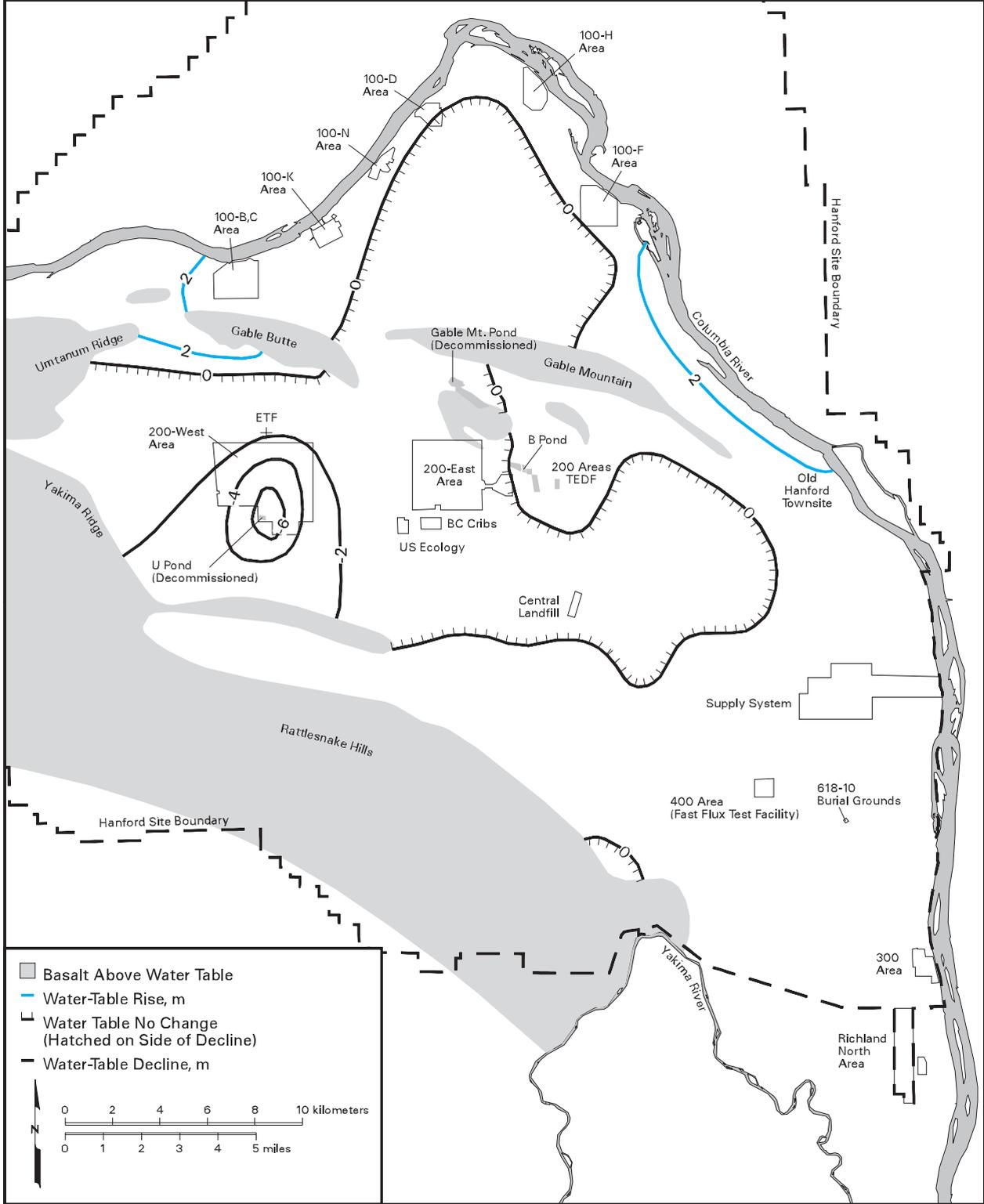




**Figure 4.8.8.** Change in Water-Table Elevations Between 1979 and 1996



**Table 4.8.1.** Major Chemical and Radiological Groundwater Contaminants and Their Link to Site Operations

Facilities Type	Areas	Constituents Generated
Reactor operations	100	Tritium, $^{60}\text{Co}$ , $^{90}\text{Sr}$ , $^{125}\text{Sb}$ , $\text{Cr}^{+6}$ , $\text{SO}_4^{-2}$
Irradiated fuel processing	200	Tritium, $^{90}\text{Sr}$ , $^{99}\text{Tc}$ , $^{129}\text{I}$ , $^{137}\text{Cs}$ , Pu, U, $\text{CN}^-$ , $\text{Cr}^{+6}$ , F, $\text{NO}_3^-$
Plutonium purification	200	Pu, $^{241}\text{Am}$ , carbon tetrachloride, chloroform, $\text{NO}_3^-$
Fuel fabrication	300	$^{99}\text{Tc}$ , U, $\text{Cr}^{+6}$ , Cu, trichloroethylene

beneath Hanford and, thus, affected the rate and direction of contamination spread. The effects of discharge have been dissipating since production operations ceased.

Liquid effluents discharged to the ground at Hanford facilities percolated downward through the unsaturated zone toward the water table. Radionuclide and chemical constituents move through the soil column and, in some cases, enter the groundwater. In some locations, sufficient water was discharged to saturate the soil column to the surface. Not all contaminants move at the same rate as the water in the subsurface. Chemical processes such as adsorption onto soil particles, chemical precipitation, and ion exchange slow the movement of some constituents such as strontium-90, cesium-137, and plutonium-239,240. However, these processes may be affected by the chemical characteristics of the waste such as high ionic strength, acidity, or presence of chemical complexants. Other radionuclides such as technetium-99, iodine-129, and tritium and chemicals such as nitrate are not as readily retained by the soil and move vertically through the soil column at a rate nearly equal to the infiltrating water. When the contaminants reach the water table, their concentrations are reduced by dilution with groundwater in the aquifer. As these constituents move with the groundwater, radionuclide and chemical concentrations are reduced further by adsorption and spreading (dispersion). Radionuclide concentrations are also reduced by radioactive decay.

