analyses, the percentage of methylene chloride blank results indicating potential contamination was ~30%. Methylene chloride is a common laboratory contaminant, and it is not unusual to have such a high number of flagged results.

Duplicate results were flagged for volatile organics, ICP metals, TOX, anions, gross alpha, gross beta, gamma scan, tritium, technetium-99, and gross uranium samples.

F.2.2 GWSP

Samples are collected by trained GWSP staff according to PNNL-approved and documented procedures. Chain-of-custody procedures (EPA 1986a) include the use of evidence tape in sealing sample bottles to maintain the integrity of the samples during shipping. Field QC samples, consisting of full trip blanks and field duplicates, were submitted periodically during field-sampling operations.

Of the 262 full trip blank chemical constituents analyzed for in FY 1996, 33 analyte results were not within control limits (Table F.4). Sample results are considered within control limits if they are less than the MDL. In most cases, the MDL is well below one-half of the drinking water standards. A GWSP data quality objective is that the MDL must be less than one-half the maximum contaminant level (MCL). In most cases, the MDL was considerably below the MCL, so results from trip blanks that were not within control limits do not have a significant impact on the quality of the data.

Of the 67 full trip blank radiochemical constituents reported for in FY 1996, 4 analyte results were not within the control limits (Table F.5). Sample results are considered within control limits if they are below the TPU.

Only 6 (2%) of the 307 duplicate field results were not within the control limits. These were one bromide, two manganese, one iron, and two potassium-40 results. Duplicate sample results are considered within control limits if they are above five times the MDL (or TPU for radiochemical analyses) and are within ±20% (relative percent difference) and/or if they are between the MDL/TPU and five times the MDL/TPU and the duplicate results agree within plus/minus the MDL/TPU.

F.3 Holding Times

B. M. Gillespie and H. Hampt

Chemical constituent concentrations in groundwater samples are required to be determined within a specified time frame, or holding time, from the time of collection to the time of analysis or preparation. Samples must be analyzed within this time frame or the concentration of the constituents of concern may, in some instances, be compromised by decomposition or chemical change. Samples are also refrigerated to slow the chemical changes within the sample matrix. For approved testing methods (EPA 1986b), the holding time is 14 days for volatile organics analysis, 7 days before extraction and 40 days after extraction for semivolatile organics analysis, 14 days for cyanide analysis, and 6 months for ICP (spectroscopy) analysis of metals. As required by American Society for Testing and Materials (ASTM 1986) and O'Dell et al. (1984) methodologies, holding times are 48 hours for the determination of nitrate, nitrite, and phosphate and 28 days for the determination of chloride, bromide, fluoride, sulfate, and ammonium. There is no designated holding time for radiochemical constituents because they do not change chemically or decompose under ambient temperatures. Results of radionuclide analysis are corrected for decay between sampling and analysis date.

Of the 672 nonradiochemical analysis tests conducted specifically for the GWSP in FY 1996, no holding times were determined to have been violated.

Of the 31,595 nonradiochemical analysis tests conducted for the ROM Program, 85 holding times were violated in FY 1996. Less than 0.3% of holding times were violated, which is very good. Data for which holding times were violated were flagged with an H.

F.4 Analytical Results

H. Hampt, B. M. Gillespie, C. J. Chou, and T. X. Washington

Routine analyses of hazardous and nonhazardous chemicals for ROM and GWSP were performed by DataChem Laboratories, Inc., Salt Lake City, Utah (DataChem). For ROM samples, however, transition occurred from DataChem to Quanterra Environmental Services, St. Louis, Missouri (Quanterra) in July 1996. Beginning with FY 1997 with the combination of the GWSP and ROM programs into one sitewide groundwater-monitoring program, all samples will be forwarded to Quanterra for routine hazardous and nonhazardous chemicals analyses.

Both laboratories participate in the EPA's Water Pollution (WP) and Water Supply (WS) Performance Evaluation Studies and maintain internal QC programs that meet the requirements of EPA (1986a). QC blind spiked samples are also submitted for analysis to both laboratories.

Routine radiochemical analyses were performed by Quanterra, who participates in DOE's Quality Assessment Program and EPA's Environmental Monitoring and Support Laboratory Intercomparison Studies and maintains an internal QC program. QC blind spiked samples are also submitted.

Routine hazardous and nonhazardous chemical and radiochemical analyses of samples for the Environmental Restoration Contractor were performed at Quanterra in Richland, Washington, and in St. Louis, Missouri, and/or at Lockheed Analytical Services, Las Vegas, Nevada (Lockheed). Lockheed and Quanterra also participate in DOE's Quality Assessment Program, EPA's Environmental Monitoring and Support Laboratory Intercomparison Studies, and the EPA's WP/WS programs.

F.4.1 EPA/DOE Studies

F.4.1.1 EPA WP/WS Studies

Every quarter the contracted laboratories report their results from the EPA WP/WS studies. The EPA distributes standard water samples as blind samples to participating laboratories. These samples contain specific organic and inorganic analytes at concentrations unknown to the participating laboratories. After analysis, results are submitted to the EPA. Regression equations are used to determine acceptance and warning limits. The results of these studies independently verify the level of laboratory performance and are expressed as a percentage of EPA-acceptable results. Results from the EPA WP/WS studies are summarized in Table F.6; results from DataChem and Quanterra are included. The percentage of EPA-acceptable results was high for both laboratories, indicating excellent performance by both for the samples analyzed.

F.4.1.2 EPA CRD-LV and DOE EML

Routine GWSP radiochemical analyses were performed under contract with Quanterra, Richland, Washington. Quanterra participates in DOE's Quality Assessment Program, Environmental Measurements Laboratory, New York, New York (DOE EML) and EPA's Laboratory Intercomparison

Studies, National Exposure Research Laboratory, Characterization Research Division, Las Vegas, Nevada (EPA CRD-LV). Routine radiochemical analyses of CERCLA samples are performed under contract with Quanterra, Richland, Washington, and Lockheed.

Quanterra and Lockheed participate in DOE's Quality Assessment Program and EPA's Laboratory Intercomparison Studies. These programs provide standard samples containing specific amounts of one or more radionuclides that are unknown to the participating laboratory. After sample analysis, the results are forwarded to DOE or EPA for comparison with known values and with results from other laboratories. Both EPA and DOE evaluate the accuracy of results by determining if results fall within ± 3 standard deviations of the mean of all results reported in the intercomparison study (Jarvis and Siu 1981; Sanderson and Greenlaw 1996a, 1996b). Summaries of FY 1996 results for water samples for the various programs are provided in Tables F.7, F.8, F.9, and F.10. Approximately 95% of the analyses conducted during the fiscal year were within the ± 3 standard deviations of the mean. This reflects good performance on the samples analyzed.

F.4.2 Laboratory Internal QA Programs

Both DataChem and Quanterra maintain internal QA/QC programs. Laboratory activities are regularly assessed by surveillance and auditing processes to ensure that quality problems are prevented and/or detected. Regular assessment supports continuous process improvement.

F.4.2.1 Hazardous/Nonhazardous Chemical Laboratories

Every quarter DataChem supplies their QC reports in the form of precision and accuracy, including results on matrix spikes, matrix duplicates, matrix spike duplicates, and blanks. Quanterra supplies an electronic table of all QC results each month. Precision and accuracy information are obtained from these reports.

The results from the DataChem report indicate that their QC program functioned adequately overall throughout FY 1996. The results from the third quarter of calendar year 1996 for Quanterra were also adequate. Only third quarter results were considered because prior to that time period, Quanterra did not analyze samples for ROM or GWSP.

F.4.2.2 Radiochemical Laboratory

The Quanterra internal QC program involves routine calibrations of counting instruments, yield determinations of radiochemical procedures, frequent radiation check source and background counts, replicate and spiked sample analyses, use of matrix and reagent blanks, and maintenance of control charts to indicate analytical deficiencies. Available calibration standards traceable to the National Institute of Standards and Technology were used for radiochemical calibrations.

The results of the internal laboratory QC programs are summarized by the laboratory in quarterly reports. The results of the QC sample summary reports and the observations noted by each laboratory indicated an acceptably functioning QC program.

F.4.3 Nonconformance Reports and Incident Reports

Nonconformance reports and incident reports are methods of documentation of any problems encountered with the analysis, data, and/or data deliverable. Nonconformance and incident reports are generated by the laboratory or the field sampling team. This documentation is intended to identify occurrences, deficiencies, and/or issues that may potentially have an adverse effect on the data integrity. These may include, but are not limited to, the following:

- lost sample
- broken bottles
- instrument malfunctions
- calibration standards out of acceptable range
- laboratory control standards out of acceptable range
- matrix spike recovery out of acceptable range
- blank contamination
- procedural noncompliance
- chain-of-custody discrepancies
- shipping temperatures out of acceptable range
- misreported data.

Nonconformance and incident reports were reviewed by ROM or the GWSP. Appropriate personnel were notified of potential data problems and data were flagged as appropriate. Instructions for ROM personnel who reviewed these reports are available in WHC (1992). During the FY 1996 reporting period, there were 27 nonconformance and incident reports affecting 188 data points, which indicates the types of problems listed above were minimal.

F.4.4 Double Blind Standard Evaluation

The ROM Program forwarded double blind standards to DataChem and Quanterra in December 1995 and March 1996. TOX standards at four levels of concentration were forwarded to DataChem, Quanterra, and an additional comparison laboratory in December 1995 and March 1996. Anion standards at three levels of concentration were forwarded to DataChem and a comparison laboratory in March 1996. The TOX standards were spiked with 2,4,6-trichlorophenol. The anion standards were spiked with fluoride, chloride, nitrate, phosphate, and sulfate. The results are summarized in Tables F.11 and F.12.

The TOX results were expected to be within $\pm 25\%$ of the spike level. For high-level standards, the relative percent difference was expected to be within $\pm 20\%$. Prior to April 1996, DataChem TOX recoveries of blind standards were low. After the results were analyzed from the December set of samples, the ROM Program worked with DataChem to improve their TOX recoveries. The DataChem standard operating procedure was modified to improve instrument calibration. The March sample set results showed an improvement (see Table F.12). Subsequent to the March results, the DataChem contract administrator forwarded a letter to the ROM Program indicating that TOX data from May 1995 to

April 15, 1996 may be biased low. Program scientists performed a TOX data review to check whether the analyzed data were impacted. Based on this review, several data points were flagged as suspect but the majority appeared to be acceptable.

Anion results from both DataChem and the comparison laboratory were within the expected recovery range of ±25%. The results from both laboratories were satisfactory.

The GWSP, in addition to the DOE and EPA interlaboratory QC programs, evaluates its analytical laboratories' precision and accuracy and conducts special intercomparisons. This includes the use of blind spiked QC samples and replicate samples. Blind spiked samples and blanks were prepared in triplicate and submitted to check the accuracy and precision of analyses at DataChem and Quanterra. Overall, 89% of the blind spike determinations were within control limits (Table F.13). This reflects acceptable performance on the samples analyzed.

