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TITLE:	Hanford Site Environmental Report for CY 1998
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4.6 Soil and Vegetation Surveillance

T. M. Poston

Soil surveillance provides information on long-term contamination trends and baseline environmental radionuclide activities at undisturbed locations (DOE/RL-91-50, Rev. 2). Surveillance of perennial vegetation provides information on atmospheric deposition of radioactive materials in uncultivated areas and at onsite locations adjacent to potential sources of man-made radioactivity. Accordingly, radionuclide activities in soil and perennial vegetation provide a baseline against which unplanned releases can be compared.

Soil and perennial vegetation samples have been collected on and around the Hanford Site for >50 yr. Consequently, a large database exists that thoroughly documents onsite and offsite activities of man-made radionuclides in soil and natural vegetation at specific locations. Because the current site mission includes environmental restoration and cleanup and because routine plutonium production operations at the site have ceased, the need for annual soil and perennial vegetation surveillance has diminished. There are several additional reasons for the reduced need for soil and perennial vegetation sampling. Man-made radionuclides with short half-lives have decayed to stable isotopes and are no longer present. Moreover, radionuclide releases from the Hanford Site in recent years have been small, and, therefore, baseline radionuclide activities have not changed appreciably for a number of years. Because only radionuclides with relatively long half-lives presently are found in soil and vegetation, sitewide environmental surveillance sampling of soil and vegetation can be less frequent. Radiological surveillance of soil and vegetation was last conducted in 1994 (Section 4.6 in PNNL-10574). In 1998, routine sampling of soil and perennial vegetation was conducted at 15 locations on site and 5 locations off site (Figure 4.6.1). Additionally, special sampling of Columbia River shoreline mulberry trees at the 100-N Area was conducted in October 1998 to verify the results of samples collected and analyzed by an external stakeholder group. Fruit and leaves from trees located near the 100-F Area and the Old Hanford Townsite were also sampled and analyzed.

Other soil and vegetation sampling by Fluor Daniel Hanford, Inc. was conducted near active facility release points and waste sites. Results are discussed in Section 3.2, "Near-Facility Environmental Monitoring."

4.6.1 Soil Sampling

Soil samples were collected at 20 locations on and around the Hanford Site in 1998 (see Figure 4.6.1). Soil samples were organized into three distinct groups: 1) onsite, 2) offsite (combined perimeter and one distant upwind location at Sunnyside), and 3) the Fitzner-Eberhardt Arid Lands Ecology Reserve site (formerly grouped with perimeter locations). Onsite sample locations are selected in areas around industrial development on the site. The offsite perimeter locations sampled in 1998 were Ringold, Byers Landing, Sagemoor, and Riverview. These four locations lie in a generally downwind location east and southeast of the site. Soil was collected from two sites on the Fitzner-Eberhardt Arid Lands Ecology Reserve.

Soil samples consisted of five plugs, 2.54 cm (1 in.) deep and 10.2 cm (4 in.) in diameter, that were

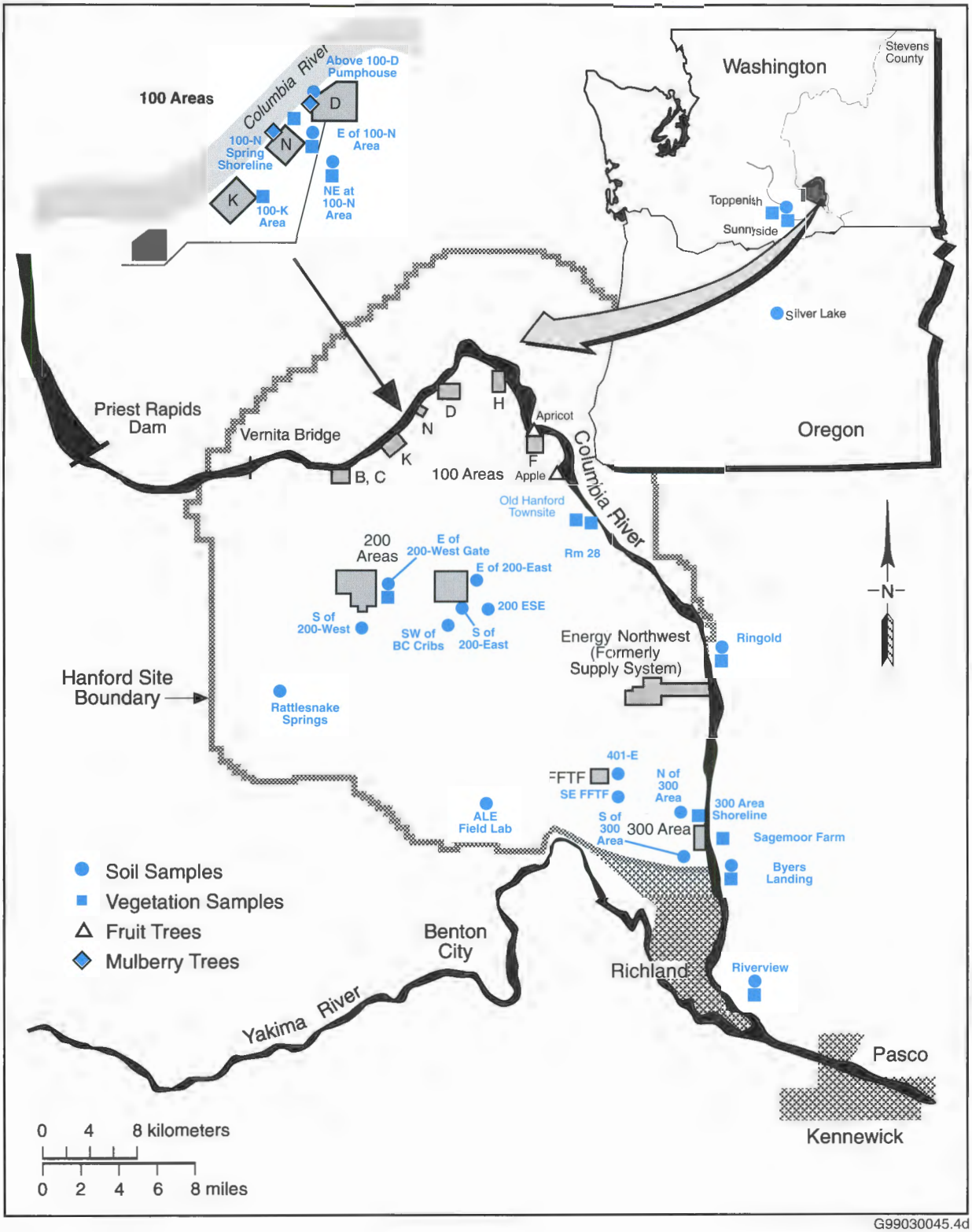

Figure 4.6.1. *Soil and Vegetation Sampling Locations, 1998*

collected within 10 m (33 ft) of one another and combined into one bulk sample. Soil samples were dried to remove residual moisture and sieved at the laboratory prior to analysis to remove rocks and plant debris.

In 1998, soil samples were analyzed for gamma-emitting radionuclides, strontium-90, uranium-234, -235, -238, plutonium-238, plutonium-239,240, and, in selected samples, americium-241 (Table 4.6.1). The 1998 results were compared to those from 1992 through 1997 (see Appendix A, Table A.8) and from soil samples collected from mountainous regions as part of special studies (Table 4.6.2). In 1996, results of an assessment of Hanford background radionuclide activities in soils were published (DOE/RL-96-12). These assessment results provide comparison values (median and 95th percentile[a] activities) for radionuclides that are routinely monitored on the Hanford Site.

In 1998, observed strontium-90 and cesium-137 activities in all soil samples were near detection limits. Median activities of strontium-90, cesium-137, and plutonium-239,240 collected from onsite locations were no different than those found at perimeter locations in 1998 and the preceding sampling years (1992 through 1994) (Figure 4.6.2). Maximum activities of strontium-90, cesium-137, and plutonium-239,240 in samples collected on the site were higher than the maximums measured at offsite locations because some of the locations on the site were selected to monitor specifically for past industrial releases. The East of 200-West Gate soil

Table 4.6.1. Routine Soil and Vegetation Samples Collected and Analyzed, 1998

Location	No. of Samples	Frequency	Analytes
Soil			
Onsite[a]	13	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}[b], Pu,[c] ^{241}Am
Distant	1	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu, ^{241}Am
Downwind perimeter[a]	4	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu, ^{241}Am
ALE[d]	2	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu, ^{241}Am
Vegetation			
Onsite	5	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu
Distant	2	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu
Perimeter	4	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu
Shoreline	3	Annual to once every 5 yr	Gamma, ^{90}Sr, U_{iso}, Pu

(a) Not all analytes are analyzed for at each location.
(b) U_{iso} is a method of analyzing for uranium by detecting alpha particles.
(c) Plutonium-238 and plutonium-239,240.
(d) Fitzner-Eberhardt Arid Lands Ecology Reserve.

(a) The percentile is a statistical grouping of values, 95% of all values fall below the 95th percentile; hence, the 95th percentile is used as an estimate of the upper bounds of uranium activities in soil.

Table 4.6.2. Comparison of Strontium-90, Cesium-137, and Plutonium-239,240 Activities (pCi/g dry wt.) in Soils at Remote Locations with Site Background Observed Onsite and Offsite Concentrations

Location[a]	Year	Radionuclide	Minimum[b]	Median (50th Percentile)	Maximum[b] (95th Percentile)	Number
Silver Lake lowland	1994	Strontium-90	0.14 ± 0.03	0.18 ± 0.04	0.23 ± 0.04	3
		Cesium-137	0.29 ± 0.05	0.33 ± 0.05	0.43 ± 0.07	
Silver Lake mountain	1994	Strontium-90	0.54 ± 0.10	0.67 ± 0.13	0.69 ± 0.13	3
		Cesium-137	1.67 ± 0.21	1.70 ± 0.20	1.72 ± 0.20	
Stevens County	1994	Strontium-90	NR[c]	NR	0.39 ± 0.07	1
		Cesium-137	NR	NR	0.82 ± 0.09	
Hanford Site background[d]	1985 to 1992	Strontium-90	NR	0.06	0.21	73
		Cesium-137	NR	0.31	1.08	149
		Plutonium-239,240	NR	0.0077	0.026	128
Hanford Site perimeter	1998	Strontium-90	0.043 ± 0.010	0.054 ± 0.008[e]	0.060 ± 0.012	4
		Cesium-137	0.16 ± 0.02	0.20 ± 0.03	0.32 ± 0.04	
		Plutonium-239,240	0.0066 ± 0.0010	0.0088 ± 0.0015	0.012 ± 0.0015	
On the Hanford Site	1998	Strontium-90	0.014 ± 0.004	0.065 ± 0.015	0.38 ± 0.069	13
		Cesium-137	0.005 ± 0.009	0.14 ± 0.021	1.8 ± 0.18	
		Plutonium-239,240	0.0004 ± 0.0002	0.0052 ± 0.0009	0.53 ± 0.058	

(a) See Figure 4.6.1 for locations.
(b) ±2 sigma total analytical error.
(c) NR = Not reported.
(d) Estimated values based on samples collected on and around the Hanford Site (see Table 3-5 in DOE/RL-95-55).
(e) 2-sigma error of highest activity used to calculate the median.

sampling location (see Figure 4.6.1) has consistently had the highest activities of these radionuclides.

In the past, soil sites on the Fitzner-Eberhardt Arid Lands Ecology Reserve were included in the perimeter grouping. Because of the transfer of management of this reserve to the U.S. Fish and Wildlife Service in 1997, results from the Rattlesnake Springs and Arid Lands Ecology Field Laboratory stations are reported separately. Results for these locations for 1998 were similar to 1993 (see Appendix A, Table A.9) and fall within the range of activities observed at other onsite or offsite locations (see Figure 4.6.2).

Uranium is a natural radionuclide that is present in all soils. Uranium activities in soil on and near the Hanford Site were analyzed in 1998 by acid leaching and alpha spectrometry of the extracted residue. In prior years, soil samples were analyzed by both alpha spectrometry and low-energy photon spectrometry.

The median background activity and the 95th percentile background activity of uranium-238 near and on the Hanford Site have been reported as 0.76 and 1.18 pCi/g, respectively (DOE/RL-95-55). These background activities are based primarily on low-energy photon spectrometry. Low-energy photon spectrometry results for uranium-238 are generally lower than alpha spectrometry results; however, the degree of difference varies, depending on the soil type and particle-size distribution. Maximum uranium-238 activities measured in soils on and around the

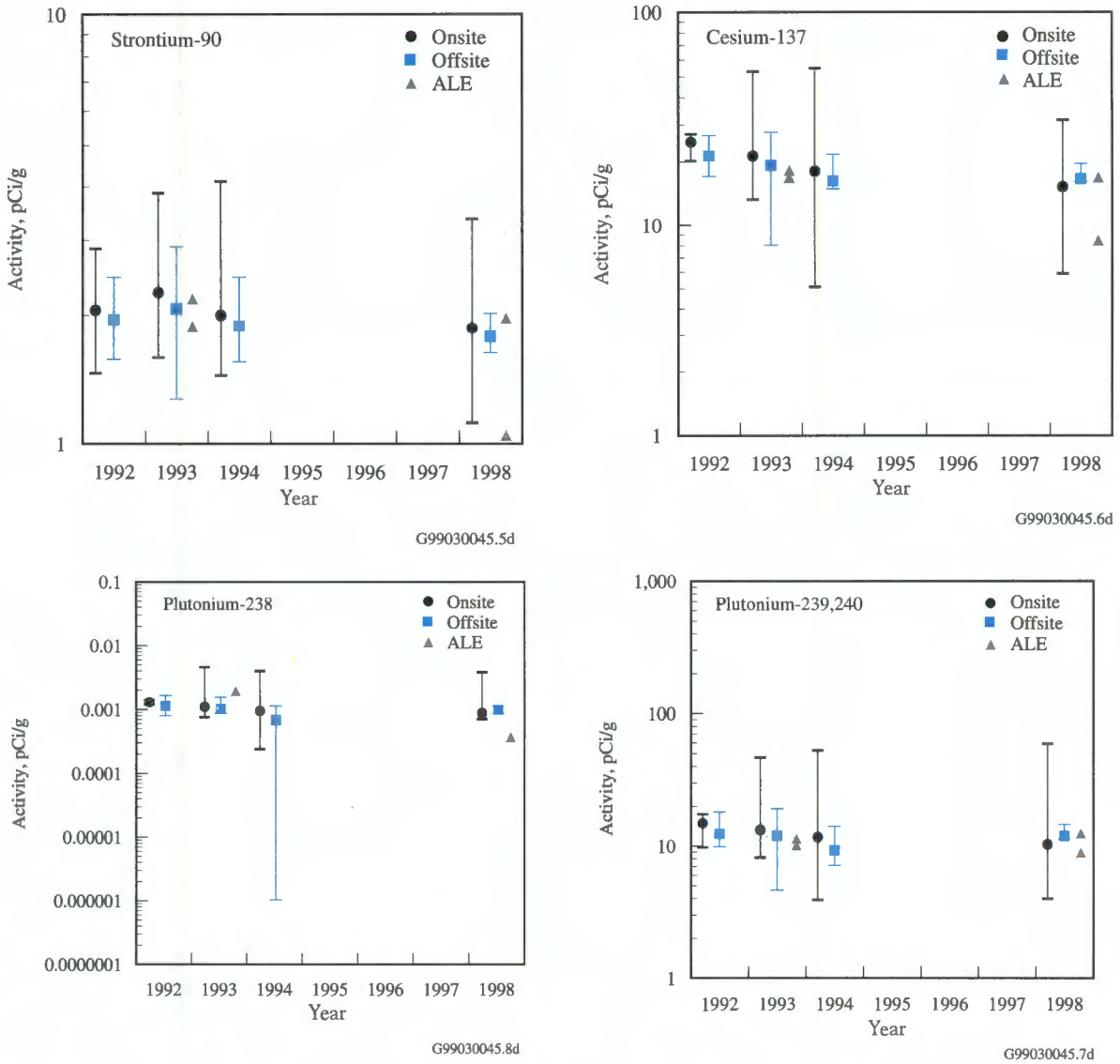

Figure 4.6.2. *Median, Maximum, and Minimum Radionuclide Activities of Strontium-90, Cesium-137, Plutonium-238, and Plutonium-239,240 in Soil (pCi/g dry wt), 1992 Through 1998 (ALE = Fitzner-Eberhardt Arid Lands Ecology Reserve)*

Hanford Site in 1998 by alpha spectrometry were below the reported median background.

Onsite and offsite soil radionuclide activities from 1998 were also compared with the background values on and near the site (DOE/RL-95-55) and with the results from distant and remote sampling sites in Stevens County, Washington, and the two locations at Silver Lake, Oregon (Table 4.6.2). The remote samples provide some indication of the concentrations of fallout radionuclides that are found in other parts of the Pacific Northwest. Background fallout radionuclide activities generally increase with increased annual precipitation and altitude.

4.6.2 Vegetation Sampling

Vegetation samples were collected at 14 locations on and around the Hanford Site in 1998 (see Figure 4.6.1). Vegetation samples collected in 1998 were organized into four distinct groups: 1) onsite, 2) perimeter, 3) distant upwind locations, and 4) Columbia River shoreline samples (see Table 4.6.1). Onsite sample locations were generally selected in areas around industrial development on the site. The downwind perimeter locations were Ringold, Byers Landing, Sagemoor, and Riverview. These four locations lie generally downwind, east and southeast, of the site. They are expected to be in areas of highest offsite accumulation of contaminants from stack emissions. Special shoreline samples were collected at the Hanford Slough (in conjunction with apple tree sampling), at Hanford River mile marker 28, and at the 300 Area.

Perennial vegetation samples consist of the current year's growth of leaves, stems and new branches collected from sagebrush and rabbitbrush. Sample vegetation is dried before analyses, and analytical results are reported on a dry weight basis. Shoreline vegetation samples usually are taken from a predominant species at the sample location site. Samples of leaves and fruit collected from abandoned fruit trees were also analyzed for trace metals by inductively coupled plasma-mass spectrometry and by cold vapor atomic adsorption spectrometry (specifically for mercury). Metals results were reported on a dry weight basis.

Surveillance of perennial vegetation samples for radionuclides in 1998 generally confirmed observations of past sampling efforts. Activities of cesium-137, uranium-238, plutonium-238, and technetium-99 (in two samples of shoreline vegetation) were all below nominal detection limits (see Appendix A, Table A.10). Nominal detection limits for these radionuclides were 0.02, 0.02, 0.0002, and 0.4 pCi/g, respectively. Plutonium-239,240 was measured in one perennial vegetation sample (0.004 ± 0.001 pCi/g) collected at the East of the 200-West Gate sampling location (see Figure 4.6.1). All other plutonium-239,240 activities were below detection (0.0003 pCi/g).

Strontium-90 was found in 12 of 14 vegetation samples collected in 1998. There was no appreciable difference between the range of strontium-90 activities measured from 1992 through 1998 or between onsite, perimeter, and distant locations (Figure 4.6.3).

Special sampling involved the collection of leaves from willows along the Columbia River shoreline at the 300 Area and rough bugleweed along the river shoreline at Hanford River mile marker 28, near the Old Hanford Townsite. Samples collected near the river shoreline at the 100-N Area consisted of rabbitbrush. The rabbitbrush samples were not collected at the river shoreline. Instead, they were collected as near to the shoreline as possible because the shoreline area was covered with basalt. Consequently, the 100-N Area shoreline results were grouped and

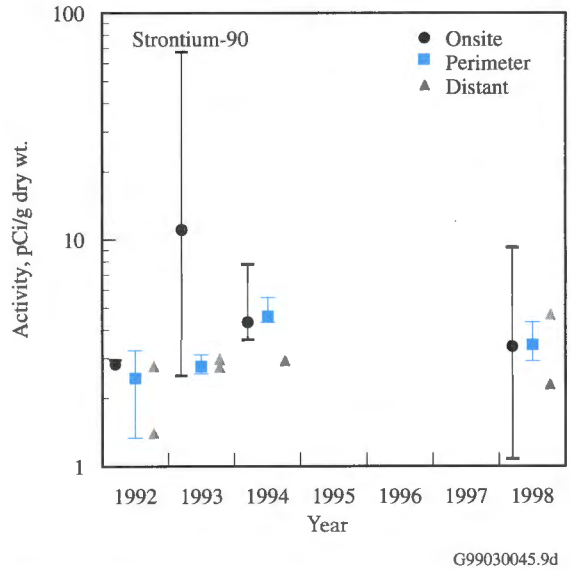

Figure 4.6.3. *Median, Maximum, and Minimum Radionuclide Activities of Strontium-90 in Natural Vegetation, 1992 Through 1998*

reported with other onsite (nonshoreline) perennial vegetation samples. Mulberry trees were sampled in October at two locations at the 100-N Area shoreline and approximately 1,600 m (1 mi) downstream of the radiological control area at the 100-N Area shoreline.

Results of shoreline vegetation samples are summarized in Table 4.6.3 and are compared to a comprehensive survey of shoreline vegetation conducted from 1990 through 1992 (PNL-8797). Generally, strontium-90 activities were comparable to results from the 1990 to 1992 study, with the exception of the 100-N Area mulberry tree samples. The maximum strontium-90 measured in the 1998 mulberry leaf sample was >10 times lower than the maximum observed in 1990. While uranium-238 was approximately 10 times higher in 1998 bugleweed samples than in onions sampled from 1990 to 1992, the activities in the bugleweed were no different than the uranium-238 observed in historical perennial vegetation and shoreline plants (PNL-8797, PNL-10728).

4.6.3 Tree Sampling

Fruit trees growing on the site were sampled in 1998 to complement samples collected in 1997 (PNNL-11795). Fruit and leaves were collected from an apple tree at the Old Hanford Townsite and an apricot tree at the 100-F Area. Samples were analyzed for radiological constituents and trace metals. These trees are located on the Hanford Site and are not generally accessible to the public.

Concentrations of 13 trace metals were measured in leaf samples in 1997 and 1998. The metals were grouped into four distinct classifications based on the relationship of the concentrations in the samples to values from the literature that define natural background metal concentrations and concentrations of metals in vegetation associated with elevated and potentially toxic environmental

Table 4.6.3. Radionuclide Activities (pCi/g dry wt.) in Shoreline Vegetation, 1998 Compared to 1990-1992 (PNL-8797)

				Historic Maximum		
Species (1998)	Location	Radionuclide	1998 Activity[a]	Species	Activity[a]	Year
Willow	300 Area	Strontium-90	0.26 ± 0.05	Mulberry	0.17 ± 0.04	1990
		Cesium-137	0.07 ± 0.02	Mulberry	0.02 ± 0.01	1990
Bugleweed	HRM 28[b] (Old Hanford Townsite)	Technetium-99	0.66 ± 0.42	Mulberry	17 ± 2.3	1992
		Cesium-137	0.25 ± 0.03	Onion	0.15 ± 0.08	1992
		Uranium-238	0.64 ± 0.07	Onion	0.085 ± 0.012	1992
		Plutonium-239,240	0.006 ± 0.001	Asparagus	0.0006 ± 0.0004	1992
Mulberry tree	100-N Area Shoreline	Strontium-90	2.0 ± 0.37	Mulberry	437 ± 85	1990
		Strontium-90	28 ± 4.9	Mulberry	437 ± 85	1990
	1,600 m (1 mi) below 100-N Area shoreline	Strontium-90	0.20 ± 0.04	Mulberry	1.1 ± 0.21	1990

(a) ±2 sigma total analytical uncertainty.
(b) HRM = Hanford river mile, as measured from the Highway 24 Vernita Bridge.

exposures to metal contamination (Coughtrey and Thorne 1983, Coughtrey et al. 1983, Kabata-Pendias and Pendias 1984). The four classifications are all measured concentrations 1) less than the analytical detection limit, 2) less than or equal to the reported background concentrations, 3) less than the reported toxic concentration range, and 4) within the nominal toxic range of metal concentrations. The last classification may indicate that trees have been exposed to elevated concentrations of metals in their immediate habitat.

Based on this classification, all trace metal constituents measured in Hanford Site tree samples were below or within the concentration ranges associated with uncontaminated (i.e., background) habitat (Table 4.6.4). Chromium was measured in apricot leaves collected in 1997 from trees growing near the 100-D Reactor, within the bounds of known chromium groundwater plumes. Chromium was not detected in the tree samples collected at the Old Hanford Townsite or 100-F Area in either 1997 or 1998. The levels in the 100-D Area apricot leaf samples were well within the range of background vegetation concentrations and were below concentrations that are potentially harmful to vegetation. Metals concentrations in leaves are summarized in Appendix A, Table A.11.

Table 4.6.4. Classification of Trace Metal Concentrations (µg/g dry wt.) in Onsite Fruit Tree Samples Collected in 1997 and 1998 Compared to Nominal Background and Nominal Toxic Reference Concentrations[a]

Classification of Metals	Metal (Detection Limit)	Measured Concentration Range	Reference Concentrations[a]: Nominal Background Concentration Range	Reference Concentrations[a]: Nominal Toxic Range
All measured concentrations <detection level	Antimony (0.02)	<0.02	7.0 to 50	≥150
	Beryllium (0.1)	<0.1	0.001 to 0.4	10 to 50
	Selenium (2.0)	<2.0	0.03 to 5.0	5.0 to 30
	Silver (0.45)	<0.45	0.07 to 1.4	5.0 to 10
	Thallium (0.01)	<0.01	0.008 to 0.125	≥20
Measured concentration ≤nominal background concentratiozn range	Arsenic (0.15)	<0.15 to 0.39	0.02 to 1.5	5.0 to 20
	Lead (0.01)	<0.01 to 0.25	1.0 to 15	30 to 300
	Zinc (1.0)	2.0 to 16.7	27 to 141	100 to 400
Measured concentration <nominal toxic range	Cadmium (0.04)	<0.04 to 0.2	0.05 to 0.2	5 to 30
	Chromium (1.0)	<1.0 to 0.31[b]	0.1 to 0.5	5 to 30
	Copper (0.8)	0.34 to 14.1	6.3 to 29	20 to 100
	Mercury (0.0016)	<0.0016 to 0.022	0.003 to 0.011	1 to 3
	Nickel (0.15)	0.15 to 1.1	0.1 to 5.0	10 to 100
Measured concentration = nominal toxic range	None	None	None	None

(a) Nominal concentrations were taken from Coughtrey and Thorne (1983), Coughtrey et al. (1983), and Kabata-Pendias and Pendias (1984).
(b) Detection limit for 1998 samples was <1.0 µg/g dry wt.; detection limit for 1997 samples was 0.2 µg/g dry wt.

Analyses of leaves and fruit from the apricot and apple trees were also performed for tritium, gamma emitters, and strontium-90. No man-made gamma emitters were detected in any fruit tree samples collected in 1997 or 1998. Tritium (as distillate from plant material) was found in fruit tree leaves and fruit in 1998 at activities slightly higher than levels found in fruit tree samples collected at the 100-F Area and Old Hanford Townsite in 1997 (Table 4.6.5). The tritium activities in 1998 samples were approximately a factor of 10 lower than those found in 100-D Area apricot tree samples in 1997.

Strontium-90 was not found in apricot or apple fruit samples collected on the site in 1998; however, strontium-90 was found in leaf samples from the apple and apricot trees (Table 4.6.6). Strontium-90 activities in leaf samples were comparable to those observed in perennial vegetation samples routinely collected on the site in 1998.

Table 4.6.5. Tritium (pCi/L of sample distillate) in Fruit Tree Samples Collected from the Hanford Site, 1997 and 1998

Sample	Location	Activity[a]
1997		
Quince leaves	Old Hanford Townsite	15.2 ± 7.40
Apricot leaves	100-D Area	618 ± 57.2
Apricot leaves	100-D Area	503 ± 47.4
Apricot leaves	100-F Area	12.1 ± 7.20
1998		
Apricot leaves	100-F Area	62.7 ± 15.1
Apricot fruit	100-F Area	39.0 ± 9.56
Apple leaves	Old Hanford Townsite	60.5 ± 15.2
Apple fruit	Old Hanford Townsite	67.4 ± 16.3

(a) ±2 sigma total analytical error.

Table 4.6.6. Strontium-90 Activities (pCi/g dry wt.) in Fruit Tree Samples Collected from the Hanford Site, 1997 and 1998

Sample	Location	Activity[a]
1997		
Apricot leaves	100-D Area	0.015 ± 0.005
Apricot leaves	100-D Area	0.011 ± 0.004
Apricot leaves	100-F Area	0.16 ± 0.013
Quince fruit	Old Hanford Townsite	0.004 ± 0.005
Quince leaves	Old Hanford Townsite	0.094 ± 0.017
1998		
Apricot fruit	100-F Area	0.018 ± 0.013
Apricot leaves	100-F Area	0.13 ± 0.026
Apple fruit	Old Hanford Townsite	0.008 ± 0.007
Apple leaves	Old Hanford Townsite	0.036 ± 0.024

(a) ±2 sigma total analytical error.

4.7 External Radiation Surveillance

E. J. Antonio

External radiation is defined as radiation originating from a source external to the body. External radiation fields consist of a natural component and an anthropogenic, or man-made, component. The natural component can be divided into 1) cosmic radiation; 2) primordial radionuclides, primarily potassium-40, thorium-232, and uranium-238; and 3) an airborne component, primarily radon and its progeny. The man-made component consists of radionuclides generated for or from nuclear medicine, power, research, waste management, and consumer products containing nuclear materials. Environmental radiation fields may be influenced by the presence of radionuclides deposited as fallout from atmospheric testing of nuclear weapons or those produced and released to the environment during the production or use of nuclear fuel. During any year, external radiation levels can vary from 15% to 25% at any location because of changes in soil moisture and snow cover (National Council on Radiation Protection and Measurements 1987).

The interaction of radiation with matter results in energy being deposited in that matter. This is why your hand feels warm when exposed to a light source (e.g., sunlight, flame). Ionizing radiation energy deposited in a mass of material is called radiation absorbed dose. A special unit of measurement, called the rad, was introduced for this concept in the early 1950s. The International System of Units introduced the gray (Gy) and is defined as follows: 1 Gy is equivalent to 100 rad (American Society for Testing and Materials 1993).

One device for measuring radiation absorbed dose is the thermoluminescent dosimeter that absorbs and stores energy of ionizing radiation within the dosimeter's crystal lattice. By heating the material under controlled laboratory conditions, the stored energy is released in the form of light, which is measured and related to the amount of ionizing radiation energy stored in the material. Thermoluminescence, or light output exhibited by dosimeters, is proportional to the amount of radiation exposure (X), which is measured in units of roentgen (R). The exposure is multiplied by a factor of 0.98 to convert to a dose (D) in rad to soft tissue (Shleien 1992). This conversion factor relating R to rad is, however, assumed to be unity (1) throughout this report for consistency with past reports. This dose is further modified by a quality factor, Q = 1, for beta and gamma radiation and the product of all other modifying factors (N). N is assumed to be one to obtain dose equivalence (H) measured in rem. The sievert (Sv) is the equivalent of the rem.

$$D\ (\text{rad}) = X\ (R) * 1.0$$

$$H\ (\text{rem}) = D * N * Q$$

To convert to units of gray and sievert, divide rad and rem by 100, respectively.