Outside the source areas (i.e., liquid disposal sites) at the Hanford Site there is typically little or no downward gradient (driving force or head), so contamination tends to remain in the upper part of the aquifer. Where large volumes of water are discharged, there may be a significant vertical hydraulic gradient that tends to move contaminants downward in the aquifer. Layers of low-permeability silt and clay within the unconfined aquifer also limit the vertical movement of contaminants. Flow in the unconfined

aquifer is generally toward the Columbia River, which acts as a drainage area for the groundwater flow system at Hanford. Contamination that reaches the river is further diluted by river water.

## Groundwater Modeling

Numerical modeling of groundwater flow and contaminant transport at the Hanford Site is performed for several different purposes. The Groundwater Monitoring Project uses models to predict future groundwater flow conditions and to assess the potential impacts of contaminants migrating from the Hanford Site through the groundwater pathway. Models have also been used by the Environmental Restoration Contractor 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 the Environmental Restoration Contractor to support the design of site-specific groundwater remediation projects. A brief description of these modeling efforts is provided in this section. Additional details and results are presented in Hartman and Dresel (1997).

During the past several years, a three-dimensional flow and transport model has been under development by the Groundwater Monitoring 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. Information on the initial development of the three-dimensional model is available in Wurstner et al. (1995). The first transport simulations using this new model were performed during 1996 and supported the state discharge

permitting effort for the startup of the new Effluent Treatment Facility. The model was applied to predict the migration of tritium from this 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 Hartman and Dresel (1997).

A separate modeling effort, with the objective of prioritizing and optimizing environmental restoration activities, was completed during 1996 by the Environmental Restoration Contractor. This modeling effort was initiated approximately 5 years ago to support development of the Hanford Sitewide Groundwater Remediation Strategy, which is required by the Tri-Party Agreement. Migration patterns of eight radionuclide and chemical contaminant plumes over the next 200 years were 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).

The Environmental Restoration Contractor also applied models based on the Micro-FEM<sup>®</sup> 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 and 200-West Areas. 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.

## Groundwater Monitoring

Groundwater monitoring at the Hanford Site is an integral part of the *Hanford Site Ground-Water Protection Management Plan* (DOE 1995k). This plan integrates monitoring at active waste disposal facilities to comply with monitoring requirements of the Resource Conservation and Recovery Act and Washington State regulations, as well as requirements for operational monitoring around reactor and chemical processing facilities, and environmental surveillance monitoring. Pacific Northwest National Laboratory manages these monitoring efforts through the Groundwater Monitoring Project. This project is responsible for assessing the distribution and movement

of existing groundwater contamination, identifying potential and emerging groundwater contamination problems, and integrating the various groundwater projects to minimize redundancy. Information on contaminant distribution and transport are integrated into a sitewide evaluation of groundwater quality, which is documented in an annual groundwater monitoring report (Hartman and Dresel 1997). Groundwater monitoring is also carried out during cleanup investigations under the Comprehensive Environmental Response, Compensation, and Liability Act as described in the five-year plan (DOE 1992d). These investigations are managed by the Environmental Restoration Contractor.

## Groundwater Sampling and Analytes of Interest

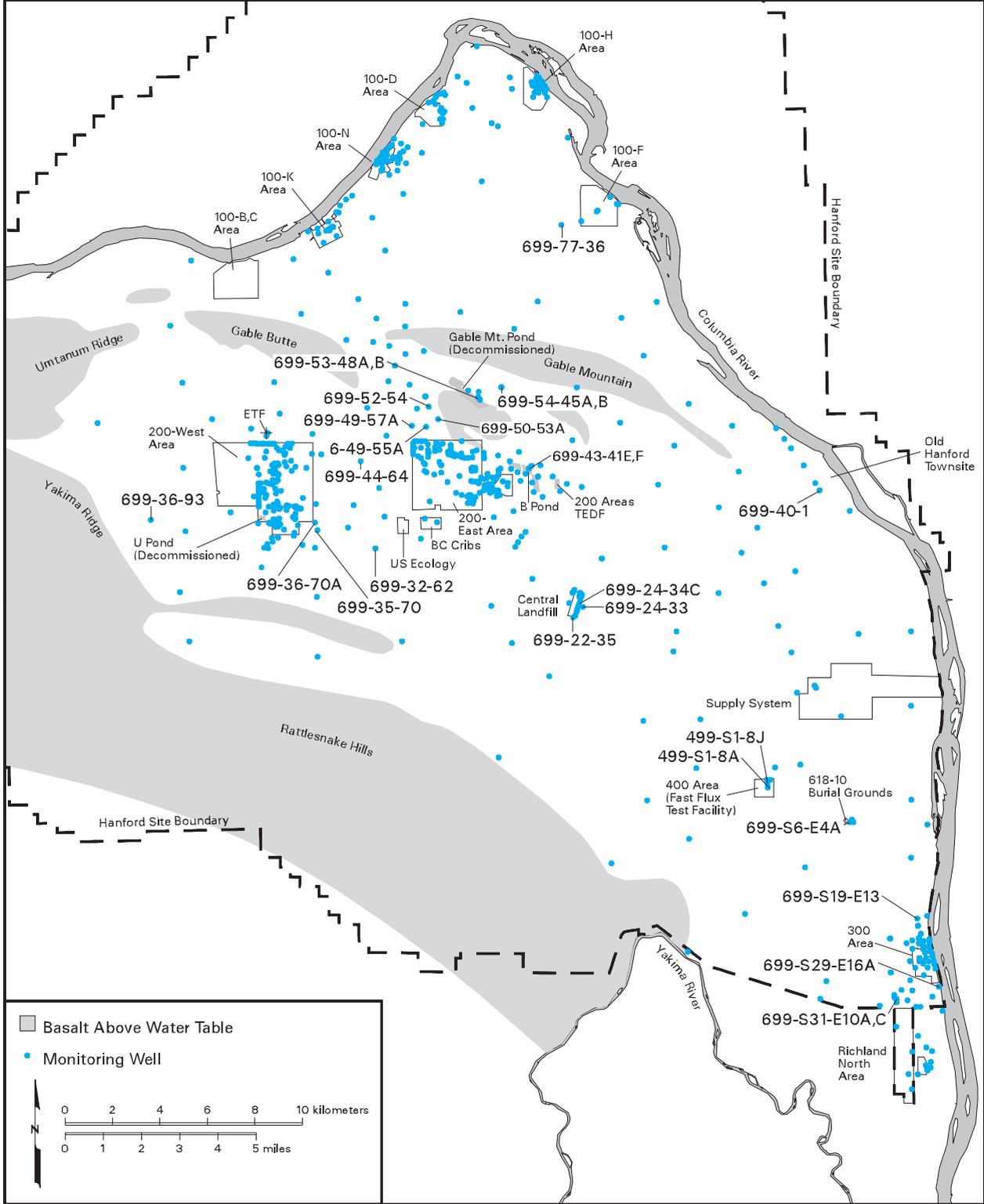
Groundwater samples were collected from approximately 800 wells for all monitoring programs during 1996. The locations of sampled wells are shown in Figures 4.8.9 and 4.8.10. Well names are indicated only for wells in the 600 Area that are specifically discussed in the text. Because of the density of unconfined aquifer wells in the operational areas, well names in these areas are shown on detailed maps in the following sections. Figure 4.8.11 shows the locations of facilities where groundwater monitoring was conducted to comply with the Resource Conservation and Recovery Act (Hartman and Dresel 1997). Wells at the Hanford Site generally follow a naming system in which the well name indicates the approximate location of the well. The prefix of the well name indicates the area of the site, as shown in Table 4.8.2. The well names for 600 Area wells follow a local coordinate system in which the numbers indicate the distance relative to an arbitrary datum location in the south-central part of the site.