F.4.5 Completeness and Comparability of ROM Program Data

For FY 1996, 94% of the data was considered complete. Flags were assigned for QC problems, violated holding times, rejected data, suspect data, and laboratory blank contamination. To evaluate comparability of data between different laboratories, samples were split in the field and forwarded to several laboratories for analysis. Procedures from both of the hazardous/nonhazardous chemical laboratories were compared to determine if the procedures were based on the same reference methods (e.g., EPA 1986b).

F.4.6 Interlaboratory Comparison Study

An interlaboratory comparison study was conducted in FY 1996 for the ROM Program to evaluate the comparability of data between the primary laboratories used in FY 1996 and the laboratories under consideration for use in FY 1997. Three laboratories were used for each comparison. Datachem, Quanterra, and the Waste Sampling and Characterization Facility (WSCF) were used for chemical methods. Quanterra, Lockheed, and WSCF analyzed radiochemical samples. The methods considered for this study were ICP metals, volatile organics, TOX, total organic carbon (TOC), gross alpha, gross beta, and tritium. The constituents of interest were chromium, carbon tetrachloride, chloroform, trichloroethene, TOX, TOC, gross alpha, gross beta, and tritium. For each method considered, three pairs of samples were collected in duplicate from one to three wells and were sent to each of the participating laboratories. Each sample was analyzed twice in the laboratory.

The data-evaluation methods are analysis of variance and Duncan's multiple range comparison procedure, as described in Bowen and Bennett (1988).

Results were evaluated from three wells for carbon tetrachloride, TOX, gross alpha, gross beta, and tritium. Results were evaluated from two wells for chromium and chloroform and one well each for TOC and trichloroethene.

The study results indicated that the three laboratories are comparable for TOC and chromium. For two of the three sets of TOX samples, the results were not comparable. The cause of the differences is being investigated, and the wells in question will be resampled and resubmitted to the laboratories for additional analysis. The results from the third set of TOX data were acceptable. The results for the volatile organics are still being evaluated. Raw data must be requested from two of the laboratories to complete the evalauation.

All three sets of gross beta results were not comparable. Two of the gross alpha sets and one of the tritium sets were also not comparable. The remaining gross alpha and tritium results were acceptable. The differences with the radiochemical results are also under investigation.

The results of the interlaboratory comparison study show that for certain methods the laboratories are comparable. Further investigation is required before more specific conclusions can be drawn from the results that were not comparable.

F.5 Limit of Detection, Limit of Quantitation, and Method Detection Limit

C. J. Chou, H. Hampt, and T. X. Washington

Detection and quantitation limits are essential in evaluating data quality and usefulness because they provide the limits of a method's measurement. The detection limit is the lower limit at which a measurement can be differentiated from background. The quantitation limit is the lower limit where a measurement becomes quantifiably meaningful. The limit of detection (LOD), limit of quantitation (LOQ), and MDL are useful for evaluating groundwater data.

The LOD is defined as the lowest concentration level that is statistically different from a blank (Currie 1988). The concentration at which an analyte can be detected depends on the variability of the blank response. For the purpose of this discussion, the blank is taken to be a method blank.

In general, the LOD is calculated as the mean concentration in the blank plus three standard deviations of that concentration (EPA 1987). The blank-corrected LOD is simply three times the blank standard deviation. At three standard deviations from the blank mean, the false-positive and the false-negative error rates are each ~7% (Miller and Miller 1988). A false-positive error is an instance when an analyte is declared to be present but is, in fact, absent. A false-negative error is an instance when an analyte is declared to be absent but is, in fact, present.

The limit of detection for a radionuclide is typically computed from the counting error associated with each reported result (e.g., Watson 1980) and represents instrumental or background conditions at the time of analysis. In contrast, the LOD and LOQ for the radionuclides shown in Table F.15 are based on variability resulting from both counting error and uncertainties introduced by sample handling. In the latter case, a sample of distilled water (submitted as a sample) is processed as if it were an

actual sample. Thus, any random cross contamination of the blank during sample processing will be included in the overall error. Thus, the values shown in Table F.15 are most useful for assessing long-term variability in the overall process.

The LOQ is defined as the level above which quantitative results may be obtained with a specified degree of confidence (Keith 1991). The LOQ is calculated as the blank mean plus 10 standard deviations of the blank (EPA 1987). The blank-corrected LOQ is simply 10 times the blank standard deviation. The LOQ is most useful for defining the lower limit of the useful range of concentration measurement technology. When the analyte signal is 10 times larger than the standard deviation of the blank measurements, there is a 95% probability that the true concentration of the analyte is $\pm$25% of the measured concentration. The LOD and LOQ are shown graphically in Figure F.1. For purposes of illustration, the numbers appearing in this figure are the respective blank mean, LOD, and LOQ for TOC and TOX (Table F.14).

The MDL is defined as the minimum concentration of a substance that can be measured and reported with a 99% confidence that the analyte concentration is greater than zero. The MDL is determined from analysis of a sample in a given matrix containing the analyte (Currie 1988). The MDL is 3.14 times the standard deviation of the results of 7 replicates of a low-level standard. Note that the MDL, as defined above, is based on the variability of the response of low-level standards rather than on the variability of the blank response.

For this report, TOC, TOX, and radionuclide field blank data are available for LOD and LOQ determinations. The field blanks are QC samples that are introduced into a process to monitor the performance of the system. The use of field blanks to calculate LOD and LOQ is preferred over the use of laboratory blanks because field blanks provide a measure of the errors in the entire sampling and analysis system. Methods to calculate LOD and LOQ are described in detail in DOE (Appendix A of DOE 1991b). Only TOC and TOX blanks analyzed by DataChem were used in the LOD/LOQ determination. Blanks analyzed by Quanterra in August and September 1996 are not included. The results of the LOD and LOQ determinations are shown in Table F.15.

Because of the lack of blanks data for other constitutes of concern, it was deemed necessary to calculate approximated LOD and LOQ values using variability information obtained from low-level standards. As shown in Figure F.1, the values along the horizontal axis are measured in units of standard deviation of the measurement process (i.e., based on a well-known blank). If low-level standards are used, the variability of the difference between the sample and blank response is increased by a factor of $\sqrt{2}$ (Currie 1988, p. 84). The formulas are summarized below:

$$MDL = 3.14 \times s$$

$$LOD = 3 \times (\sqrt{2} \times s)$$
$$= 4.24 \times s$$

$$LOQ = 10 \times (\sqrt{2} \times s)$$
$$= 14.14 \times s$$

where s = standard deviation from the seven replicates of the low-level standard.

The results of MDL, LOD, and LOQ calculations for other constituents of concern are shown in Table F.16.

F.6 References

American Society for Testing and Materials (ASTM). 1986. *Annual Book of ASTM Standards*. Philadelphia, Pennsylvania.

Bowen, W. M., and C. A. Bennett. 1988. *Statistical Methods for Nuclear Material Management*. NUREG/CR-4604, U.S. Nuclear Regulatory Commission, Washington, D.C., pp. 256-309.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, Public Law 96-510, 94 Stat. 2767, 42 USC 9601 et seq.

Currie, L. A. (ed.). 1988. *Detection in Analytical Chemistry: Importance, Theory, and Practice*, ACS Symposium Series 361, American Chemical Society, Washington, D.C., pp. 17, 79-92.

DOE (see U.S. Department of Energy)

EPA (see U.S. Environmental Protection Agency)

Jarvis, A. B., and L. Siu. 1981. *Environmental Radioactivity Laboratory Intercomparison Studies Program: Fiscal Year 1980-81*. EPA-600/4-81-004, U.S. Environmental Protection Agency, Las Vegas, Nevada.

Keith, L. H. 1991. *Environmental Sampling and Analysis: A Practical Guide*. Lewis Publishers, CRC Press, Inc., Boca Raton, Florida, pp. 93-115.

Miller, J. C., and J. N. Miller. 1988. *Statistics for Analytical Chemistry, Second Edition*. Ellis Horwood Limited, Chichester, England, pp. 115-116.

Mitchell, W. J., R. C. Rhodes, and F. F. McElroy. 1985. "Determination of Measurement Data Quality and Establishment of Achievable Goals for Environmental Measurements." *Quality Assurance for Environmental Measurements, ASTM STP 867*. J. K. Taylor and T. W. Stanley (eds.), American Society for Testing and Materials, Philadelphia, Pennsylvania, pp. 41-52.

O'Dell, J. W., J. D. Pfaff, M. E. Gales, and G. D. McKee. 1984. *Test Method: The Determination of Inorganic Anions in Water by Ion Chromatography - Method 300.0*. EPA-600/4-84-017, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Resource Conservation and Recovery Act of 1976, as amended, Public Law 94-580, 90 Stat 2795, 42 USC 6901 et seq.

Sanderson, C. G., and P. Greenlaw. 1996a. *Semi-Annual Report of the Department of Energy, Office of Environmental Management, Quality Assessment Program.* EML-565, Environmental Measurements Laboratory, U.S. Department of Energy, New York.

Sanderson, C. G., and P. Greenlaw. 1996b. *Semi-Annual Report of the Department of Energy, Office of Environmental Management, Quality Assessment Program.* EML-576. Environmental Measurements Laboratory, U.S. Department of Energy, New York.

U.S. Department of Energy (DOE). 1991a. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-2 Operable Unit, Hanford Site, Richland, Washington.* DOE/RL-91-46, Draft A, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1991b. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1990.* DOE/RL-91-03, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992a. *Annual Report for RCRA Groundwater Monitoring Projects at Hanford Site Facilities for 1991.* DOE/RL-92-03, prepared by Geosciences Group, Westinghouse Hanford Company for Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992b. *Remedial Investigation/Feasibility Study Work Plan for 100-BC-5 Operable Unit, Hanford Site, Richland, Washington.* DOE/RL-90-08, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992c. *Remedial Investigation/Feasibility Study Work Plan for 100-FR-3 Operable Unit, Hanford Site, Richland, Washington.* DOE/RL-91-53, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992d. *Remedial Investigation/Feasibility Study Work Plan for 100-KR-4 Operable Unit, Hanford Site, Richland, Washington.* DOE/RL-90-21, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1992e. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-HR-3 Operable Unit, Hanford Site, Richland, Washington.* DOE/RL-88-36, Rev. 0, Richland Field Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996a. *Interim Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units, DOE/RL-96-90, Draft A.* Richland Operations Office, Richland, Washington.

U.S. Department of Energy (DOE). 1996b. *RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-2 Operable Unit Hanford Site, Richland, Washington, Rev. 0*, DOE/RL-91-46, Richland Operations Office, Richland, Washington.

U.S. Environmental Protection Agency (EPA). 1986a. *Resource Conservation and Recovery Act (RCRA) Groundwater Monitoring Technical Enforcement Guidance Document*. OWSER-9950.1, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1986b. *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, 3rd ed.* SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. Environmental Protection Agency (EPA). 1987. *A Compendium of Superfund Field Operations Methods*. EPA/540/P-87/001, OWSER 9355.0-14, Washington, D.C., pp. 16-3 to 16-5.

Watson, J. E. 1980. *Upgrading Environmental Radiation Data. Health Physics Report HPSR-1 (1980)*. EPA 520/1-80-012, Office of Radiation Programs, U.S. Environmental Protection Agency, Washington, D.C.