In 1998, environmental external radiation exposure rates were measured at locations on and off the Hanford Site using thermoluminescent dosimeters and pressurized ionization chambers. External radiation and surface contamination surveys at specified locations were performed with portable radiation survey instruments.

4.7.1 External Radiation Measurements

In 1995, the Harshaw 8800-series system replaced the former Hanford Standard environmental dosimeter system. The Harshaw environmental dosimeter consists of two TLD-700 chips and two TLD-200 chips and also provides both shallow and deep dose measurement capabilities. Thermoluminescent dosimeters are positioned approximately 1 m (3 ft) above the ground at 26 onsite locations (Figure 4.7.1). Figure 4.7.2 shows the locations around the site perimeter, in nearby communities, and distant locations. Figure 4.7.3 gives the locations along the Columbia River shoreline. The number of thermoluminescent dosimeter measurement locations changed in 1998, with the addition of two onsite and five perimeter locations and the discontinuation of four Columbia River shoreline locations. All thermoluminescent dosimeters are collected and read quarterly. The two TLD-700 chips at each location are used to determine the average total environmental dose at that location. The average dose rate is computed by dividing the average total environmental dose by the length of time the dosimeter was in the field. Quarterly dose equivalent rates (millirem per day) at each location were converted to annual dose equivalent rates (millirem per year) by averaging the quarterly dose rates and multiplying by 365 d/yr. The two TLD-200 chips are included only to determine doses in the event of a radiological emergency.

To determine the maximum dose rate at each location, the quarterly doses were summed and divided by the total number of days a dosimeter was in the field at the specific location. The error uncertainties associated with the maximum dose rates were calculated as two times the square root of the summed quarterly variances divided by the total number of days the dosimeters were in the field. This method of determining the location with the maximum dose rate is slightly different, but statistically more accurate than simply determining the maximum dose rate based on quarterly dose rates, as calculated in previous years.

All community and most of the onsite and perimeter thermoluminescent dosimeter locations are collocated with air monitoring stations. The onsite and perimeter locations were selected based on determinations of the highest potentials for public exposures (i.e., access areas, downwind population centers) from past and current Hanford Site operations. The two background stations in Yakima and Toppenish were chosen because they are generally upwind and distant from the site.

The shoreline of the Hanford Reach of the Columbia River is monitored by a series of 24 thermoluminescent dosimeters located in the area from upstream of the 100-B Reactor shoreline to downstream of Bateman Island at the mouth of the Yakima River. Ground contamination surveys are also conducted quarterly at 13 shoreline locations. These measurements are made to estimate radiation exposure levels attributed to sources on the Hanford Site, to estimate background levels along the shoreline, and to help assess exposures to onsite personnel and offsite populations. Ground contamination surveys are conducted using Geiger-Müeller meters (Geiger counters) and Bicron® Microrem meters. Results are reported in counts per minute and microrem per hour, respectively. Geiger counter measurements are made within 2.54 cm (1 in.) of the ground and cover a 1-m^2 (10-ft^2) area. The Bicron® measurements are taken 1 m (3 ft) above the ground surface and at least 10 m (33 ft) away from devices or structures, which may contribute to the ambient radiation levels.

Pressurized ionization chambers are situated at four community-operated monitoring stations (see Section 7.4, "Community-Operated Environmental Surveillance Program"). These instruments provide a means of measuring ambient exposure rates near and downwind of the site and at locations distant and upwind of the site. Real-time exposure rate data are displayed at each station to provide information to

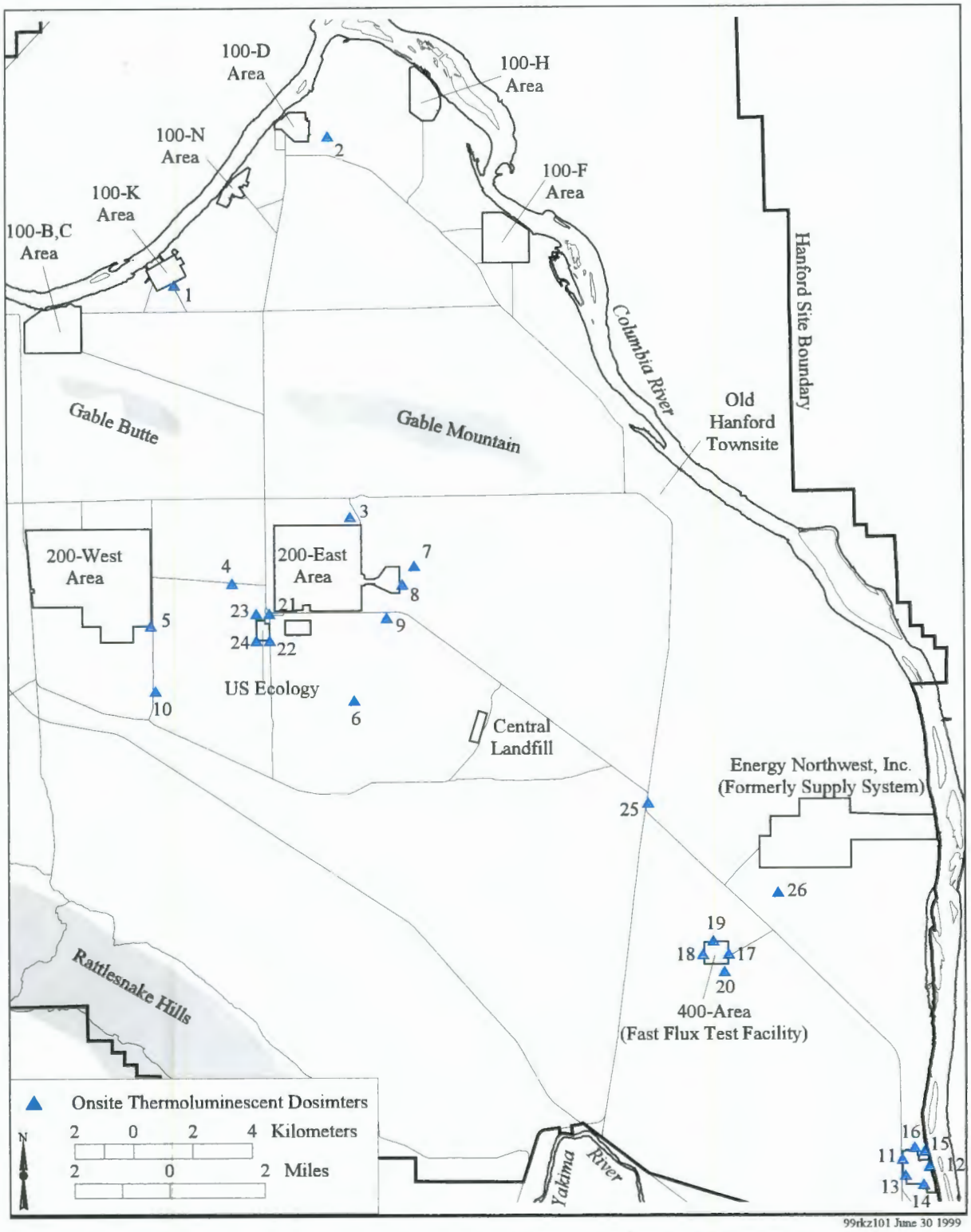

Figure 4.7.1. *Thermoluminescent Dosimeter Locations and Station Numbers on the Hanford Site, 1998*

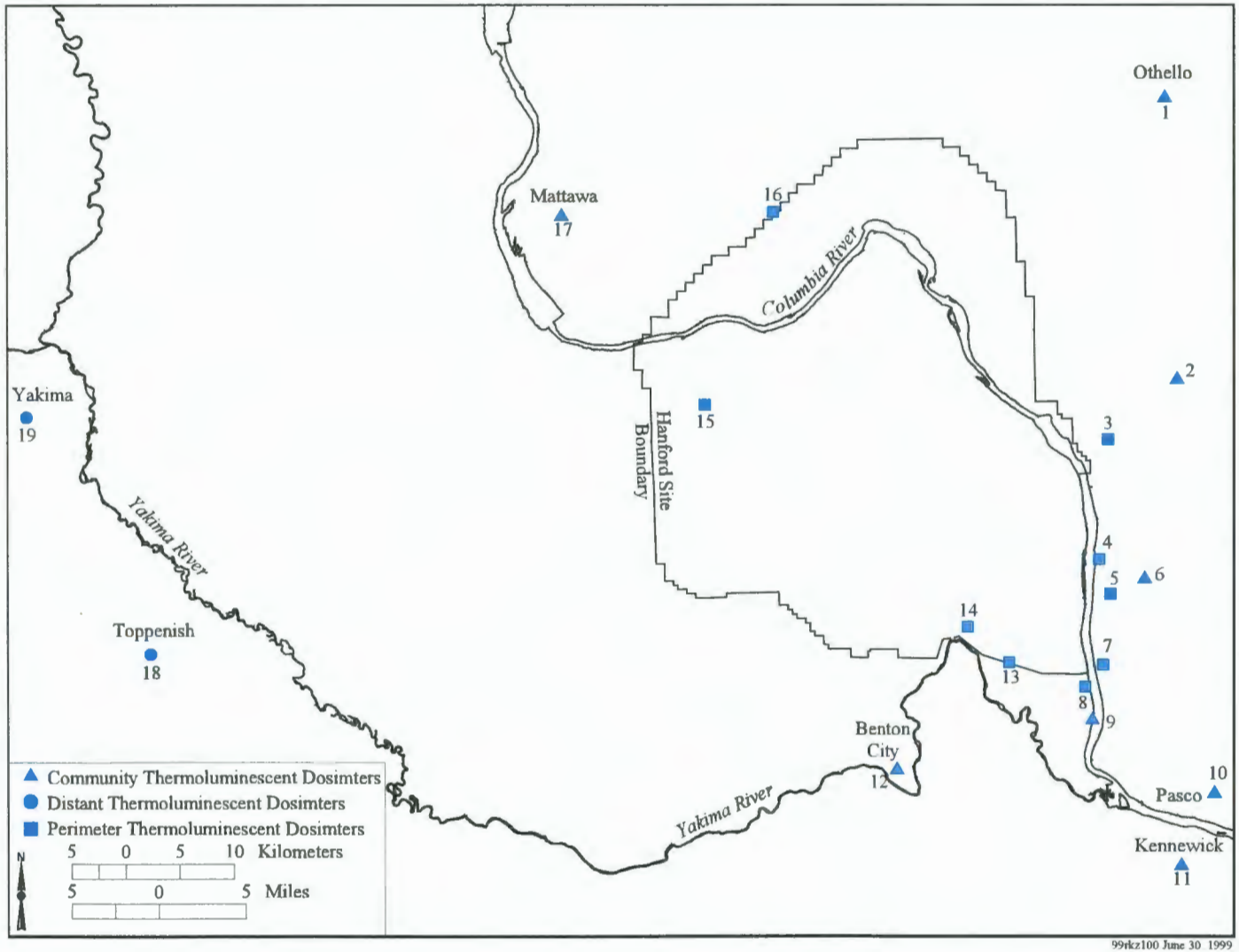

Figure 4.7.2. *Thermoluminescent Dosimeter Locations and Station Numbers for Community, Distant, and Perimeter Sites, 1998*

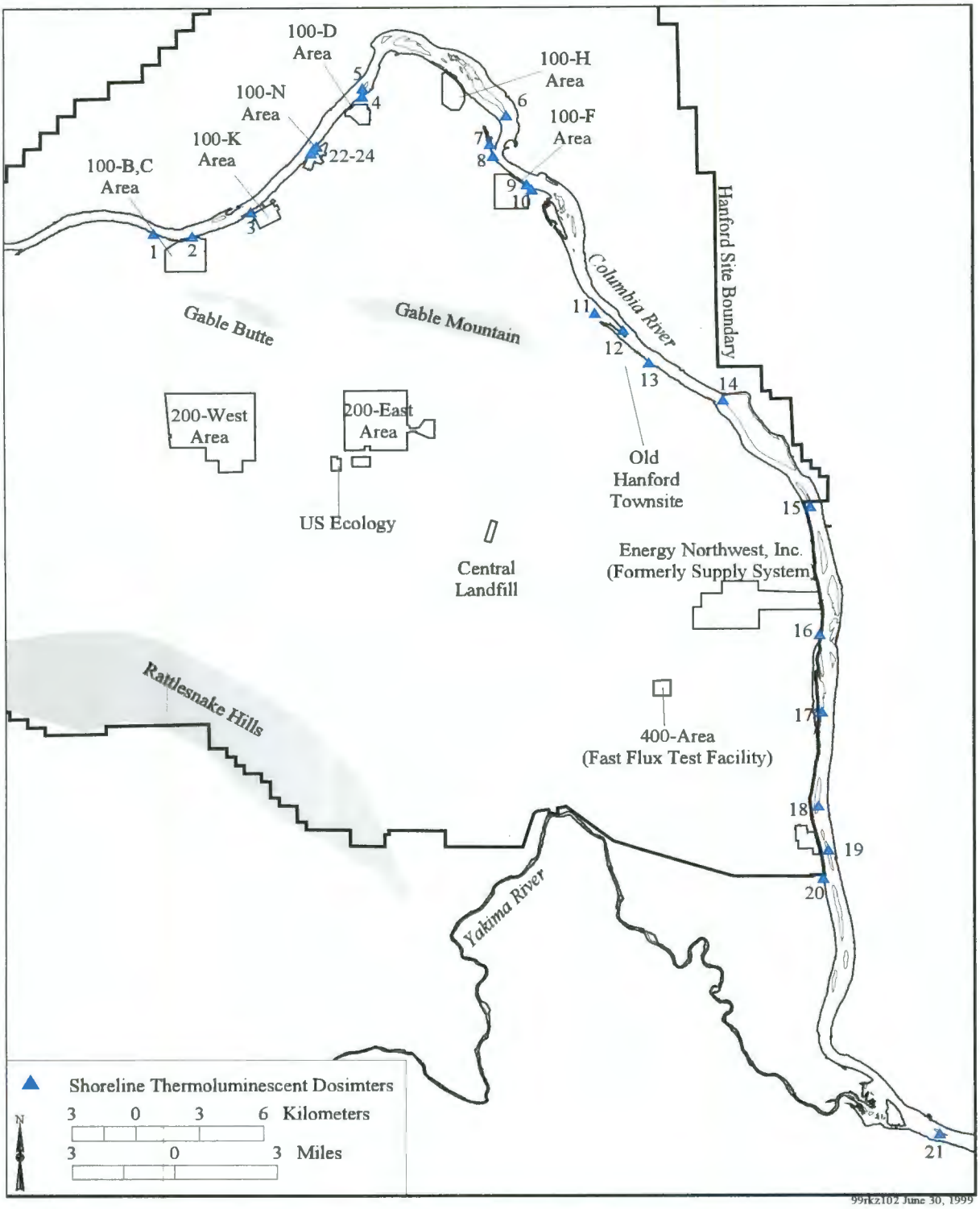

Figure 4.7.3. *Thermoluminescent Dosimeter Locations and Station Numbers on the Columbia River, 1998*

the public and to serve as an educational tool for the teachers who manage the stations.

4.7.1.1 External Radiation Results

Thermoluminescent dosimeter readings have been converted to annual dose equivalent rates by the process described above. Table 4.7.1 shows the maximum and mean dose rates for perimeter and offsite locations measured in 1998 and the previous 5 yr. External dose rates reported in Tables 4.7.1 through 4.7.3 include the maximum annual dose rate (±2 standard deviations) for all locations within a given surveillance zone and the mean dose rate (±2 standard error of the mean) for each distance class. Locations were classified (or grouped) based on their proximity to the site.

The annual dose rates measured in 1998 are given in Table 4.7.1. The mean perimeter dose rate was 89 ± 5 mrem/yr; in 1997, the mean was 89 ± 10 mrem/yr and the 5-year perimeter mean dose rate was 94 ± 6 mrem/yr. The mean background dose rate (measured at distant communities) in 1998, was 71 ± 1 mrem/yr, compared to the previous year's mean of 67 ± 1 mrem/yr and the current 5-year average of 78 ± 7 mrem/yr. The variation in dose rates may be partially attributed to changes in natural background radiation that can occur as a result of changes in annual cosmic radiation (up to 10%) and terrestrial radiation (15% to 25%) (National Council on Radiation Protection and Measurements 1987). Other factors possibly affecting the annual dose rates reported here have been described in PNL-7124 and include variations in the sensitivity of individual thermoluminescent dosimeter zero-dose readings, fading, random errors in the readout equipment, and changes in station locations, to name a few. Figure 4.7.4 displays a comparison of dose rates between onsite, perimeter, and distant thermoluminescent dosimeter locations from 1993 through 1998.

Table 4.7.2 provides the measured dose rates for thermoluminescent dosimeters positioned along the Columbia River shoreline. Dose rates were highest along the shoreline near the 100-N Area and were approximately 1.5 times the typical shoreline dose rates. The higher dose rates measured along the 100-N Area shoreline have been attributed to past waste management practices in that area (PNL-3127). The 1998 maximum annual shoreline dose rate was 152 ± 2 mrem/yr, which is not significantly different

Table 4.7.1. Dose Rates (mrem/yr[a]) Measured by Thermoluminescent Dosimeters at Perimeter and Offsite Locations, 1998 Compared to Previous 5 Years

		1998		1993-1997		
Location	Map Location[b]	Maximum[c]	Mean[d]	No. of Samples	Maximum[c]	Mean[d]
Perimeter	1 - 9	95 ± 2	89 ± 5	23	120 ± 11	94 ± 6
Community	10 - 17	90 ± 3	78 ± 4	38	107 ± 16	84 ± 3
Distant	18 - 19	72 ± 1	71 ± 1	11	101 ± 14	78 ± 7

(a) ±2 standard error of the mean.
(b) All station locations are shown on Figure 4.7.2.
(c) Maximum annual average dose rate for all locations within a given distance classification.
(d) Means computed by averaging annual means for each location within each distance classification.

Table 4.7.2. Dose Rates (mrem/yr[a]) Measured by Thermoluminescent Dosimeters Along the Hanford Reach of the Columbia River, 1998 Compared to Previous 5 Years

		1998		1993-1997		
Location	Map Location[b]	Maximum[c]	Mean[d]	No. of Samples	Maximum[c]	Mean[d]
Typical shoreline	1 - 21	102 ± 1	88 ± 3	120	141 ± 26	96 ± 3
100-N shoreline	22 - 24	152 ± 2	128 ± 27	19	257 ± 16	164 ± 21
All shoreline	1 - 24	152 ± 2	93 ± 7	139	257 ± 16	105 ± 5

(a) ±2 standard error of the mean.
(b) All locations are shown on Figure 4.7.3.
(c) Maximum annual average dose rate for all locations within a given distance classification.
(d) Means computed by averaging annual means for each location within each distance classification.

Table 4.7.3. Dose Rates (mrem/yr[a]) Measured by Thermoluminescent Dosimeters on the Hanford Site, 1998 Compared to Previous 5 Years

		1998		1993-1997		
Location	Map Location[b]	Maximum[c]	Mean[d]	No. of Samples	Maximum[c]	Mean[d]
100 Areas	1 - 2	89 ± 2	81 ± 15	11	108 ± 10	88 ± 8
200 Areas	3 - 10	94 ± 1	88 ± 4	35	121 ± 10	94 ± 4
300 Area	11 - 16	85 ± 2	83 ± 2	30	110 ± 12	88 ± 4
400 Area	17 - 20	86 ± 3	83 ± 3	20	111 ± 16	91 ± 9
600 Area	21 - 26	126 ± 2	92 ± 13	28	165 ± 14	103 ± 9
Combined onsite	1 - 26	126 ± 2	86 ± 4	124	165 ± 14	94 ± 3

(a) ±2 standard error of the mean.
(b) All locations shown on Figure 4.7.1.
(c) Maximum annual average dose rate for all locations within a given area classification.
(d) Means computed by averaging the annual means for each location within each distance classification.

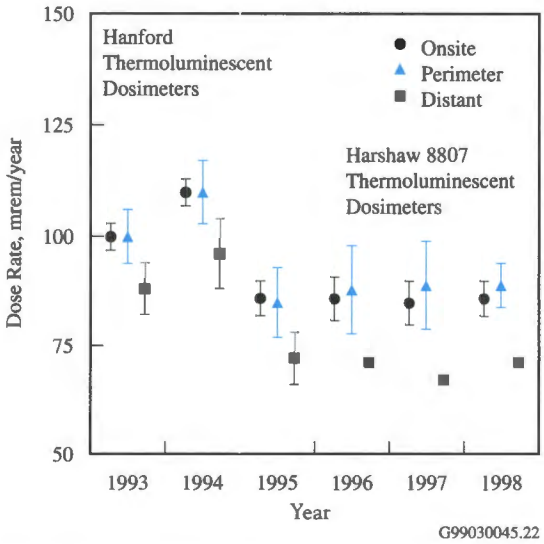

Figure 4.7.4. *Annual Average Dose Rates (±2 standard error of the mean), 1993 Through 1998*

from the maximum of 153 ± 31 mrem/yr measured in 1997, but is significantly different than the 5-year maximum of 257 mrem/yr. The 5-year maximum was measured in 1993 using the old Hanford standard dosimeter. The general public does not have legal access to the 100-N Area shoreline but does have access to the adjacent Columbia River. The dose implications associated with this access are discussed in Section 5.0, "Potential Radiological Doses from 1998 Hanford Operations."

Table 4.7.3 summarizes the results of 1998 onsite measurements, which are grouped by operational area. The average dose rates in all operational areas were higher than average dose rates measured at distant locations. The highest average dose rate on the site (126 ± 2 mrem/yr) was seen in the 600 Area and was due to waste disposal activities at US Ecology, Inc., a non-DOE facility. The 5-yr maximum onsite dose rate was 165 ± 14 mrem/yr.

4.7.2 Radiological Survey Results

In 1998, Geiger counters and Bicron® Microrem meters were used to perform radiological surveys at selected Columbia River shoreline locations. These surveys provide a coarse screening for elevated radiation fields. The surveys showed that radiation levels at the selected locations were comparable to levels observed at the same locations in previous years. The highest dose rate measured with the Bicron® Microrem meter (20 µRem/h) was measured in winter along the 100-N Area shoreline; the lowest dose rate measured was 4 µRem/h and was recorded at other locations in the spring and autumn. The highest reported count rate measured with the Geiger counter in ground level surveys was 100 cpm. The lowest ground level count rate (<50 cpm) was recorded at the same location and on the same day that the lowest Bicron® reading was recorded.

Survey data are not included in the 1998 surveillance data (PNNL-12088, APP. 1) but are maintained in the Surface Environmental Surveillance Project files at Pacific Northwest National Laboratory and can be obtained on written request.

Gamma radiation levels in air were continuously monitored in 1998 at four community-operated air monitoring stations (Section 7.4, "Community-Operated Environmental Surveillance Program"). These stations were located in Leslie Groves Park in Richland, at Edwin Markham Elementary School in north Franklin County, at Basin City Elementary School in Basin City, and at Heritage College in Toppenish (see Figure 4.1.1) Measurements were collected to determine ambient gamma radiation levels near and downwind of the site and upwind and distant from the site, to display real-time exposure rate information to the public living near the station, and to be an educational aid for the teachers who manage the stations.

Measurements at the Basin City and Edwin Markham Schools were obtained using Reuter-Stokes

Model S 1001-EM19 pressurized ionization chambers connected to Reuter-Stokes RSS-112 Radiation Monitoring Systems. Data were collected every 5 s; an average reading was calculated and recorded on an electronic data card every 30 s. Data cards were exchanged monthly. Readings at the Leslie Groves Park and Heritage College stations were collected every 10 s with a Reuter-Stokes Model RSS-121 pressurized ionization chamber, and an average reading was recorded every hour by a flat panel computer system located at the station. Data were obtained monthly from the computer via modem. Data were not collected at every station every month because of problems with the instrument batteries and electrical power. The data collected at each station each month are summarized in Table 4.7.4.

The measurements recorded at Basin City, Edwin Markham, and Leslie Groves Park during the year were similar and at background levels. The readings at Heritage College were also within normal levels, but were, on average, slightly lower than those measured near the Hanford Site.

Generally, monthly exposure rates ranged from a maximum of 13.7 mR/h at Edwin Markham in October to a minimum of 4.9 mR/h at Leslie Groves Park in November (see Table 4.7.4). The data collected in February at Basin City ranged from 0.1 to 177 μR/h. Several abnormally high and low readings were recorded during the first week of the month at Basin City and were related to a weak battery in the detector. Median readings at the stations near Hanford were consistently between 8.1 and 8.8 mR/h, and readings at the distant station (Heritage College) ranged between 7.7 and 8.2 mR/h. These dose rates were consistent with those measured by thermoluminescent dosimeters at these locations (Table 4.7.5).

Table 4.7.4. Average Exposure Rates Measured by Pressurized Ionization Chambers at Four Offsite Locations[a], 1998

Month		Exposure Rate, μR/h (number of readings)[b]							
		Leslie Groves Park[c]		Basin City[d]		Edwin Markham[d]		Toppenish[c]	
January	Median	8.6	(744)	ND		8.8	(695)	7.8	(744)
	Maximum	10.4		ND[e]		10.7		10	
	Minimum	5.0		ND		8.1		6.9	
February	Median	8.5	(672)	8.3	(433)	8.8	(1,503)	7.9	(672)
	Maximum	9.8		177		11.1		10.9	
	Minimum	5.0		0.1		8.4		7.5	
March	Median	8.5	(744)	ND		8.7	(294)	7.8	(737)
	Maximum	9.2		ND		9.4		8.8	
	Minimum	5.4		ND		8.5		7.6	
April	Median	8.4	(720)	8.3	(1,428)	8.7	(1,463)	7.8	(720)
	Maximum	9.5		9.9		11.7		8.6	
	Minimum	5.5		7.8		8.3		7.5	
May	Median	8.3	(744)	ND		8.6	(1,225)	7.8	(725)
	Maximum	9.9		ND		9.3		10.6	
	Minimum	6.3		ND		8.3		7.4	
June	Median	8.2	(720)	8.2	(1,471)	8.5	(294)	7.7	(696)
	Maximum	8.6		9.2		8.8		9.9	
	Minimum	7.1		7.9		8.3		7.4	
July	Median	8.2	(363)	ND		8.3	(822)	7.7	(225)
	Maximum	10.5		ND		11.7		10.4	
	Minimum	6.1		ND		7.5		7.5	
August	Median	8.7	(744)	8.1	(1,446)	8.4	(1,398)	ND	
	Maximum	8.7		8.7		8.8		ND	
	Minimum	7.8		7.8		7.5		ND	
September	Median	8.4	(658)	ND		8.6	(1,424)	8.0	(132)
	Maximum	9.9		ND		9.1		8.5	
	Minimum	6.6		ND		8.2		7.6	
October	Median	8.4	(716)	8.2	(1,524)	8.7	(1,347)	8.2	(744)
	Maximum	9.4		9.3		13.7		9.2	
	Minimum	5.8		7.9		8.2		7.7	
November	Median	8.5	(720)	ND		8.8	(1,321)	8.1	(722)
	Maximum	9.4		ND		11.4		12.6	
	Minimum	4.9		ND		8.4		7.7	
December	Median	8.5	(744)	8.1	(552)	ND		7.9	(746)
	Maximum	9.4		9.1		ND		8.6	
	Minimum	5.1		7.8		ND		7.4	

(a) Sampling locations are illustrated in Figure 4.1.1.
(b) Number of 30- or 60-min averages used to compute monthly average.
(c) Readings are stored every 60 min. Each 60-min reading is an average of 360 individual measurements.
(d) Readings are stored every 30 min. Each 30-min reading is an average of 360 individual measurements.
(e) ND = No data collected; equipment or power problems.

Table 4.7.5. Quarterly Average Exposure Rates (μR/h[a]) Measured by Thermoluminescent Dosimeters at Four Offsite Locations,[b] 1998

Quarter Ending	Leslie Groves Park	Basin City	Edwin Markham	Toppenish
March	8.958 ± 0.167	8.833 ± 0.167	8.500 ± 0.208	7.833 ± 0.000
June	NS[c]	NS	8.625 ± 0.167	8.167 ± 0.417
September	7.417 ± 0.500	NS	8.292 ± 0.208	7.708 ± 0.417
December	7.917 ± 0.125	8.833 ± 0.125	9.125 ± 0.375	8.542 ± 0.208

(a) ±2 standard deviation of the exposure rate.
(b) Sampling locations shown on Figure 4.1.1.
(c) NS = No sample; thermoluminescent dosimeter missing.

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5.0 Potential Radiological Doses from 1998 Hanford Operations

E. J. Antonio and K. Rhoads

During 1998, radionuclides reached the environment in gaseous and liquid effluents from Hanford Site operations. Monitored gaseous effluents were released from operating stacks and ventilation exhausts. Other potential sources include fugitive emissions from contaminated soil areas and unmonitored facilities. Liquid effluents were released from operating wastewater treatment facilities and from contaminated groundwater seeping into the Columbia River.

Potential radiological doses to the public from these releases were evaluated in detail to determine compliance with pertinent regulations and limits. Dose calculation methodology is discussed in Appendix D. The radiological impacts of 1998 Hanford operations were assessed in terms of the following:

- dose to a hypothetical, maximally exposed individual at an offsite location
- maximum dose rate from external radiation at a publicly accessible location on or within the site boundary
- dose to an avid sportsman who consumes wildlife that may have acquired contamination from radionuclides on the site
- total dose to the population residing within 80 km (50 mi) of the Hanford operating areas
- absorbed dose rate (rad/d) received by animals caused by radionuclide releases to the Columbia River.

It is generally accepted that radiological dose assessments should be based on direct measurements of radiation dose rates and radionuclide activities in the surrounding environment. However, the amounts of most radioactive materials released during 1998 from Hanford sources were generally too small to be measured directly once they were dispersed in the offsite environment. For many of the measurable radionuclides, it was difficult to identify the contributions from Hanford sources in the presence of contributions from worldwide fallout and from naturally occurring uranium and its decay products. Therefore, in nearly all instances, offsite doses were estimated using the Generation II (GENII) computer code Version 1.485 (PNL-6584) and Hanford Site-specific parameters listed in Appendix D and in PNNL-12088, APP. 1 to calculate activities of radioactive materials in the environment from effluent releases reported by the operating contractors.

As in the past, radiological doses from the water pathway were calculated based on the differences in radionuclide activities between upstream and downstream sampling points. During 1998, tritium, iodine-129, and uranium were found in the Columbia River downstream of Hanford at greater levels than predicted based on direct discharges from the 100 Areas. All other radionuclide activities were lower than those predicted from known releases. Riverbank springs water, containing these radionuclides, is known to enter the river along the portion of shoreline extending from the Old Hanford Townsite downstream to the 300 Area (see Section 4.2, "Surface Water and Sediment Surveillance" and Section 6.1, "Hanford Groundwater Monitoring Project"). No direct discharges of radioactive materials from the 300 Area to the Columbia River were reported in 1998.

The estimated dose[(a)] to the maximally exposed, offsite individual from Hanford operations in 1998 was 0.02 mrem (2×10^{-4} mSv) compared to 0.01 mrem

(a) Unless stated otherwise, the term "dose" in this section is the "total effective dose equivalent" (see Appendix B, "Glossary").