The monitoring frequency for the wells is selected based on regulatory requirements, proximity to waste sources, and characteristics of the groundwater flow system at the sample location. Of the wells sampled, approximately 270 were sampled once, 280 twice, 100 three times, 90 four times, and 60 more frequently during the year.

Each monitoring program has access to groundwater data collected by other programs through a common database, the Hanford Environmental Information System. This database currently contains approximately 1.4 million groundwater monitoring result records. After the data are verified and/or validated, they are made available to federal and state regulators for retrieval.

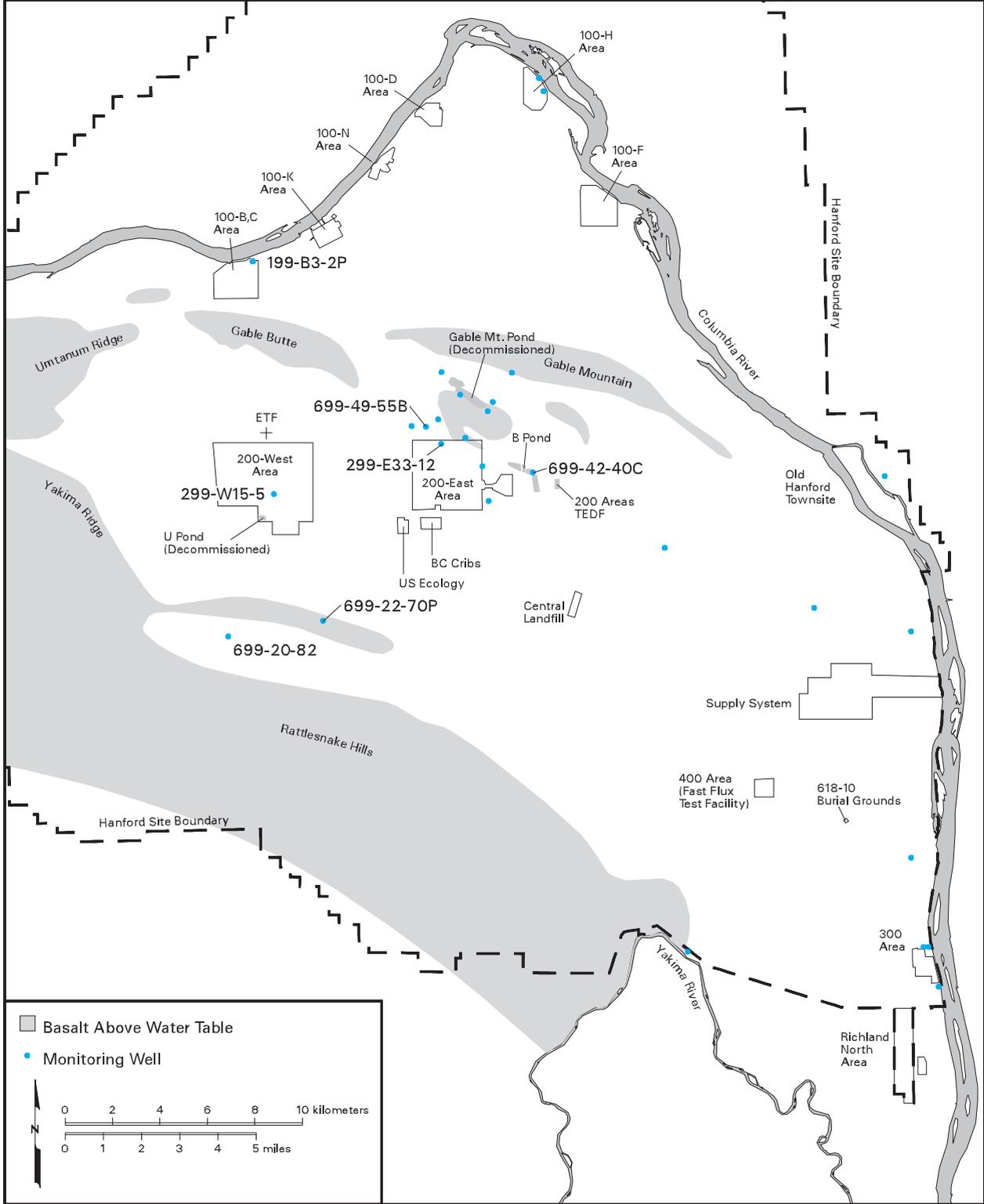


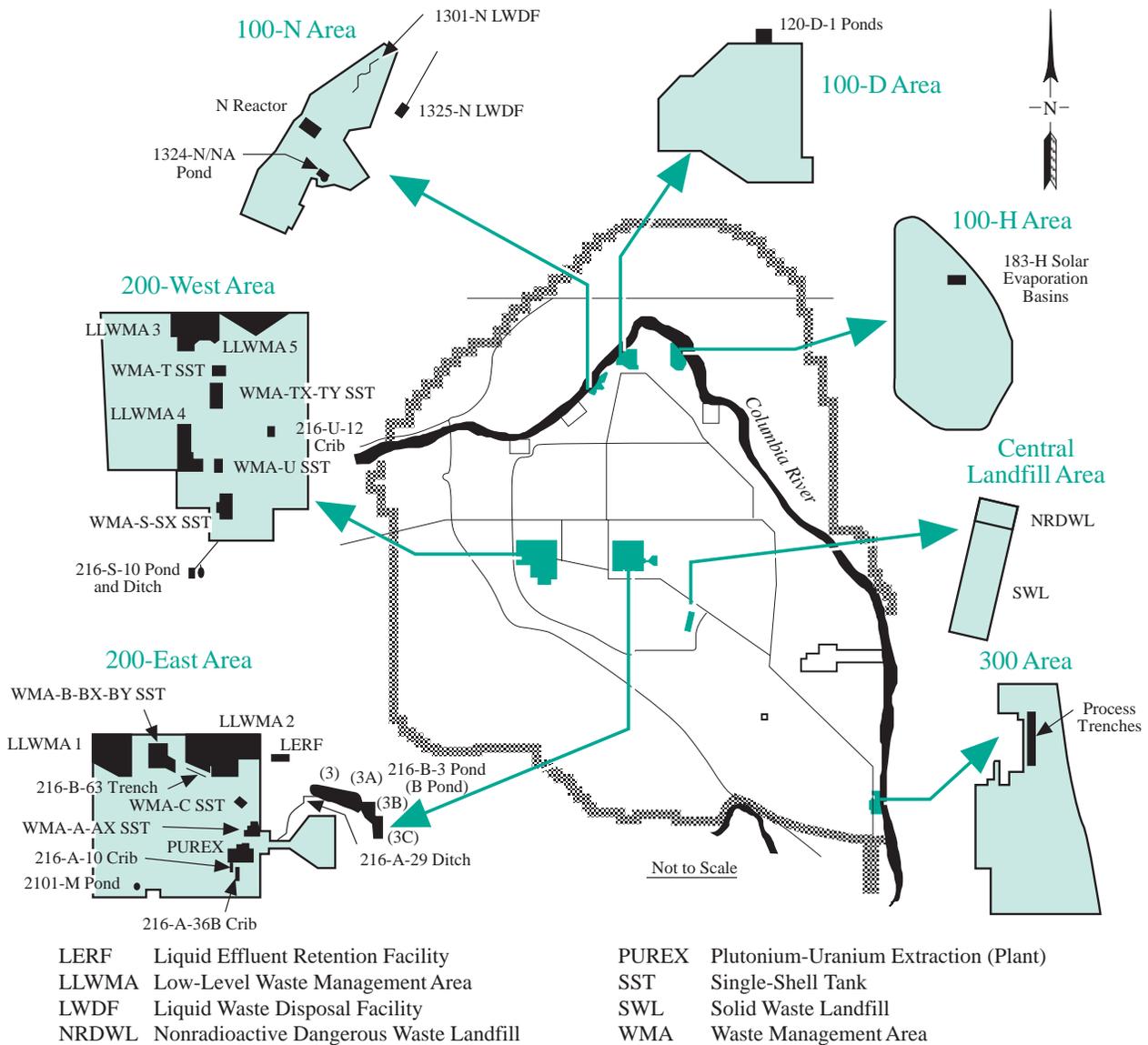
**Figure 4.8.9.** Hanford Site Unconfined Aquifer Monitoring Well Locations, 1996





**Figure 4.8.10.** Hanford Site Confined Aquifer Monitoring Well Locations, 1996





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**Figure 4.8.11.** Locations of Resource Conservation and Recovery Act Groundwater Monitoring Projects on the Hanford Site

Most groundwater monitoring wells on the site are 10 to 20 cm (4 to 8 in.) in diameter. Monitoring wells for the unconfined aquifer are constructed with well screens or perforated casing generally in the upper 3 to 6 m (10 to 20 ft) of the unconfined aquifer, with the open interval extending across the water table. This construction allows sample collection at the top of the aquifer, where maximum concentrations of radionuclides tend to be found. Wells monitoring the shallowest of the basalt-confined aquifers have screens, perforated casing, or an open hole