Westinghouse Hanford Company (WHC). 1988. *Environmental Investigations and Site Characterization Manual*. WHC-CM-7-7, Vol. 1, Richland, Washington.

Westinghouse Hanford Company (WHC). 1992. *Environmental Activities*. WHC-CM-7-8, Richland, Washington.

Westinghouse Hanford Company (WHC). 1995. *Quality Assurance Project Plan for RCRA Groundwater Monitoring Activities*. WHC-SD-EN-QAPP-001, Rev. 3, Richland, Washington.

Table F.1. Summary of ROM Program FY 1996 QC Sample Results

Quarter	Field Duplicates, % acceptable	Field Blanks, % acceptable
October - December 1995	96.4	94.9
January - March 1996	99.2	97.0
April - June 1996	98.9	97.7
July - September 1996	99.1	94.3

Table F.2. Field Blanks Exceeding QC Limits in FY 1996 for ROM Program Samples

Method Name	Constituent	Total Analyses	Q Flags	% Out of Limits
SW-846 8010/8020	Methylene Chloride	15	5	33
SW-846 8260	Chloroform	47	12	26
SW-846 8260	Methylene Chloride	47	14	30
SW-846 8260	Tetrachloroethene	47	1	2
SW-846 8260	Toluene	47	1	2
SW-846 6010	Aluminum	28	1	4
SW-846 6010	Barium	28	1	4
SW-846 6010	Cadmium	28	1	4
SW-846 6010	Calcium	28	5	18
SW-846 6010	Cobalt	28	1	4
SW-846 6010	Copper	28	1	4
SW-846 6010	Iron	28	10	36
SW-846 6010	Magnesium	28	3	11
SW-846 6010	Manganese	28	4	14
SW-846 6010	Nickel	28	1	4
SW-846 6010	Potassium	28	4	14
SW-846 6010	Sodium	28	26	93
SW-846 6010	Strontium	28	7	25
SW-846 6010	Tin	28	1	4
SW-846 6010	Vanadium	28	1	4
SW-846 6010	Zinc	28	1	4
SW-846 9020	TOX	97	4	4
SW-846 7470/7471	Mercury	8	1	13
EPA 160.1/SM 209B	TDS	10	1	10
SW-846 9310	Gross Alpha	38	1	3
SW-846 9310	Gross Beta	38	1	3
ITAS H-3	Tritium	33	1	3
ITAS Tc-99	Technetium-99	14	1	7

Table F.3. Field Duplicates Exceeding QC Limits in FY 1996 for ROM Program Samples

Method Name	Constituent	Total Analyses	Q Flags	% Out of Limits
SW-846 8010/8020	Chloroform	6	2	33
SW-846 6010	Calcium	29	1	3
SW-846 6010	Chromium	29	1	3
SW-846 6010	Iron	29	1	3
SW-846 6010	Magnesium	29	1	3
SW-846 6010	Sodium	29	1	3
SW-846 6010	Strontium	29	1	3
SW-846 6010	Vanadium	29	1	3
ASTM D 4327-88/EPA 300.0	Chloride	31	1	3
ASTM D 4327-88/EPA 300.0	Nitrate	31	1	3
ASTM D 4327-88/EPA 300.0	Sulfate	31	1	3
SW-846 9020	TOX	54	2	4
SW-846 9310	Gross Alpha	32	2	6
SW-846 9310	Gross Beta	33	1	3
ITAS Gamma Scan	Potassium-40	7	1	14
ITAS H-3	Tritium	29	1	3
ITAS Tc-99	Technetium-99	15	2	13
ITAS-U	Uranium	8	1	13

Table F.4. Summary of FY 1996 GWSP Chemical Constituents not Within Blank Control Limits[a]

Constituent[b]	Result, µg/L	MDL, µg/L	One-Half MCL,[c] µg/L
Aluminum	38	31	100[c]
Cobalt	15	5.3	NA
Copper	2.4	2.1	500[c]
Copper	3.7	2.1	500[c]
Copper	20	8.7	500[c]
Magnesium	27	26	NA
Magnesium	27	26	NA
Manganese	0.61	0.55	25[c]
Manganese	0.59	0.55	25[c]
Tin	44	30	NA
Zinc	3.9	3.7	2,500[c]
Nickel	11	7.4	50
Potassium	240	18	NA
Iron	12	8.9	150[c]
Iron	79	8.9	150[c]
Bromide	99	72	NA
Chloride	120	110	125,000[c]
Fluoride	69	23	1,000
Nitrate	290	18	22,500
Nitrate	200	120	22,500
Nitrate	69	18	22,500
Nitrate	23	18	22,500
Nitrate	140	18	22,500
Phosphate	780	83	NA
Sulfate	71	21	125,000[c]
Carbon tetrachloride	1	0.05	2.5
Methylene chloride	0.1	0.1	NA
Chloroform	0.27	0.07	50

(a) Control limits = less than method detection limit (MDL).
(b) Five sodium results above MDL not listed.
(c) Secondary maximum contaminant level (MCL).
NA = Not applicable.

Table F.5. Summary of FY 1996 GWSP Radiochemical Constituents not Within Blank Control Limits[a]

Constituent	Results, pCi/L	2-Sigma TPU[b]	One-Half MCL,[c] pCi/L
^{60}Co	1.41	1.14	50[c]
^{99}Tc	2.628	2.414	450[c]
Tritium	63.4	10.7	1,000[d]
Tritium	85.1	12.5	1,000[d]

(a) Control limits = less than method detection limit (MDL).
(b) Total propagated analytical uncertainty (TPU).
(c) One-half the derived 4-mrem dose requirement.
(d) Reportable limit set for early-warning limit and/or to better determine plume edge.

Table F.6. EPA Water Pollution/Water Supply Study Results

Laboratory	WS036 January 1996 % Acceptable	WP035 April 1996 % Acceptable	WS037 September 1996 % Acceptable
DataChem	94.9[a]	100	93.8[b]
QES	98.3[c]	97.3[d]	95.2[e]

(a) Unacceptable results were for 1-1, dichloroethylene, 1-2-dibromo-3-chloropropane, ethylenedibromide, 1,1,2-trichloroethane, 1,2,3-trichloropropane.
(b) Unacceptable results were for nitrate as N, dieldrin, vinyl chloride, tetrachloroethylene.
(c) Unacceptable result for molybdenum.
(d) Unacceptable results were for aroclor 1016/1242(PCB), aroclor 1248(PCB), PCB in oil, chlordane.
(e) Unacceptable results were for 1,1-dichloroethylene, 1,2,3-trichloropropane, and sulfate.

Table F.7. Summary of Quanterra Performance on DOE Quality Assessment ROM Program Samples, FY 1996

Radionuclides	Number of Results Reported for Each	Number Within Acceptable Control Limits[a]
Gross alpha, gross beta, tritium, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am	2	2
^{54}Mn, ^{60}Co, total uranium	2	1

(a) Control limits from Sanderson and Greenlaw (1996a) and Sanderson and Greenlaw (1996b).

Table F.8. Summary of Lockheed Performance on DOE Quality Assessment CERCLA Program Samples, FY 1996

Radionuclides	Number of Results Reported for Each	Number Within Acceptable Control Limits[a]
Gross alpha, tritium, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	2	2
Gross beta, ^{54}Mn	2	1

(a) Control limits from Sanderson and Greenlaw (1996a) and Sanderson and Greenlaw (1996b).

Table F.9. Summary of Quanterra Performance on EPA Intercomparison Program Samples, FY 1996

Radionuclides	Number of Results Reported for Each	Number Within Control Limits[a]
Tritium, ^{65}Zn, ^{131}I, ^{133}Ba	2	2
^{226}Ra,total uranium	3	3
^{228}Ra	3	2
^{60}Co, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs	4	4
Total alpha, total beta	5	5

(a) Control limits from Jarvis and Siu (1981).

Table F.10. Summary of Lockheed Performance on EPA Intercomparison Program Samples, FY 1996

Radionuclides	Number of Results Reported for Each	Number Within Control Limits[a]
^{131}I	1	1
Tritium, ^{65}Zn, ^{133}Ba	2	2
^{226}Ra, ^{228}Ra, total uranium	3	3
Total beta, ^{60}Co, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs	4	4
Total alpha	4	3

(a) Control limits from Jarvis and Siu (1981).

Table F.11. Summary ROM Program Double Blind TOX Sample Results, FY 1996

Date	Concentration	DataChem Recovery, %	Quanterra Recovery, %	Comparison Laboratory Recovery, %
December 1995	10	100.5	105[a]	107.9
December 1995	100	73	73[a]	104
December 1995	1,000	82	97[a]	94
December 1995	5,000	59	100[a]	102
March 1996	20.2	138.9	116.3	109.9
March 1996	80.8	110.1	84.8	102.6
March 1996	202	108.2	86.6	100.6
March 1996	1,077	108.6	95.6	94.5

(a) Samples analyzed by the Richland, Washington laboratory.

Table F.12. Summary of ROM Program Double Blind Anion Sample Results, FY 1996

Date	Analyte	Standard Concentration, µg/L	DataChem Recovery, %	Comparison Laboratory Recovery, %
March 1996	Chloride	750	89	105
March 1996	Fluoride	500	102	96
March 1996	Nitrate (as N)	5,000	100	96
March 1996	Sulfate	5,000	100	100
March 1996	Chloride	7,500	96	108
March 1996	Fluoride	5,000	108	100
March 1996	Nitrate (as N)	50,000	100	98
March 1996	Sulfate	50,000	100	106
March 1996	Chloride	15,000	93	104
March 1996	Fluoride	10,000	100	96
March 1996	Nitrate (as N)	100,000	99	102
March 1996	Sulfate	100,000	99	97

Table F.13. Summary of GWSP Quarterly Double Blind Spike Determinations, FY 1996

Constituent	Number of Results Reported[a]	Number Within ±30% Relative Percent Difference
Tritium	12	12
Cobalt-60	12	12
Strontium-90	12	12
Technetium-99	12	7
Iodine-129	12	11
Cesium-137	12	12
Plutonium-239	12	8
Total uranium	12	11
Cyanide	12	11
Chromium	12	12
Nitrate	12	12
Fluoride	12	9
Carbon tetrachloride	12	7
Chloroform	12	12
Trichloroethylene	12	12

(a) Blind samples were submitted in triplicate each quarter and compared to actual spike values.

Table F.14. Summary of DataChem Groundwater Field Blanks Data

Period	Number of Samples	Mean, µg/L	Standard Deviation, µg/L	LOD,[(a)] µg/L	LOQ,[(a)] µg/L
Constituent: Total Organic Carbon Method Code: 122					
10/27/95 - 12/19/95	22	78.7	54.5	242	624
01/05/96 - 03/12/96	22	89.8	34.4	193	434
04/11/96 - 06/21/96	18	82.0	35.5	189	437
07/11/96 - 08/14/96	9	105.8	50.5	257	611
Summary	71	86.4	43.9	218	525
Constituent: Total Organic Halogen Method Code: 67					
10/27/95 - 12/01/95	20	0.55	1.54	4.6	15.4
01/04/96 - 03/23/96	18	1.10	2.00	6.0	20.0
06/06/96 - 06/27/96	18	-0.42	1.39	4.2	13.9
07/29/96 - 07/29/96	4	-0.61	0.57	1.7	5.7
Summary	60	0.34	1.62	4.9	16.2

(a) LOD (blank corrected) equals the mean blank concentration plus 3 standard deviations; LOQ (blank corrected) equals the mean blank concentration plus 10 standard deviations.