(1 x 10^{-4} mSv) reported for 1997. The dose to the local population of 380,000 (PNL-7803) from 1998 operations was the same as reported for 1997, 0.2 person-rem (0.002 person-Sv) (Section 5.0 in PNNL-11472). The 1998 average dose to the population was approximately 0.0005 mrem (5 x 10^{-6} mSv) per person (the same as 1997). The current U.S. Department of Energy (DOE) radiological dose limit (DOE Order 5400.5) for an individual member of the public is 100 mrem/yr (1 mSv/yr) from all pathways, which includes the U.S. Environmental Protection Agency's (EPA's) limit of 10 mrem/yr (0.1 mSv/yr) from airborne radionuclide emissions (Title 40, Code of Federal Regulations, Part 61 [40 CFR 61]). The national average radiological dose from natural sources is approximately 300 mrem/yr (3 mSv/yr) (National Council on Radiation Protection and Measurements 1987). Thus, 1998 Hanford emissions potentially contributed to the maximally exposed individual a dose equivalent to only 0.02% of the DOE dose limit, 0.2% of the EPA limit, or 0.006% of the average dose received from natural radioactivity in the environment. For the average member of the local population, these contributions were approximately 0.0005%, 0.005%, and 0.0002%, respectively.

The uncertainty associated with the radiological dose calculations on which this report is based has not been quantified. However, when Hanford-specific data were not available for parameter values (e.g., vegetation uptake and consumption factors), conservative values were selected from the literature for use in environmental transport models. Thus, radiological doses calculated using environmental models should be viewed as hypothetical maximum estimates of doses resulting from Hanford operations.

5.0.1 Maximally Exposed Individual Dose

The maximally exposed individual is a hypothetical person who lives at a location and has a lifestyle such that it is unlikely that other members of the public would receive a higher radiological dose. This individual's diet, dwelling place, and other factors were chosen to maximize the combined doses from all reasonable environmental pathways of exposure to radionuclides in Hanford Site effluents. In reality, such a combination of maximized parameters is highly unlikely to apply to any single individual.

The hypothetical location of the maximally exposed individual can vary from year to year, depending on the relative contributions of the several sources of radioactive effluents released to the air and to the Columbia River from Hanford facilities. Historically, two separate locations have been used to assess the dose to the maximally exposed individual: 1) the Ringold area, 26 km (16 mi) east of separations facilities in the 200 Areas and 2) the Riverview area across the river from Richland (Figure 5.0.1). The Ringold area is closer than Riverview to Hanford facilities that historically were major contributors of airborne effluents. At Riverview, the maximally exposed individual has the highest exposure to radionuclides in the Columbia River.

Since 1993, a third location across the Columbia River from the 300 Area has been considered. Because of the shift in site operations from strategic materials production to the current mission of developing waste treatment and disposal technologies and cleaning up contamination, the significance of the air emissions from the production facilities in the 200 Areas has decreased relative to those from the 300 Area. Therefore, a receptor directly across the river from the 300 Area, at Sagemoor, would be maximally exposed to airborne radionuclides from those facilities. The applicable exposure pathways for each of these locations are described below.

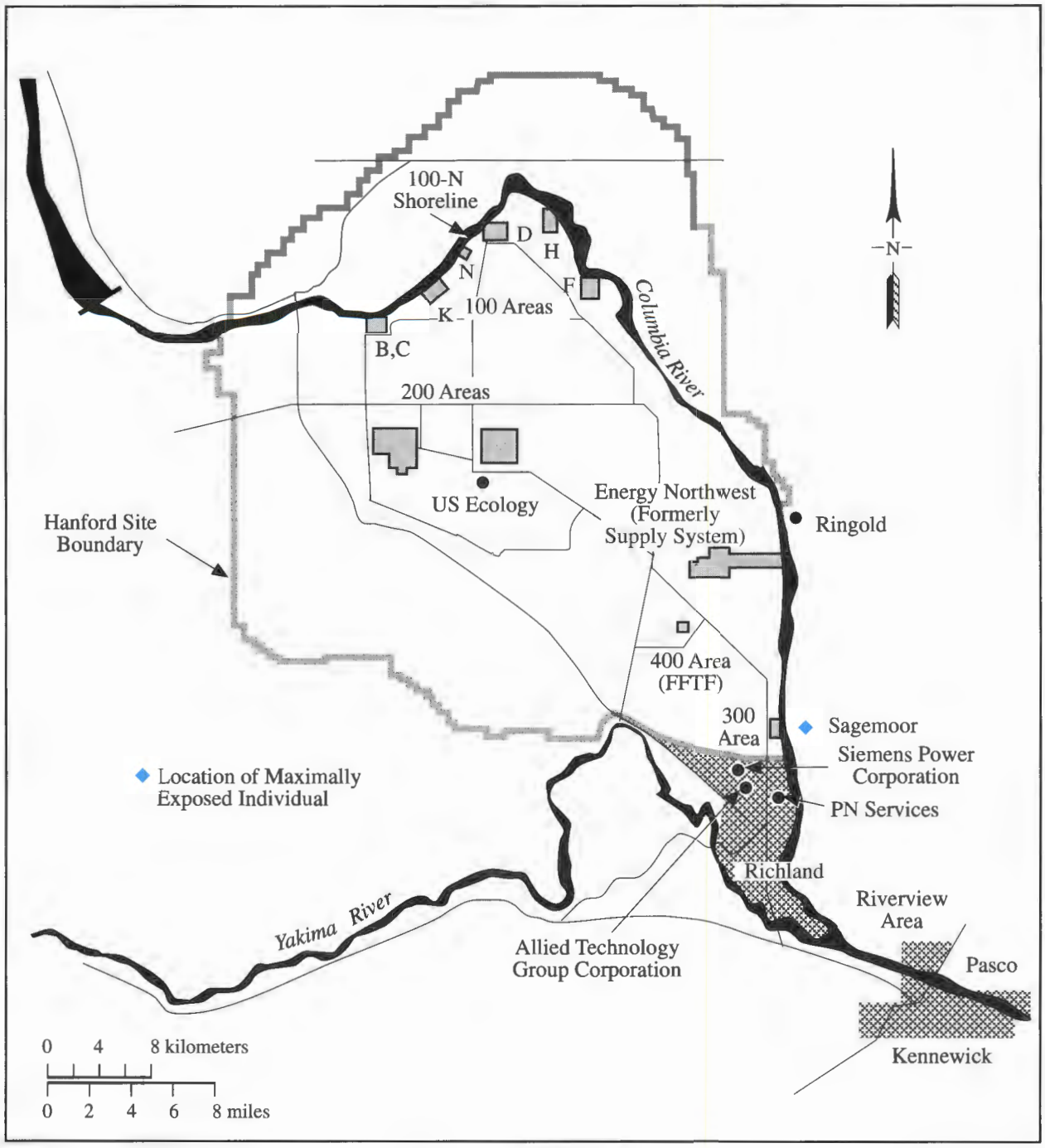

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Figure 5.0.1. *Locations Important to Dose Calculations*

The Ringold area is situated to maximize air pathway exposures from emissions in the 200 Areas, including direct exposure to the plume, inhalation, external exposure to radionuclides that deposit on the ground, and ingestion of locally grown food products. In addition, it is assumed that individuals at Ringold irrigate their crops with water taken from the Columbia River downstream of where groundwater enters the river from the 100 and 200-East Areas (discussed in Section 6.1, "Hanford Groundwater Monitoring Project"). This results in additional exposures from ingestion of irrigated food products and external irradiation from radionuclides deposited on the ground by irrigation. Recreational use of the Columbia River is also considered for this individual, resulting in direct exposure from water and radionuclides deposited on the shoreline and internal dose from ingestion of locally caught fish.

The Riverview area receptor is assumed to be exposed via the same pathways as the individual at Ringold, except that irrigation water from the Columbia River may contain radionuclides that enter the river at the 300 Area, in addition to those from upstream release points. This individual is also assumed to obtain domestic water from the river via a local water treatment system. Exposure of this individual from the air pathway is typically lower than exposure at Ringold because of the greater distance from the major, onsite, air emission sources.

The individual at Sagemoor, assumed to be located 1.5 km (1 mi) directly across the Columbia River from the 300 Area, receives the maximum exposure to airborne effluents from the 300 Area, including the same pathways as the individual at Ringold. Domestic water at this location comes from a well rather than from the river, and wells in this region are not contaminated by radionuclides of Hanford origin (EPS-87-367A). Although the farms located across from the 300 Area obtain irrigation water from upstream of the Hanford Site, the conservative assumption was made that the diet of the maximally exposed individual residing 1.5 km (1 mi) east of the 300 Area consisted totally of foods purchased from the Riverview area, which could contain radionuclides present in both liquid and gaseous effluents. The added contribution of radionuclides in the Riverview irrigation water maximizes the calculated dose from the air and water pathways combined.

The 1998 hypothetical, maximally exposed individual at Sagemoor was calculated to have received a slightly higher dose (0.022 mrem/yr) than the maximally exposed individual located at either Ringold (0.009 mrem/yr) or Riverview (0.012 mrem/yr). Radiological doses to the maximally exposed individual were calculated using the effluent data in Tables 3.1.1 and 3.1.4. Quantities of radionuclides assumed to be present in the Columbia River from riverbank springs were also calculated for input to the GENII code. The estimated releases to the river from these sources were derived from the difference between the upstream and downstream activities. These radionuclides were assumed to enter the river through groundwater seeps between the Old Hanford Townsite and the 300 Area.

The calculated doses for the hypothetical, maximally exposed individual (at Sagemoor) in 1998 are summarized in Table 5.0.1. These values include the doses received from exposure to liquid and airborne effluents during 1998, as well as the future, or committed dose from radionuclides that were inhaled or ingested during 1998. As releases from facilities and the doses from these sources decrease, the contribution of diffuse sources such as wind-blown contaminated soil becomes relatively more significant. An upper estimate of the dose from diffuse sources is discussed in Section 5.0.3, "Comparison with Clean Air Act Standards." The estimated dose from diffuse sources was similar to the dose reported in Table 5.0.1 for measured emissions. Site-specific parameters for food pathways, diet, and recreational activity used for the dose calculations are contained in Appendix D (Tables D.2, D.2, and D.4, respectively).

Table 5.0.1. Dose to the Hypothetical, Maximally Exposed Individual Residing at Sagemoor from 1998 Hanford Operations

Effluent	Pathway	Dose Contributions from Operating Areas, mrem: 100 Areas	200 Areas	300 Area	400 Area	Pathway Total
Air	External	1.2×10^{-8}	8.8×10^{-8}	2.2×10^{-8}	1.9×10^{-8}	1.4×10^{-7}
	Inhalation	6.6×10^{-6}	1.6×10^{-4}	1.4×10^{-3}	1.4×10^{-5}	1.6×10^{-3}
	Foods	2.9×10^{-7}	2.8×10^{-5}	1.3×10^{-2}	9.4×10^{-5}	1.3×10^{-2}
	Subtotal air	6.9×10^{-6}	1.9×10^{-4}	1.4×10^{-2}	1.1×10^{-4}	1.5×10^{-2}
Water	Recreation	1.7×10^{-6}	3.2×10^{-5}	0.0[a]	0.0	3.4×10^{-5}
	Foods	8.5×10^{-4}	3.7×10^{-3}	0.0	0.0	4.6×10^{-3}
	Fish	7.0×10^{-4}	2.4×10^{-3}	0.0	0.0	3.1×10^{-3}
	Drinking water	0.0	0.0	0.0	0.0	0.0
	Subtotal water	1.6×10^{-3}	6.1×10^{-3}	0.0	0.0	7.7×10^{-3}
Combined total		1.6×10^{-3}	6.3×10^{-3}	1.4×10^{-2}	1.1×10^{-4}	2.2×10^{-2}

(a) Zeros indicate no dose contribution to maximally exposed individual through water pathway.

The total radiological dose to the hypothetical, maximally exposed, offsite individual in 1998 was calculated to be 0.02 mrem (2×10^{-4} mSv) compared to 0.01 mrem (1×10^{-4} mSv) calculated for 1997. The primary pathways contributing to this dose (and the percentage of all pathways) were the following:

- consumption of foods grown downwind of the 300 Area (59%), principally tritium released from the 300 and 400 Areas
- consumption of food irrigated with Columbia River water or fish from the Columbia River (27%), principally isotopes of uranium and tritium.

The DOE radiological dose limit for any member of the public from all routine DOE operations is 100 mrem/yr (1 mSv/yr) (DOE Order 5400.5). The dose calculated for the maximally exposed individual for 1998 was 0.02% of the DOE limit. Thus, the Hanford Site was in compliance with applicable federal and state regulations.

The doses from Hanford operations for the maximally exposed individual for 1993 through 1998 are illustrated in Figure 5.0.2. During each year, the doses were estimated using methods and computer codes previously described. In 1992, the maximally exposed individual was located at Riverview. For 1993 through 1998, the hypothetical, maximally exposed individual was located across the Columbia River from the 300 Area at Sagemoor.

5.0.2 Special Case Exposure Scenarios

Exposure parameters used to calculate the dose to the maximally exposed individual are selected to define a high-exposure scenario that is unlikely to occur. Such a scenario does not necessarily result in the highest conceivable radiological dose. Low-probability exposure scenarios exist that could

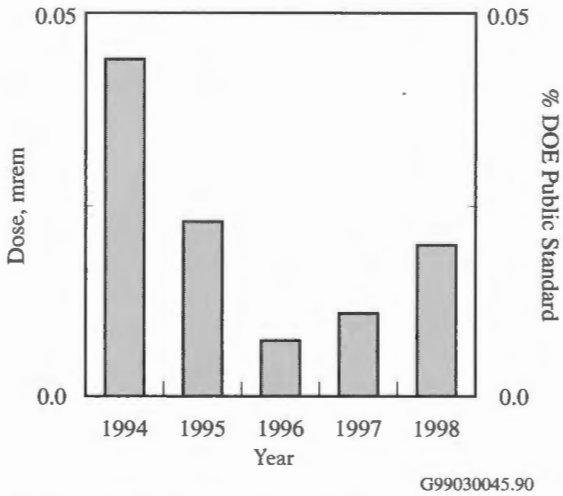

***Figure 5.0.2**. Calculated Dose to the Hypothetical, Maximally Exposed Individual, 1994 Through 1998*

result in somewhat higher doses. Three scenarios that could potentially lead to larger doses include 1) an individual who would spend time at the site boundary location with the maximum external radiological dose rate, 2) a sportsman who might consume contaminated wildlife that migrated from the site, and 3) a consumer of drinking water at the Fast Flux Test Facility in the 400 Area.

5.0.2.1 Maximum "Boundary" Dose Rate

The boundary radiological dose rate is the external radiological dose rate measured at publicly accessible locations on or near the site. The boundary dose rate was determined from radiation exposure measurements using thermoluminescent dosimeters at locations of expected elevated dose rates on the site and at representative locations off the site. These boundary dose rates should not be used to calculate annual doses to the general public because no one can actually reside at any of these boundary locations. However, these rates can be used to determine the dose to a specific individual who might spend some time at that location.

External radiological dose rates measured in the vicinity of the 100-N, 200, 300, and 400 Areas are described in Section 4.7, "External Radiation Surveillance." Results for the 200 Areas were not used because these locations are not accessible to the public. Radiation measurements made at the 100-N Area shoreline (see Figure 5.0.1) were consistently above the background level and represent the highest measured boundary dose rates. The Columbia River provides public access to an area within approximately 100 m (330 ft) of the N Reactor and supporting facilities.

The dose rate at the location with the highest exposure rate along the 100-N Area shoreline during 1998 was 0.02 mrem/h (2×10^{-4} mSv/h), or approximately twice the average background dose rate of 0.01 mrem/h (1×10^{-4} mSv/h) normally observed at other shoreline locations. Therefore, for every hour someone spent at the 100-N Area shoreline during 1998, the external radiological dose received from Hanford operations would be approximately 0.01 mrem (1×10^{-4} mSv) above the natural background dose. If an individual spent 2 h at this location, a dose would be received that is similar to the annual dose calculated for the hypothetical, maximally exposed individual at Sagemoor. The public can approach the shoreline by boat but they are legally restricted from stepping onto the shoreline. Therefore, an individual is unlikely to remain on or near the shoreline for an extended period of time.

5.0.2.2 Sportsman Dose

Wildlife have access to areas of the site that contain radioactive materials, and some do become contaminated. Sometimes contaminated wildlife travel off the site. Sampling is conducted on the site to estimate the maximum contamination levels that might possibly exist in animals hunted off the site. Because this scenario has a relatively low probability of occurring, these doses are not included in the maximally exposed individual calculation.

Listed below are estimates of the radiological doses that could have resulted if wildlife containing the maximum levels measured in onsite wildlife in 1998 migrated off the site, were hunted, and were eaten.

- The dose from eating 1 kg (2.2 lb) of sucker or carp fillets that contains the maximum cesium-137 activity (0.04 pCi/g) measured in samples collected from the Hanford Reach of the Columbia River in 1998 is estimated to be 2×10^{-2} mrem (2×10^{-5} mSv).
- The dose from eating 1 kg (2.2 lb) of pheasant meat that contains the maximum cesium-137 activity (0.018 pCi/g) measured in samples collected on the site in 1998 is estimated to be 9×10^{-4} mrem (9×10^{-6} mSv).
- The dose from ingesting 1 kg (2.2 lb) of venison that contains the maximum cesium-137 activity (0.005 pCi/g) measured in a sample harvested on the site in 1998 is estimated to be 3×10^{-4} mrem (3×10^{-6} mSv).

These are very low doses and do not exceed the hypothetical, maximally exposed individual dose at Sagemoor. In fact, the hypothetical person who ate 1 kg (2.2 lb) of sucker or carp fillets at the maximum measured cesium-137 activity would receive the same dose as the maximally exposed individual located at Sagemoor. A person would have to consume 22 kg (48 lb) of pheasant meat or 66 kg (145 lb) of venison that contain the maximum measured cesium-137 activity to receive the same dose as the hypothetical, maximally exposed individual at Sagemoor. The methodology for determining doses from consumption of wildlife was to multiply the maximum activity measured in edible tissue by a dose conversion factor for ingestion of that flesh, which is addressed in more detail in PNL-7539.

5.0.2.3 Fast Flux Test Facility Drinking Water

During 1998, groundwater was used as drinking water by workers at the Fast Flux Test Facility in the 400 Area. Therefore, this water was sampled and analyzed throughout the year in accordance with applicable drinking water regulations (40 CFR 61). All annual average radionuclide activities measured during 1998 were well below applicable drinking water standards, but tritium was detected at levels greater than typical background values (see Section 4.3, "Hanford Site Drinking Water Surveillance," and Appendix D). Based on the measured groundwater well concentrations, the potential dose to Fast Flux Test Facility workers (an estimate derived by assuming a consumption of 1 L/d [0.26 gal/d] for 240 working days) would be approximately 0.02 mrem (0.0002 mSv). Although the hypothetical Fast Flux Test Facility worker would receive approximately the same dose as the 1998 offsite maximally exposed individual, the dose is well below the drinking water dose limit of 4 mrem for public drinking water supplies.

5.0.3 Comparison with Clean Air Act Standards

Limits for radiation dose to the public from airborne radionuclide emissions at DOE facilities are provided in 40 CFR 61, Subpart H. The regulation specifies that no member of the public shall receive a dose of >10 mrem/yr (0.1 mSv/yr) from exposure to airborne radionuclide effluents, other than radon, released at DOE facilities (EPA 520/1-89-005). The regulation also requires that each DOE facility submit an annual report that supplies information about atmospheric emissions for the preceding year and their potential offsite impacts. Washington Administrative Code (WAC) 246-247 imposes requirements similar to those in 40 CFR 61, Subpart H, except that the 10-mrem/yr dose standard includes the dose resulting from radon emissions from other than naturally occurring sources. The following summarizes information that is provided in more detail in the 1998 air emissions report (DOE/RL-99-41), which addresses both EPA and Washington State regulations.

The 1998 air emissions from monitored Hanford Site facilities resulted in a potential dose to a maximally exposed individual at Sagemoor of 0.013 mrem (1.3×10^{-4} mSv), which represents <0.13% of the 10-mrem/yr standard. The Clean Air Act of 1986 requires the use of CAP-88 (EPA-402-B-92-001) or other EPA-approved models to demonstrate compliance with the standard, and the assumptions embodied in these codes differ slightly from standard assumptions used at Hanford for reporting to DOE via this report. Nevertheless, the result of calculations performed with CAP88-PC for air emissions from Hanford facilities agrees well with doses calculated for this report using the GENII code (0.015 mrem, or 1.5×10^{-4} mSv, for air pathways).

The December 15, 1989 revisions to the Clean Air Act (40 CFR 61, Subpart H) require DOE facilities to estimate the dose to a member of the public for radionuclides released from all potential sources of airborne radionuclides. DOE, Washington State, and EPA have interpreted the regulation to include diffuse and unmonitored sources as well as monitored point sources. The EPA has not specified or approved methods for estimating emissions from diffuse sources, and standardization is difficult because of the wide variety of such sources at DOE sites. Estimates of potential diffuse source emissions at Hanford have been developed using environmental surveillance measurements of airborne radionuclides at the site perimeter.

During 1998, the estimated dose from diffuse sources to the maximally exposed individual at Sagemoor was 0.025 mrem (2.5×10^{-4} mSv), which was greater than the estimated dose at that location from stack emissions (0.013 mrem, or 1.3×10^{-4} mSv). Doses at other locations around the Hanford perimeter ranged from 0.006 to 0.04 mrem (6×10^{-5} to 4×10^{-4} mSv). Based on these results, the combined dose from stack emissions and diffuse and unmonitored sources during 1998 was well below the EPA standard.

5.0.4 Collective Dose to the Population Within 80 km (50 mi)

Exposure pathways for the general public from releases of radionuclides to the atmosphere include inhalation, air submersion, and consumption of contaminated food. Pathways of exposure for radionuclides present in the Columbia River include consumption of drinking water, fish, and irrigated foods and external exposure during aquatic recreation. The regional collective dose from 1998 Hanford Site operations was estimated by calculating the radiological dose to the population residing within an 80-km (50-mi) radius of the onsite operating areas. Results of the dose calculations are shown in Table 5.0.2. Food pathway, dietary, residency, and recreational activity assumptions for these calculations are given in Appendix D (Tables D.1 through D.4).

The collective dose calculated for the population was 0.2 person-rem (0.002 person-Sv) in 1998, and remained unchanged from the 1997 population dose. The 80-km (50-mi) collective doses attributed to Hanford operations from 1994 through 1998 are compared in Figure 5.0.3. Primary pathways contributing to the 1998 population dose were the following:

- consumption of drinking water (57%) contaminated with radionuclides released to the Columbia River at Hanford, principally tritium
- consumption of foodstuffs (33%) contaminated with radionuclides released in gaseous effluents, primarily tritium from the 300 and 400 Areas and iodine-129 from the Plutonium-Uranium Extraction Plant stack
- inhalation of radionuclides (14%) that were released to the air, principally tritium emitted from the 300 Area stacks and the 400 Area, and plutonium-239,240 released from the 200 Area stacks.

Table 5.0.2. Dose to the Population from 1998 Hanford Operations

Effluent	Pathway	Dose Contributions from Operating Areas, person-rem: 100 Areas	200 Areas	300 Area	400 Area	Pathway Total
Air	External	2.2×10^{-6}	5.5×10^{-6}	1.1×10^{-7}	5.9×10^{-7}	8.4×10^{-6}
	Inhalation	1.8×10^{-3}	1.5×10^{-2}	9.6×10^{-3}	6.3×10^{-4}	2.7×10^{-2}
	Foods	4.5×10^{-5}	1.8×10^{-3}	5.3×10^{-2}	2.5×10^{-3}	5.7×10^{-2}
	Subtotal air	1.8×10^{-3}	1.7×10^{-2}	6.3×10^{-2}	3.1×10^{-3}	8.4×10^{-2}
Water	Recreation	1.3×10^{-5}	2.0×10^{-4}	0.0[a]	0.0	2.1×10^{-4}
	Foods	9.0×10^{-4}	4.1×10^{-3}	0.0	0.0	5.0×10^{-3}
	Fish	2.6×10^{-4}	8.8×10^{-4}	0.0	0.0	1.1×10^{-3}
	Drinking water	2.1×10^{-3}	1.0×10^{-1}	0.0	0.0	1.0×10^{-1}
	Subtotal water	3.3×10^{-3}	1.1×10^{-1}	0.0	0.0	1.1×10^{-1}
Combined total		5.1×10^{-3}	1.2×10^{-1}	6.3×10^{-2}	3.1×10^{-3}	1.9×10^{-1}

(a) Zeros indicate no dose contribution to the population through the water pathway.

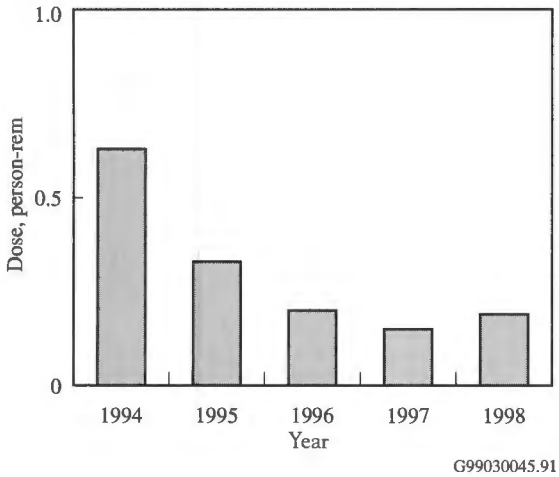

Figure 5.0.3. *Calculated Dose to the Population Within 80 km (50 mi) of the Hanford Site, 1994 Through 1998*

The average per capita dose from 1998 Hanford Site operations based on a population of 380,000 within 80 km (50 mi) was 0.0005 mrem (5×10^{-6} mSv). To place this dose from Hanford activities into perspective, the estimate may be compared with doses from other routinely encountered sources of radiation such as natural terrestrial and cosmic background radiation, medical treatment and x-rays, natural radionuclides in the body, and inhalation of naturally occurring radon. The national average radiological dose from these other sources is illustrated in Figure 5.0.4. The estimated average per capita dose to members of the public from Hanford sources is only approximately 0.0002% of the annual per capita dose (300 mrem) from natural background sources.

The doses from Hanford effluents to the maximally exposed individual and to the population within 80 km (50 mi) are compared to appropriate standards and natural background radiation in Table 5.0.3. This table shows that the calculated radiological doses from Hanford operations in 1998 are a small percentage of the standards and of natural background.

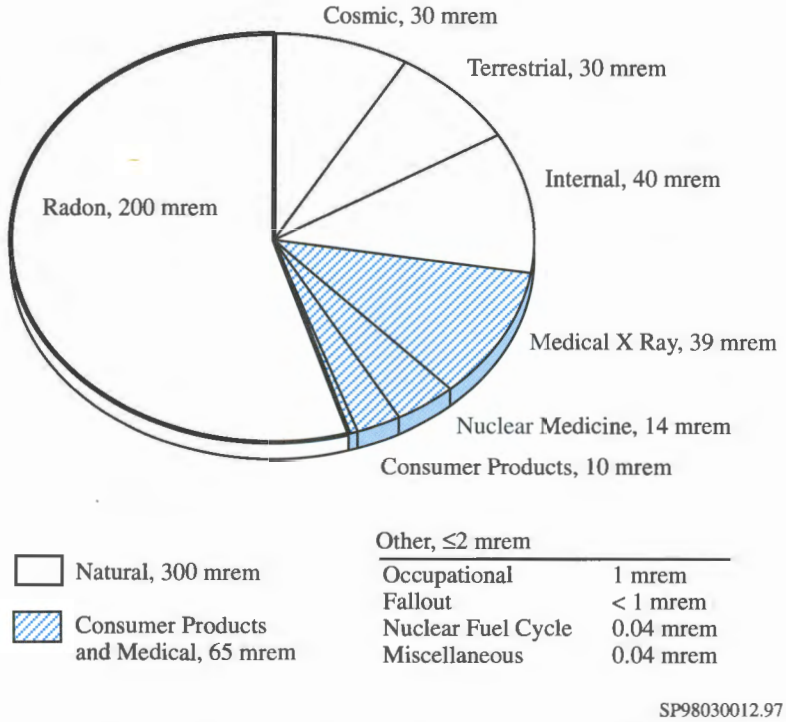

***Figure 5.0.4**. National Annual Average Radiological Doses from Various Sources (National Council on Radiation Protection and Measurements 1987)*

Table 5.0.3. Summary of Doses to the Public in the Vicinity of the Hanford Site from Various Sources, 1998

Source	Maximum Individual	Population
All Hanford effluents	0.022 mrem[a]	0.2 person-rem[a]
DOE limit	100 mrem	--
Percent of DOE limit[b]	0.022	--
Background radiation	300 mrem	110,000 person-rem
Hanford dose percent of background	<0.01	2×10^{-4}
Doses from gaseous effluents	0.015 mrem	--
EPA air standard[c]	10 mrem	--
Percent of EPA standard	0.15	--

(a) To convert the dose values to mSv or person-Sv, divide by 100.
(b) DOE Order 5400.5.
(c) 40 CFR 61.

5.0.5 Doses from Other than DOE Sources

Various non-DOE industrial sources of public radiation exposure exist at or near the Hanford Site. These include the low-activity, commercial, radioactive waste burial ground at Hanford operated by US Ecology; the nuclear power generating station at Hanford operated by Energy Northwest (formerly known as the Washington Public Power Supply System); the nuclear fuel production plant operated by Siemens Power Corporation; the commercial, low-activity, radioactive waste compacting facility operated by Allied Technology Group Corporation; and a commercial decontamination facility operated by PN Services (see Figure 5.0.1). DOE maintains an awareness of other man-made sources of radiation, which, if combined with the DOE sources, might have the potential to cause a dose exceeding 10 mrem (0.1 mSv) to any member of the public. With information gathered from these companies, it was conservatively estimated that the total 1998 individual dose from their combined activities is on the order of 0.05 mrem (5×10^{-4} mSv). Therefore, the combined dose from Hanford area non-DOE and DOE sources to a member of the public for 1998 was well below any regulatory dose limit.

5.0.6 Hanford Public Radiological Dose in Perspective

This section provides information to put the potential health risks of radionuclide emissions from the Hanford Site into perspective. Several scientific studies (National Research Council 1980, 1990; United Nations Science Committee on the Effects of Atomic Radiation 1988) have been performed to estimate the possible risk of detrimental health effects from exposure to low levels of radiation. These studies have provided vital information to government and scientific organizations that recommend radiological dose limits and standards for public and occupational safety.

Although no increase in the incidence of health effects from low doses of radiation has actually been confirmed by the scientific community, some scientists accept the hypothesis that low-level doses might increase the probability of cancer or other health effects. Regulatory agencies conservatively (cautiously) assume that the probability of these types of health effects at low doses (down to zero dose) is the same per unit dose as the same health effects observed at much higher doses (e.g., in atomic bomb victims, radium dial painters). This is also known as the linear no threshold hypothesis. Under these assumptions, even natural background radiation (which is hundreds of times greater than radiation from current Hanford releases) increases each person's probability or chance of developing a detrimental health effect.