within the monitored aquifer. Wells drilled before 1985 were generally constructed with carbon steel casing. Wells recently constructed for Resource Conservation and Recovery Act monitoring projects and Comprehensive Environmental Response, Compensation, and Liability Act characterizations have been constructed with stainless-steel casing and screens. Most monitoring wells onsite are sampled using either submersible or Hydrostar™ pumps, though some wells are sampled with bailers or air-lift systems.

**Table 4.8.2.** Explanation of the Hanford Site Well Naming System

Example Well Name	Area
<b>199-</b>	<b>100 Areas</b>
199-B3-47	100-B,C Area
199-D5-12	100-D Area
199-F8-3	100-F Area
199-H4-3	100-H Area
199-K-30	100-K Area
199-N-67	100-N Area
<b>299-</b>	<b>200 Areas</b>
299-W19-3	200-West Area
299-E28-4	200-East Area
<b>399-</b>	<b>300 Area</b>
399-1-17A	300 Area
<b>499-</b>	<b>400 Area</b>
499-S1-8J	400 Area
<b>699-</b>	<b>600 Area</b>
699-50-53A	600 Area north and west of datum
699-42-E9A	600 Area north and east of datum
699-S19-11	600 Area south and west of datum
699-S19-E13	600 Area south and east of datum

Note: Letters at end of well names distinguish either multiple wells located close together or multiple intervals within a single well bore.