Table F.15. Summary of International Technologies Groundwater Field Blanks Data

Period	Number of Samples	Mean, pCi/L	Standard Deviation, pCi/L	LOD,[a] pCi/L	LOQ,[a] pCi/L
Constituent: Cesium-137 Method Code: 140					
11/19/95 - 09/05/96	7	0.126	0.744	2.23	7.44
Constituent: Cesium-134 Method Code: 140					
11/19/95 - 09/05/96	6	-0.873	0.624	1.87	6.24
Constituent: Cobalt-60 Method Code: 140					
11/19/95 - 09/05/96	7	-0.048	1.091	3.27	10.91
Constituent: Europium-154 Method Code: 140					
11/19/95 - 09/05/96	6	-0.409	1.743	5.23	17.43
Constituent: Gross Alpha Method Code: 135					
10/18/95 - 12/20/95	8	0.040	0.253	0.76	2.53
01/16/96 - 03/13/96	10	-0.053	0.105	0.32	1.05
04/08/96 - 06/21/96	10	-0.138	0.117	0.35	1.17
07/25/96 - 08/15/96	3	-0.063	0.152	0.46	1.52
Summary	31	-0.057	0.163	0.49	1.63
Constituent: Gross Beta Method Code: 136					
10/18/95 - 12/20/95	9	0.318	1.151	3.45	11.51
10/04/96 - 03/13/96	10[b]	-0.421	1.049	3.15	10.49
04/08/96 - 06/21/96	9[b]	-0.159	0.949	2.85	9.49
07/25/96 - 08/15/96	2[b]	0.068	0.735	2.20	7.35
Summary	30	-0.088	1.042	3.13	10.42
Constituent: Iodine-129 Method Code: 138					
03/16/96 - 06/21/96	3	-0.595	2.135	6.40	21.35

Table F.15. (contd)

Period	Number of Samples	Mean, pCi/L	Standard Deviation, pCi/L	LOD,[a] pCi/L	LOQ,[a] pCi/L
Constituent: Iodine-129 (Low Level) Method Code: 139					
01/04/96 - 09/05/96	6	0.008	0.162	0.49	1.62
Constituent: Strontium-90 Method Code: 141					
12/11/95 - 04/25/96	7	-0.027	0.105	0.32	1.05
Constituent: Technetium-99 Method Code: 143					
11/29/95 - 12/04/95	2	0.871	0.198	0.59	1.98
01/04/96 - 03/13/96	5	-0.242	0.439	1.32	4.39
04/01/96 - 06/21/96	4[b]	0.199	0.822	2.46	8.22
07/01/96 - 09/05/96	3	1.215	1.377	4.13	13.78
Summary	14	0.355	0.81	2.44	8.14
Constituent: Tritium Method Code: 142					
10/18/95 - 12/20/95	8	141.67	188.27	564.8	1,882.7
01/04/96 - 03/21/96	11	47.92	64.49	193.5	644.9
04/18/96 - 06/21/96	11	63.48	109.09	327.3	1,090.9
07/01/96 - 09/05/96	4	90.91	75.42	226.3	1,191.3
Summary	34	80.07	119.13	357.4	1,191.3
Constituent: Uranium, μg/L Method Code: 145					
10/23/95 - 12/04/95	5	-0.018	0.018	0.055	0.185
02/28/96 - 03/04/96	3	-0.100	0.020	0.060	0.199
04/01/96 - 06/11/96	5	-0.103	0.022	0.066	0.219
Summary	13	-0.070	0.021	0.064	0.213

(a) LOD (blank corrected) equals the mean blank concentration plus 3 standard deviations; LOQ (blank corrected) equals the mean blank concentration plus 10 standard deviations.
(b) Excluded outlier.

Table F.16. Calculations (μg/L) for Selected Constituents[a]

Method Name	Constituent Name	MDL	LOD	LOQ
ASTM, Ammonium	Ammonium ion	16	22	72
ASTM, Hydrazine	Hydrazine	0.79	1.1	3.6
Chemical Oxygen Demand	Chemical Oxygen Demand	2.8	3.8	13
EPA 600, Alkalinity	Alkalinity	2800	3800	13000
EPA SW-846, Arsenic	Arsenic	0.82	1.1	3.7
EPA SW-846, Coliform 9132	Coliform Bacteria	1.0	1.4	4.5
EPA SW-846, Cyanide	Cyanide	2.4	3.2	11
EPA SW-846, Herbicides	2,4,5-T	0.011	0.015	0.050
	2,4,5-TP	0.046	0.062	0.21
	2,4-Dichlorophenoxyacetic acid	0.043	0.058	0.19
	2-secButyl-4,6-dinitrophenol(DNBP)	0.11	0.15	0.50
EPA SW-846, ICP Metals	Aluminum	15	20	68
	Antimony	43	58	190
	Arsenic	2.6	3.5	12
	Barium	0.80	1.1	3.6
	Beryllium	0.20	0.27	0.90
	Boron	15	20	68
	Cadmium	3.2	4.3	14
	Calcium	44	59	200
	Chromium	1.8	2.4	8.1
	Cobalt	5.0	6.8	23
	Copper	8.7	12	39
	Iron	13	18	59
	Lead	1.7	2.3	7.7
	Magnesium	24	32	110
	Manganese	0.29	0.39	1.3
	Nickel	7.4	10	33
	Potassium	18	24	81
	Selenium	3.8	5.1	17
	Silicon	66	89	300
	Silver	4.5	6.1	20
	Sodium	37	50	170
	Strontium (elemental)	0.15	0.20	0.68
	Thallium	3.7	5.0	17
	Tin	17	23	77
	Vanadium	1.7	2.3	7.7
	Zinc	7.7	10	35
EPA SW-846, Lead	Lead	1.1	1.5	5.0
EPA SW-846, Mercury	Mercury	0.047	0.064	0.21
EPA SW-846, Pesticides	Disulfoton	2.0	2.7	9.0
	Methyl parathion	0.33	0.45	1.5
	Phorate	0.45	0.61	2.0
EPA SW-846, Pesticides/PCBs	4,4'-DDD	0.0030	0.0041	0.014
	4,4'-DDE	0.0023	0.0031	0.010
	4,4'-DDT	0.0019	0.0026	0.0086
	Aldrin	0.0016	0.0022	0.0072
	Alpha-BHC	0.0011	0.0015	0.0050

Table F.16. (contd)

Method Name	Constituent Name	MDL	LOD	LOQ
EPA SW-846, Pesticides/PCBs	Aroclor-1016	0.041	0.055	0.18
	Aroclor-1221	0.22	0.30	0.99
	Aroclor-1232	0.15	0.20	0.68
	Aroclor-1242	0.067	0.09	0.30
	Aroclor-1248	0.029	0.039	0.13
	Aroclor-1254	0.016	0.022	0.072
	Aroclor-1260	0.025	0.034	0.11
	Beta-BHC	0.0012	0.0016	0.0054
	Chlordane	0.016	0.022	0.072
	Delta-BHC	0.0012	0.0016	0.0054
	Dieldrin	0.0012	0.0016	0.0054
	Endosulfan I	0.0013	0.0018	0.0059
	Endosulfan II	0.0031	0.0042	0.014
	Endosulfan sulfate	0.0022	0.0030	0.010
	Endrin	0.0021	0.0028	0.0095
	Endrin aldehyde	0.0023	0.0031	0.010
	Gamma-BHC (Lindane)	0.0011	0.0015	0.0050
	Heptachlor	0.0013	0.0018	0.0059
	Heptachlor epoxide	0.0011	0.0015	0.0050
	Methoxychlor	0.014	0.019	0.063
	Toxaphene	0.43	0.58	1.9
EPA SW-846, Phenol	2,4,6-Trichlorophenol	0.26	0.35	1.2
	2,4-Dichlorophenol	0.27	0.36	1.2
	2,4-Dimethylphenol	1.3	1.8	5.9
	2,4-Dinitrophenol	1.5	2.0	6.8
	2,6-Dichlorophenol	0.24	0.32	1.1
	2-Chlorophenol	0.21	0.28	0.95
	2-Nitrophenol	0.23	0.31	1.0
	2-secButyl-4,6-dinitrophenol(DNBP)	1.4	1.9	6.3
	4,6-Dinitro-2methyl phenol	1.9	2.6	8.6
	4-Chloro-3-methylphenol	0.26	0.35	1.2
	4-Nitrophenol	2.5	3.4	11
	Pentachlorophenol	1.1	1.5	5.0
	Phenol	0.29	0.39	1.3
	Tetrachlorophenol	1.1	1.5	5.0
	Total cresols	0.67	0.90	3.0
	Trichlorophenol	0.47	0.63	2.1
EPA SW-846, Selenium	Selenium	0.57	0.77	2.6
EPA SW-846, Semi-VOAs	0,0,0-Triethyl phosphorothioate	0.58	0.78	2.6
	0,0-Diethyl 0-2-pyrazinyl phosphorothioa	1.1	1.5	5.0
	1,2,4,5-Tetrachlorobenzene	4.3	5.8	19
	1,2,4-Trichlorobenzene	1.1	1.5	5.0
	1,2-Dichlorobenzene	0.32	0.43	1.4
	1,3-Dichlorobenzene	0.36	0.49	1.6
	1,4-Dichlorobenzene	0.32	0.43	1.4
	1,4-Naphthoquinone	1.1	1.5	5.0
	1-Naphthylamine	0.26	0.35	1.2

Table F.16. (contd)