Not all scientists agree on how to translate the available data on health effects into the numerical probability (risk) of detrimental effects from low-level radiological doses. Some scientific studies have indicated that low radiological doses may cause beneficial effects (Sagan 1987). Because cancer and hereditary diseases in the general population may be caused by many sources (e.g., genetic defects, sunlight, chemicals, background radiation), some scientists doubt that the risk from low-level radiation exposure can ever be conclusively proved. In developing Clean Air Act regulations, the EPA uses a probability value of approximately 4 per 10 million (4×10^{-7}) for the risk of developing a fatal cancer after receiving a dose of 1 mrem (0.01 mSv) (EPA 520/1-89-005). Additional data (National Research Council 1990) support the reduction of even this

small risk value, possibly to zero, for certain types of radiation when the dose is spread over an extended time.

Government agencies are trying to determine what level of risk is safe for members of the public exposed to pollutants from industrial activities (e.g., DOE facilities, nuclear power plants, chemical plants, hazardous waste sites). All of these industrial activities are considered beneficial to people in some way such as providing electricity, national defense, waste disposal, and consumer products. These government agencies have a complex task in establishing environmental regulations that control levels of risk to the public without unnecessarily reducing needed benefits from industry.

One perspective on risks from industrial activities is to compare them to risks involved in other typical activities. For instance, two risks that an individual receives from flying on an airliner are the risks of added radiological dose (from a stronger cosmic radiation field that exists at higher altitudes) and the possibility of being in an aircraft accident. Table 5.0.4 compares the estimated risks from various radiological doses to the risks of some activities encountered in everyday life. Table 5.0.5 lists some activities considered approximately equal in risk to that from the dose received by the maximally exposed individual from monitored Hanford effluents in 1998.

Table 5.0.4. Estimated Risk from Various Activities and Exposures[a]

Activity or Exposure Per Year	Risk of Fatality
Smoking 1 pack of cigarettes per day (lung/heart/other diseases)	$3{,}600 \times 10^{-6}$
Home accidents	100×10^{-6}[b]
Taking contraceptive pills (side effects)	20×10^{-6}
Drinking 1 can of beer or 0.12 L (4 oz) of wine per day (liver cancer/cirrhosis)	10×10^{-6}
Firearms, sporting (accidents)	10×10^{-6}[b]
Flying as an airline passenger (cross-country roundtrip--accidents)	8×10^{-6}[b]
Eating approximately 54 g (4 tbsp) of peanut butter per day (liver cancer)	8×10^{-6}
Pleasure boating (accidents)	6×10^{-6}[b]
Drinking chlorinated tap water (trace chloroform--cancer)	3×10^{-6}
Riding or driving in a passenger vehicle (483 km [300 mi])	2×10^{-6}[b]
Eating 41 kg (90 lb) of charcoal-broiled steaks (gastrointestinal tract cancer)	1×10^{-6}
Natural background radiation dose (300 mrem, 3 mSv)	0 to 120×10^{-6}
Flying as an airline passenger (cross-country roundtrip--radiation)	0 to 5×10^{-6}
Dose of 1 mrem (0.01 mSv) for 70 yr	0 to 0.4×10^{-6}
Dose to the maximally exposed individual living near Hanford in 1998 (0.02 mrem, 2×10^{-4} mSv)	0 to 0.008×10^{-6}

(a) These values are generally accepted approximations with varying levels of uncertainty; there can be significant variation as a result of differences in individual lifestyle and biological factors (Atallah 1980; Dinman 1980; Ames et al. 1987; Wilson and Crouch 1987; Travis and Hester 1990).

(b) Real actuarial values. Other values are predicted from statistical models. For radiation dose, the values are reported in a possible range from the least conservative (0) to the currently accepted most conservative value.

Table 5.0.5. Activities Comparable in Risk to the 0.02-mrem (2 x 10^{-4} mSv) Dose Calculated for the 1998 Maximally Exposed Individual

Driving or riding in a car 1.1 km (approximately 0.66 mi)
Smoking less than 1/100 of a cigarette
Flying 2.7 km (1.7 mi) on a commercial airliner
Eating approximately 4/5 tbsp of peanut butter
Eating one 0.18-kg (0.4-lb) charcoal-broiled steak
Drinking approximately 1 L (1.1 qt) of chlorinated tap water
Being exposed to natural background radiation for approximately 19 min in a typical terrestrial location
Drinking approximately 0.056 L (<2 oz) of beer or 0.02 L (0.6 oz) of wine

5.0.7 Dose Rates to Animals

Conservative (upper) estimates have been made of the radiological dose to native aquatic organisms in accordance with the DOE Order 5400.5 interim requirement for management and control of liquid discharges. Possible radiological dose rates during 1998 were calculated for several exposure modes, including exposure to radionuclides in water entering the Columbia River from springs near the 100-N Area and internally deposited radionuclides measured in animals collected from the river and on the site.

The animal receiving the highest potential dose from N Springs water was a duck that consumes aquatic plants. The water flow of the N Springs is very low; no aquatic animal was observed to live directly in this spring water. Exposure to the radionuclides from the springs cannot occur until the spring water has been noticeably diluted in the Columbia River. The assumption was made that a few aquatic animals might be exposed to the maximum radionuclide activities measured in the spring water (see Table 4.2.4) after a 10-to-1 dilution by the river. Radiological doses were calculated for several different types of aquatic and riparian animals, using these extremely conservative assumptions and the CRITRII computer code (PNL-8150). If a duck spent 100% of its time in the one-tenth-diluted spring water and consumed only plants growing there, it would receive a dose rate of 0.11 mrad/d. This hypothetical dose rate is 0.011% of the limit of 1 rad/d for native aquatic animal organisms established by DOE Order 5400.5. The intent of the DOE Order 5400.5 native aquatic animal organism dose limit is to protect the population of a species, not necessarily individual organisms. It is not possible for a population of ducks to live in this spring for an entire year.

Doses also were estimated using the CRITRII code (PNL-8150) for aquatic and riparian organisms based on measured radionuclide activities in river water. The highest potential dose rate from all the radionuclides reaching the Columbia River from Hanford sources during 1998 was 6 x 10^{-6} rad/d for a hypothetical muskrat and a hypothetical duck, both of which consume contaminated vegetation. The radiological dose rate to individual animals collected on the site or from the Columbia River was calculated using the maximum activities of radionuclides measured in muscle. These doses ranged from 1 x 10^{-6} rad/d for a deer to 1 x 10^{-3} rad/d for a pheasant. Neither the doses calculated based on river water activities nor the doses based on actual biota activities approach the dose limit set forth in DOE Order 5400.5.

5.0.8 References

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6.0 Groundwater and Vadose Zone Monitoring

6.0.1 Groundwater Monitoring

The Hanford Groundwater Monitoring Project includes sitewide groundwater monitoring mandated by U.S. Department of Energy (DOE) Orders and near-field groundwater monitoring conducted to ensure that operations in and around specific waste disposal facilities are in compliance with applicable regulations.

Collection and analysis of groundwater samples to determine the distributions of radiological and chemical constituents were major parts of the groundwater monitoring effort. In addition, hydrogeologic characterization and modeling of the groundwater flow system were used to assess the monitoring network and to evaluate potential impacts of Hanford Site groundwater contamination. Other activities are data management, interpretation, and reporting. The purpose of this section is to provide an overall summary of groundwater monitoring during 1998. Additional details concerning the Hanford Groundwater Monitoring Project are available in PNNL-12086.

6.0.1.1 Monitoring Objectives

Groundwater monitoring was conducted for the following:

- assess the impact of radiological and hazardous chemicals on groundwater as a result of Hanford Site operations
- provide an integrated assessment of groundwater quality on the Hanford Site
- evaluate potential offsite impacts from the groundwater pathway
- verify compliance with applicable environmental laws and regulations
- evaluate effectiveness of groundwater remediation activities
- identify new or existing groundwater quality problems.

Sitewide groundwater monitoring activities are designed to meet the project objectives stated in DOE Order 5400.1 and described above. The impacts of Hanford Site operations on groundwater have been monitored for >50 yr under this project and its predecessors. Near-field monitoring of groundwater around specific waste facilities was performed to meet the requirements of the Resource Conservation and Recovery Act of 1976 (RCRA) of Title 40, Code of Federal Regulations, Part 265 (40 CFR 265) and Washington Administrative Codes (WACs) 173-303 and 173-304 as well as applicable DOE Orders (e.g., 5400.1, 5400.5). Groundwater monitoring was also performed in conjunction with cleanup investigations under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) (40 CFR 300).

6.0.1.2 Monitoring Design

Groundwater monitoring was designed to satisfy regulatory requirements using various criteria. Specific chemicals and radionuclides analyzed at each monitoring well and their sampling frequencies were selected based on past waste disposal activities (PNL-6456, WHC-EP-0527-2) and on previous analytical results. Also considered was information on the location of potential contaminant sources and hydrogeology, including groundwater flow directions. Selections involved determining those chemicals and radionuclides important in assessing health risk and for understanding contaminant distribution and movement.

Groundwater surveillance was conducted using established quality assurance plans (see Section 8.0, "Quality Assurance") and written procedures (ES-SSPM-001). Computerized data management systems are used to schedule sampling activities; generate sample labels and chain-of-custody forms; track sample status; and load, store, and report data. The Hanford Environmental Information System is the central, consolidated database for storing and managing the results of groundwater monitoring.

Groundwater samples were collected from both the unconfined and upper confined aquifers. The unconfined aquifer was monitored extensively because it contains contaminants from Hanford Site operations (PNNL-12086) and provides a potential pathway for contaminants to reach points of human exposure (e.g., water supply wells, Columbia River). The upper confined aquifer was monitored, though less extensively than the unconfined aquifer, because it also provides a potential pathway for contaminants to migrate off the site. Also, some sampling was conducted at the request of the Washington State Department of Health.

Contaminant source areas were monitored to characterize and define trends in the condition of the groundwater and to identify and quantify existing, emerging, or potential problems in groundwater quality. Source areas included active waste disposal facilities or facilities that had generated or received wastes in the past. Most of these facilities are located within the 100, 200, and 300 Areas. However, some sources such as the Solid Waste Landfill are located outside the operational areas.

Wells located within known contaminant plumes were monitored to characterize and define trends in the concentrations of the associated radiological or chemical constituents. These wells were also monitored to quantify existing groundwater quality problems and to provide a baseline of environmental conditions against which future changes can be assessed. Even though releases of liquid waste to all but a few permitted disposal facilities have ceased, these wells will continue to be monitored as cleanup of the Hanford Site continues. This will provide a continuing assessment of the effect of remediation efforts on groundwater.

Water supplies on and near the Hanford Site potentially provide the most direct route for human exposure to contaminants in groundwater. In 1998, three of the site's 12 drinking water systems provided groundwater for human consumption on the site. One system supplied water at the Fast Flux Test Facility, one supplied water to personnel at the Yakima Barricade guardhouse, and one was located at the Hanford Patrol Training Academy (see Section 4.3, "Hanford Site Drinking Water Surveillance"). Water supply wells used by the city of Richland are located near the site's southern boundary. Monitoring wells near these water systems were routinely sampled to ensure that any potential water quality problems would be identified long before regulatory limits were reached.

To assess the impact of Hanford Site operations on groundwater quality, background conditions, or the quality of groundwater on the site unaffected by operations, must be known. Data on the concentration of contaminants of concern in groundwater that existed before site operations began are not available. Therefore, concentrations of naturally occurring chemical and radiological constituents in groundwater sampled from wells located in areas unaffected by site operations, including upgradient locations, provide the best estimate of pre-Hanford groundwater quality. A summary of background conditions is tabulated in PNL-6886 and PNL-7120.

Groundwater samples are collected at various frequencies, depending on the historical trends of constituent data, regulatory or compliance requirements, and characterization needs. Sampling frequencies range from monthly to every 3 yr.

Summary results for 1998 are discussed in Section 6.1, "Hanford Groundwater Monitoring Project."

6.0.2 Vadose Zone Monitoring

The vadose zone is defined as the area between the ground surface and the water table. This subsurface zone is also referred to as the unsaturated zone, zone of suspended water, or zone of aeration. The vadose zone functions as a transport pathway or storage area for water and other materials located between the soil surface and the groundwater aquifers. Historically, the vadose zone at the Hanford Site has been contaminated with large amounts of radioactive and nonradioactive materials through the intentional and unintentional discharge of liquid wastes to the soil column, the burial of contaminated solid wastes, and the deposition of airborne contaminants to the ground. Depending on the makeup of the soil, the geology of the area, the nature of the wastes, the amount of water or other fluids available to mobilize the contaminant, and other factors, contaminants can move downward and laterally through the soil column, can be chemically bound to soil particles (and immobilized), or can be contained by geologic formations.

Because of concerns of the impact of some vadose zone contaminants on the groundwater beneath the Hanford Site and the potential for contaminated groundwater to reach the Columbia River, characterization efforts are under way to learn more about the nature and extent of vadose zone contamination. At Hanford, the primary method for investigating radiological contamination in the vadose zone consists of borehole logging (monitoring radiation levels in narrow shafts bored or drilled into the soil column). Borehole logging is being conducted in existing boreholes located in and around the 200 Areas single-shell tank farms and beneath former waste disposal facilities also in or near the 200 Areas. Additionally, soil-vapor extraction and monitoring are being conducted as part of an expedited response action in the 200-West Area to remove carbon tetrachloride from the vadose zone.

Results for the 1998 vadose zone monitoring program are discussed in Section 6.2, "Vadose Zone Characterization and Monitoring." Section 6.2 has been divided into vadose zone characterization activities in the 200 Areas tank farms and the vadose zone monitoring beneath former 200 Areas waste disposal facilities and carbon tetrachloride remediation work in the 200-West Area.

6.1 Hanford Groundwater Monitoring Project

D. R. Newcomer and M. J. Hartman

The strategy for managing and protecting groundwater resources at the Hanford Site was recently presented in DOE/RL-98-48, Draft C and DOE/RL-98-56. The strategy focuses on protection of the Columbia River, protection of human health and the environment, treatment of groundwater contamination, and limitation of contaminant migration from the 200 Areas. Implementation of the strategy includes continued monitoring of groundwater quality through the Hanford Groundwater Monitoring Project. The project is designed to detect new contaminant plumes and to document the distribution and movement of existing groundwater contamination. Monitoring provides the historical baseline for evaluating current and future risk from exposure to groundwater contamination and for deciding on remedial options. Hydrogeologic studies are an integral part of the project because the geology and hydrology of the site control the movement of contaminants in groundwater.

The effort to protect groundwater quality at the Hanford Site is being implemented through programs to minimize wastes being discharged to the soil column and through site remediation activities. The Hanford Federal Facility Agreement and Consent Order (also known as the Tri-Party Agreement; Ecology et al. 1989) provides a framework for remediation of the Hanford Site, including groundwater, over a 40-yr period. A summary of accomplishments in waste minimization and site remediation is presented in Section 2.3, "Activities, Accomplishments, and Issues."

DOE prepared a *Plan and Schedule to Discontinue Disposal of Liquids Into the Soil Column at the Hanford Site* (DOE 1987), which includes an alternative for treatment and disposal of contaminated effluents discharged to the soil. Of the 33 major waste streams identified in DOE (1987), the Phase I (higher-priority) streams have either been eliminated or are being treated and diverted to the 200 Areas Treated Effluent Disposal Facility. In addition, process condensate from the 242-A Evaporator is treated at the 200 Areas Effluent Treatment Facility and then discharged to the 616-A Crib (also known as the State-Approved Land Disposal Site) north of the 200-West Area. The State-Approved Land Disposal Site is the only facility at Hanford that received radionuclide-bearing liquid effluent discharged to the soil column in 1998. The locations of active permitted facilities are shown in Figures 1.0.2 and 6.1.1 and are discussed in detail in Section 2.3, "Activities, Accomplishments, and Issues." All other facilities (e.g., cribs, trenches) that historically discharged liquid waste to the soil column are out of service. The only operational injection wells are associated with pump-and-treat remediation systems. Disposal of liquids to soil has been significantly reduced during the last several years. For example, in 1987, >23 billion L (6 billion gal) of liquid effluents were discharged to the soil. This was reduced to approximately 4.9 billion L (1.3 billion gal) in 1995 and <0.9 billion L (<240 million gal) in 1998. In 1998, approximately 10% of the liquid volume was discharged to the State-Approved Land Disposal Site and approximately 90% was discharged to the 200 Areas Treated Effluent Disposal Facility.

Groundwater is used for drinking water and other purposes at a few locations on the Hanford Site. DE&S Hanford, Inc., DynCorp Tri-Cities Services, Inc., and Pacific Northwest National Laboratory monitor drinking water supplies at the point of use or

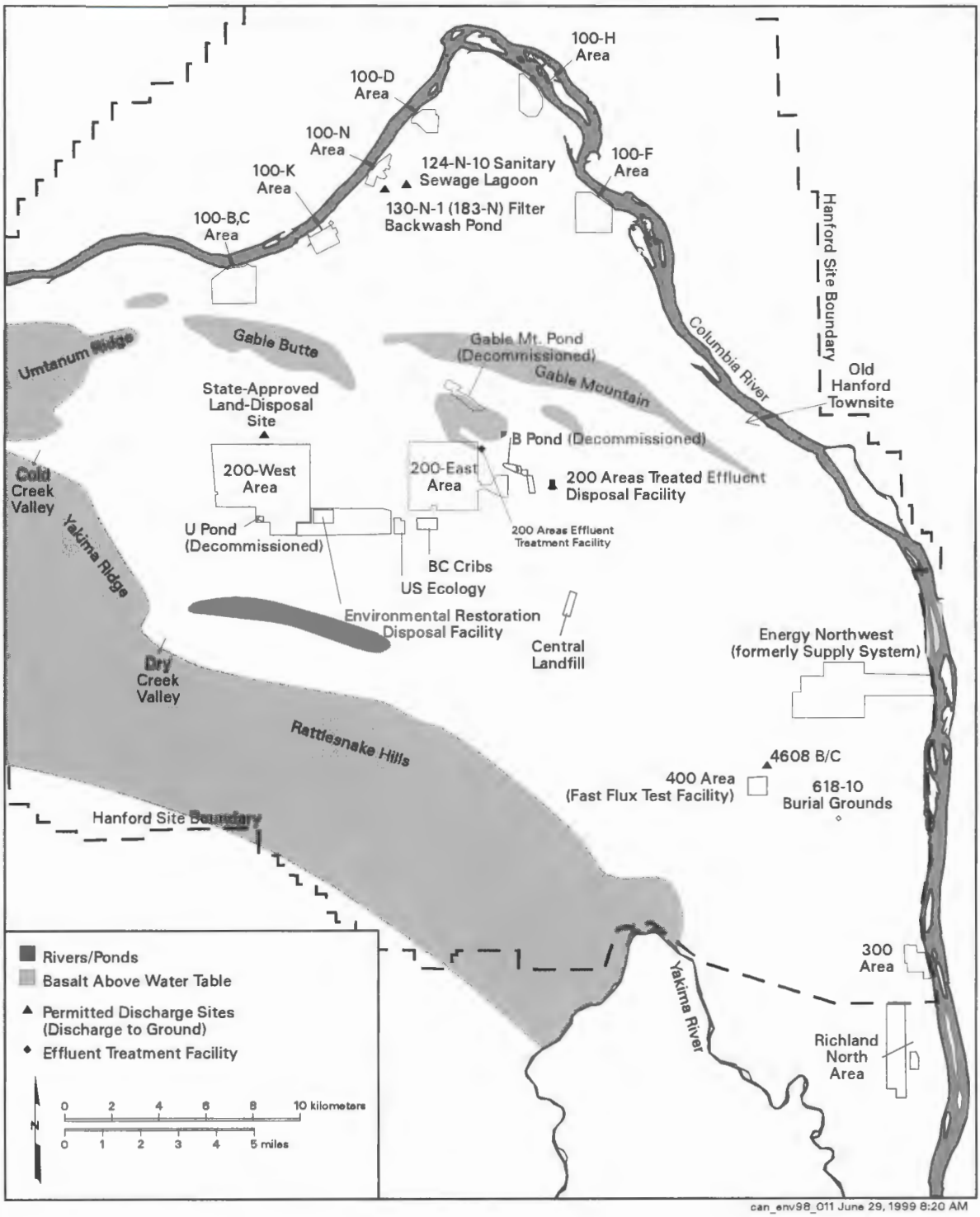


Figure 6.1.1. *Active Liquid Wastewater Discharge Sites at Hanford*

at the source. DynCorp Tri-Cities Services, Inc. monitors for nonradiological constituents and DE&S Hanford, Inc. and Pacific Northwest National Laboratory monitor for radiological constituents. Results of the radiological monitoring are summarized in Section 4.3, "Hanford Site Drinking Water Surveillance." The locations of wells completed in the unconfined aquifer that provide water for drinking, fire suppression, and cooling are shown in Figure 6.1.2.

6.1.1 Geologic Setting

The Hanford Site lies within the Pasco Basin, one of several structural basins within the Columbia Plateau. Principal geologic units beneath the Hanford Site include, in ascending order, the Columbia River Basalt Group, the Ringold Formation, and the Hanford formation (informal name) (Figure 6.1.3).

The Columbia River basalts were formed from lava that periodically erupted from volcanic fissures. The regional river system eroded the basalt and deposited sediments across the basalt surfaces between eruptions. Zones between the basalt flows and the sediments deposited as interbeds between basalt eruptions are frequently water bearing zones that are used as water sources in areas around the Hanford Site.

During the period of basalt deposition, tectonic pressure was very slowly deforming the basalt flows into the generally east-west trending ridges that border the Pasco Basin today. After the last major basalt eruption, sand and gravel of the Ringold Formation were deposited in the central portion of the Pasco Basin by the ancestral Columbia River as it meandered back and forth across the relatively flat basalt surface. Following uplift of the basalts and overlying sediments, the Columbia River began to erode, rather than deposit, sediments in the Pasco Basin. The uppermost mud layer was eroded from much of the Pasco Basin, and a caliche layer, part of the Plio-Pleistocene unit, developed in places on the eroded surface of the Ringold Formation.

More recently, the Hanford formation sediments were deposited by catastrophic ice age floods. Fine sands and silts were deposited in slackwater areas at the margins of the basin. However, primarily sand and gravel were deposited on the Hanford Site. In places, these sediments are covered by up to a few meters (feet) of recent stream or windblown deposits.

More-detailed information on the geology of the Pasco Basin can be found in BHI-00184, DOE/RW-0164 (Vol. 1), PNNL-12086 (Section 3.1), WHC-MR-0391, WHC-SD-EN-TI-014, and WHC-SD-EN-TI-019.

6.1.2 Groundwater Hydrology

Both confined and unconfined aquifers are present beneath the Hanford Site. An aquifer is a water-saturated geologic interval or unit that has a high permeability, meaning it can transmit significant quantities of water. A confined aquifer is bounded above and below by low-permeability materials that restrict the vertical movement of water. The confining layers may be dense rock, such as the central parts of basalt flows, silt, clay, or well-cemented sediments. Areally extensive, confined aquifers at the site are found primarily within interflows and interbeds of the Columbia River basalts. These are referred to as basalt-confined aquifers. Locally confined aquifers are also found below the clays and silts of the Ringold Formation.

An unconfined aquifer, or water-table aquifer, is overlain by unsaturated sediments. The upper surface of the saturated zone in an unconfined aquifer,

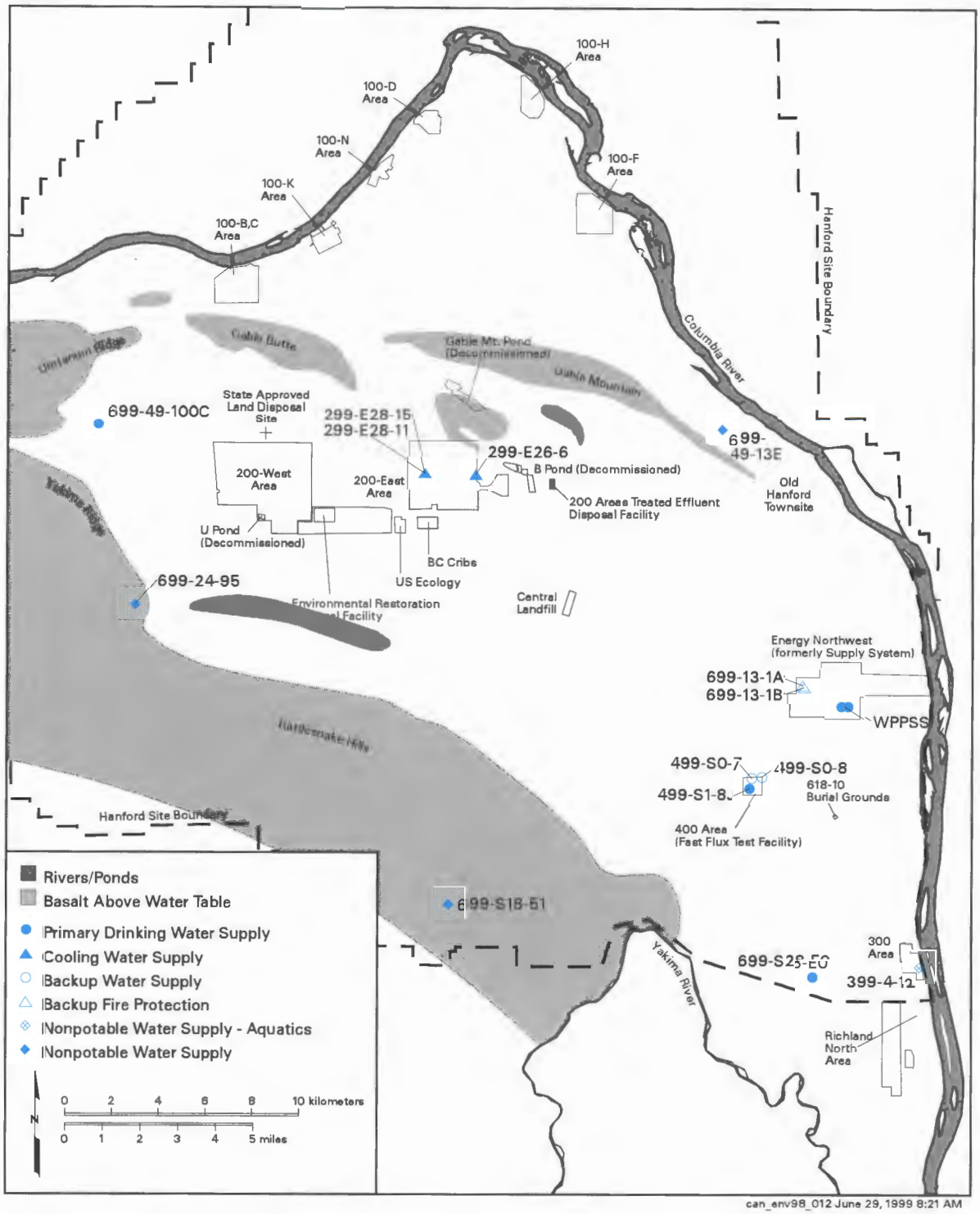


Figure 6.1.2. *Water Supply Wells in the Unconfined Aquifer*

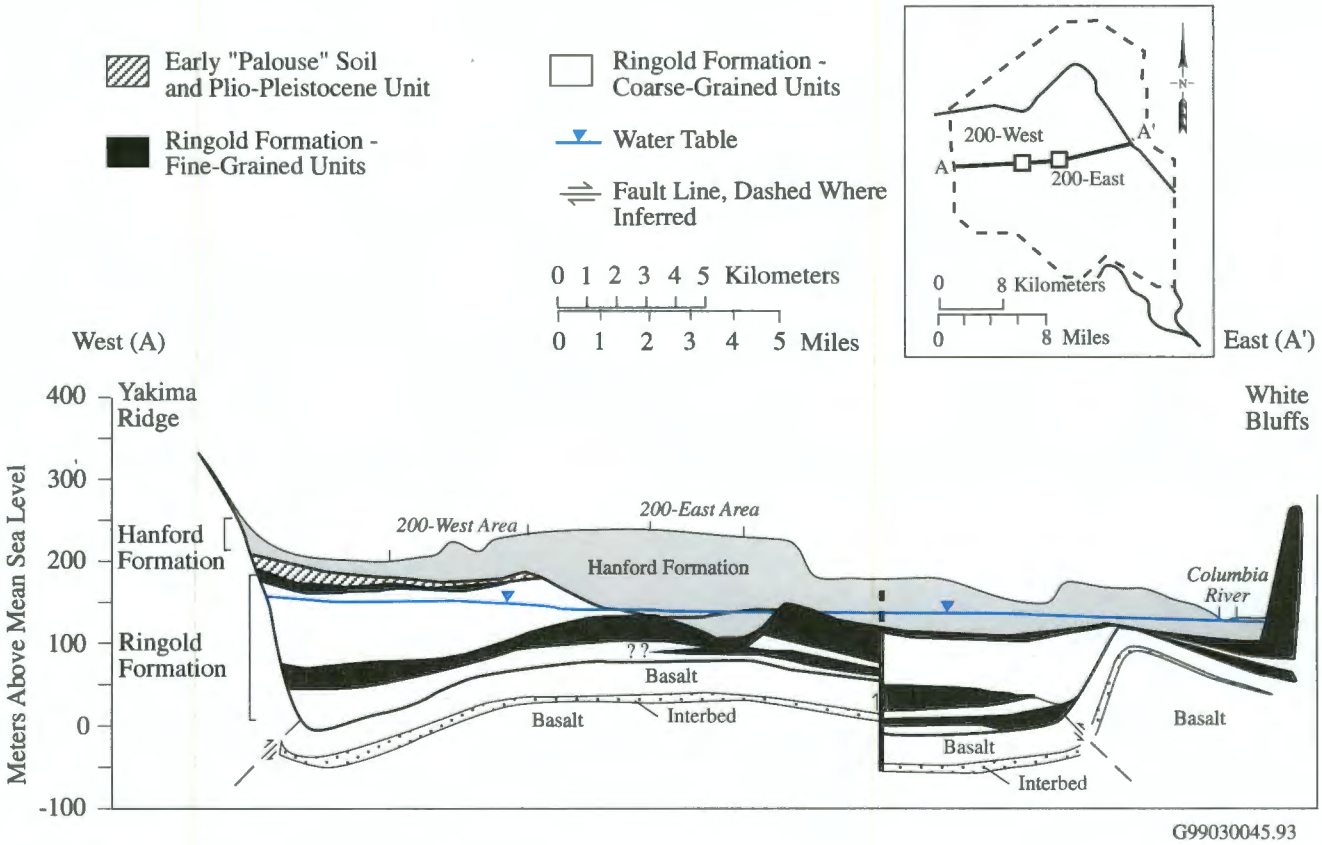


Figure 6.1.3. *Geologic Cross Section of the Hanford Site*

which is called the water table, rises and falls in response to changes in the volume of water stored in the aquifer. In general, the unconfined aquifer at the Hanford Site is located in the Hanford and Ringold Formations. In some areas, the water table is below the bottom of the Hanford formation and the unconfined aquifer is entirely within the Ringold Formation. The Hanford formation sands and gravels are unconsolidated and are generally much more permeable than the compacted and silty Ringold Formation gravels. Clay and silt units and zones of natural cementation form low-permeability zones within the Ringold Formation.