Samples were collected for all programs following documented sampling procedures (Westinghouse Hanford Company 1991a, Pacific Northwest Laboratory 1993) based on EPA guidelines (EPA 1986a). Analytical techniques used are listed in DOE (1994a), Dresel et al. (1995), and Comprehensive Environmental Response, Compensation, and Liability Act work plans. The radionuclides and chemicals analyzed are listed in Table 4.8.3. Of the parameters listed in Table 4.8.3, several were not measured during 1996 because sufficient characterization had been obtained by past analyses.

Most groundwater samples collected onsite in 1996 were analyzed for tritium. Selected samples were analyzed for

other radionuclides. Sample results for radionuclides are generally presented in picocuries per liter (pCi/L). However, the results for total uranium, which is usually measured by laser fluorescence, are given in micrograms per liter ( $\mu\text{g/L}$ ). The results for analyses of individual uranium isotopes are reported in picocuries per liter.

Nitrate analyses were performed on many samples collected during 1996 because of the extensive areas with elevated nitrate concentrations originating from onsite and offsite sources. However, nitrate concentrations were below the EPA drinking water standard (40 CFR 141) for most of the affected area. Selected monitoring wells were used for additional chemical surveillance. The results of previous chemical analyses and the proximity to known active and inactive chemical disposal sites were considered in choosing wells for sampling for chemical contaminants.

## Data Interpretation

Each analysis of a groundwater sample provides information on the composition of groundwater at one time at one location in the aquifer. Uncertainty in the analyses results from a number of sources. Some of the sources of uncertainty are discussed below. Several techniques used to interpret the sample results are also discussed.

Groundwater sampling techniques are designed to collect a sample that is representative of the constituent concentration in the aquifer when the sample is taken. However, there are limitations in collecting representative samples or even defining precisely the volume of the aquifer represented by the sample. Proper well construction and maintenance, well purging, sample preservation, and, in some instances, filtering are used to help ensure consistent and representative samples. Careful sample labeling protocols, chain-of-custody documentation, and bottle preparation avoid many gross errors in sample results. Duplicate samples and field blanks are used to assess the sampling procedure.

Uncertainties are inherent in laboratory analysis of samples. Gross errors can be introduced in the laboratory or during sampling. Gross errors include transcription errors, calculation errors, mislabeling results, or other errors that result from not following established procedures. Often, these gross errors can be recognized because unreasonably high or unreasonably low values result. Data review protocols are used to investigate and correct gross errors. Even if the source of a possible gross error cannot be identified, a marker is entered into the database that indicates the review has occurred and the datum may be suspect.

**Table 4.8.3.** Radionuclides and Chemicals Analyzed for in Groundwater

Radiological Parameters	Chemical Parameters
<sup>3</sup> H	pH (field and laboratory)
<sup>14</sup> C	Conductance (field)
<sup>60</sup> Co	Alkalinity
<sup>90</sup> Sr	Total carbon
<sup>99</sup> Tc	Total organic carbon
<sup>103</sup> Ru	Total organic halogens
<sup>106</sup> Ru	B, Be, Na, Mg, Al, K, Co, Si
<sup>125</sup> Sb	Ca, V, Cr, Mn, Fe, Ni
<sup>129</sup> I	Cu, Zn, Sr, Ag, Cd, Sb, Ba
<sup>131</sup> I	F, Cl <sup>-</sup> , NO <sub>3</sub> <sup>-</sup> , PO <sub>4</sub> <sup>-3</sup> , SO <sub>4</sub> <sup>-2</sup> , NO <sub>2</sub> <sup>-</sup> , Br <sup>-</sup>
<sup>137</sup> Cs	CN <sup>-</sup>
<sup>241</sup> Am	NH <sub>4</sub> <sup>+</sup>
Total alpha	Volatile organic compounds
Total beta	Semivolatile organic constituents
Plutonium isotopes	Polychlorinated biphenyls
Uranium isotopes	Dioxins/furans
Uranium (total)	Pesticides/herbicides
	Biological oxygen demand/chemical oxygen demand
	Dissolved oxygen

Random errors are unavoidably introduced in the analytical procedures. Usually, there are insufficient replicate analyses to assess the overall random error at each sample location. Instruments for analysis of radioactive constituents count the number of radioactive decay products at a detector, and background counts are subtracted. The nature of radioactive decay and the instrument design result in a random counting error that is reported with the analytical result. Generally, a sample result less than the counting error indicates the constituent was not detected. The background subtraction may result in the reporting of results that are less than zero. Although below-zero results are physically impossible, the negative values are of use for some statistical analyses (see "Helpful Information" section for more details).

Systematic errors may result from instrument calibration, standard or sample preparation, chemical interferences in analytical techniques, as well as sampling methodology

and sample handling. Sample and laboratory protocols have been designed to minimize systematic errors. The laboratories used by the Groundwater Monitoring Project and other programs participate in interlaboratory comparisons in which many laboratories analyze blind samples prepared by the EPA (Section 7.0, "Quality Assurance").

In 1996, double-blind samples for specific constituents were analyzed as part of the Groundwater Monitoring Project (Section 7.0, "Quality Assurance," discusses double-blind results). Several wells were also cosampled with the Washington State Department of Health for comparison. Results of the comparison sampling are available from the Washington State Department of Health.

The chemical composition of groundwater may fluctuate from differences in the contaminant source, recharge, or the groundwater flow field. The range of this concentration fluctuation can be estimated by taking many samples,

but there is a limit to the number that can be practicably taken. Comparison of results through time helps interpret this variability.

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 overall 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.

Plume maps presented in this section are diagrams that illustrate site groundwater chemistry. Although analytical data are available only at 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 simplified representations of plume geometry because of map scale, the lack of detailed information, and the fact that plume depth and thickness cannot be fully represented on a two-dimensional map. Plume maps are a powerful tool because knowledge of concentrations in surrounding wells, groundwater flow, site geology, and other available information are factored into their preparation.