Method Name	Constituent Name	MDL	LOD	LOQ
	2,2'-Oxybix(1-chloropropane)	0.35	0.47	1.6
	2,3,4,6-Tetrachlorophenol	0.44	0.59	2.0
	2,4,5-Trichlorophenol	0.19	0.26	0.86
	2,4,6-Trichlorophenol	0.17	0.23	0.77
	2,4-Dichlorophenol	0.16	0.22	0.72
	2,4-Dimethylphenol	0.11	0.15	0.50
	2,4-Dinitrophenol	13	18	59
	2,4-Dinitrotoluene	0.064	0.086	0.29
	2,6-Dichlorophenol	0.50	0.68	2.3
	2,6-Dinitrotoluene	0.22	0.30	1.0
	2-Acetylaminofluorene	0.61	0.82	2.7
	2-Chloronaphthalene	0.12	0.16	0.54
	2-Chlorophenol	0.27	0.36	1.2
	2-Methylnaphthalene	0.29	0.39	1.3
	2-Methylphenol	0.058	0.078	0.26
	2-Naphthylamine	0.29	0.39	1.3
	2-Nitroaniline	0.11	0.15	0.50
	2-Nitrophenol	0.24	0.32	1.1
	2-Picoline	3.5	4.7	16
	2-secButyl-4,6-dinitrophenol(DNBP)	1.4	1.9	6.3
	3,3'-Dichlorobenzidine	4.0	5.4	18
	3,3'-Dimethylbenzidine	4.9	6.6	22
	3-Methylcholanthrene	0.16	0.22	0.72
	3-Nitroaniline	0.085	0.11	0.38
	4,6-Dinitro-2methyl phenol	3.4	4.6	15
	4-Aminobiphenyl	0.55	0.74	2.5
	4-Bromophenylphenyl ether	0.21	0.28	0.95
	4-Chloro-3-methylphenol	0.28	0.38	1.3
	4-Chloroaniline	0.77	1.0	3.5
	4-Chlorophenylphenyl ether	0.23	0.31	1.0
	4-Nitroaniline	1.3	1.8	5.9
	4-Nitrophenol	0.39	0.53	1.8
	4-Nitroquinoline-1-oxide	20	27	90
	5-Nitro-o-toluidine	0.51	0.69	2.3
	7,12-Dimethylbenz[a]anthracene	5.8	7.8	26
	Acenaphthene	0.21	0.28	0.95
	Acenaphthylene	0.11	0.15	0.50
	Acetophenone	0.12	0.16	0.54
	Aniline	0.26	0.35	1.2
	Anthracene	0.24	0.32	1.1
	Aramite	0.69	0.93	3.1
	Benzo(a)anthracene	0.19	0.26	0.86
	Benzo(a)pyrene	0.15	0.20	0.68
	Benzo(b)fluoranthene	0.16	0.22	0.72
	Benzo(ghi)perylene	0.32	0.43	1.4
	Benzo(k)fluoranthene	0.16	0.22	0.72
	Benzothiazole	0.12	0.16	0.54

Table F.16. (contd)

Method Name	Constituent Name	MDL	LOD	LOQ
	Benzyl alcohol	0.29	0.39	1.3
	Bis(2-Chloroethoxy)methane	0.25	0.34	1.1
	Bis(2-chloroethyl) ether	0.29	0.39	1.3
	Bis(2-ethylhexyl) phthalate	0.30	0.41	1.4
	Butylbenzylphthalate	0.64	0.86	2.9
	Chlorobenzilate	0.83	1.1	3.7
	Chrysene	0.21	0.28	0.95
	Decane	0.52	0.70	2.3
	Di-n-butylphthalate	0.41	0.55	1.8
	Di-n-octylphthalate	0.15	0.20	0.68
	Diallate	0.52	0.70	2.3
	Dibenz[a,h]anthracene	0.28	0.38	1.3
	Dibenzofuran	0.11	0.15	0.50
	Diethylphthalate	0.23	0.31	1.0
	Dimethoate	0.50	0.68	2.3
	Dimethyl phthalate	0.084	0.11	0.38
	Diphenylamine	0.12	0.16	0.54
	Dodecane	0.17	0.23	0.77
	Ethyl methanesulfonate	1.6	2.2	7.2
	Famphur	2.7	3.6	12
	Fluoranthene	0.23	0.31	1.0
	Fluorene	0.22	0.30	0.99
	Hexachlorobenzene	0.21	0.28	0.95
	Hexachlorobutadiene	0.30	0.41	1.4
	Hexachlorocyclopentadiene	0.17	0.23	0.77
	Hexachloroethane	0.35	0.47	1.6
	Hexachlorophene	3.5	4.7	16
	Hexachloropropene	0.29	0.39	1.3
	Indeno(1,2,3-cd)pyrene	0.22	0.30	0.99
	Isodrin	0.34	0.46	1.5
	Isophorone	0.22	0.30	0.99
	Isosafrole	0.49	0.66	2.2
	Kepone	4.4	5.9	20
	Kerosene	1.1	1.5	5.0
	Methapyrilene	37	50	170
	Methyl methanesulfonate	0.24	0.32	1.1
	N-Nitroso-di-n-dipropylamine	0.27	0.36	1.2
	N-Nitrosodi-n-butylamine	0.11	0.15	0.50
	N-Nitrosodiethylamine	0.42	0.57	1.9
	N-Nitrosodimethylamine	0.23	0.31	1.0
	N-Nitrosodiphenylamine	0.12	0.16	0.54
	N-Nitrosomethylethylamine	3.0	4.1	14
	N-Nitrosomorpholine	0.54	0.73	2.4
	N-Nitrosopiperidine	1.3	1.8	5.9
	Naphthalene	0.29	0.39	1.3
	Nitrobenzene	0.36	0.49	1.6
	Nitrosopyrrolidine	0.50	0.68	2.3

Table F.16. (contd)

Method Name	Constituent Name	MDL	LOD	LOQ
	Parathion	1.8	2.4	8.1
	Pentachlorobenzene	2.0	2.7	9.0
	Pentachloronitrobenzene (PCNB)	4.7	6.3	21
	Pentachlorophenol	0.24	0.32	1.1
	Phenacetin	0.11	0.15	0.50
	Phenanthrene	0.21	0.28	0.95
	Phenol	0.62	0.84	2.8
	Pronamide	5.3	7.2	24
	Pyrene	0.25	0.34	1.1
	Pyridine	0.47	0.63	2.1
	Safrol	1.9	2.6	8.6
	Tetradecane	0.16	0.22	0.72
	Tetraethyl dithiopyrophosphate	1.3	1.8	5.9
	Tributyl phosphate	0.52	0.70	2.3
	Tris-2-chloroethyl phosphate	0.17	0.23	0.77
	alpha,alpha-Dimethylphenethylamine	4.1	5.5	18
	m-Cresol and p-Cresol, total	0.05	0.068	0.23
	m-Dinitrobenzene	0.43	0.58	1.9
	o-Toluidine	1.5	2.0	6.8
	p-Dimethylaminoazobenzene	12	16	54
	p-Phenylenediamine	1.1	1.5	5.0
	sym-Trinitrobenzene	0.28	0.38	1.3
EPA SW-846, Thallium	Thallium	0.63	0.85	2.8
EPA SW-846, VOAs	1,1,1,2-Tetrachloroethane	0.46	0.62	2.1
	1,1,1-Trichloroethane	0.11	0.15	0.50
	1,1,1-Trichloroethane	0.36	0.49	1.6
	1,1,2,2-Tetrachloroethane	1.2	1.6	5.4
	1,1,2-Trichloroethane	0.047	0.063	0.21
	1,1,2-Trichloroethane	0.53	0.72	2.4
	1,1-Dichloroethane	0.081	0.11	0.36
	1,1-Dichloroethane	0.37	0.50	1.7
	1,1-Dichloroethene	0.44	0.59	2.0
	1,2,3-Trichloropropane	1.6	2.2	7.2
	1,2-Dibromo-3-chloropropane	0.48	0.65	2.2
	1,2-Dibromoethane	0.50	0.68	2.3
	1,2-Dichloroethane	0.085	0.11	0.38
	1,2-Dichloroethane	0.43	0.58	1.9
	1,2-Dichloropropane	0.26	0.35	1.2
	1,4-Dichlorobenzene	0.11	0.15	0.50
	1,4-Dichlorobenzene	0.50	0.68	2.3
	1,4-Dioxane	110	150	500
	1-Butanol	25	34	110
	2-Butanone	3.4	4.6	15
	2-Hexanone	1.1	1.5	5.0
	4-Methyl-2-Pentaone	1.1	1.5	5.0
	Acetone	1.4	1.9	6.3
	Acetonitrile	21	28	95

Table F.16. (contd)

Method Name	Constituent Name	MDL	LOD	LOQ
	Acrolein	4.5	6.1	20
	Acrylonitrile	1.5	2.0	6.8
	Allyl chloride	1.2	1.6	5.4
	Benzene	0.12	0.16	0.54
	Benzene	0.38	0.51	1.7
	Bromodichloromethane	0.50	0.68	2.3
	Bromoform	0.44	0.59	2.0
	Bromomethane	0.25	0.34	1.1
	Carbon disulfide	0.33	0.45	1.5
	Carbon tetrachloride	0.047	0.063	0.21
	Carbon tetrachloride	0.35	0.47	1.6
	Chlorobenzene	0.49	0.66	2.2
	Chloroethane	1.4	1.9	6.3
	Chloroform	0.065	0.088	0.29
	Chloroform	0.41	0.55	1.8
	Chloromethane	0.37	0.50	1.7
	Chloroprene	0.21	0.28	0.95
	Dibromochloromethane	0.43	0.58	1.9
	Dibromomethane	0.49	0.66	2.2
	Dichlorodifluoromethane	0.37	0.50	1.7
	Ethyl cyanide	2.1	2.8	9.5
	Ethyl methacrylate	1.9	2.6	8.6
	Ethylbenzene	0.066	0.089	0.30
	Ethylbenzene	0.44	0.59	2.0
	Iodomethane	0.13	0.18	0.59
	Isobutyl alcohol	56	76	250
	Methacrylonitrile	1.1	1.5	5.0
	Methyl methacrylate	0.31	0.42	1.4
	Methylenechloride	0.097	0.13	0.44
	Methylenechloride	0.35	0.47	1.6
	Pentachloroethane	0.41	0.55	1.8
	Styrene	0.40	0.54	1.8
	Tetrachloroethene	0.073	0.099	0.33
	Tetrachloroethene	0.35	0.47	1.6
	Tetrahydrofuran	2.5	3.4	11
	Toluene	0.15	0.20	0.68
	Toluene	0.44	0.59	2.0
	Trichloroethene	0.099	0.13	0.45
	Trichloroethene	0.39	0.53	1.8
	Trichloromonofluoromethane	0.36	0.49	1.6
	Vinyl acetate	0.46	0.62	2.1
	Vinyl chloride	0.27	0.36	1.2
	Vinyl chloride	1.3	1.8	5.9
	Xylenes (total)	0.16	0.22	0.72
	Xylenes (total)	1.3	1.8	5.9
	cis-1,2-Dichloroethylene	0.12	0.16	0.54
	cis-1,2-Dichloroethylene	0.47	0.63	2.1

Table F.16. (contd)

Method Name	Constituent Name	MDL	LOD	LOQ
	cis-1,3-Dichloropropene	0.40	0.54	1.8
	trans-1,2-Dichloroethylene	0.13	0.18	0.59
	trans-1,2-Dichloroethylene	0.48	0.65	2.2
	trans-1,3-Dichloropropene	0.47	0.63	2.1
	trans-1,4-dichloro-2-butene	0.47	0.63	2.1
Ion Chromatography	Bromide	15	20	68
	Chloride	84	110	380
	Fluoride	23	31	100
	Nitrate	18	24	81
	Nitrite	11	15	50
	Phosphate	83	110	370
	Sulfate	21	28	95
UST, Perchlorate	Perchlorate	210	280	950