The unconfined aquifer forms the uppermost groundwater zone and has been directly impacted by wastewater disposal at the Hanford Site. The unconfined aquifer discharges primarily into the Columbia River and is the most thoroughly monitored aquifer beneath the site. The Rattlesnake Ridge interbed is the uppermost, basalt-confined aquifer within the Pasco Basin and the Hanford Site. This aquifer and other confined aquifers are generally isolated from the unconfined aquifer by dense rock that forms the interior of the basalt flows. However, interflow between the unconfined aquifer and the basalt-confined aquifer system is known to occur at faults that bring a water bearing interbed in contact with other sediments or where the overlying basalt has been eroded to reveal an interbed (Newcomb et al. 1972, RHO-RE-ST-12 P, WHC-MR-0391). Additional information on the basalt-confined aquifer system can be found in PNL-10158 and PNL-10817.

The thickness of saturated sediments above the basalt bedrock is >200 m (656 ft) in some areas of the

Hanford Site and thins out along the flanks of the uplifted basalt ridges (Figures 6.1.3 and 6.1.4). Depth from the ground surface to the water table ranges from <0.3 m (1 ft) near the Columbia River to >106 m (348 ft) in the center of the site. The unconfined aquifer is bounded below by either the basalt surface or, in places, by relatively impervious clays and silts within the Ringold Formation. The water table defines the upper boundary of the unconfined aquifer. Laterally, the unconfined aquifer is bounded by basalt ridges and by the Yakima and Columbia Rivers. The basalt ridges have a low permeability and act as a barrier to the lateral flow of groundwater where they rise above the water table (RHO-BWI-ST-5, p. II-116).

The water-table elevation contours shown in Figure 6.1.5 indicate the direction of groundwater flow and the magnitude of the hydraulic gradient in the unconfined aquifer. Groundwater flow is generally perpendicular to the water-table contours from areas of higher elevation, or head, to areas of lower head. Areas where the contours are closer together are high-gradient areas, where the "driving force" for groundwater flow is greater. However, because sediments with low permeabilities inhibit groundwater flow, producing steeper gradients, a high gradient does not necessarily mean high groundwater velocity. Lower transmissivity and steeper gradients are often associated with areas where the water table is below the bottom of the Hanford formation and the aquifer is entirely within the less-permeable Ringold sediments. Figure 6.1.6 shows the generalized distribution of transmissivity as determined from aquifer pumping tests and groundwater flow model calibration. Additional information on aquifer hydraulic properties at Hanford is presented in DOE/RW-0164 (Vol. 2) and PNL-8337.

Recharge of water within the unconfined aquifer (RHO-ST-42) comes from several sources. Natural recharge occurs from infiltration of precipitation along the mountain fronts, runoff from intermittent streams such as Cold and Dry Creeks on the western margin of the site, and limited infiltration of precipitation on the site. The Yakima River, where it flows along the southern boundary of the site, also recharges the unconfined aquifer. The Columbia River is the primary discharge area for the unconfined aquifer. However, the Columbia River also recharges the unconfined aquifer for short periods during high-river stage, when river water is transferred into the aquifer along the riverbank. Recharge from infiltration of precipitation is highly variable on the Hanford Site both spatially and temporally. The rate of natural recharge depends primarily on soil texture, vegetation, and climate (Gee et al. 1992, PNL-10285) and ranges from near zero, where fine-grained soils and deep-rooted vegetation are present, to >10 cm/yr (4 in./yr) in areas where soils are coarse textured and bare of vegetation.

Large-scale, artificial recharge to the unconfined aquifer occurred as a result of liquid waste disposal in the operating areas and offsite agricultural irrigation to the west and south. Discharge of wastewater caused the water table to rise over most of the Hanford Site. Local areas with elevated water tables are called groundwater mounds. Figure 6.1.7 shows the change in water-table elevations between 1944 and 1979, when the water table had stabilized over most of the site. Figure 6.1.8 shows the water table decline between 1979 and 1995, when many waste streams were consolidated and wastewater discharge was reduced. The greatest decline in the water table occurred in the 200-West Area and is discussed below. The water table continues to decline over much of the Hanford Site, as illustrated by Figure 6.1.9, which shows the water-level changes between 1997 and 1998.

Two major groundwater mounds formed in the vicinity of the 200-East and 200-West Areas in response to wastewater discharges. The first of these mounds was created by disposal at the 216-U-10 Pond (U Pond) in the 200-West Area. After U Pond was decommissioned in 1984, the mound slowly dissipated and has become much less distinct over

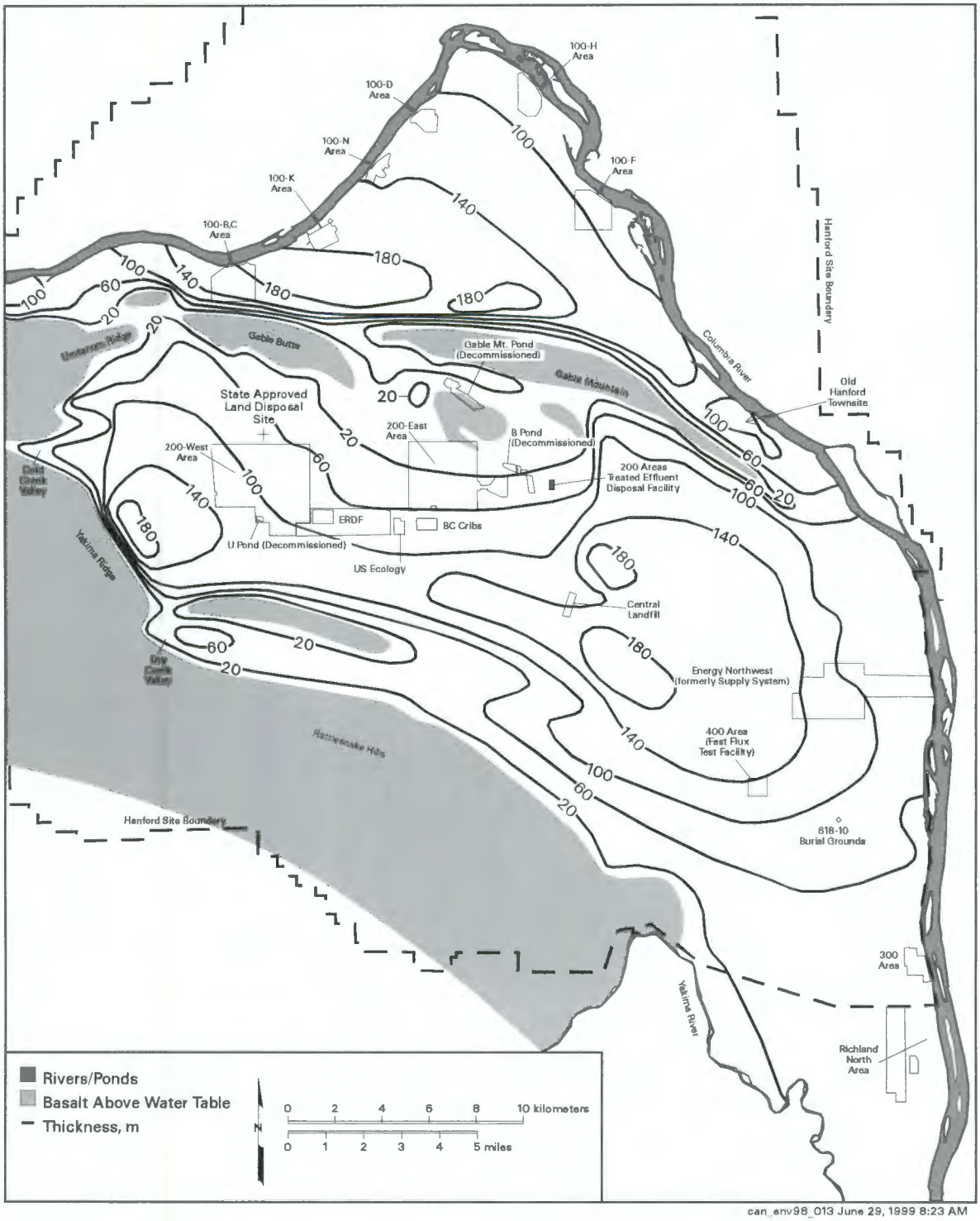


Figure 6.1.4. *Saturated Thickness of the Unconfined Aquifer*

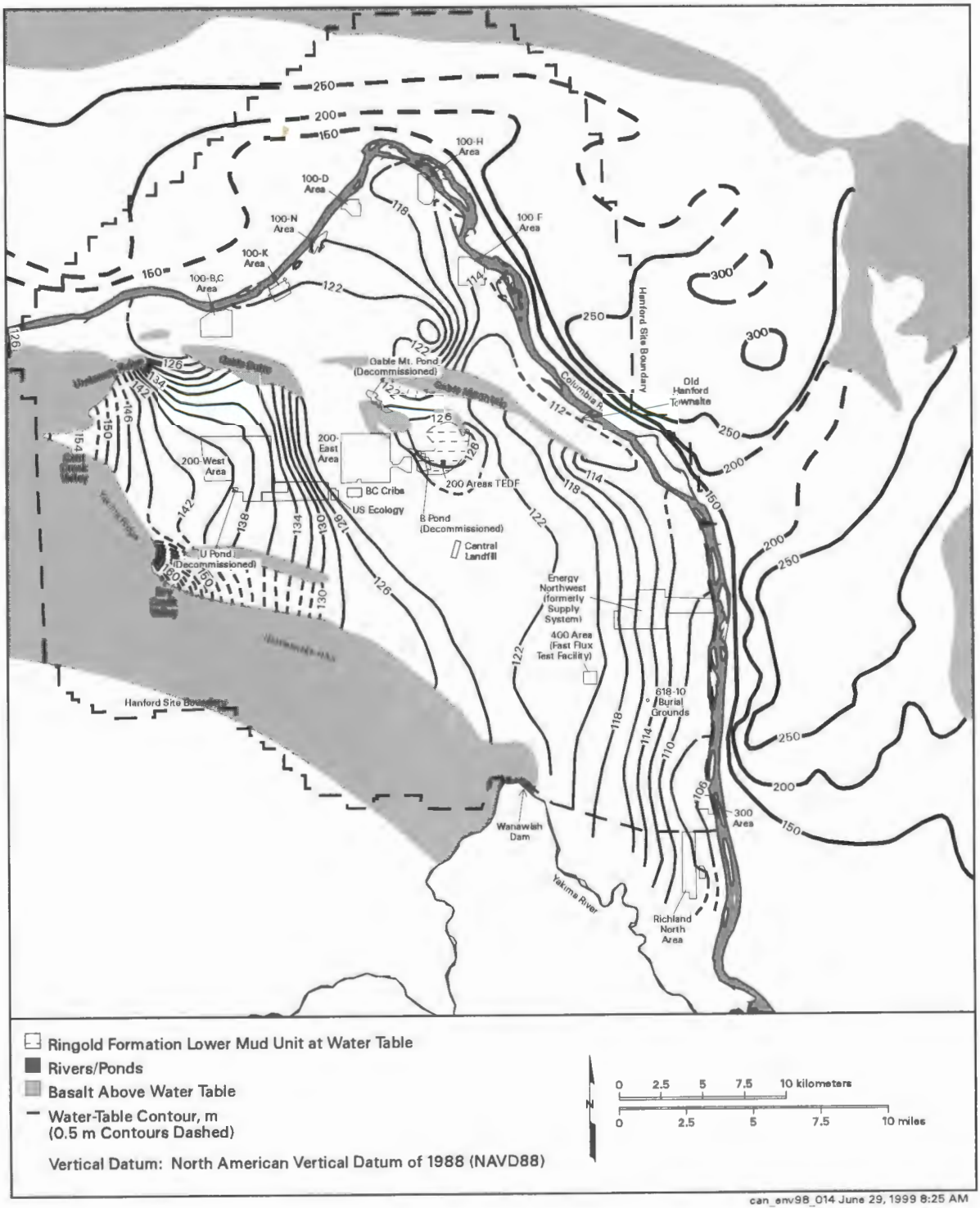


Figure 6.1.5. *Water-Table Evaluations for the Unconfined Aquifer at the Hanford Site and in Adjacent Areas East and North of the Columbia River, June 1998*

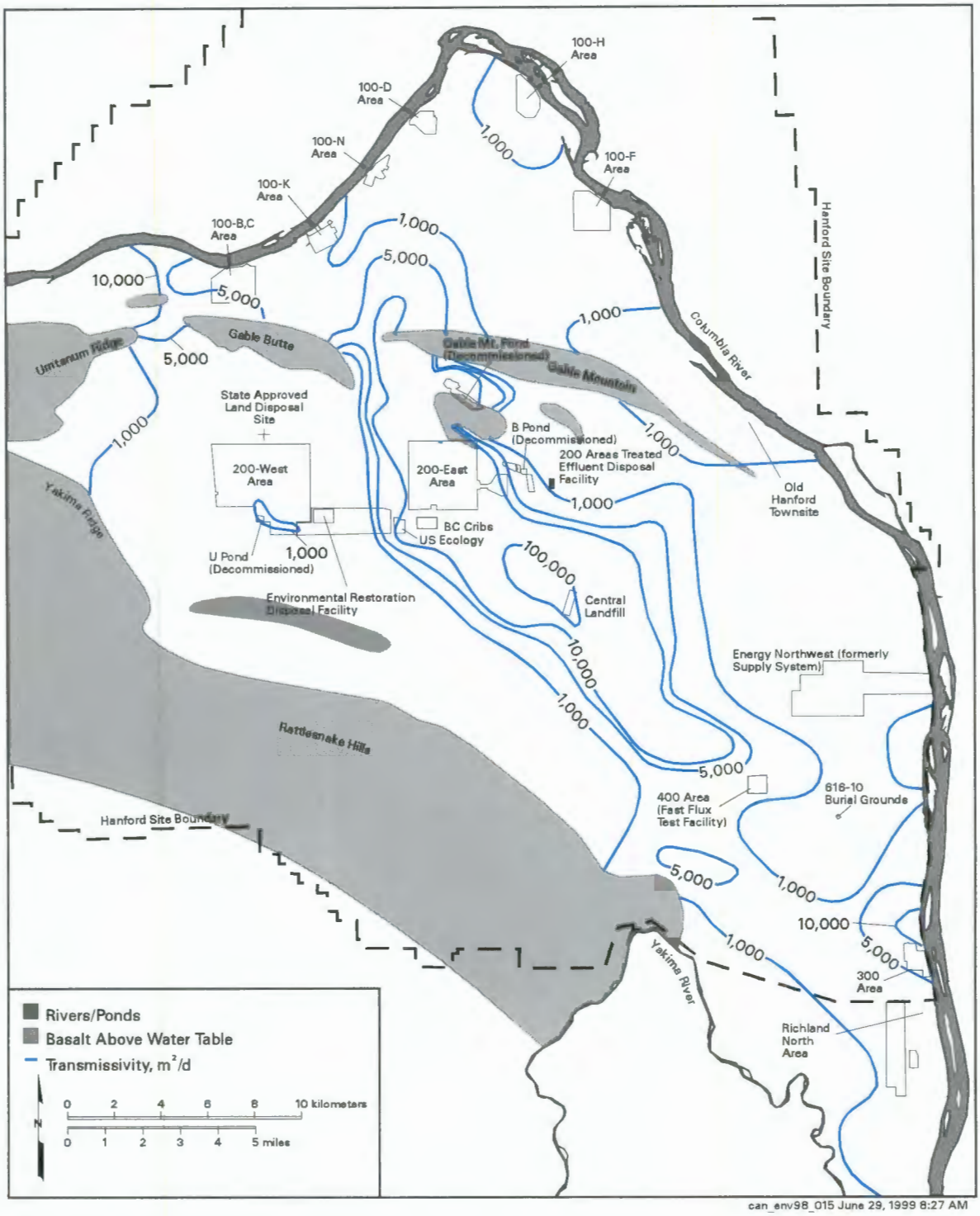


Figure 6.1.6. Transmissivity Distribution in the Unconfined Aquifer

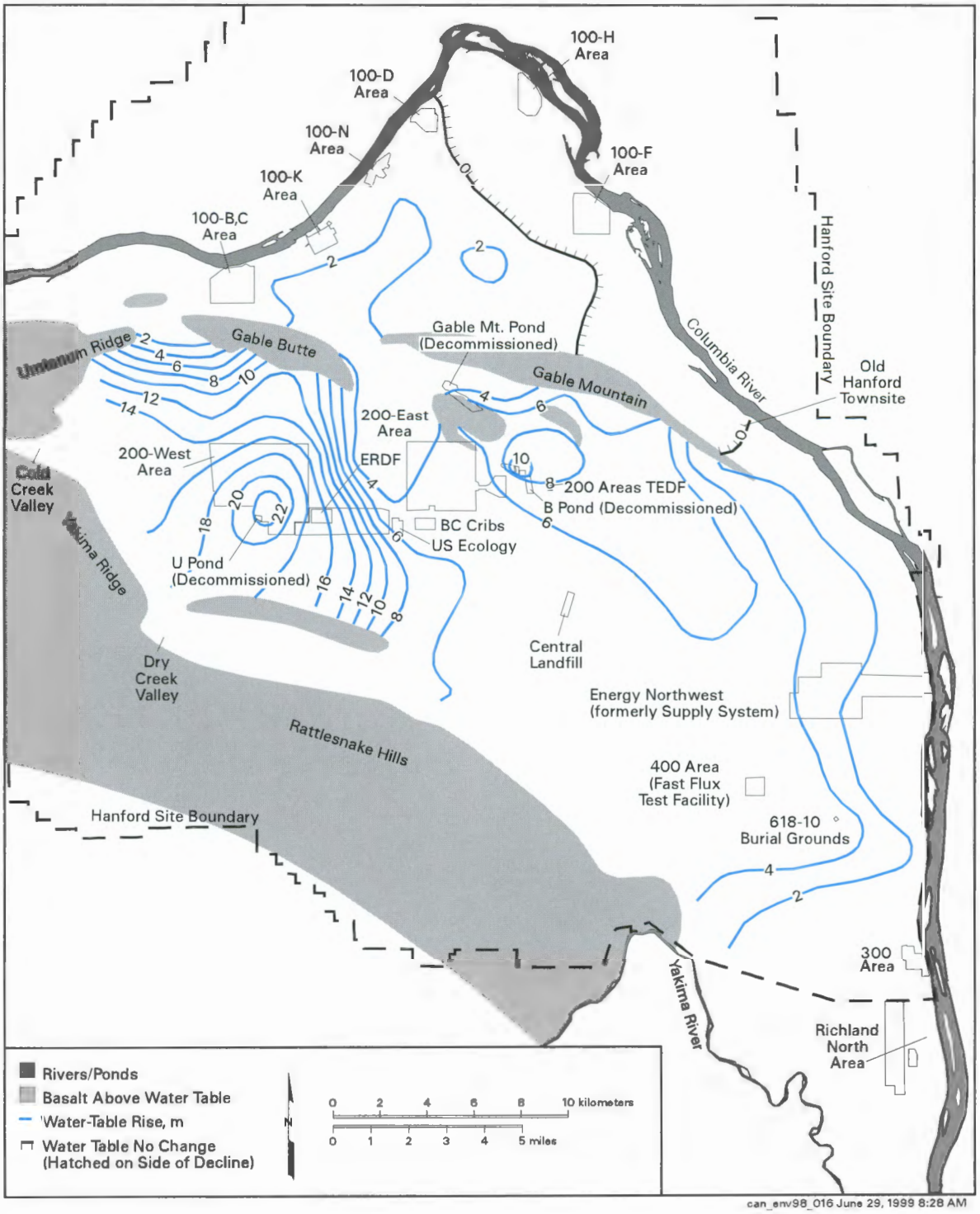


Figure 6.1.7. *Change in Water-Table Elevations Between 1949 and 1979*

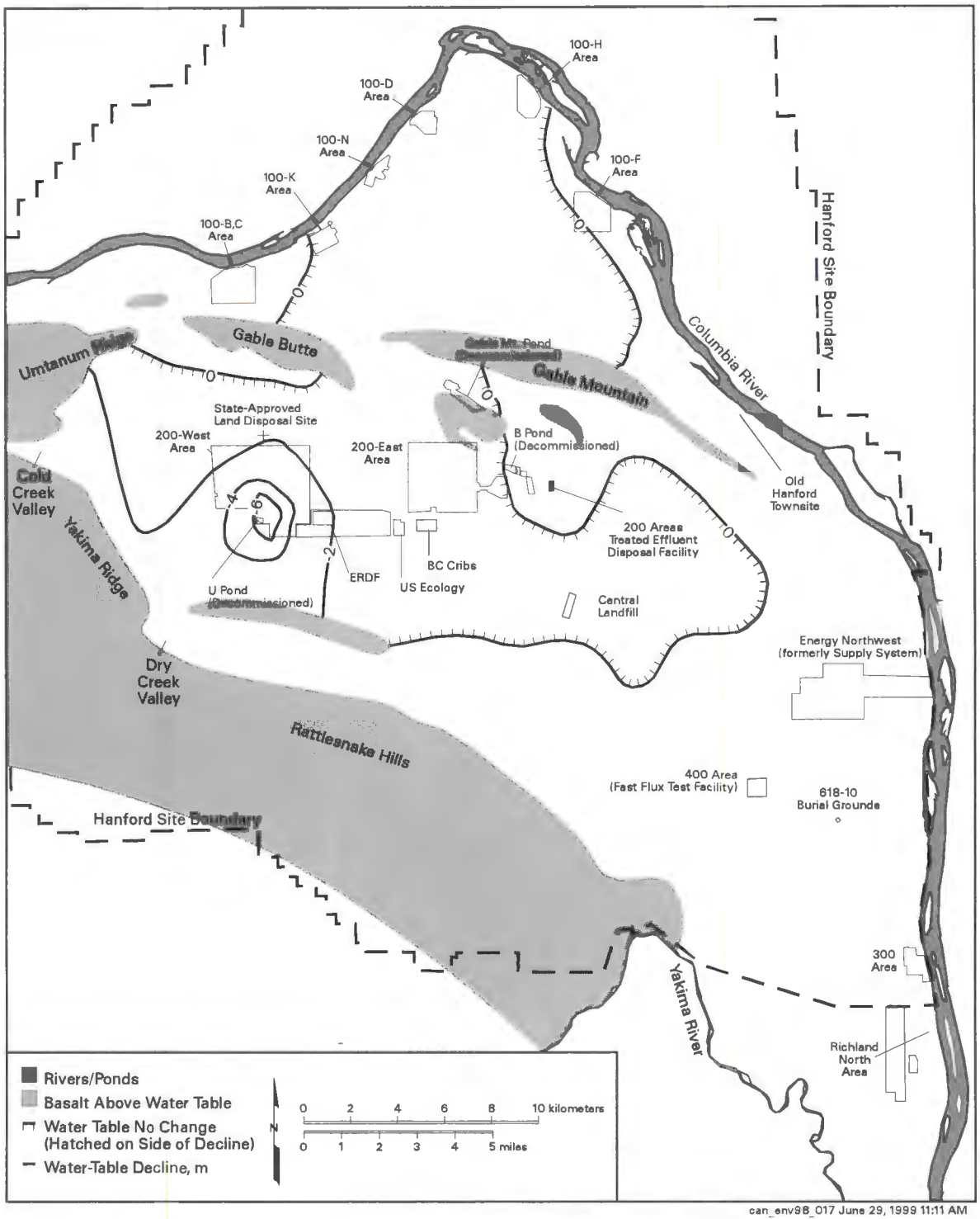


Figure 6.1.8. *Change in Water-Table Elevations Between 1979 and 1995*

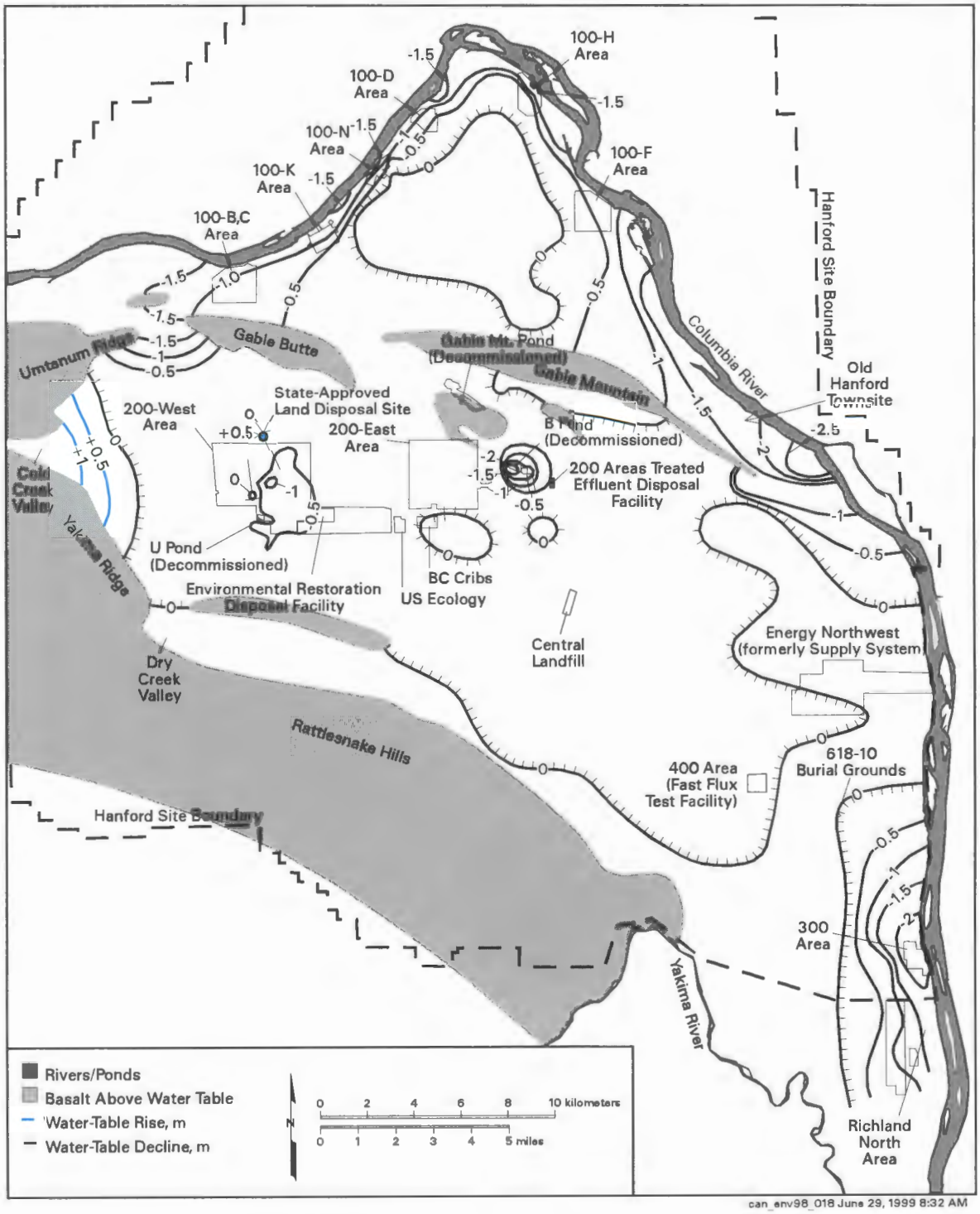


Figure 6.1.9. Change in Water-Table Elevations Between 1997 and 1998

the last several years. The water table continues to decline in this area (see Figure 6.1.9). The second major mound was created by discharge to the decommissioned, or former, 216-B-3 Pond (B Pond), east of the 200-East Area. The water-table elevation near B Pond increased to a maximum before 1990 and then decreased because of reduced discharge. After discharge to B Pond ceased in August 1997, the decline in the water-table elevation accelerated. The recent decline in the water-table elevation at B Pond is illustrated by the contours in Figure 6.1.9. These mounds have altered the unconfined aquifer's natural flow pattern, which is generally from the recharge areas in the west to the discharge areas (primarily the Columbia River) in the east and north. Water levels in the unconfined aquifer have continually changed as a result of variations in the volume and location of wastewater discharge. Consequently, the movement of groundwater and its associated constituents has also changed with time. Groundwater mounding related to wastewater discharges has also occurred in the 100 and 300 Areas; however, groundwater mounding in these areas is not as great as in the 200 Areas primarily because of lower discharge volumes.

In the 100 Areas, 300 Area, and other locations near the Columbia River, groundwater levels are influenced by river stage (PNL-9437). The Columbia River stage returned to normal levels in 1998 after an unusually high-river stage throughout most of 1996 and 1997. This resulted in a lowering of the water table near the river. As a result, water flowed from the aquifer into the river during much of the year.

6.1.3 Contaminant Transport

The history of contaminant releases and the physical and chemical principles of mass transport control the distribution of radionuclides and chemicals in groundwater. Processes that control the movement of these contaminants at the Hanford Site are discussed below.

Most of the groundwater contamination at the Hanford Site resulted from discharge of wastewater from reactor operations, reactor fuel fabrication, and processing of spent reactor fuel. Table 6.1.1 lists the principal contaminants found in each operational area and the type of operation that generated them. In the 100 Areas, discharges included reactor cooling water, fuel storage basin water, filter backwash, and smaller amounts of waste from a variety of other processes. In the 200 Areas, large quantities of wastewater from fuel reprocessing were discharged. Other contamination sources in the 200 Areas included plutonium purification waste and decontamination waste. The plutonium purification process resulted in the discharge of large amounts of liquid organic chemicals in addition to aqueous solutions. This organic liquid, once in contact with groundwater, slowly dissolves and produces contaminant plumes. The presence of nonaqueous liquid has a major impact on the site's groundwater remediation strategy because the organic liquid in the subsurface represents a continuing source of contamination but is very difficult to clean up. Groundwater contamination in the 300 Area resulted mainly from discharge of fuel fabrication wastes.

Liquid effluents discharged to the ground at Hanford Site 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

Table 6.1.1. Chemical and Radiological Groundwater Contaminants and Their Link to Site Operations

Constituents Generated	Areas	Facilities Type
Tritium, ^{60}Co, ^{90}Sr, Cr^{6}, SO_4^{-2}	100	Reactor operations
Tritium, ^{90}Sr, ^{99}Tc, ^{129}I, ^{137}Cs, Pu, U, CN^-, Cr^{6}, F^-, NO_3^-	200	Irradiated fuel processing
Pu, carbon tetrachloride, chloroform, NO_3^-	200	Plutonium purification
^{99}Tc, U, Cr^{6}, trichloroethylene	300	Fuel fabrication

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 activities/concentrations are reduced by dilution with groundwater. As these dissolved constituents move with the groundwater, many radionuclides and chemicals adhere to sediment particle surfaces (adsorption) or diffuse into the particles (absorption). Radionuclide activities are reduced by radioactive decay.

Outside the source areas (i.e., liquid disposal sites), there is typically little or no downward gradient (driving force or head), so contamination tends to remain in the upper part of the aquifer. In the source areas, where large volumes of wastewater were discharged, a large vertical hydraulic gradient developed that moved 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.