## Groundwater Monitoring Results

The following sections summarize the distribution of radioactive and chemical contaminants detected in Hanford Site groundwater during 1996. These discussions are followed by a summary of groundwater monitoring results for Resource Conservation and Recovery Act sites. More detailed information on groundwater monitoring, including listings of analysis results for each monitoring well in electronic format, is available in *Hanford Site Groundwater Monitoring for Fiscal Year 1996* (Hartman and Dresel 1997). However, because the annual groundwater report covers the fiscal year, it does not include results from the last three months of 1996.

One way to assess the impact of radionuclides and chemicals in groundwater is to compare the concentrations to EPA's drinking water standards and DOE's derived concentration guides (40 CFR 141 and WAC 246-290; see Appendix C, Tables C.2 and C.5). Specific drinking water standards have been proposed for only a few radiological constituents. Drinking water standards resulting

in an annual dose of 4 mrem/yr have been calculated for other radionuclides by considering the half-life of the isotope, the energy and nature of the radioactive decay for that isotope, and the physiological factors such as the buildup of the isotope in particular organs. Drinking water standards are more restrictive than derived concentration guides. This is because the standards are based on an annual dose to the affected organ of 4 mrem/yr, while the guides are based on an effective dose equivalent of 100 mrem/yr (see Appendix C, Tables C.2 and C.5). In addition, the standards use older factors for calculating the concentrations that would produce a 4-mrem/yr dose than are used in calculating the guides. Thus, the values used below for standards are not always in agreement with the guides. The guides are available only for radionuclides. Primary and secondary drinking water standards are given for some chemical constituents; secondary standards are based on aesthetic rather than health considerations.

## Radiological Monitoring Results for the Unconfined Aquifer

The radionuclides analyzed for in Hanford Site groundwater were listed in Table 4.8.3. The distribution of tritium, iodine-129, strontium-90, technetium-99, uranium, cobalt-60, cesium-137, plutonium, and antimony-125 are discussed in the following sections. Iodine-131, ruthenium-103, and ruthenium-106 are also analyzed for but have relatively short half-lives. These radionuclides have not been observed in concentrations above the drinking water standards and have rarely been detected since soon after the shutdown of N Reactor and the Plutonium-Uranium Extraction Plant. Total alpha and beta are used as indicators of radionuclide distribution and are not discussed in detail because the specific radionuclides contributing to these measurements are discussed individually. Several other radionuclides are associated with wastes from Hanford operations. Because of their very low concentrations in groundwater, they are not discussed in this section.

### Tritium

Tritium was present in many historical waste streams at Hanford and is highly mobile, essentially moving at the same velocity as the groundwater. As a result, the extent of groundwater contamination from site operations is generally reflected by tritium distribution. Tritium is the radionuclide most frequently monitored at the Hanford Site for this reason. Tritium is present in irradiated nuclear fuel and was released in process condensates associated with decladding and dissolution of the fuel. Tritium was

also manufactured as part of the Hanford mission by irradiating targets containing lithium in several reactors from 1949 to 1952 (DOE 1992c, Gerber 1993). In the late 1960s, tritium production took place in N Reactor (Gerber 1992). Figure 4.8.12 shows the 1996 distribution of tritium in the unconfined aquifer.

**Tritium in the 100 Areas.** Tritium concentrations greater than the 20,000-pCi/L drinking water standard were detected in the 100-B,C, 100-D, 100-F, 100-K, and 100-N Areas.

One sample from the 100-B,C Area (well 199-B5-2) contained a maximum of 27,000 pCi/L of tritium during 1996, slightly above the drinking water standard. Although this well has shown an increasing trend in tritium concentration, the maximum 1996 value was the same as that observed during 1995, and upgradient wells show lower tritium levels.

Tritium concentrations greater than the drinking water standard were detected in two wells in the 100-D Area. The maximum tritium level reported during 1996 was 37,800 pCi/L in monitoring well 199-D2-6.

One well in the 100-F Area (199-F8-3) contained tritium at concentrations greater than the drinking water standard (a maximum of 111,000 pCi/L) in 1995. This well was not analyzed for tritium in 1996, and no other wells in this area showed a concentration higher than the standard.

Well 199-K-30, located in the 100-K Area, continued to contain the highest tritium concentration within the 100 Areas, with a maximum concentration of 576,000 pCi/L reported in 1996. Previously, in April and May 1993, this well contained tritium in excess of the 2,000,000-pCi/L derived concentration guide. The tritium trend for well 199-K-30 is shown in Figure 4.8.13 and has been declining since mid-1995. The probable source is past disposal to a french drain east of the reactor building (DOE 1993a). A careful evaluation of the contaminant trends and distribution of other constituents such as carbon-14, strontium-90, and antimony-125 suggests that the primary source of tritium is not leakage of the K-East Reactor fuel storage basin. However, basin leakage is implicated in contamination found in well 199-K-27, located just north of the K-East Reactor. Tritium concentrations in monitoring well 199-K-27 continue to decline but remained well above the drinking water standard (maximum of 66,000 pCi/L) in 1996. Well 199-K-106A was installed in 1994 adjacent to a french drain near the K-West Reactor. Samples from this well revealed high

tritium concentrations from basin leakage or from a related sump overflow discharge system leading to the french drain. The maximum concentration of tritium detected in well 199-K-106A in 1996 was 499,000 pCi/L.