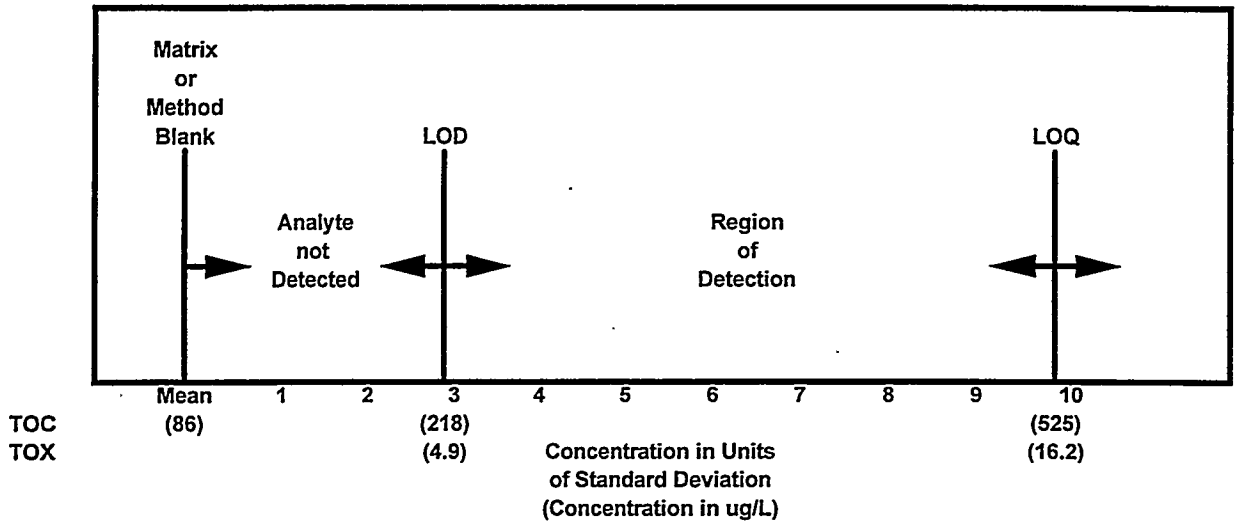


Figure F.1. Levels of Detection and Quantitation

Appendix G

RCRA and Operational Monitoring Results Exceeding Maximum Contaminant Levels

Appendix G

RCRA and Operational Monitoring Results Exceeding Maximum Contaminant Levels

M. J. Hartman

Groundwater samples from wells that monitor waste-disposal facilities on the Hanford Site are analyzed for a variety of drinking water parameters required by 40 CFR 265. The following table summarizes groundwater results that exceeded primary or secondary maximum contaminant levels (MCLs) or interim drinking water standards (see Table 6.1-29 in the main text). The groundwater database was queried for all wells sampled by the *Resource Conservation and Recovery Act of 1976* (RCRA) and Operational (DOE Order 5400.1) Monitoring Program between October 1, 1995 and September 30, 1996, with results greater than each constituent's drinking water standard. Results were excluded from this table if the analyte was undetected and the drinking water standard was smaller than the detection limit (i.e., result was flagged with a U in the database). Results that are suspected to be erroneous are also excluded (results flagged with F, Y, or R in the database). This table does not distinguish between filtered and unfiltered metals results. Most of the analyses for metals in fiscal year 1996 were for filtered samples and results reflect dissolved metals. However, some unfiltered sample results are also included.

This table may be used to determine where constituents are consistently greater than the drinking water standards, as reflected by a high number of exceedances and/or exceedances in multiple wells. Results of upgradient wells are included, reflecting possible upgradient sources of contaminants. Interpretation of the most significant contaminants for each RCRA unit are included in Chapter 6.0 of the main text.

References

40 CFR 265, Code of Federal Regulations, Title 40, Part 265. *Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.*

Resource Conservation and Recovery Act of 1976, as amended, Public Law 94-580, 90 Stat. 2795, 42 USC 6901 et seq.

U.S. Department of Energy (DOE). "General Environmental Protection Program." DOE Order 5400.1.

WAC-173-216, Washington Administrative Code. *State Waste Discharge Permit Program.* Olympia, Washington.

WAC-173-304, Washington Administrative Code. *Minimum Functional Standards for Solid Waste Handling.* Olympia, Washington.

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
		120-D-1 Ponds -- RCRA Unit			
Aluminum, µg/L	199-D5-13	Up	2	323.00	50
	199-D8-4	Down	1	170.00	50
	199-D8-5	Down	3	83.00	50
	199-D8-6	Down	3	170.00	50
Chromium, µg/L	199-D5-13	Up	14	294.00	100
Iron, µg/L	199-D5-13	Up	1	894.00	300
Nitrate, µg/L	199-D5-13	Up	1	49,000.00	45,000
Nitrogen in nitrate, µg/L	199-D5-13	Up	1	13,300.00	10,000
pH	199-D8-4	Down	14	9.24	8.5
	199-D8-6	Down	28	9.26	8.5
		100-K Area.-- Operational Monitoring			
Aluminum, µg/L	199-K-107A	Down	1	63.10	50
	199-K-108A	Up	1	76.70	50
	199-K-109A	Down	1	113.00	50
Antimony, µg/L	199-K-106A	Down	2	27.60	6
	199-K-107A	Down	2	27.60	6
	199-K-108A	Up	2	27.60	6
	199-K-109A	Down	2	31.70	6
	199-K-110A	Up	3	45.90	6
	199-K-27	Down	3	31.70	6
	199-K-30	Down	3	43.00	6
	199-K-34	Down	2	27.60	6
	699-70-68	Down	2	31.70	6
	699-72-73	Down	2	27.60	6
	699-73-61	Down	2	31.70	6
	699-78-62	Down	2	31.70	6
Chromium, µg/L	199-K-107A	Down	2	239.00	100
	199-K-108A	Up	2	216.00	100
Iron, µg/L	199-K-106A	Down	1	584.00	300
	199-K-110A	Up	1	467.00	300
	199-K-34	Down	1	621.00	300
Nitrate, µg/L	199-K-106A	Down	4	89,000.00	45,000
	199-K-30	Down	4	77,000.00	45,000
	199-K-34	Down	1	59,000.00	45,000
Nitrogen in nitrate, µg/L	199-K-106A	Down	1	19,000.00	10,000
	199-K-30	Down	1	11,500.00	10,000
Strontium-89/90, pCi/L	199-K-107A	Down	1	37.90	8
	199-K-109A	Down	1	1090.00	8
	199-K-34	Down	1	25.40	8

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Strontium-90, pCi/L	199-K-109A	Down	5	6089.00	8
Trichloroethylene, µg/L	199-K-106A	Down	1	27.00	5
Tritium, pCi/L	199-K-106A	Down	4	498,520.00	20,000
	199-K-109A	Down	4	117,820.00	20,000
	199-K-27	Down	7	90,506.00	20,000
	199-K-30	Down	5	856,980.00	20,000
	100-N Area – RCRA Unit (1301-N, 1324-N/NA, and 1325-N)				
Aluminum, µg/L	199-N-14	Down	1	78.00	50
	199-N-3	Down	1	320.00	50
Barium, µg/L	199-N-3	Down	1	150,000.00	2,000
Beryllium, µg/L	199-N-3	Down	1	840.00	4
Chromium, µg/L	199-N-3	Down	1	5,400.00	100
Copper, µg/L	199-N-3	Down	1	37,400.00	1,000
Iron, µg/L	199-N-3	Down	2	53,000.00	300
	199-N-71	Up	1	1,030.00	300
	199-N-74	Up	1	358.00	300
Manganese, µg/L	199-N-3	Down	1	10,600.00	50
Nitrate, µg/L	199-N-3	Down	1	51,000.00	45,000
	199-N-57	Up	1	59,000.00	45,000
Nitrogen in nitrate, µg/L	199-N-32	Down	3	11,600.00	10,000
Strontium-90, pCi/L	199-N-14	Down	9	858.00	8
	199-N-2	Down	4	2,220.00	8
	199-N-27	Down	1	336.00	8
	199-N-3	Down	4	1,060.00	8
	199-N-34	Up	1	63.50	8
	199-N-57	Up	1	18.68	8
	199-N-67	Down	5	15,641.00	8
	199-N-75	Down	8	604.00	8
	199-N-76	Down	13	3,110.00	8
	199-N-81	Down	1	661.94	8
Sulfate, µg/L	199-N-72	Down	2	370,000.00	250,000
	199-N-73	Down	3	420,000.00	250,000
	199-N-77	Down	3	320,000.00	250,000
Total dissolved solids, µg/L	199-N-59	Down	1	610,000.00	500,000
	199-N-72	Down	2	730,000.00	500,000
	199-N-73	Down	2	810,000.00	500,000
	199-N-77	Down	2	670,000.00	500,000

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Tritium, pCi/L	199-N-14	Down	2	53,901.00	20,000
	199-N-2	Down	1	26,922.00	20,000
	199-N-32	Down	1	56,900.00	20,000
	199-N-43	Down	1	24,922.00	20,000
	199-N-67	Down	1	25,937.00	20,000
	199-N-69	Down	1	27,778.00	20,000
	199-N-70	Down	1	31,900.00	20,000
	199-N-75	Down	2	48,900.00	20,000
	199-N-76	Down	2	61,894.00	20,000
Zinc, µg/L	199-N-3	Down	1	787,000.00	5,000
pH	199-N-14	Down	4	9.17	8.5
	199-N-41	Down	4	8.80	8.5
	199-N-76	Down	5	8.57	8.5
	199-N-81	Down	4	8.52	8.5
	183-H Solar Evaporation Basins -- RCRA Unit				
Aluminum, µg/L	199-H3-2B	Up	2	210.00	50
	199-H3-2C	Up	7	440.00	50
	199-H4-11	Down	2	600.00	50
	199-H4-12A	Down	1	96.00	50
	199-H4-12B	Down	2	94.00	50
	199-H4-13	Down	1	69.70	50
	199-H4-15B	Down	2	77.00	50
	199-H4-17	Up	1	69.00	50
	199-H4-9	Down	1	58.00	50
Antimony, µg/L	199-H4-10	Up	1	32.80	6
	199-H4-12A	Down	1	52.00	6
	199-H4-18	Down	1	58.00	6
	199-H4-3	Down	1	47.00	6
Cadmium, µg/L	199-H4-12B	Down	2	6.00	5
Chromium, µg/L	199-H4-12C	Down	12	280.00	100
	199-H4-15B	Down	1	120.00	100
	199-H4-18	Down	2	120.00	100
	199-H4-3	Down	7	240.00	100
Iron, µg/L	199-H3-2C	Up	3	490.00	300
	199-H4-11	Down	1	1,000.00	300
	199-H4-14	Up	1	1,210.00	300
	199-H4-15B	Down	1	360.00	300
	199-H4-17	Up	1	759.00	300
	199-H4-4	Down	1	360.00	300
Manganese, µg/L	199-H4-12B	Down	1	59.00	50
	199-H4-6	Up	1	59.00	50