6.1.4 Groundwater Modeling

Numerical modeling of groundwater flow and contaminant transport is performed to simulate future groundwater-flow conditions and predict the migration of contaminants through the groundwater pathway. During 1998, a model was used to support the composite analysis (PNNL-11800) for low-level waste disposal at the Hanford Site. The objective of the composite analysis was to predict the flow of groundwater and transport of radioactive contaminants during a 1,000-yr compliance period following closure of the Hanford Site in the future. The transport simulation was based on radioactive contaminants that were expected to exist on the site in the year 2050, the assumed closure date, and on predicted future groundwater flow conditions. Simulated contaminants included tritium, carbon-14, chlorine-36, selenium-79, technetium-99, iodine-129, uranium, and other radionuclides from waste sites and the vadose zone. Other models were used in the design and evaluation of pump-and-treat activities aimed at remediation of contaminated groundwater in the 200-West Area. A brief description of these modeling efforts is provided here; additional details and results are presented in PNNL-12086 (Section 6.0) and DOE/RL-99-02.

During the past several years, a three-dimensional flow and transport model has been under

development. The objective of developing a three-dimensional model was to provide more accurate simulations of contaminant transport within the sitewide unconfined aquifer system. The model is based on the Coupled Fluid, Energy, and Solute Transport (CFEST) code (BMI/ONWI-660). The model has since been updated to a new version of the CFEST code called CFEST-96, which was used for the composite analysis. The model includes up to nine layers above the top of basalt to represent the major hydrogeologic units within the unconfined aquifer system.

The water table was predicted to decline significantly and return to near pre-Hanford Site groundwater flow conditions over an approximately 300-yr period following site closure. Wastewater discharges to the ground were assumed to be eliminated before site closure. The areas where the future water table was predicted to be different from pre-Hanford conditions include effects of increased offsite irrigation on the western part of the site and effects from the city of Richland's North Well Field recharge ponds near the southern part of the site.

Predicted distributions of contaminants in the unconfined aquifer during the 1,000-yr compliance period are presented in PNNL-11801.

Groundwater models were also used to assess the performance of groundwater pump-and-treat systems in the 200-UP-1 and 200-ZP-1 Operable Units in the 200-West Area. In these systems, contaminated water is removed by means of extraction wells, treated, and either disposed of to the State-Approved Land Disposal Site (200-UP-1) or returned to the aquifer through injection wells (200-ZP-1) (BHI-01126). The models were used to predict system performance and progress toward remediation goals. The modeling was used to evaluate different extraction and injection well configurations, predict effects of pumping, assess the extent of hydraulic influence and the capture zone, and evaluate groundwater travel times. Modeling was conducted using the MicroFEM© finite-element code developed by C. J. Hemker, Amsterdam, The Netherlands. Groundwater modeling for the 200-UP-1 plume indicated that the area of high technetium-99 activity and uranium concentration was captured using the one extraction well (299-W19-39) (DOE/RL-99-02). Modeling of the 200-ZP-1 pump-and-treat operation predicts that the high-concentration area of the carbon tetrachloride plume will be captured. As of September 1998, measurable progress was made toward hydraulic containment of the high-concentration areas of the plumes at each of these pump-and-treat operations (DOE/RL-99-02).

6.1.5 Groundwater Monitoring

Groundwater monitoring at the Hanford Site is an integral part of the *Hanford Site Ground-Water Protection Management Plan* (DOE/RL-89-12, Rev. 2). That plan integrates monitoring at active waste disposal facilities to comply with requirements of the RCRA 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 to assess the distribution and movement of existing groundwater contamination, to identify potential and emerging groundwater contamination problems, and to integrate the various groundwater projects to minimize redundancy.

The *Integrated Monitoring Plan for the Hanford Groundwater Monitoring Project* (PNNL-11989) describes how the DOE will implement the groundwater monitoring requirements outlined in DOE (1987) and DOE/RL-89-12, Rev. 2. The purpose of the integrated monitoring plan is to 1) describe the monitoring well networks, constituents, sampling frequencies, and criteria used to design the monitoring

program; 2) identify federal and state groundwater monitoring requirements and regulations; and 3) provide a list of wells, constituents, and sampling frequencies for groundwater monitoring conducted on the Hanford Site. Federal and state regulations include RCRA, CERCLA, and Washington Administrative Codes.

Information on contaminant distribution and transport are integrated into a sitewide evaluation of groundwater quality, which is documented in an annual groundwater monitoring report (e.g., PNNL-12086). Groundwater monitoring is also carried out during CERCLA cleanup investigations. These investigations, managed by Bechtel Hanford, Inc., are documented in annual summary reports (e.g., DOE/RL-99-02).

6.1.5.1 Groundwater Sampling and Analytes of Interest

Groundwater samples were collected from 671 wells for all monitoring programs during 1998. The locations of sampled wells are shown in Figures 6.1.10 and 6.1.11; well names are indicated only for those 400 and 600 Area wells 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 6.1.12 shows the locations of facilities where groundwater monitoring was conducted to comply with RCRA (Appendix A in PNNL-12086). Wells at the Hanford Site generally follow a naming system that indicates the approximate location of the well. The prefix of the well name indicates the area of the site, as shown in Table 6.1.2. The 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, variability of historical data, proximity to waste sources, and characteristics of the groundwater flow system at the sample location. Of the 671 wells sampled, 286 were sampled once, 174 twice, 25 three times, 99 four times, and 87 more than four times during the year. In 1998, the sampling frequency was changed to every 3 yr for several wells that showed concentrations with steady historical trends. Wells showing larger variability are sampled more frequently (annually or more often). Wells that monitor source areas are sampled more frequently than wells that do not monitor source areas. Contaminants with greater mobility (e.g., tritium) may be sampled more frequently than those that are not very mobile in groundwater (e.g., strontium-90).

Each monitoring program has access to groundwater data collected by other programs through a common database, the Hanford Environmental Information System. This database contains >1.5 million groundwater monitoring result records. After the data are verified and/or validated, they are made available to federal and state regulators for retrieval.

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 activities 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. Since 1985, RCRA monitoring wells and CERCLA characterization wells have been constructed with stainless steel casing and screens. Most monitoring wells on the site are sampled using either submersible or Hydrostar™ pumps (a registered trademark of Instrumentation Northwest, Inc., Redmond, Washington), though some wells are sampled with bailers or airlift systems.

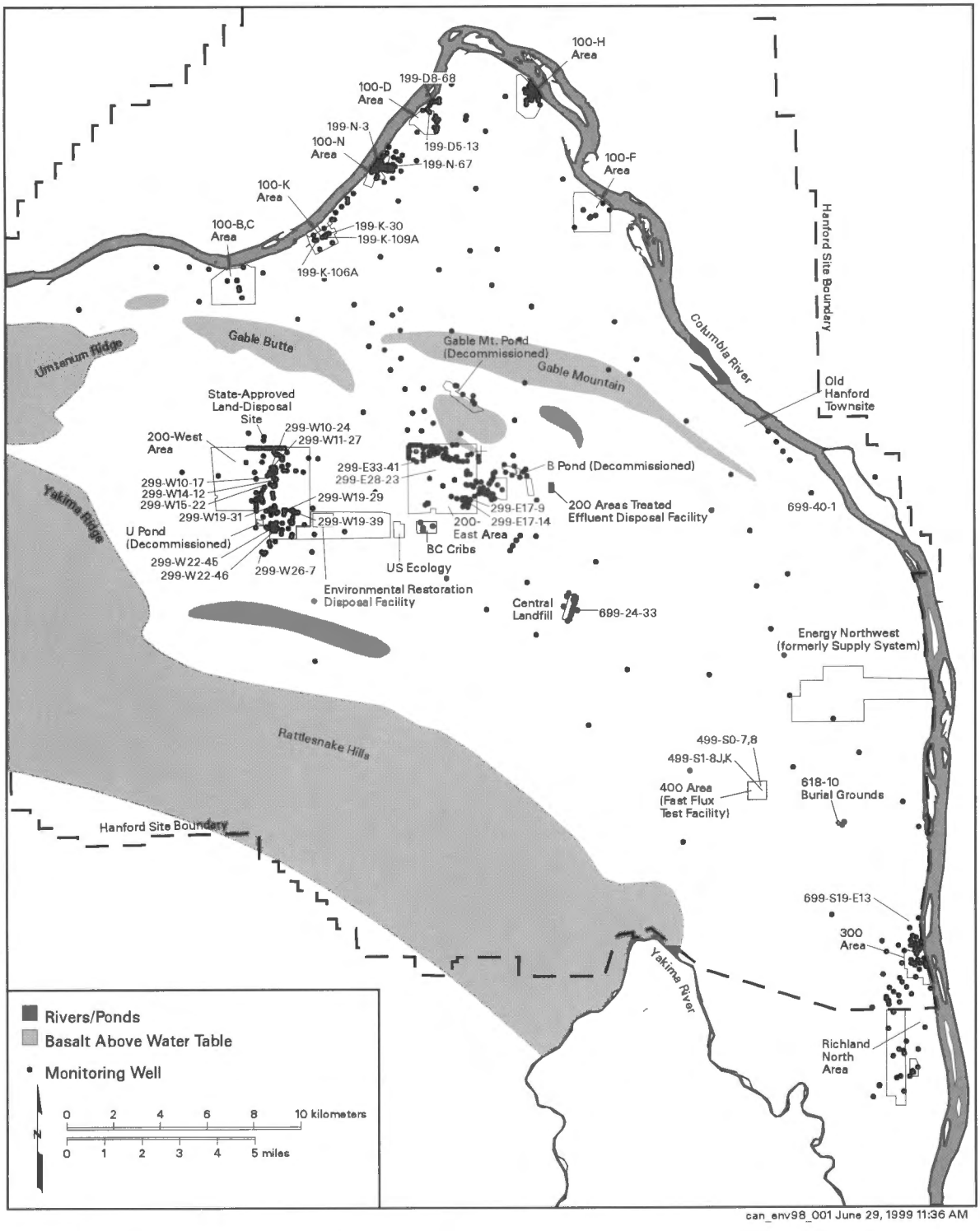


Figure 6.1.10. *Unconfined Aquifer Monitoring Well Locations, 1998*

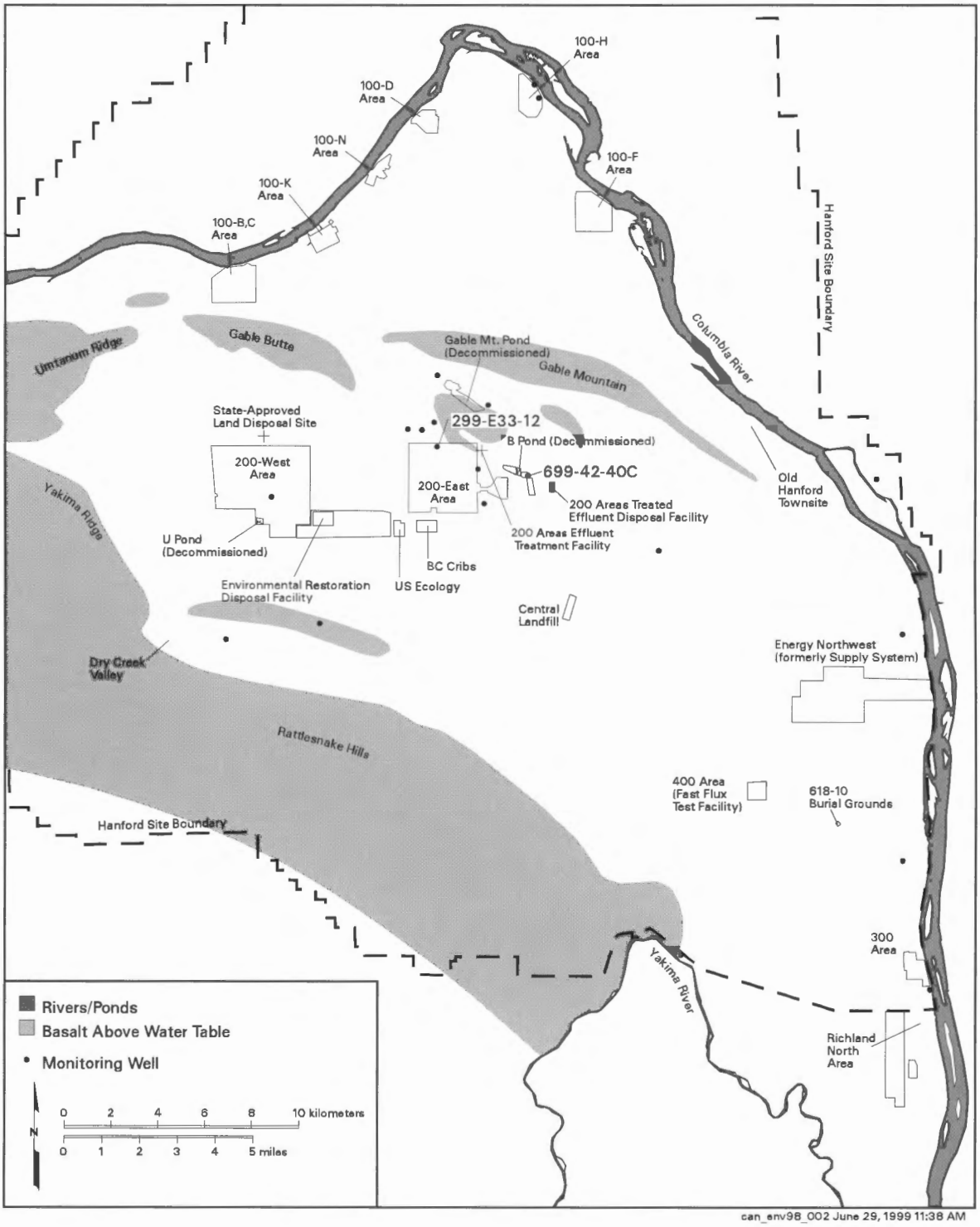
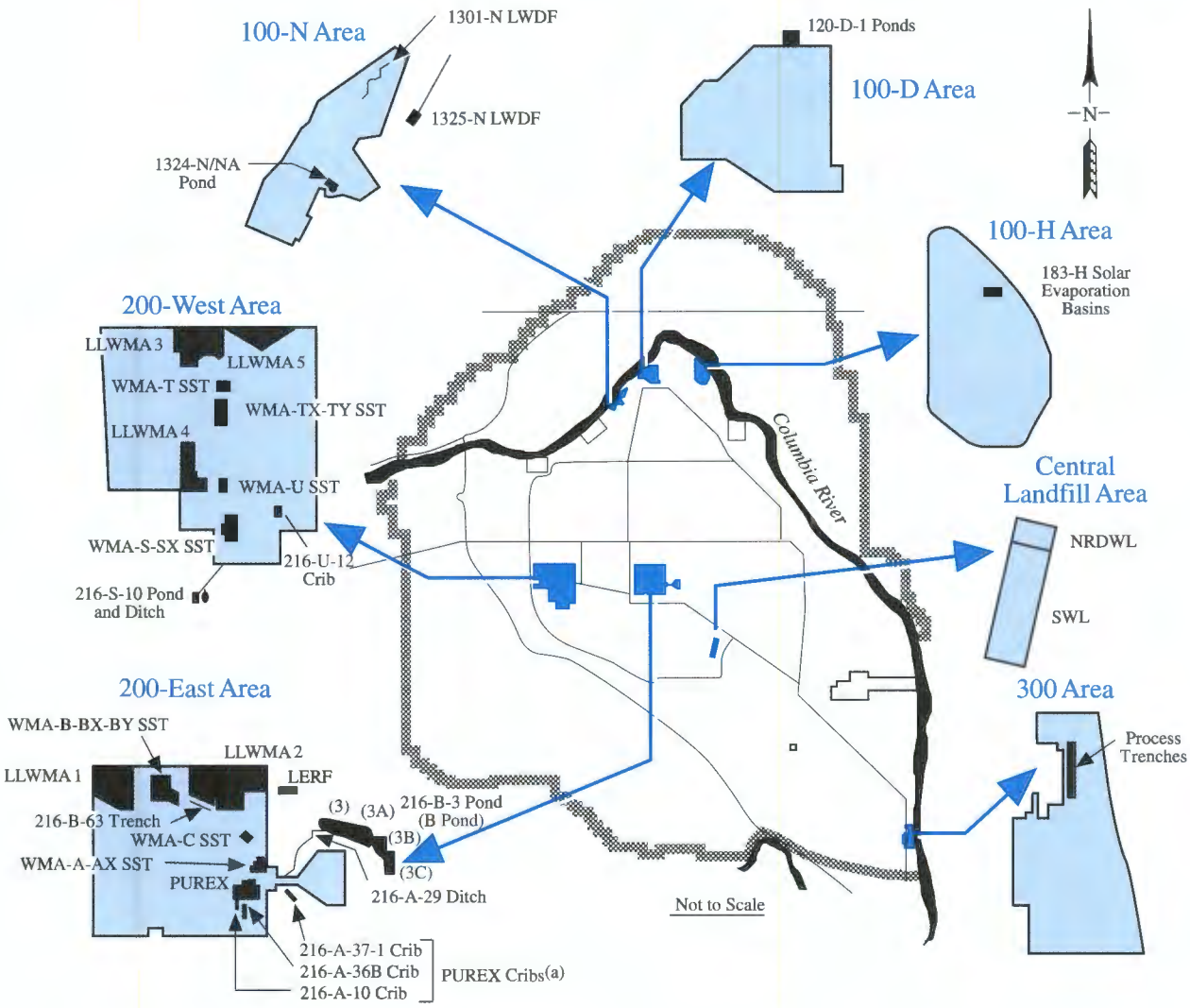


Figure 6.1.11. *Confined Aquifer Monitoring Well Locations, 1998*



LERF	Liquid Effluent Retention Facility	PUREX	Plutonium-Uranium Extraction (Plant)
LLWMA	Low-Level Waste Management Area	SST	Single-Shell Tank
LWDF	Liquid Waste Disposal Facility	SWL	Solid Waste Landfill
NRDWL	Nonradioactive Dangerous Waste Landfill	WMA	Waste Management Area

G99030045.94

(a) PUREX cribs are one RCRA groundwater monitoring project

Figure 6.1.12. *Locations of RCRA Groundwater Monitoring Projects*

Table 6.1.2. Hanford Site Well Naming System

Example Well Name	Area
199-	**100 Areas**
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
299-	**200 Areas**
299-W19-3	200-West Area
299-E28-4	200-East Area
399-	**300 Area**
399-1-17A	300 Area
499-	**400 Area**
499-S1-8J	400 Area
699-	**600 Area**
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 (PNL-6894, Rev. 1; ES-SSPM-001) based on U.S. Environmental Protection Agency (EPA) guidelines (OSWER 9950-1). Analytical techniques used are listed in DOE/RL-91-50, Rev. 2; PNL-10698 (Section 4.1.7); and CERCLA work plans. The radionuclides and chemicals analyzed for are listed in Table 6.1.3.

Most groundwater samples collected on the site in 1998 were analyzed for tritium. Selected samples were analyzed for other radionuclides. Sample results for radionuclides are generally presented in picocuries per liter; however, the results for total uranium, which is usually measured by laser fluorescence, are given in micrograms per liter.

Nitrate analyses were performed on many samples collected during 1998 because of the extensive areas with elevated nitrate concentrations that originate from onsite and offsite sources. However, nitrate concentrations were below the EPA 45-mg/L drinking water standard (40 CFR 141) for most of the affected area. Selected monitoring wells were used for additional chemical surveillance.

6.1.5.2 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, field equipment problems, or other errors that result from not following established procedures.

Table 6.1.3. Radionuclides and Chemicals Analyzed for in Groundwater, 1998

Radiological Parameters	Chemical Parameters
Tritium	pH (field and laboratory)
Beryllium-7	Conductance (field and laboratory)
Carbon-14	Total dissolved solids
Potassium-40	Alkalinity
Cobalt-58	Total carbon
Iron-59	Total organic carbon
Cobalt-60	Total organic halogens
Strontium-90	B, Be, Na, Mg, Al, K, Co, Si, As, Se
Technetium-99	Ca, V, Cr, Mn, Fe, Ni, Pb, Li, Hg
Ruthenium-106	Cu, Zn, Sr, Ag, Cd, Sb, Ba, Sn, Tl, Ti
Antimony-125	F^-, Cl^-, NO_3^-, PO_4^{-3}, SO_4^{-2}, NO_2^-, Br^-
Iodine-129	CN^-
Cesium-134	NH_4^+
Cesium-137	Hexavalent chromium
Neptunium-237	Volatile organic compounds
Americium-241	Semivolatile organic compounds
Gross alpha	Polychlorinated biphenyls
Gross beta	Pesticides/herbicides
Europium isotopes	Chemical oxygen demand
Plutonium isotopes	Dissolved oxygen
Radium isotopes	Total petroleum hydrocarbons
Uranium isotopes	Oil and grease
Uranium (total)	Diesel oil
	Gasoline

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.

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 problems with 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 analytical laboratories participate in interlaboratory comparisons, in which many laboratories analyze blind samples prepared by the EPA (see Section 8.0, "Quality Assurance").

In 1998, double-blind samples for specific constituents were analyzed (Section 8.0, "Quality Assurance," discusses double-blind results). Several wells were also cosampled with the Washington State Department of Health for comparison, and the results are available from that agency.

The chemical composition of groundwater may fluctuate from differences in the contaminant source, recharge, or 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 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 levels. 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.

6.1.6 Groundwater Monitoring Results

The following sections summarize the distribution of radioactive and chemical contaminants detected in Hanford Site groundwater during 1998. These discussions are followed by a summary of groundwater monitoring results for RCRA sites. More detailed information on groundwater monitoring, including listings of analysis results for each monitoring well in electronic format, is available in PNNL-12086. However, because PNNL-12086 (the annual groundwater report) covers the fiscal year, it does not include results from the last 3 mo of 1998.

One way to assess the impact of radionuclides and chemicals in groundwater is to compare them to EPA's drinking water standards and DOE's derived concentration guides (40 CFR 141 and DOE Order 5400.5; see Appendix C, Tables C.2 and C.5). The drinking water standards are for protecting public drinking water supplies. The derived concentration guides are for protecting the public from radionuclides resulting from DOE activities. Specific drinking water standards have been promulgated 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 its half-life, the energy and nature of the radioactive decay, and the physiological factors such as its buildup in particular organs. Drinking water standards are more restrictive than derived concentration guides 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, which 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.

6.1.6.1 Radiological Monitoring Results for the Unconfined Aquifer

The radionuclides for which analyses were conducted on Hanford Site groundwater were listed in Table 6.1.3. The distribution of tritium, iodine-129, technetium-99, uranium, strontium-90, carbon-14, cesium-137, cobalt-60, and plutonium are discussed in the following sections. Tritium and iodine-129 are the most widespread contaminants associated with past site operations. Technetium-99 and uranium plumes are extensive in the 200 Areas and adjacent 600 Area. Strontium-90 plumes exhibit very high concentrations in the 100 Areas but are of relatively smaller extent. A carbon-14 plume is widely distributed in the 100-K Area. Cesium-137, cobalt-60, and plutonium contamination occurs in isolated areas in the 200 Areas. Gross alpha and gross 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, including ruthenium-106, antimony-125, and americium-241, are associated with wastes from Hanford Site operations. Because of their very low activities in groundwater, they are not discussed in this section. Half-lives of the radionuclides are presented in Table H.5 in the "Helpful Information" section.

Tritium. 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/EIS-0119F, WHC-SD-EN-RPT-004). In the late 1960s, tritium production took place in N Reactor (WHC-MR-0388).

Tritium was present in many historical waste streams at the Hanford Site 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. For this reason, tritium is the radionuclide most frequently monitored for at the Hanford Site. Figure 6.1.13 shows the 1998 distribution of tritium in the unconfined aquifer. Tritium is one of the most widespread contaminants in groundwater across the Hanford Site and exceeded the 20,000-pCi/L drinking water standard in the 100, 200, 400, and 600 Areas. Tritium levels exceeded the 2,000,000-pCi/L derived concentration guide in the 100-K and 200 Areas. Tritium levels are expected to decrease because of dispersion and radioactive decay (half-life is 12.35 yr).

In 1998, the only tritium bearing liquid effluent discharged to the soil column on the Hanford Site occurred at the State-Approved Land Disposal Site, which began operating in 1995 and is located just north of the 200-West Area. The total radioactivity received by this facility in 1998 was 31.5 Ci.

Tritium in the 100 Areas. Tritium activities greater than the drinking water standard were detected in the 100-B,C, 100-D, 100-F, 100-K, and 100-N Areas. Tritium was detected above the derived concentration guide in the 100-K Area. The largest tritium plume in the 100 Areas with activities above the drinking water standard occurs along the Columbia River from the 100-N Area to the 100-D Area.

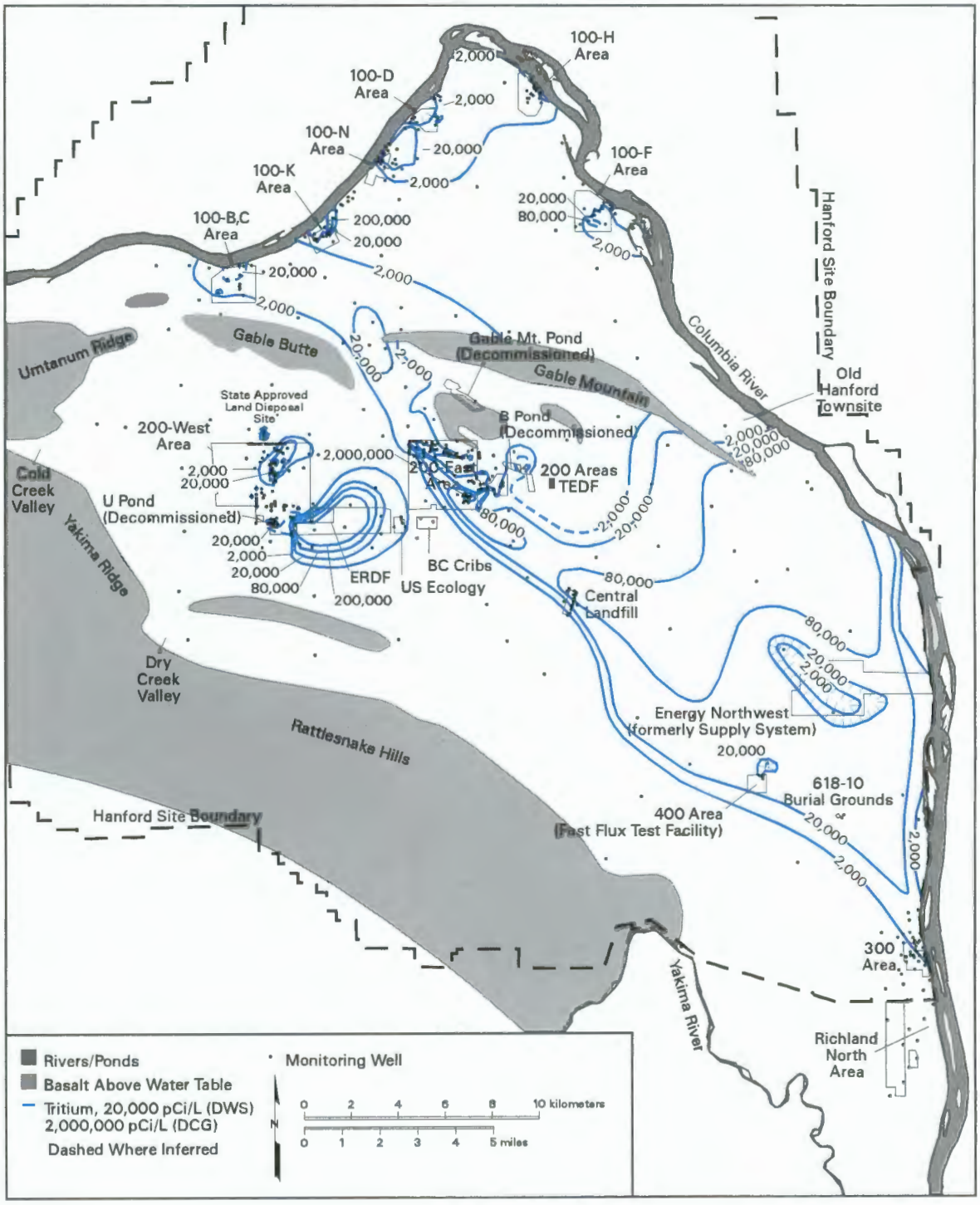


Figure 6.1.13. Average Tritium Activities in the Unconfined Aquifer, 1998

Tritium activities increased to levels above the drinking water standard in several wells in the northern and southwestern parts of the 100-B,C Area in 1998. Most of these are associated with past liquid disposal practices at the 116-B-11 and 116-C-5 Retention Basins and the 116-B-1 and 116-C-1 Trenches near the Columbia River. The maximum tritium activity was 91,900 pCi/L in the southwestern part of the 100-B,C Area. The maximum in the northern part of the 100-B,C Area was 88,100 pCi/L adjacent to the 116-B-11 Retention Basin.

In the 100-D Area, tritium activities were greater than the drinking water standard in the southwestern corner of the area and near D Reactor. The maximum tritium reported during 1998 was 47,000 pCi/L in the southwestern corner of the area and is associated with the tritium plume that extends southwest to the 100-N Area. High activities near D Reactor are associated with past liquid waste disposal to 100-D Area trenches.

One well in the 100-F Area contained tritium at activities greater than the drinking water standard. A maximum of 38,500 pCi/L occurred near the 118-F-1 Burial Ground in 1998. This burial ground received only solid waste, and the source of the tritium contamination is not known.

Well 199-K-30, located near the KE Reactor in the 100-K Area, continued to contain the highest tritium within the 100 Areas, with a maximum activity of 2,360,000 pCi/L. This is the only tritium activity in the 100 Areas that exceeded the derived concentration guide in 1998. The tritium trend for well 199-K-30 is shown in Figure 6.1.14. The probable source is past disposal to a French drain east of the reactor building (DOE/EIS-0119F). The tritium plume with levels greater than the drinking water standard extends downgradient at least 900 m (3,000 ft) from the KE Reactor toward the Columbia River.