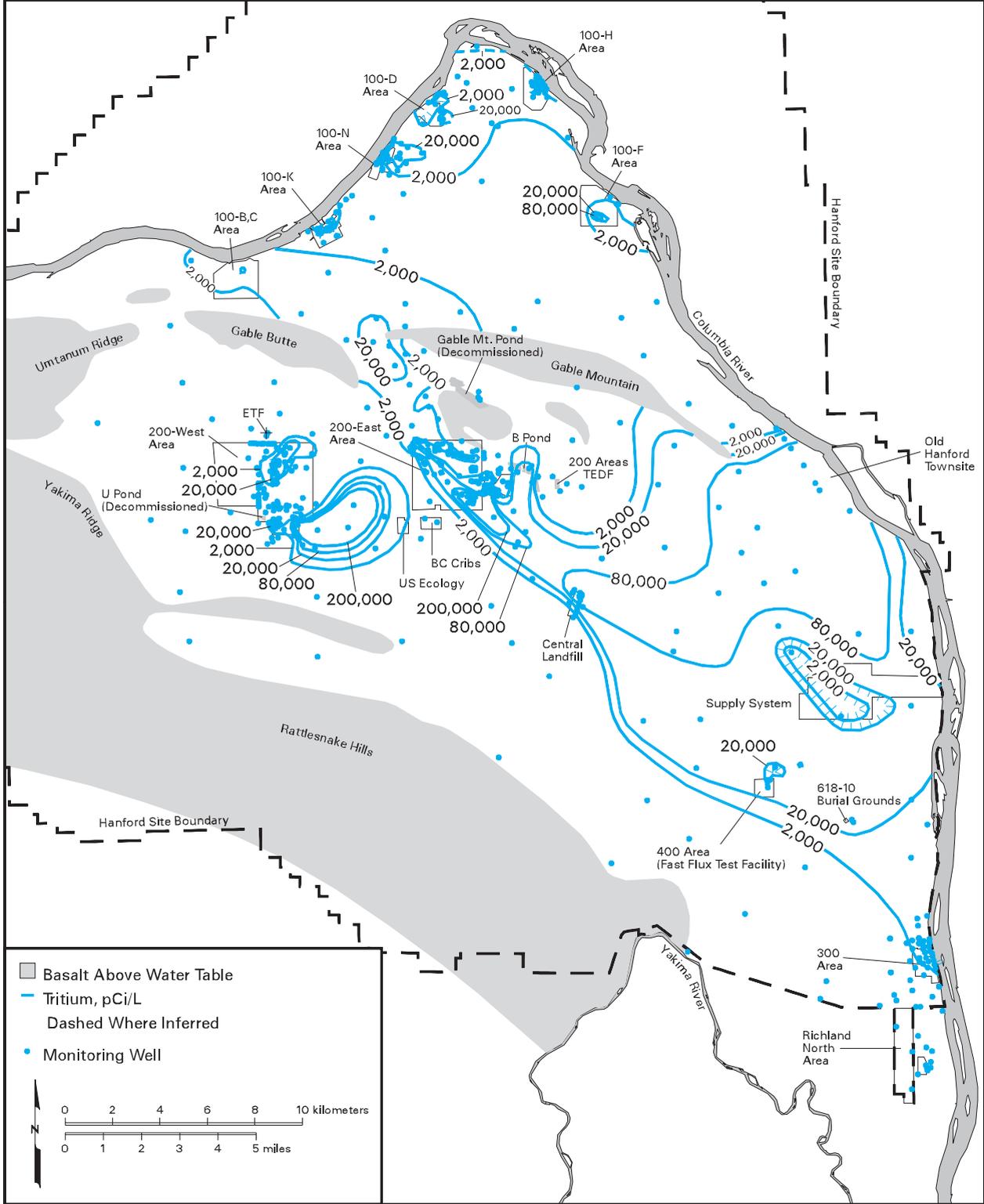
Tritium in the 100-N Area is found in concentrations greater than the drinking water standard in the northern part of the area, extending to the surrounding 600 Area. This plume is associated with the 1301-N and 1325-N Liquid Waste Disposal Facilities. The maximum tritium level reported in the 100-N Area in 1996 was 61,900 pCi/L in well 199-N-76, located between the 1301-N Liquid Waste Disposal Facility and the Columbia River.

**Tritium in the 200, 400, and 600 Areas.** The highest tritium concentrations in the 200-East Area continued to be in wells near cribs that received effluent from the Plutonium-Uranium Extraction Plant. Concentrations greater than the 2,000,000-pCi/L derived concentration guide were detected in only one well (299-E17-9) in 1996 in the 200-East Area. The maximum tritium level detected in this well, which monitors the 216-A-36B Crib, was 2,940,000 pCi/L. This was the highest tritium concentration detected in any well onsite. The tritium concentration in this well is declining slowly, as shown in Figure 4.8.14. Concentrations in monitoring wells downgradient of the 216-A-10 Crib decreased to less than the derived concentration guide in 1993 and remained below the guide in 1996. Tritium concentrations are generally decreasing in wells near the Plutonium-Uranium Extraction Plant cribs.

The movement of the widespread tritium plume (see Figure 4.8.12), extending from the southeastern portion of the 200-East Area to the Columbia River, was consistent with patterns noted in past monitoring reports (Dirkes and Hanf 1996, Hartman and Dresel 1997). Separate tritium pulses associated with the two episodes of Plutonium-Uranium Extraction Plant operations can be distinguished in the plume. High tritium concentrations east of the 200-East Area near the Columbia River result from discharges to ground during the operation of the Plutonium-Uranium Extraction Plant from 1956 to 1972. Following an 11-year shutdown, plant operation began again in 1983 and ceased in December 1988. This resulted in elevated tritium concentrations measured in several wells downgradient from the 200-East Area. Movement of the leading edge of this second plume is clearly observable in well 699-24-33 (Figure 4.8.15), which shows arrival of the plume in early 1987. Tritium concentrations from the first plume were much higher than from the second. Concentrations of tritium detected in 1996 in this plume