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Nitrate, µg/L	199-H4-18	Down	5	580,000.00	45,000
	199-H4-3	Down	8	1,300,000.00	45,000
	199-H4-4	Down	3	220,000.00	45,000
	199-H4-9	Down	3	69,000.00	45,000
Nitrogen in nitrate, µg/L	199-H4-18	Down	2	77,100.00	10,000
	199-H4-3	Down	3	100,600.00	10,000
Strontium-90, pCi/L	199-H4-11	Down	1	15.49	8
Technetium-99, pCi/L	199-H4-18	Down	3	2,303.10	900
	199-H4-3	Down	9	5,140.60	900
	199-H4-4	Down	1	923.34	900
Thallium, µg/L	199-H3-2C	Up	1	105.00	2
		316-5 Process Trenches -- RCRA Unit			
Gross alpha, pCi/L	399-1-10A	Down	1	30.13	15
	399-1-11	Down	2	52.81	15
	399-1-12	Down	1	41.08	15
	399-1-16A	Down	2	67.20	15
	399-1-17A	Down	3	131.90	15
	399-2-1	Down	2	97.91	15
	399-3-10	Down	1	36.50	15
Iron, µg/L	399-1-17B	Down	2	400.00	300
Manganese, µg/L	399-1-16B	Down	2	59.00	50
	399-1-17B	Down	2	77.00	50
Nickel, µg/L	399-1-16A	Down	1	120.00	100
cis-1,2-Dichloroethylene, µg/L	399-1-16B	Down	1	140.00	70
		216-A-10 Crib -- RCRA Unit			
Gross alpha, pCi/L	299-E24-18	Up	1	16.64	15
Iodine-129, pCi/L	299-E24-17	Down	1	13.18	1
Nitrate, µg/L	299-E17-1	Down	1	100,000.00	45,000
	299-E17-19	Down	1	50,000.00	45,000
	299-E17-20	Down	2	84,000.00	45,000
	299-E24-16	Down	1	57,000.00	45,000
Nitrogen in nitrate, µg/L	299-E17-20	Down	1	18,100.00	10,000
Tritium, pCi/L	299-E17-1	Down	2	1,241,500.00	20,000
	299-E17-19	Down	2	773,400.00	20,000
	299-E17-20	Down	2	1,110,800.00	20,000
	299-E24-16	Down	2	803,950.00	20,000
	299-E24-17	Down	2	800,110.00	20,000
	299-E24-18	Up	2	382,000.00	20,000

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
pH	299-E24-17	Down	4	8.54	8.5
		216-A-29 Ditch -- RCRA Unit			
Tritium, pCi/L	299-E25-35	Down	1	24,701.00	20,000
pH	299-E25-28	Down	8	8.89	8.5
	299-E25-35	Down	4	8.56	8.5
		216-A-36B Crib -- RCRA Unit			
Gross alpha, pCi/L	299-E24-18	Up	1	16.64	15
Nitrate, µg/L	299-E17-14	Down	1	100,000.00	45,000
	299-E17-15	Down	1	97,000.00	45,000
Strontium-90, pCi/L	299-E17-14	Down	1	15.67	8
Tritium, pCi/L	299-E17-14	Down	2	1,058,600.00	20,000
	299-E17-15	Down	2	881,090.00	20,000
	299-E17-16	Down	2	396,400.00	20,000
	299-E17-17	Up	2	616,740.00	20,000
	299-E17-18	Down	2	388,940.00	20,000
	299-E17-9	Down	3	3,606,000.00	20,000
	299-E24-18	Up	2	382,000.00	20,000
		216-B-63 Trench -- RCRA Unit			
Aluminum, µg/L	299-E27-11	Up	1	66.00	50
	299-E27-8	Up	1	62.00	50
	299-E27-9	Up	1	61.00	50
Antimony, µg/L	299-E33-36	Down	1	38.00	6
Iodine-129, pCi/L	299-E33-33	Down	2	5.17	1
	299-E33-36	Down	2	9.62	1
Thallium, µg/L	299-E34-10	Up	1	3.80	2
pH	299-E33-36	Down	1	8.51	8.5
	299-E33-37	Down	4	8.64	8.5
		216-B-3 Pond -- RCRA Unit			
Antimony, µg/L	299-E32-4	Up	2	46.00	6
	699-42-41	Down	1	70.00	6
	699-43-41G	Down	1	32.00	6
	699-44-43B	Down	1	44.00	6
Tritium, pCi/L	699-41-40	Down	1	111,120.00	20,000
	699-42-39B	Down	1	72,505.00	20,000
	699-42-42B	Down	1	34,478.00	20,000
	699-43-40	Down	1	41,198.00	20,000
	699-43-41E	Down	1	49,796.00	20,000

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
pH	699-41-40	Down	4	8.54	8.5
	699-41-42	Down	4	8.61	8.5
	699-42-39B	Down	4	8.69	8.5
	699-42-40C	Down	1	8.88	8.5
	699-43-41G	Down	6	8.68	8.5
	Environmental Treatment Facility -- State Permitted				
pH	699-48-77D	Down	4	8.60	8.5
	Liquid Effluent Retention Facility -- RCRA Unit				
pH	299-E26-9	Down	4	8.59	8.5
	Low-Level Waste Management Area (LLWMA)-1 -- RCRA Unit				
Antimony, µg/L	299-E28-28	Up	1	51.00	6
	299-E32-4	Up	2	46.00	6
	299-E32-5	Down	1	24.00	6
	299-E32-6	Down	1	37.00	6
	299-E32-8	Down	1	79.00	6
	299-E33-28	Up	1	61.00	6
	299-E33-29	Up	1	25.00	6
	299-E33-30	Down	1	28.00	6
	299-E33-35	Up	1	25.00	6
Gross alpha, pCi/L	299-E32-3	Down	1	15.85	15
	299-E33-34	Down	4	29.00	15
Nitrate, µg/L	299-E32-5	Down	1	47,000.00	45,000
	299-E33-34	Down	1	47,000.00	45,000
Tritium, pCi/L	299-E28-27	Up	2	49,371.00	20,000
	299-E32-2	Down	2	31,164.00	20,000
	299-E32-3	Down	3	35,461.00	20,000
	299-E32-5	Down	2	36,815.00	20,000
	299-E32-6	Down	2	34,499.00	20,000
	LLWMA-2 -- RCRA Unit				
Aluminum, µg/L	299-E27-11	Down	1	66.00	50
	299-E27-8	Down	1	62.00	50
	299-E27-9	Down	1	61.00	50
	299-E34-5	Up	1	59.00	50
Thallium, µg/L	299-E34-10	Down	1	3.80	2
	299-E34-11	Down	1	6.40	2
	299-E34-2	Down	1	4.90	2
pH	299-E27-10	Up	4	8.52	8.5
	299-E34-7	Down	4	8.58	8.5

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
		LLWMA-3 -- RCRA Unit			
Aluminum, µg/L	299-W7-3	Down	1	53.00	50
Carbon tetrachloride, µg/L	299-W10-13	Up	2	16.00	5
	299-W10-19	Up	2	1,800.00	5
	299-W10-20	Up	12	2,700.00	5
	299-W10-21	Up	12	550.00	5
	299-W6-2	Down	2	120.00	5
	299-W7-10	Down	2	14.00	5
	299-W7-4	Down	2	710.00	5
	299-W7-5	Down	2	180.00	5
	299-W8-1	Down	1	6.00	5
Methylene chloride, µg/L	299-W10-19	Up	1	58.00	5
Nitrate, µg/L	299-W10-19	Up	4	140,000.00	45,000
	299-W10-20	Up	3	150,000.00	45,000
	299-W10-21	Up	2	160,000.00	45,000
	299-W7-11	Down	1	46,000.00	45,000
	299-W7-4	Down	1	100,000.00	45,000
	299-W7-5	Down	1	59,000.00	45,000
Nitrogen in nitrate, µg/L	299-W10-19	Up	2	31,300.00	10,000
	299-W10-20	Up	1	28,400.00	10,000
	299-W10-21	Up	1	30,700.00	10,000
	299-W6-2	Down	1	11,000.00	10,000
	299-W7-11	Down	1	10,600.00	10,000
	299-W7-4	Down	1	23,900.00	10,000
	299-W7-5	Down	1	13,600.00	10,000
Thallium, µg/L	299-W10-19	Up	1	3.90	2
	299-W10-20	Up	1	3.90	2
	299-W6-2	Down	1	4.20	2
	299-W7-10	Down	1	4.50	2
Total dissolved solids, µg/L	299-W10-20	Up	1	508,000.00	500,000
Trichloroethylene, µg/L	299-W10-19	Up	1	5.90	5
	299-W10-20	Up	9	7.00	5
	299-W10-21	Up	8	6.00	5
pH	299-W7-2	Down	4	8.67	8.5
	299-W7-9	Down	4	8.60	8.5

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
		LLWMA-4 -- RCRA Unit			
Aluminum, µg/L	299-W15-16	Up	1	51.00	50
	299-W15-20	Down	1	76.00	50
	299-W15-23	Down	1	58.00	50
	299-W18-21	Down	1	360.00	50
	299-W18-22	Down	1	54.00	50
	299-W18-23	Down	1	66.00	50
	299-W18-24	Up	1	51.00	50
	299-W18-28	Down	1	62.00	50
	299-W18-32	Up	1	74.00	50
Antimony, µg/L	299-W15-24	Down	1	30.00	6
	299-W18-26	Down	1	61.00	6
Carbon tetrachloride, µg/L	299-W15-15	Down	4	1,060.00	5
	299-W15-16	Up	3	5,170.00	5
	299-W15-18	Up	4	3,880.00	5
	299-W15-19	Down	2	660.00	5
	299-W15-20	Down	2	160.00	5
	299-W15-23	Down	2	300.00	5
	299-W15-24	Down	3	390.00	5
	299-W18-21	Down	3	1,500.00	5
	299-W18-23	Down	4	350.00	5
	299-W18-24	Up	4	1,940.00	5
	299-W18-26	Down	7	170.00	5
	299-W18-27	Down	2	310.00	5
	299-W18-28	Down	3	22.00	5
Iron, µg/L	299-W18-21	Down	1	540.00	300
Nitrate, µg/L	299-W15-15	Down	2	60,000.00	45,000
	299-W15-16	Up	2	87,000.00	45,000
	299-W15-18	Up	2	110,000.00	45,000
	299-W15-19	Down	2	82,000.00	45,000
	299-W15-24	Down	1	89,000.00	45,000
	299-W18-21	Down	1	77,000.00	45,000
Thallium, µg/L	299-W15-16	Up	1	5.00	2
	299-W18-26	Down	1	3.90	2
pH	299-W15-20	Down	4	8.75	8.5
		LLWMA-5 -- RCRA Unit			
Aluminum, µg/L	299-W11-31	Up	2	93.00	50
	299-W6-4	Up	1	69.00	50
	299-W6-9	Up	1	53.00	50
Carbon tetrachloride, µg/L	299-W6-2	Up	2	120.00	5
	299-W6-5	Down	2	509.00	5
	299-W7-10	Up	2	14.00	5