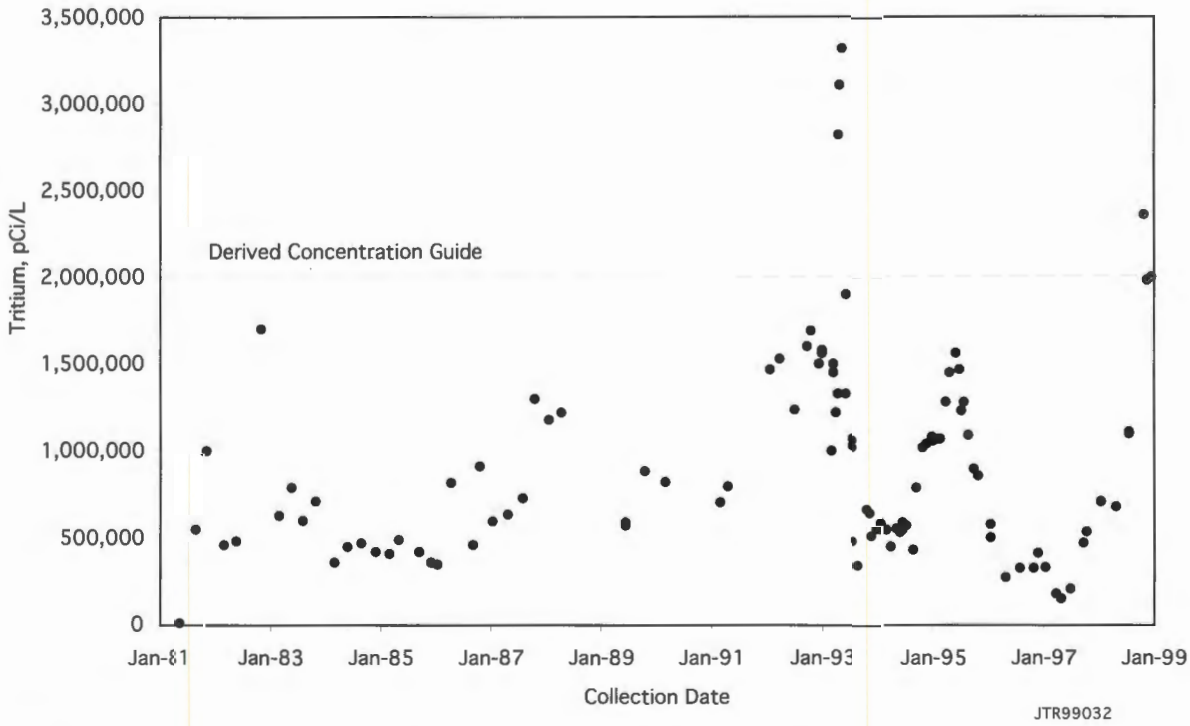


Figure 6.1.14. *Tritium Activities in Well 199-K-30, 1982 Through 1998*

Tritium in the northern part of the 100-N Area is found at levels greater than the drinking water standard. The tritium plume in this area extends northeast to the 600 and 100-D Areas. This plume is associated with past liquid disposal to the 1301-N and 1325-N Liquid Waste Disposal Facilities. The highest activities, which have decreased in recent years, continued to decrease in 1998. The maximum tritium level reported in the 100-N Area in 1998 was 59,700 pCi/L between the 1301-N facility and the Columbia River.

Tritium in the 200-East and 600 Areas. The highest tritium activities in the 200-East Area continued to be measured in wells near cribs that received effluent from the Plutonium-Uranium Extraction Plant. However, tritium levels are generally decreasing slowly in this area. Levels greater than the derived concentration guide were detected in only one well (299-E17-9) in 1998 in the 200-East Area. The maximum tritium level detected in this well, which monitors the 216-A-36B Crib in the southeastern part of the 200-East Area, was 3,870,000 pCi/L. This was the highest tritium level detected in any well on the Hanford Site.

In the plume that extends from the southeastern portion of the 200-East Area, tritium activities >200,000 pCi/L occurred in a small area downgradient of the Plutonium-Uranium Extraction Plant and did not extend beyond the 200-East Area boundary. These levels were generally lower in 1998 than in previous years as a result of dispersion and radioactive decay. The plume area at levels >200,000 pCi/L has extended at least as far southeast as the Central Landfill in the recent past (PNL-8073).

The movement of the widespread tritium plume (see Figure 6.1.13), extending from the southeastern portion of the 200-East Area to the Columbia River, was consistent with patterns noted in recent monitoring reports (Section 6.1.6.1 in PNNL-11795, Section 5.10.3.2 in PNNL-12086). Separate tritium pulses associated with the two episodes of Plutonium-Uranium Extraction Plant operations can be distinguished in the plume. High-tritium activities east of the 200-East Area near the Columbia River result from discharges to the ground during the operation of the Plutonium-Uranium Extraction Plant from 1956 to 1972. Following an 11-yr shutdown, plant operation began in 1983 and ceased in December 1988. This resulted in elevated tritium levels measured in several wells downgradient from the 200-East Area. Movement of the leading edge of this second pulse is clearly observable near the Central Landfill (Figure 6.1.15), which shows arrival in early 1987. Tritium activities from the first pulse were much higher than from the second. The effects of the second operational period have not been detected near the Columbia River. A trend plot (Figure 6.1.16) of the tritium activities in well 699-40-1 near the shore of the Columbia River shows the arrival of the first pulse in the mid-1970s, but shows no indication that the second pulse has yet arrived.

The tritium plume has been monitored since the 1960s and provides information on the extent of groundwater contamination over time. Figure 6.1.17 shows the distribution of tritium in selected years from 1964 through 1988. This figure was created from maps in BNWL-90, BNWL-1970, PNL-5041, and PNL-6825 (Section 5.0). The contours in the original references were recalculated and interpreted to provide uniform contour intervals. Figure 6.1.17 shows that tritium at levels greater than the drinking water standard reached the Columbia River in approximately the mid-1970s.

The configuration of the western portion of the tritium plume shown in Figure 6.1.13 closely matches previous predictions of the direction of contaminant movement from the 200-East Area (PNL-6328). Movement is forced to the south by the flow that originates at the groundwater mound beneath the former B Pond. Flow to the southeast also appears to be controlled by a zone of highly permeable sediments, stretching from the 200-East Area toward the 400 Area (PNL-7144).

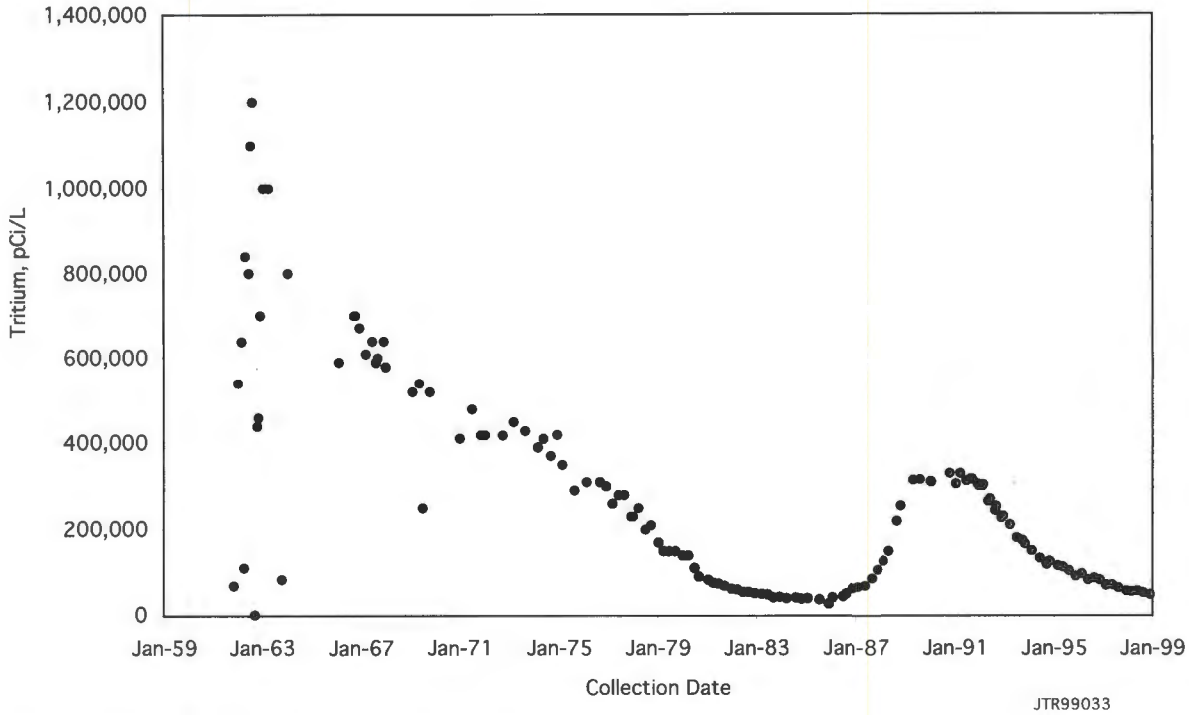


Figure 6.1.15. *Tritium Activities in Well 699-24-33, 1962 Through 1998*

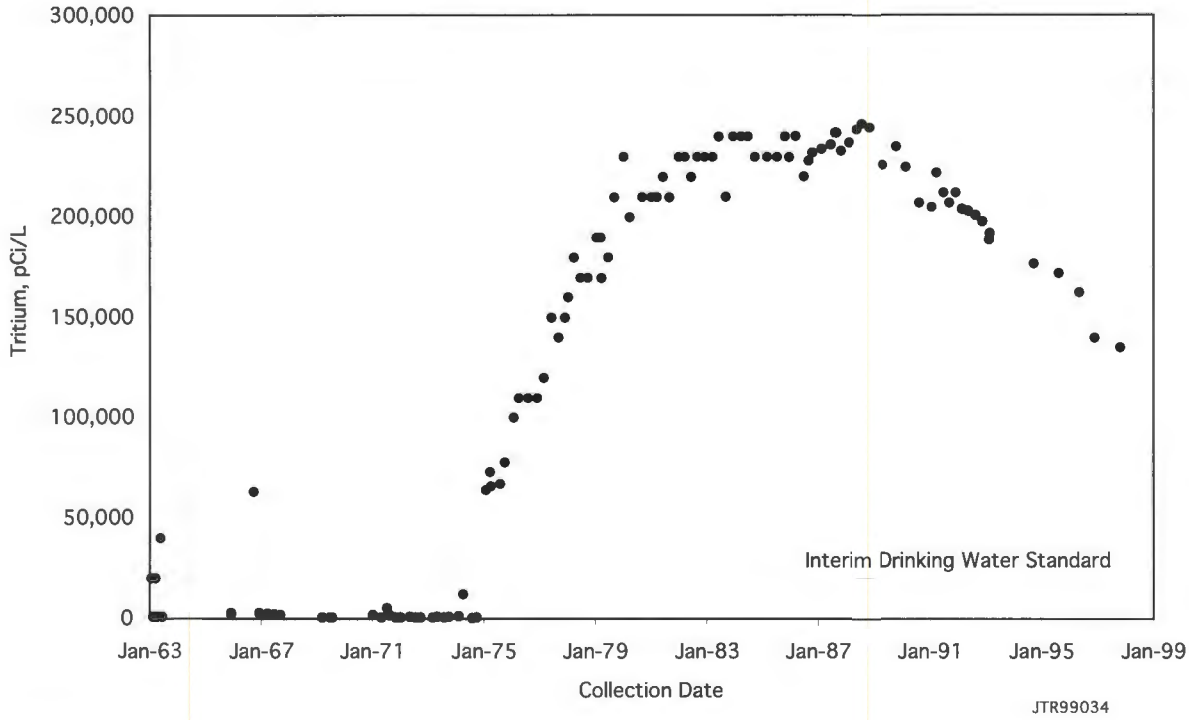


Figure 6.1.16. *Tritium Activities in Well 699-40-1, 1963 Through 1998*

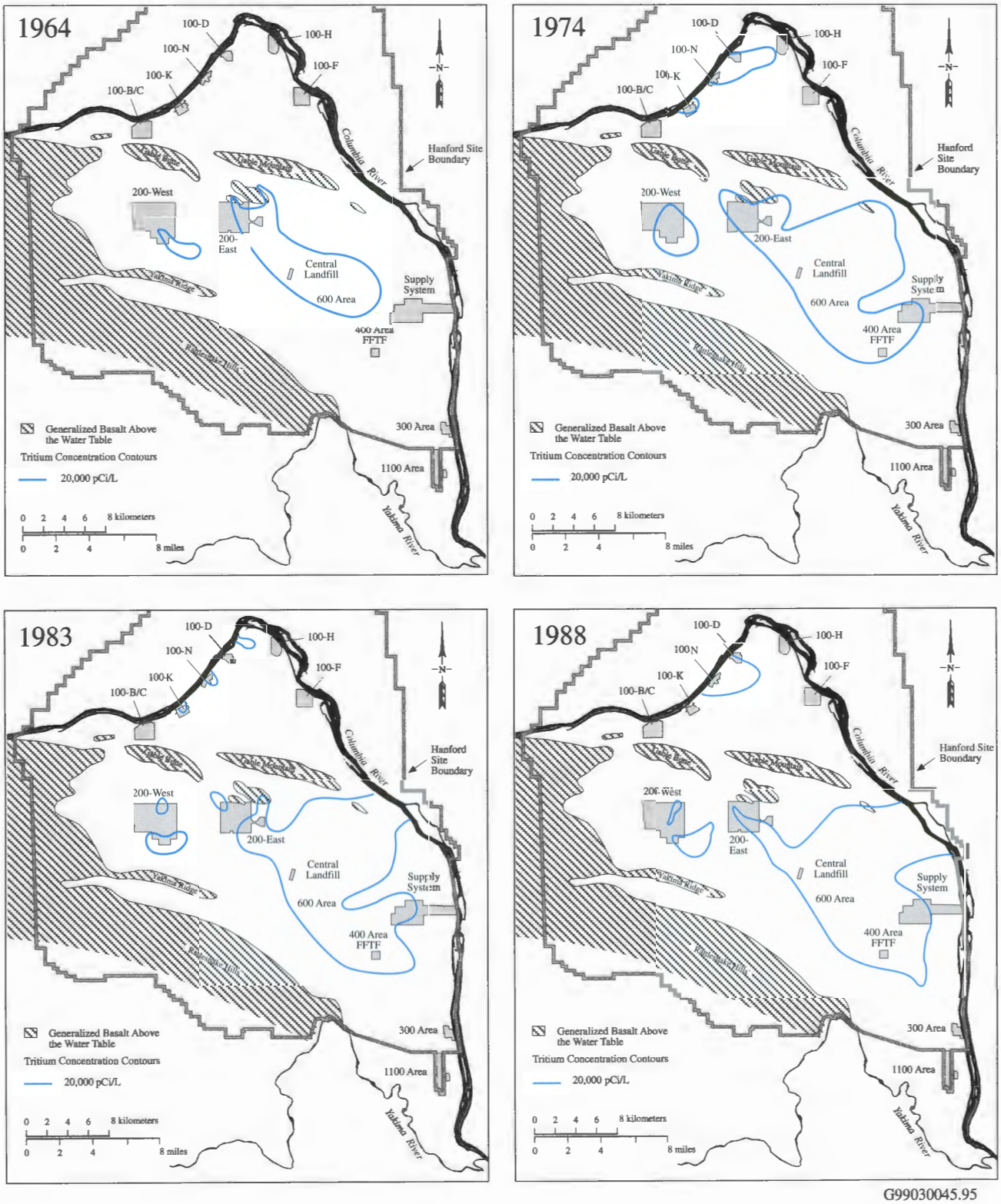


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Figure 6.1.17. *Historical Tritium Activities on the Hanford Site*

The distribution of tritium near the former B Pond shows an area of activity above the drinking water standard in a limited area near the former B Pond. B Pond produced a radial flow pattern of groundwater that mostly had low contaminant levels. The mound under the former B Pond has begun to dissipate since wastewater flow was diverted to the 200 Areas Treated Effluent Disposal Facility in August 1997.

Tritium is also found at levels above the drinking water standard in the northwestern part of the 200-East Area (see Figure 6.1.13). This plume appears to extend to the northwest through the gap between Gable Mountain and Gable Butte. The tritium distribution to the northwest and southeast of the 200-East Area indicates a divide in groundwater flow direction across the 200-East Area. A pulse of tritium levels above the standard also occurred between Gable Mountain and Gable Butte.

Tritium in the 200-West Area. Tritium from sources near the Reduction-Oxidation Plant forms the most extensive plume in the 200-West Area. The Reduction-Oxidation Plant is located in the southeastern part of the 200-West Area and operated from 1951 through 1967. This plume extends into the 600 Area east of the 200-West Area to US Ecology's facility. The eastern part of the plume curves to the north, but the tritium activities in the northern part of the plume are declining. However, activities continue to increase slowly in the eastern part of the plume near the US Ecology facility. Tritium activities exceeded the drinking water standard in much of the plume, including a small area near the former 216-S-25 Crib upgradient of the Reduction-Oxidation Plant. The maximum activity in this plume in 1998 was 451,000 pCi/L in the 600 Area east of the Reduction-Oxidation Plant. The movement of groundwater in the 200-West Area is slow because Ringold Formation sediments have low permeability. Movement of the plumes in the 200-West Area is also slow as a result of declining hydraulic gradients since the closure of U Pond in 1984.

A smaller tritium plume that covers much of the northern part of the 200-West Area occurs in the vicinity of the TX and TY Tank Farms (see Figures 6.1.12 and 6.1.13) and T Plant disposal facilities, which received liquid waste from historical T Plant operations. The highest tritium activity was 3,210,000 pCi/L detected near the TX and TY Tank Farms. This was a sharp increase from 1997 levels and was the only activity that exceeded the derived concentration guide in the 200-West Area in 1998. The area where the drinking water standard was exceeded extends northeast past the northern boundary of the 200-West Area.

Two wells monitoring the State-Approved Land Disposal Site just north of the 200-West Area showed tritium activities that exceeded the drinking water standard, with one of the wells showing a maximum value (2,100,000 pCi/L) that exceeded the derived concentration guide in 1998. These activities are associated with the disposal site, which receives treated effluent containing tritium. This disposal site has been in operation since 1995.

Tritium in the 300 Area. The eastern portion of the tritium plume that emanates from the 200-East Area continues to move to the east-southeast and discharge into the Columbia River (see Figure 6.1.13). The southern edge of the tritium plume extends into the 300 Area, as shown in Figure 6.1.18. Figure 6.1.19 shows the trend of tritium activities in well 699-S19-E13 just north of the 300 Area. Tritium in this well decreased slightly in 1998 after reaching a maximum in 1997. Even though tritium in the 300 Area is below the drinking water standard, a concern has been the potential migration of the tritium plume to an offsite municipal water supply to the south. The municipal water supply consists of the city of Richland's well field recharge basins (see Figure 6.1.18).

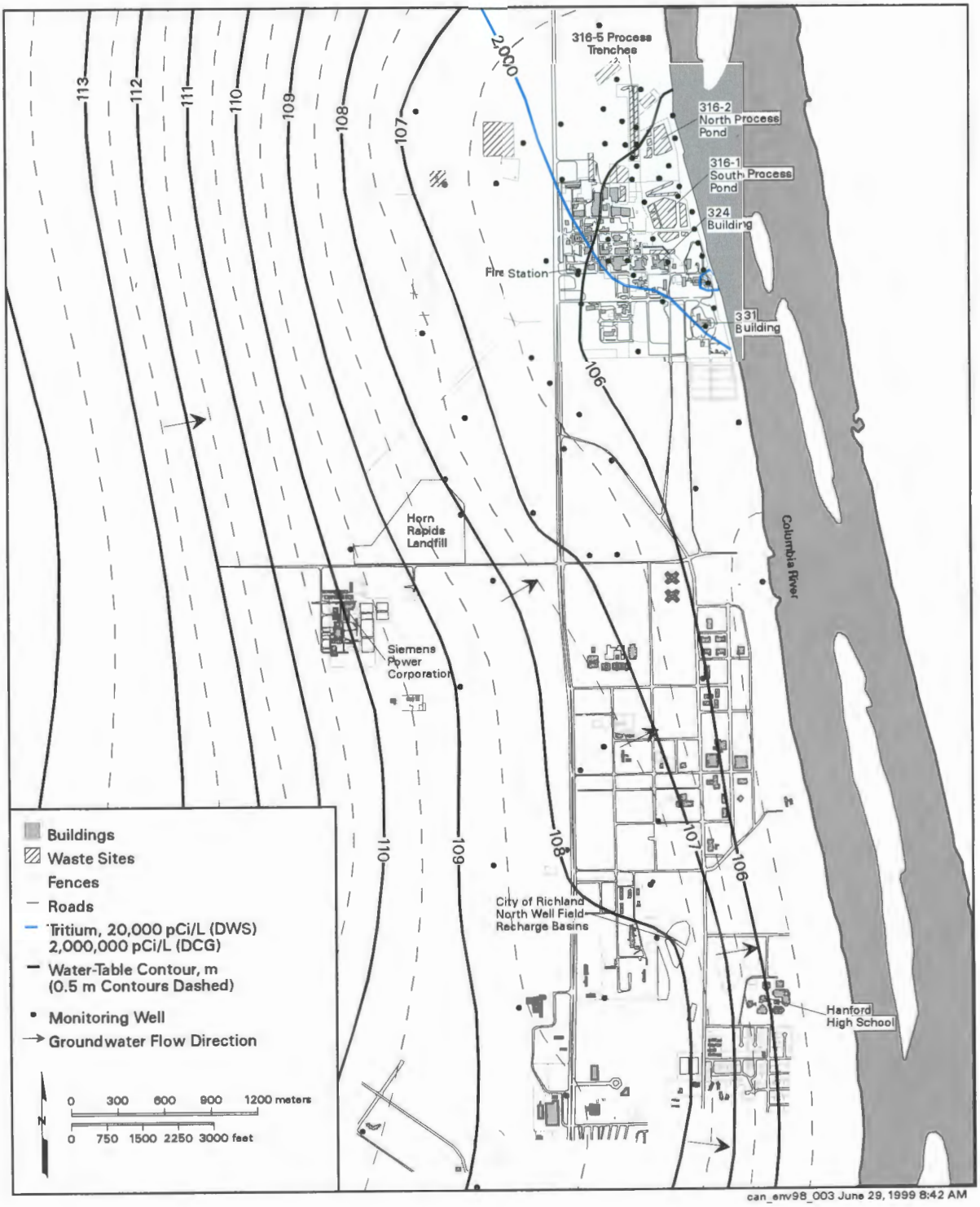

Figure 6.1.18. *Average Tritium Activities and Groundwater Flow Near the 300 Area, 1998*

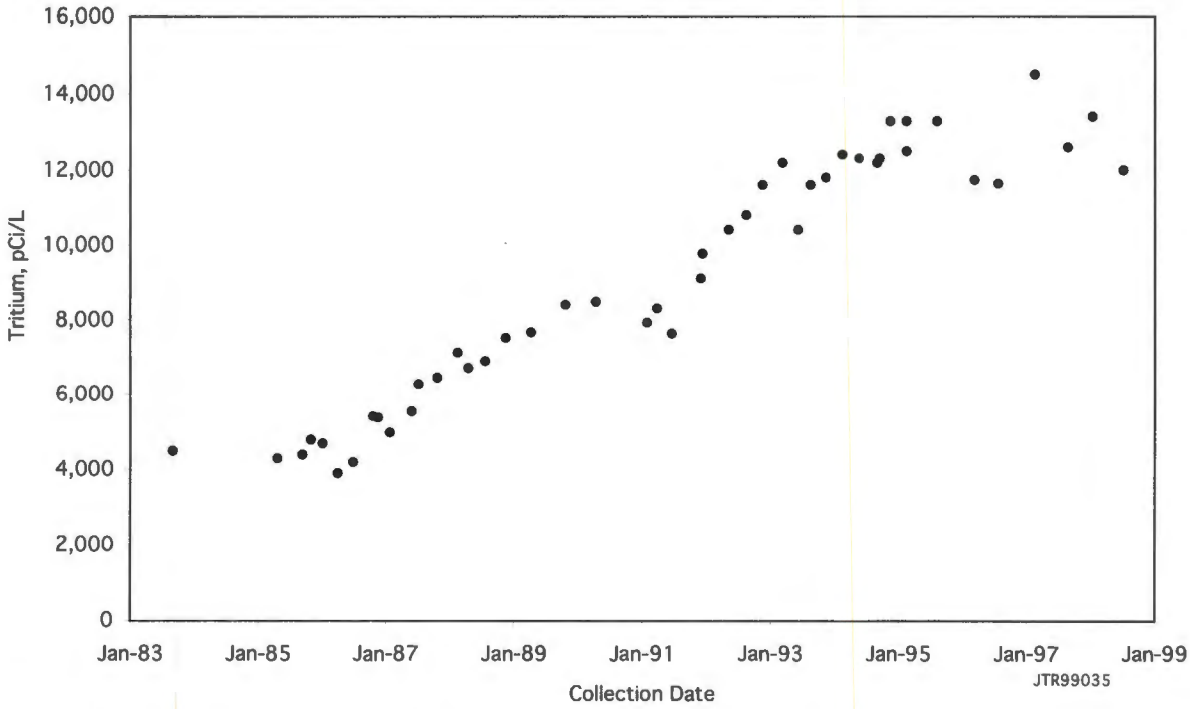

Figure 6.1.19. *Tritium Activities in Well 699-S19-E13, 1983 Through 1998*

The tritium plume is not expected to impact the well field recharge basins because of the influence of groundwater flow from the Yakima River, recharge from agricultural irrigation, and recharge from infiltration ponds at the well field (see Figure 6.1.18). The Yakima River is at a higher elevation and recharges the groundwater in this area. As a result, groundwater flows from west to east (see Figure 6.1.18), minimizing the southward movement of the contaminant plume. Recharge from agricultural irrigation occurs south of the Hanford Site boundary and also contributes to eastward flow. The recharge basins are supplied with Columbia River water, which infiltrates to the groundwater. The amount of recharge water exceeds the amount pumped at the well field by a factor of approximately 2:1, resulting in groundwater flow away from the well field. This further ensures that tritium-contaminated groundwater will not reach the well field. Ongoing monitoring is performed to confirm this interpretation.

Tritium in the 400 Area. The tritium plume that originated in the 200-East Area extends under the 400 Area. The observed maximum in this area during 1998 was 36,300 pCi/L in well 499-S1-8K. The primary water supply well for the 400 Area (499-S1-8J) is completed in the lower part of the aquifer and had a maximum tritium activity of 19,500 pCi/L. However, the sample may have been switched and mislabeled with a sample from a backup water supply well. The average activity in the primary water supply in 1998 was 5,947 pCi/L. The activities at wells used for backup water supply (499-S0-7 and 499-S0-8) were above the drinking water standard. The maximum in the backup water supply was 31,500 pCi/L, which is an increase from 1997 levels. The water supply wells are located in the northern part of the 400 Area. Additional information on the 400 Area water supply is provided in Section 4.3, "Hanford Site Drinking Water Surveillance."

Samples collected from wells near the 400 Area Process Ponds showed a maximum tritium activity (22,300 pCi/L) that exceeded the drinking water standard. The 400 Area Process Ponds are located in the 600 Area north of the 400 Area. Discharge of wastewater to this facility does not contribute tritium contamination to groundwater because the source of the wastewater is water supply usage from local groundwater wells.

Iodine-129. Iodine-129 has a relatively low drinking water standard (1 pCi/L), has the potential for accumulation in the environment as a result of long-term releases from nuclear fuel reprocessing facilities (Soldat 1976), and has a long half-life (16,000,000 yr). The relatively low fission yield for production of iodine-129 combined with its long half-life limits its specific activity in Hanford Site wastes. Iodine-129 may be released as a vapor during fuel dissolution and other elevated temperature processes and, thus, may be associated with process condensate wastes. At the site, the main contributor of iodine-129 to groundwater has been liquid discharges to cribs in the 200 Areas. Iodine-129 has essentially the same high mobility in groundwater as tritium. No groundwater samples showed iodine-129 activities above the 500-pCi/L derived concentration guide in 1998.

Iodine-129 in the 200-East Area. The highest iodine-129 activities in the 200-East Area are in the northwest near the BY Cribs and in the southeast near the Plutonium-Uranium Extraction Plant. The maximum level of iodine-129 detected in 1998 in the 200-East Area was 12.9 pCi/L south of the Plutonium-Uranium Extraction Plant near the 216-A-10 Crib. The iodine-129 plume extends from the Plutonium-Uranium Extraction Plant area southeast into the 600 Area and appears coincident with the tritium plumes (see Figure 6.1.13). The plume appears smaller than the tritium plume because of the lower initial activity of iodine-129. The iodine-129 contamination can be detected as far east as the Columbia River but at levels below the drinking water standard. Data indicate that iodine-129 at levels above the drinking water standard is approaching the Columbia River (Figure 6.1.20). The plume likely had the same sources as the tritium plume. Iodine-129 is also present in groundwater at levels above the drinking water standard in the northwestern 200-East Area; however, a definite source for this plume has not been determined. This plume extends northwest into the gap between Gable Mountain and Gable Butte.

Iodine-129 in the 200-West Area. The distribution of iodine-129 in Hanford Site groundwater is shown in Figure 6.1.20. The highest level observed in 1998 was 81.4 pCi/L near the T, TX, and TY Tank Farms in the northern part of the 200-West Area. This level occurs in a plume that originates near the tank farms and nearby disposal facilities and extends northeast toward T Plant. The iodine-129 plume is coincident with the technetium-99 and tritium plumes in this area. A much larger iodine-129 plume occurs in the southeastern part of the 200-West Area, which originates near the Reduction-Oxidation Plant, and extends east into the 600 Area. This plume is essentially coincident with the tritium plume, though there appears to be a contribution from cribs to the north near U Plant. In 1998, the maximum in this plume was 49.6 pCi/L in an area east of the Reduction-Oxidation Plant.

Technetium-99. Technetium-99, which has a half-life of 210,000 yr, is produced as a fission byproduct and is present in waste streams associated with fuel reprocessing. Reactor operations may also result in the release of some technetium-99 associated with fuel element breaches. Under the chemical conditions that exist in Hanford Site groundwater, technetium-99 is normally present in solution as anions that sorb poorly to sediments. Therefore, technetium-99 is very mobile in site groundwater.