**Figure 4.8.12.** Distribution of Tritium in the Unconfined Aquifer, 1996



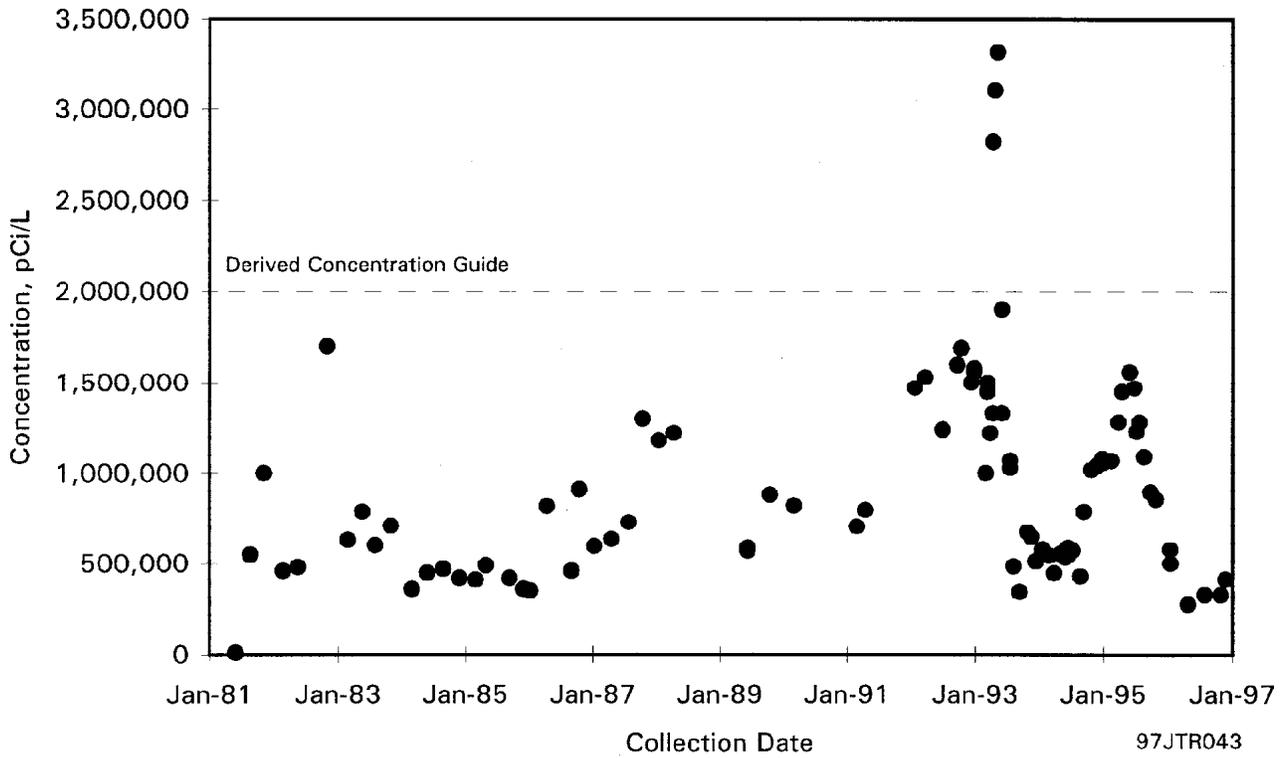


Figure 4.8.13. Tritium Concentrations in Well 199-K-30, 1981 Through 1996

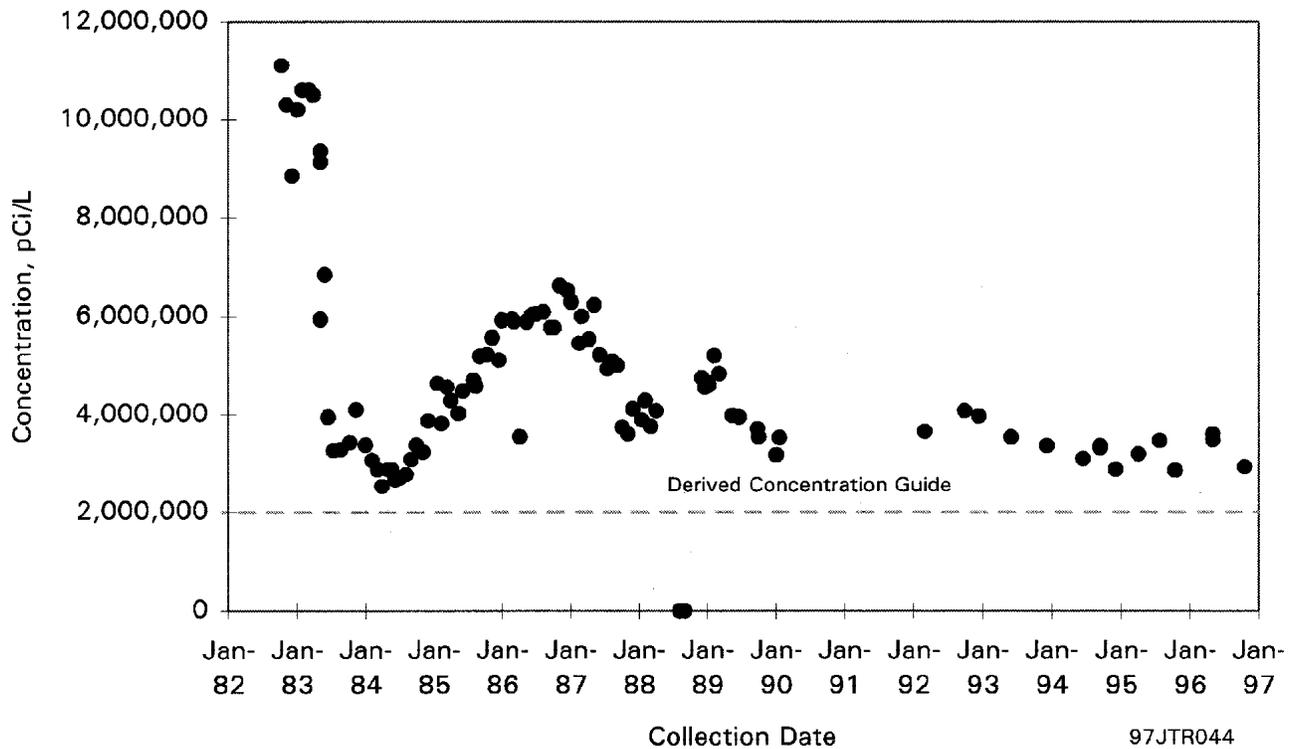


Figure 4.8.14. Tritium Concentrations in Well 299-E17-9, 1982 Through 1996