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Nitrate, µg/L	299-W11-31	Up	5	130,000.00	45,000
	299-W6-10	Up	4	130,000.00	45,000
	299-W6-4	Up	4	110,000.00	45,000
	299-W6-9	Up	5	76,000.00	45,000
Nitrogen in nitrate, µg/L	299-W6-2	Up	1	11,000.00	10,000
Thallium, µg/L	299-W6-2	Up	1	4.20	2
	299-W7-10	Up	1	4.50	2
Trichloroethylene, µg/L	299-W6-5	Down	2	8.10	5
Tritium, pCi/L	299-W11-31	Up	5	68,140.00	20,000
	299-W6-10	Up	4	77,969.00	20,000
	299-W6-4	Up	4	29,145.00	20,000
pH	299-W6-4	Up	4	8.89	8.5
	Nonradioactive Dangerous Waste Landfill -- RCRA Unit				
Tritium, pCi/L	699-25-34A	Down	2	130,280.00	20,000
	699-25-34B	Down	2	142,710.00	20,000
	699-25-34D	Down	2	124,260.00	20,000
	699-26-33	Down	2	132,720.00	20,000
	699-26-34A	Up	2	119,440.00	20,000
	699-26-34B	Down	2	109,600.00	20,000
	699-26-35A	Up	4	129,000.00	20,000
	699-26-35C	Up	2	37,995.00	20,000
	Operational Monitoring Program				
Tritium, pCi/L	299-E25-11	Down	1	20,951.00	20,000
	299-E25-18	Down	3	53,770.00	20,000
	299-E25-19	Down	2	458,000.00	20,000
	299-E25-20	Down	3	102,810.00	20,000
	216-S-10 Pond and Ditch -- RCRA Unit				
Chromium, µg/L	299-W26-7	Up	1	110.00	100
pH	299-W26-8	Up	8	8.82	8.5
	WMA-A-AX Single-Shell Tank Farms -- RCRA Unit				
Antimony, µg/L	299-E25-40	Up	1	38.00	6
Chromium, µg/L	299-E24-19	Down	1	140.00	100
Iodine-129, pCi/L	299-E24-19	Down	2	10.01	1
	299-E24-20	Down	1	6.52	1
	299-E25-40	Up	2	7.11	1
	299-E25-41	Up	2	5.55	1
	299-E25-46	Down	2	5.01	1
Nickel, µg/L	299-E24-19	Down	1	160.00	100

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
		WMA-B-BX-BY Single-Shell Tank Farms -- RCRA Unit			
Antimony, µg/L	299-E33-31	Down	1	76.00	6
	299-E33-32	Down	1	46.00	6
	299-E33-36	Up	1	38.00	6
	299-E33-43	Down	1	38.00	6
Iodine-129, pCi/L	299-E33-31	Down	2	9.17	1
	299-E33-32	Down	2	7.28	1
	299-E33-33	Up	2	5.17	1
	299-E33-36	Up	2	9.62	1
	299-E33-41	Down	1	7.74	1
	299-E33-42	Down	2	5.16	1
	299-E33-43	Down	2	5.68	1
pH	299-E33-36	Up	1	8.51	8.5
		WMA-C Single-Shell Tank Farm -- RCRA Unit			
Iodine-129, pCi/L	299-E27-12	Down	1	3.21	1
	299-E27-13	Down	1	4.32	1
	299-E27-14	Up	2	4.95	1
	299-E27-15	Down	2	4.02	1
		WMA-S-SX Single-Shell Tank Farms -- RCRA Unit			
Antimony, µg/L	299-W22-46	Down	1	69.00	6
	299-W23-14	Up	1	61.00	6
	299-W23-15	Down	1	46.00	6
Carbon tetrachloride, µg/L	299-W23-15	Down	1	7.50	5
Tritium, pCi/L	299-W23-14	Up	13	256,460.00	20,000
	299-W23-15	Down	2	26,848.00	20,000
		WMA-T Single-Shell Tank Farm -- RCRA Unit			
Aluminum, µg/L	299-W10-15	Down	1	52.00	50
	299-W10-16	Up	1	71.00	50
	299-W11-27	Down	1	56.00	50
	299-W11-31	Down	2	93.00	50
	299-W6-4	Down	1	69.00	50
	299-W6-9	Down	1	53.00	50
Carbon tetrachloride, µg/L	299-W10-15	Down	1	1,600.00	5
	299-W10-19	Down	2	1,800.00	5
	299-W10-20	Down	12	2,700.00	5
	299-W10-21	Down	12	550.00	5
	299-W11-28	Down	1	1,900.00	5
	299-W6-2	Down	2	120.00	5
Chromium, µg/L	299-W10-15	Down	2	110.00	100
	299-W11-27	Down	2	590.00	100
Fluoride, µg/L	299-W10-15	Down	5	5,000.00	4,000

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Methylene chloride, µg/L	299-W10-19	Down	1	58.00	5
Nitrate, µg/L	299-W10-15	Down	5	300,000.00	45,000
	299-W10-16	Up	4	140,000.00	45,000
	299-W10-19	Down	4	140,000.00	45,000
	299-W10-20	Down	3	150,000.00	45,000
	299-W10-21	Down	2	160,000.00	45,000
	299-W11-27	Down	2	190,000.00	45,000
	299-W11-28	Down	4	140,000.00	45,000
	299-W11-31	Down	5	130,000.00	45,000
	299-W6-4	Down	4	110,000.00	45,000
	299-W6-9	Down	5	76,000.00	45,000
Nitrogen in nitrate, µg/L	299-W10-19	Down	2	31,300.00	10,000
	299-W10-20	Down	1	28,400.00	10,000
	299-W10-21	Down	1	30,700.00	10,000
	299-W6-2	Down	1	11,000.00	10,000
Sulfate, µg/L	299-W11-27	Down	2	320,000.00	250,000
Technetium-99, pCi/L	299-W11-27	Down	2	17,914.00	900
Thallium, µg/L	299-W10-19	Down	1	3.90	2
	299-W10-20	Down	1	3.90	2
	299-W6-2	Down	1	4.20	2
Total dissolved solids, µg/L	299-W10-15	Down	5	770,000.00	500,000
	299-W10-16	Up	3	540,000.00	500,000
	299-W10-20	Down	1	508,000.00	500,000
	299-W11-27	Down	2	900,000.00	500,000
	299-W11-28	Down	4	590,000.00	500,000
Trichloroethylene, µg/L	299-W10-15	Down	1	7.30	5
	299-W10-19	Down	1	5.90	5
	299-W10-20	Down	9	7.00	5
	299-W10-21	Down	8	6.00	5
	299-W11-28	Down	1	15.00	5
Tritium, pCi/L	299-W10-15	Down	5	34,381.00	20,000
	299-W10-16	Up	4	48,701.00	20,000
	299-W11-28	Down	4	67,966.00	20,000
	299-W11-31	Down	5	68,140.00	20,000
	299-W6-4	Down	4	29,145.00	20,000
pH	299-W10-16	Up	1	8.53	8.5
	299-W6-4	Down	4	8.89	8.5
	WMA-TX-TY Single-Shell Tank Farms -- RCRA Unit				
Chromium, µg/L	299-W14-12	Down	1	150.00	100
Iodine-129, pCi/L	299-W10-17	Down	1	4.32	1
	299-W14-12	Down	3	18.45	1
	299-W15-22	Up	1	4.20	1

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Nitrate, µg/L	299-W10-17	Down	6	150,000.00	45,000
	299-W10-18	Down	6	94,000.00	45,000
	299-W14-12	Down	4	250,000.00	45,000
	299-W15-22	Up	4	170,000.00	45,000
Technetium-99, pCi/L	299-W14-12	Down	3	3,014.90	900
Total dissolved solids, µg/L	299-W10-17	Down	5	520,000.00	500,000
	299-W14-12	Down	3	670,000.00	500,000
Tritium, pCi/L	299-W10-17	Down	6	33,914.00	20,000
	299-W14-12	Down	4	184,670.00	20,000
	299-W15-22	Up	4	39,694.00	20,000
	WMA-U Single-Shell Tank Farm -- RCRA Unit				
Carbon tetrachloride, µg/L	299-W18-30	Down	1	994.00	5
	299-W19-32	Up	1	34.00	5
Iron, µg/L	299-W19-32	Up	1	970.00	300
Manganese, µg/L	299-W19-32	Up	1	90.00	50
Nickel, µg/L	299-W19-32	Up	1	270.00	100
pH	299-W19-12	Down	1	8.54	8.5
	Solid Waste Landfill -- State Permitted				
Aluminum, µg/L	699-23-34A	Down	1	52.80	50
	699-23-34B	Down	1	61.00	50
	699-24-33	Down	1	75.00	50
	699-24-34A	Down	1	65.00	50
	699-24-34B	Down	2	54.80	50
	699-25-34C	Down	1	57.80	50
Antimony, µg/L	699-23-34B	Down	1	40.00	6
	699-25-34C	Down	1	46.00	6
Cadmium, µg/L	699-25-34C	Down	1	7.00	5
Carbon tetrachloride, µg/L	699-24-34B	Down	1	9.30	5
Tritium, pCi/L	699-24-33	Down	4	97,317.00	20,000
	699-24-34A	Down	4	25,600.00	20,000
	699-24-34B	Down	5	54,400.00	20,000
	699-24-34C	Down	4	97,026.00	20,000
	699-25-34C	Down	6	127,230.00	20,000
	699-26-35A	Up	4	129,000.00	20,000
	216-U-12 Crib -- RCRA Unit				
Antimony, µg/L	299-W22-40	Down	1	25.00	6
	299-W22-42	Down	1	24.00	6
	299-W22-43	Up	1	46.00	6
	699-36-70A	Down	2	47.00	6

Constituent	Well Name	Upgradient/ Downgradient	Number of Exceedances	Maximum Result	Drinking Water Standards
Carbon tetrachloride, µg/L	299-W22-43	Up	11	27.00	5
	699-36-70A	Down	1	7.00	5
Iodine-129, pCi/L	299-W22-40	Down	2	1.94	1
	299-W22-42	Down	2	7.66	1
	699-36-70A	Down	6	19.45	1
Methylene chloride, µg/L	299-W22-43	Up	2	6.00	5
Nitrate, µg/L	299-W22-41	Down	5	270,000.00	45,000
	299-W22-42	Down	4	500,000.00	45,000
	699-36-70A	Down	5	140,000.00	45,000
Nitrogen in nitrate, µg/L	699-36-70A	Down	1	30,700.00	10,000
Total dissolved solids, µg/L	299-W22-42	Down	2	750,000.00	500,000
Tritium, pCi/L	299-W22-42	Down	1	22,287.00	20,000
	699-36-70A	Down	6	291,440.00	20,000
	Treated Effluent Disposal Facility -- State Permitted				
Aluminum, µg/L	699-40-36	Down	1	96.60	50
Iron, µg/L	699-40-36	Down	1	767.00	300
Manganese, µg/L	699-40-36	Down	2	75.80	50
	699-41-35	Down	1	64.20	50

Appendix H

Listing of Chemical and Radiological Data for Fiscal Year 1996

Appendix H

Listing of Chemical and Radiological Data for Fiscal Year 1996

This appendix is on the 3-1/2-in. computer diskette included with this report. The introductory material is formatted in WordPerfect 5.1 for personal computers.

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