Technetium-99 was found at activities greater than the 900-pCi/L interim drinking water standard in the 200-East and 200-West Areas, with the highest

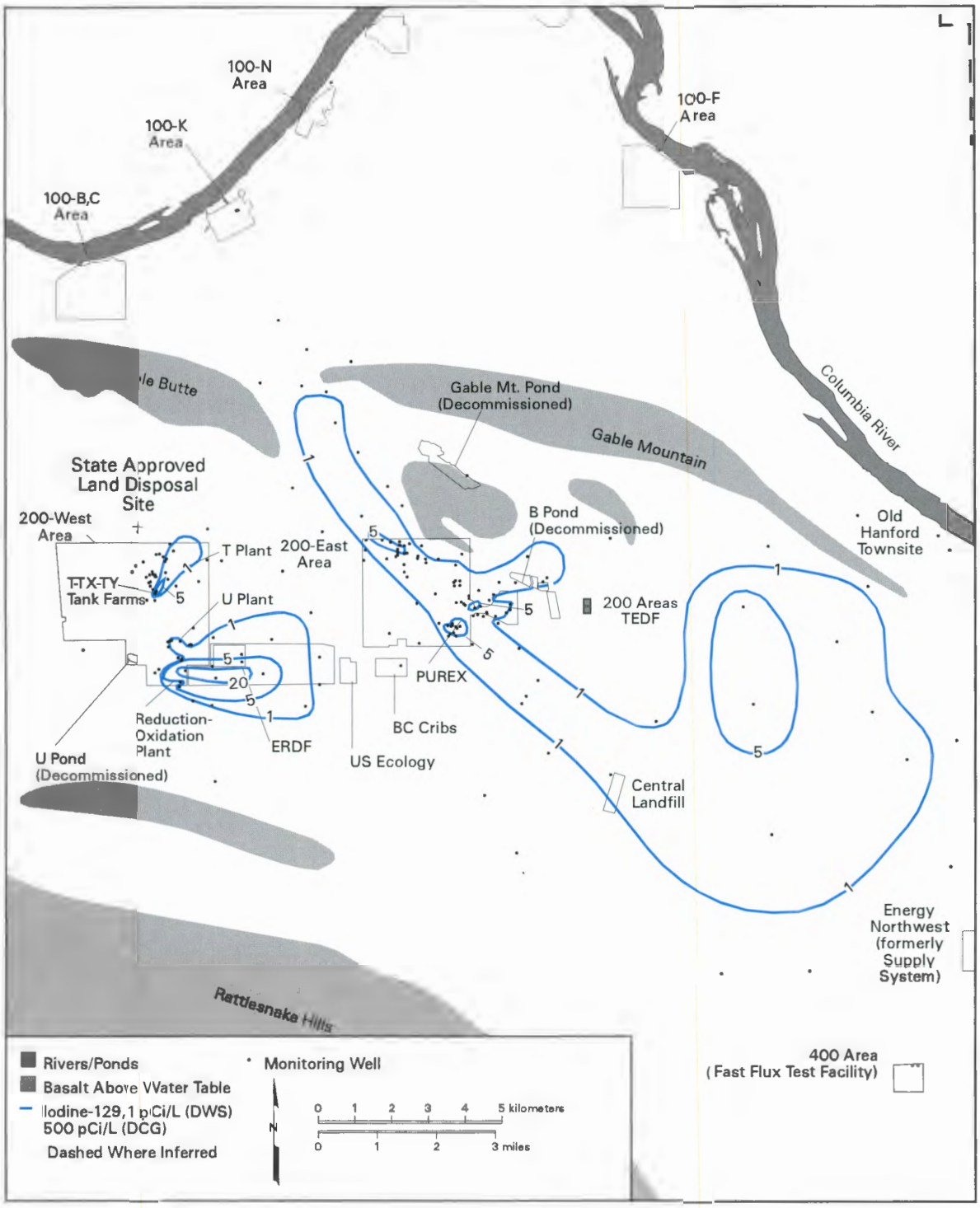

Figure 6.1.20. *Average Iodine-129 Activities in the Unconfined Aquifer, 1998*

measured in the 200-West Area. In the 100-H Area, levels in a localized area fell below the interim drinking water standard in 1998. The derived concentration guide for technetium-99 is 100,000 pCi/L.

Technetium-99 in the 200-East Area. Groundwater in the northwestern part of the 200-East Area and a part of the 600 Area north of the 200-East Area contains technetium-99 at activities above the interim drinking water standard (Figure 6.1.21). The source of these technetium plumes was apparently the BY Cribs (Section 5.8.2 in PNL-10698). However, some of this contamination is believed to originate from the B, BX, and BY Tank Farms (PNNL-11826). Technetium-99 increased in several monitoring wells during 1998, creating a new local center of high technetium-99 levels in the area north and west of the tank farms. The largest increase occurred in the northwestern corner of the BY Cribs, where the maximum in the 200-East Area was 7,030 pCi/L. The maximum technetium-99 in the plume north of the 200-East Area in 1998 was 2,210 pCi/L. This plume appears to be moving through the gap between Gable Mountain and Gable Butte.

Technetium-99 in the 200-West Area. The largest technetium-99 plume in the 200-West Area originates from the cribs that received effluent from U Plant and extends into the 600 Area to the east (Figure 6.1.22). The technetium plume is approximately in the same location as the uranium plume because technetium-99 and uranium, which are typically associated with the same fuel reprocessing cycle, were disposed to the same cribs. The highest technetium-99 activities in this plume in 1998 were measured in several wells in the vicinity of the 216-U-17 Crib, where remediation by the pump-and-treat method is occurring. The high-activity portion of the plume, which has decreased in size, appears to be moving downgradient toward the extraction center (well 299-W19-39). The maximum level was detected in well 299-W19-29 at a level of 22,600 pCi/L, the highest observed at the Hanford Site. This well is located approximately midway between the 216-U-1, 216-U-2, and the 216-U-17 Cribs. Technetium-99 activities in the extraction well decreased in 1998.

The purpose of the pump-and-treat system near the 216-U-17 Crib is to contain and reduce the highest activities/concentrations in the technetium-99 and uranium plumes (Record of Decision 1997). As of September 1998, approximately 53.9 g (1.9 oz) of technetium-99 have been removed from approximately 338 million L (89 million gal) of extracted groundwater since pump-and-treat operations began in 1994 (DOE/RL-99-02). This mass of technetium-99 is equivalent to approximately 0.9 Ci of radioactivity. Contaminated groundwater is currently pumped from one extraction well (299-W19-39) and transported via pipeline to the 200 Areas Effluent Treatment Facility, where it is treated using a number of processes. The treated groundwater is disposed of to the State-Approved Land Disposal Site north of the 200-West Area.

Technetium-99 occurs at levels above the interim drinking water standard in the vicinity of the T, TX, and TY Tank Farms (see Figure 6.1.22). Four wells that monitor these tank farms consistently showed technetium-99 activities above the interim drinking water standard in 1998. Near the TX and TY Tank Farms, the highest was 3,680 pCi/L in the southwestern corner of the tank farms (well 299-W15-22), where technetium-99 levels have been increasing. In the northeastern corner of T Tank Farm, technetium-99 levels were above the interim drinking water standard in two wells. The maximum in this area was 13,000 pCi/L in 1998 (well 299-W11-27). The sources of this technetium-99 contamination were the T, TX, and TY Tank Farms (PNNL-11809).

The small plume in the southern part of the 200-West Area originates near the S and SX Tank Farms and the 216-S-13 Crib. The maximum detected in this area was approximately 4,330 pCi/L near the southeastern corner of the SX Tank Farm. Leakage

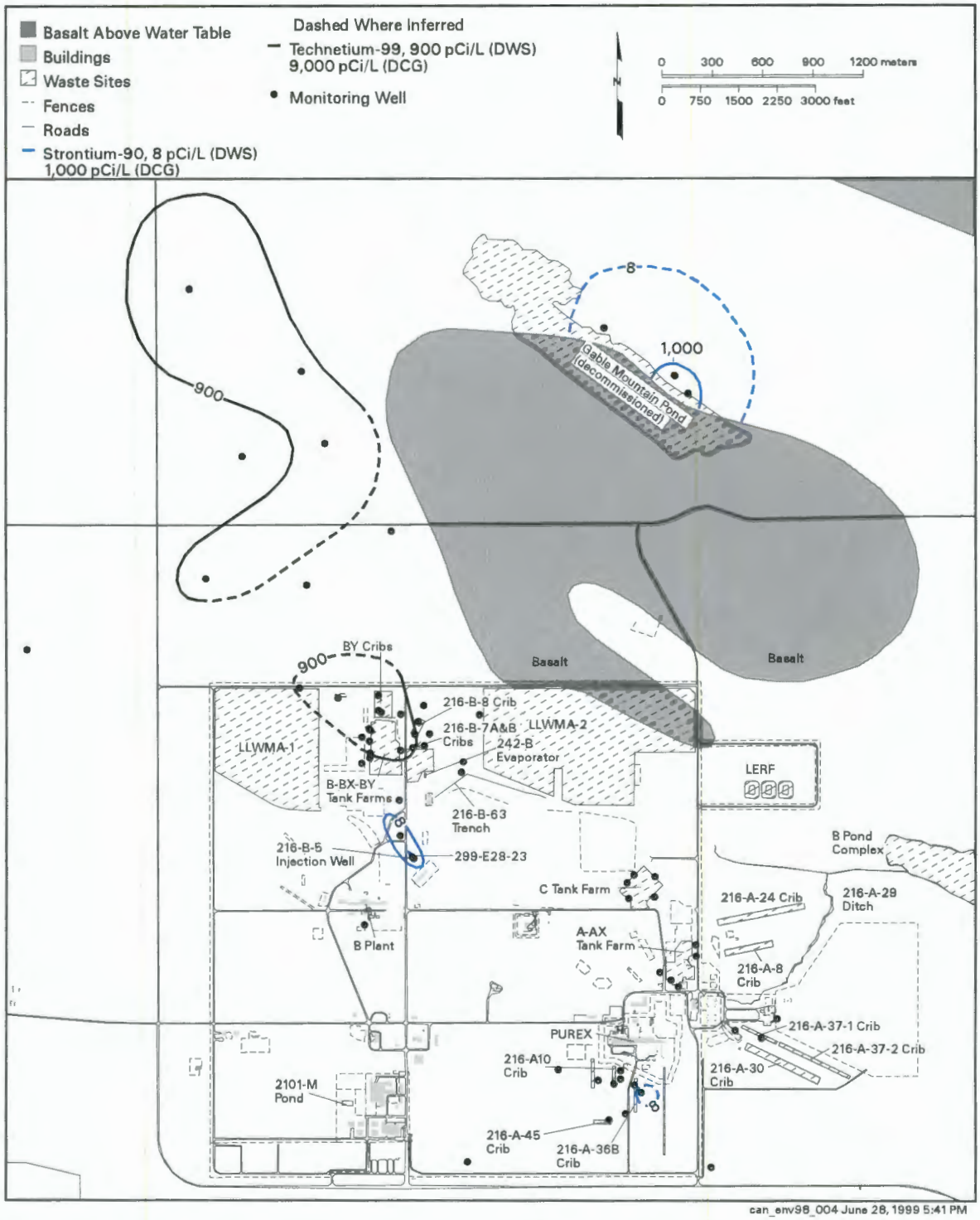

Figure 6.1.21. *Average Technetium-99 and Strontium-90 Activities in the Unconfined Aquifer Near the 200-East Area, 1998*

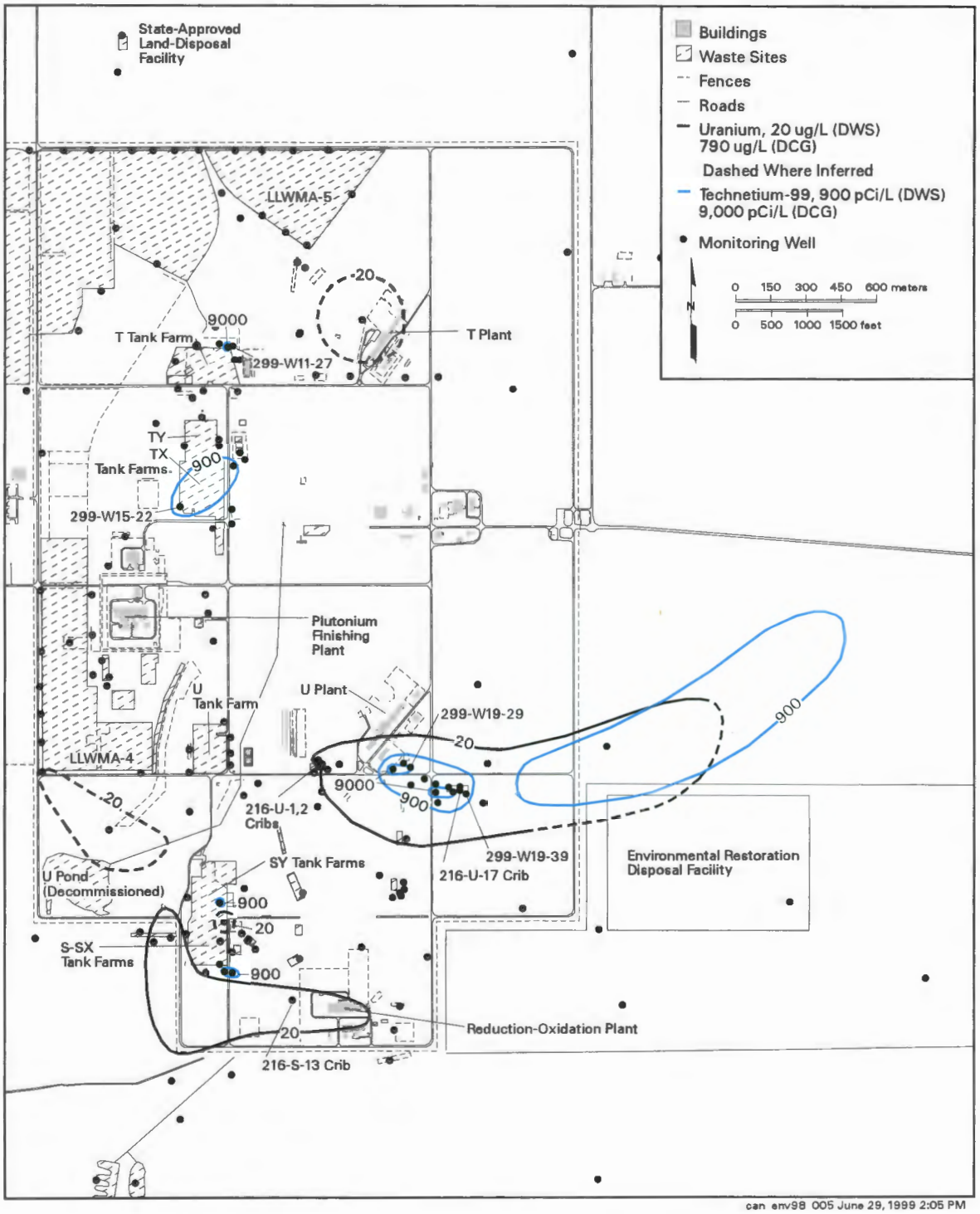

Figure 6.1.22. *Average Technetium-99 Activities and Uranium Concentrations in the Unconfined Aquifer in the 200-West Area, 1998*

from the single-shell tanks is believed to be a source of the technetium-99 in this vicinity (PNNL-11810).

Uranium. There were numerous possible sources of uranium released to the groundwater at the Hanford Site, including fuel fabrication, fuel reprocessing, and uranium recovery operations. Uranium may exist in several states, including elemental uranium or uranium oxide as well as tetravalent and hexavalent cations. Only the hexavalent form has significant mobility in groundwater, largely by forming dissolved carbonate species. Uranium mobility is thus dependent on both oxidation state and pH. Uranium is observed to migrate in site groundwater but is retarded relative to more-mobile species such as technetium-99 and tritium. The EPA's proposed drinking water standard is 20 µg/L for uranium. The derived concentration guide that represents an annual effective dose equivalent of 100 mrem/yr is 790 µg/L for uranium.

Uranium has been detected at concentrations greater than the proposed drinking water standard in portions of the 100, 200, 300, and 600 Areas. The highest levels detected at the Hanford Site in 1998 were in the 200-West Area near U Plant, where uranium levels exceeded the derived concentration guide.

Uranium in the 100 Areas. In 1998, uranium was detected at a concentration greater than the 20-µg/L proposed drinking water standard in one well near F Reactor in the 100-F Area. The maximum detected was 20.3 µg/L.

Uranium was detected at levels higher than the proposed drinking water standard in three wells in the 100-H Area. The maximum detected in 1998 was 57 µg/L. Past leakage from the 183-H Solar Evaporation Basins is considered to be the source of the 100-H Area uranium contamination. These basins were remediated in 1996.

Uranium in the 200-East Area. In 1998, several wells in the northwestern part of the 200-East Area contained uranium at levels greater than the proposed drinking water standard. The distribution of uranium in this area suggests that contamination is of limited extent, with the highest concentrations in the vicinity of the B, BX, and BY Tank Farms; BY Cribs; and 216-B-5 Injection Well that has been inactive since 1947. The highest detected was 282 µg/L east of the BY Tank Farm (southeast of the BY Cribs). The source of the uranium contamination in this area is unclear. Near the inactive 216-B-5 Injection Well, one well showed a uranium concentration greater than the proposed drinking water standard. The concentration at this well was 69 µg/L. Near B Plant, uranium concentrations have been increasing in one well and reached 20 µg/L in 1998. One well adjacent to the inactive 216-B-62 Crib showed a concentration of 21 µg/L in 1998.

Uranium in the 200-West Area. The highest uranium concentrations in Hanford Site groundwater occurred near U Plant, at wells adjacent to the inactive 216-U-1, 216-U-2, and 216-U-17 Cribs (see Figure 6.1.22). The uranium plume, which extends into the 600 Area to the east, is approximately in the same location as the technetium-99 plume discussed above. Uranium and technetium-99 are typically associated with the same fuel reprocessing cycle and were disposed to the same cribs. The high concentrations exceeded the derived concentration guide for uranium. The maximum detected in this area in 1998 was 2,800 µg/L adjacent to the 216-U-17 Crib. Uranium concentrations in this area have been increasing as a result of a pump-and-treat operation at an extraction well (299-W19-39) located near the 216-U-17 Crib. However, the size of the overall plume did not change significantly between 1997 and 1998.

As of September 1998, the pump-and-treat system removed a total of 80.4 kg (177 lb) of uranium from approximately 338 million L (89 million gal) of extracted groundwater since operations began in 1994 (DOE/RL-99-02).

Other areas with uranium contamination at levels above the proposed drinking water standard are also shown in Figure 6.1.22, including fairly widespread areas west and northwest of the Reduction-Oxidation Plant. Uranium concentrations in those areas are considerably lower than the concentrations detected near U Plant. The maximum uranium in these areas was 90.5 µg/L immediately east of the S and SX Tank Farms (northwest of the Reduction-Oxidation Plant). In the northern part of the 200-West Area, a localized area of uranium contamination, where a single sample showed a concentration above the proposed drinking water standard, was found near T Plant.

Uranium in the 300 Area. A plume of uranium contamination exists in the vicinity of uranium fuel fabrication facilities and inactive sites known to have received uranium waste. The plume extends downgradient from inactive liquid waste disposal facilities to the Columbia River (Figure 6.1.23). The major source of the contamination is the inactive 316-5 Process Trenches, as indicated by the distribution of the uranium concentrations downgradient from these trenches (see Section 5.13.3.1 in PNNL-12086). Movement of the plume toward the Columbia River has resulted in increased uranium concentrations near the river in recent years, as shown by the trend plots for wells 399-2-1 and 399-2-2 in Figure 6.1.23. The maximum detected in 1998 was 252 µg/L. Elevated concentrations at the south end of the 316-5 Process Trenches indicate that the soil column is contributing uranium contamination to the groundwater.

A localized area of elevated levels of uranium between the 324 Building and the Columbia River showed a maximum concentration of 128 µg/L in 1998 (see Figure 6.1.23).

Uranium in the 600 Area. The uranium concentration in a well southeast of the 400 Area (adjacent to Route 4S) decreased to a maximum of 91.3 µg/L in 1998. The contamination at this well is attributed to the nearby inactive 316-4 Crib (Section 5.12.3.3 in PNNL-11793). The retired 618-10 Burial Grounds are also located near this well.

Strontium-90. Strontium-90 was produced as a high-yield fission product and was present in waste streams associated with fuel reprocessing. Reactor operations also resulted in the release of some strontium-90 associated with fuel element breaches. Strontium-90 mobility in Hanford Site groundwater is reduced by adsorption onto sediment particles. However, strontium-90 is moderately mobile in groundwater because its adsorption is much weaker than for other radionuclides such as cesium-137 and plutonium. Because of sorption, a large proportion of the strontium-90 in the subsurface is not present in solution. The half-life of strontium-90 is 29.1 yr.

In 1998, strontium-90 activities at greater than the 8-pCi/L interim drinking water standard were found in one or more wells in each of the 100, 200, and 600 Areas. Levels of strontium-90 were greater than the 1,000-pCi/L derived concentration guide in portions of the 100, 200, and 600 Areas. The 100-N Area had the widest distribution with the highest activities detected at the Hanford Site during 1998.

Strontium-90 in the 100 Areas. Strontium-90 activities greater than the interim drinking water standard extend from the B Reactor complex to the Columbia River in the northeastern part of the 100-B,C Area (Figure 6.1.24). The highest continued to be found in wells near the inactive 116-B-1 and 116-C-1 Trenches. The maximum detected in 1998 was 170 pCi/L near the inactive 116-C-1 Trench. The sources for the strontium-90 appear to be liquid waste disposal sites near B Reactor and liquid overflow trenches near the Columbia River (DOE/EIS-0119F).

Strontium-90 is not widely distributed in the 100-D Area. One well continues to show levels that are consistently greater than the interim drinking water standard near the inactive D Reactor fuel

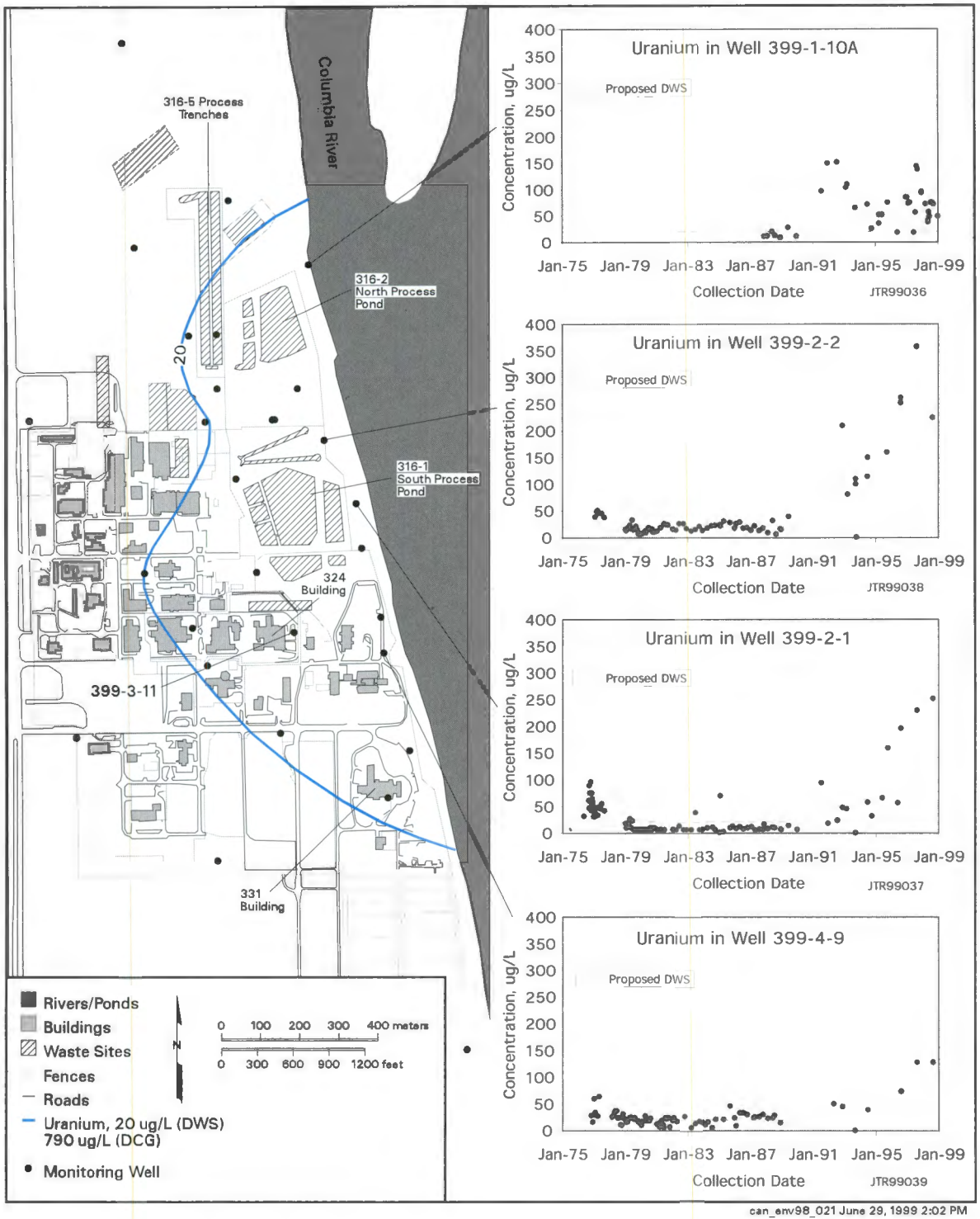

***Figure 6.1.23**. Average Uranium Concentrations in the Unconfined Aquifer in the 300 Area, 1998, and Concentration Trends for Select Wells*

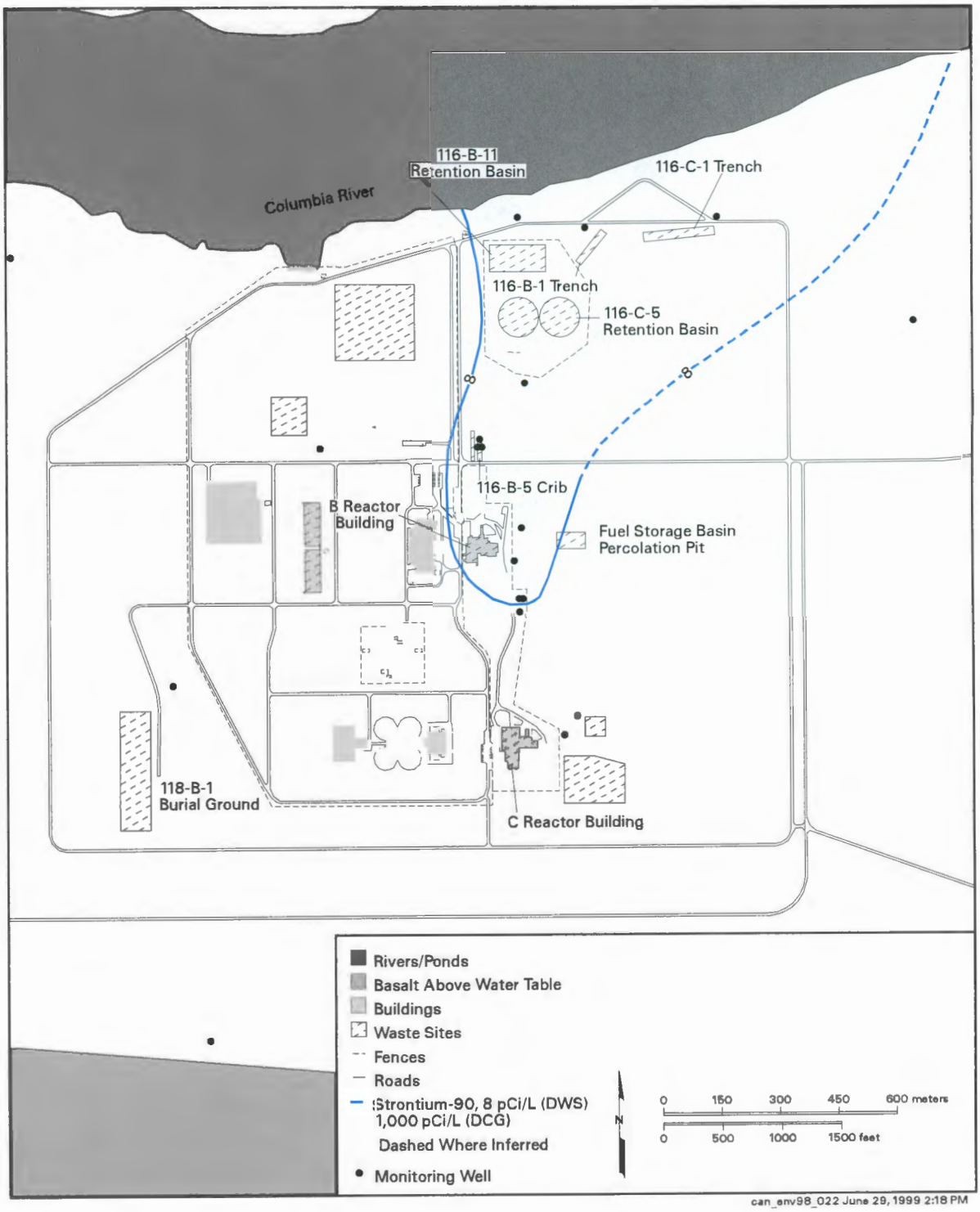

Figure 6.1.24. *Average Strontium-90 Activities in the Unconfined Aquifer in the 100-B,C Area, 1998*

storage basin. The maximum level was 42 pCi/L in 1998. Strontium-90 was detected at levels greater than the interim drinking water standard in well 199-D8-68 near the former 116-D-7 Retention Basin in the northern part of the 100-D Area.

Strontium-90 exceeded the interim drinking water standard in several wells near the 116-F-14 Retention Basins and 116-F-2 Trench in the eastern part of the 100-F Area. The maximum detected in 1998 was 359 pCi/L.

In the 100-H Area, strontium-90 contamination levels greater than the interim drinking water standard were present in an area adjacent to the Columbia River near the 107-H Retention Basin. The maximum detected in the 100-H Area in 1998 was 50 pCi/L between the retention basin and the Columbia River. The source of the contamination is past disposal of liquid effluent containing strontium-90 to retention basins and trenches in the 100-H Area.

Strontium-90 at levels greater than the interim drinking water standard continues to show up in isolated areas in the 100-K Area. These areas include the vicinity of the KE and KW Reactors and between the 116-K-2 Liquid Waste Disposal Trench and the Columbia River. The maximum detected in 1998 was 6,290 pCi/L at well 199-K-109A, the only well in the 100-K Area where levels were above the derived concentration guide. The original source of the strontium-90 in this well, located near the KE Reactor, is believed to be the former 116-K-3 Injection Well/Drain Field. Maximum strontium-90 activities near the KW Reactor and the disposal trench were significantly lower than those near KE Reactor by approximately two orders of magnitude.

The distribution of strontium-90 in the 100-N Area is shown in Figure 6.1.25. Strontium-90 was detected at activities greater than the derived concentration guide in several wells located between the 1301-N Liquid Waste Disposal Facility, a source of the strontium-90, and the Columbia River. The 1325-N Liquid Waste Disposal Facility is also a source of strontium-90 in groundwater. The maximum level detected in 1998 was 26,000 pCi/L near the head end of the 1301-N facility (well 199-N-67). Strong, positive correlations between high-elevation groundwater levels and high-strontium-90 activities in wells indicate that strontium-90 is remobilized during periods of high water levels.

Strontium-90 discharges to the Columbia River through springs along the shoreline in the 100-N Area. Section 4.2, "Surface Water and Sediment Surveillance" and Section 3.2, "Near-Facility Environmental Monitoring," give the results of springs water sampling. Because of large levels in wells near the river, it was expected that strontium-90 exceeded the interim drinking water standard at the interface between the groundwater and the river (DOE/RL-96-102). Groundwater contaminated with strontium-90 entering the river could potentially reach an aquatic and riparian ecological receptor through direct uptake.

A pump-and-treat method began in 1995 to remove strontium-90 in the 100-N Area. The objective is to pump from the extraction wells to create a hydraulic barrier between the river and the 1301-N facility, thus reducing the volume of contaminated groundwater to the river. The pump-and-treat system, which uses ion-adsorption technology, removed approximately 0.1 Ci of strontium-90 from extracted groundwater during fiscal year 1998 (DOE/RL-99-02). This is compared to an estimated total of 76 to 88 Ci in the aquifer (in groundwater and adsorbed on the saturated sediments) (DOE/RL-95-110).

Strontium-90 in the 200 Areas. Strontium-90 distribution in the 200-East Area is shown in Figure 6.1.21. Strontium-90 activities in the 200-East Area were above the derived concentration guide in two wells near the inactive 216-B-5 Injection Well. The maximum was 10,800 pCi/L in well 299-E28-23. This injection well received an estimated 27.9 Ci of strontium-90 during 1945 and 1946 (PNL-6456). Strontium-90 was detected at a level above the

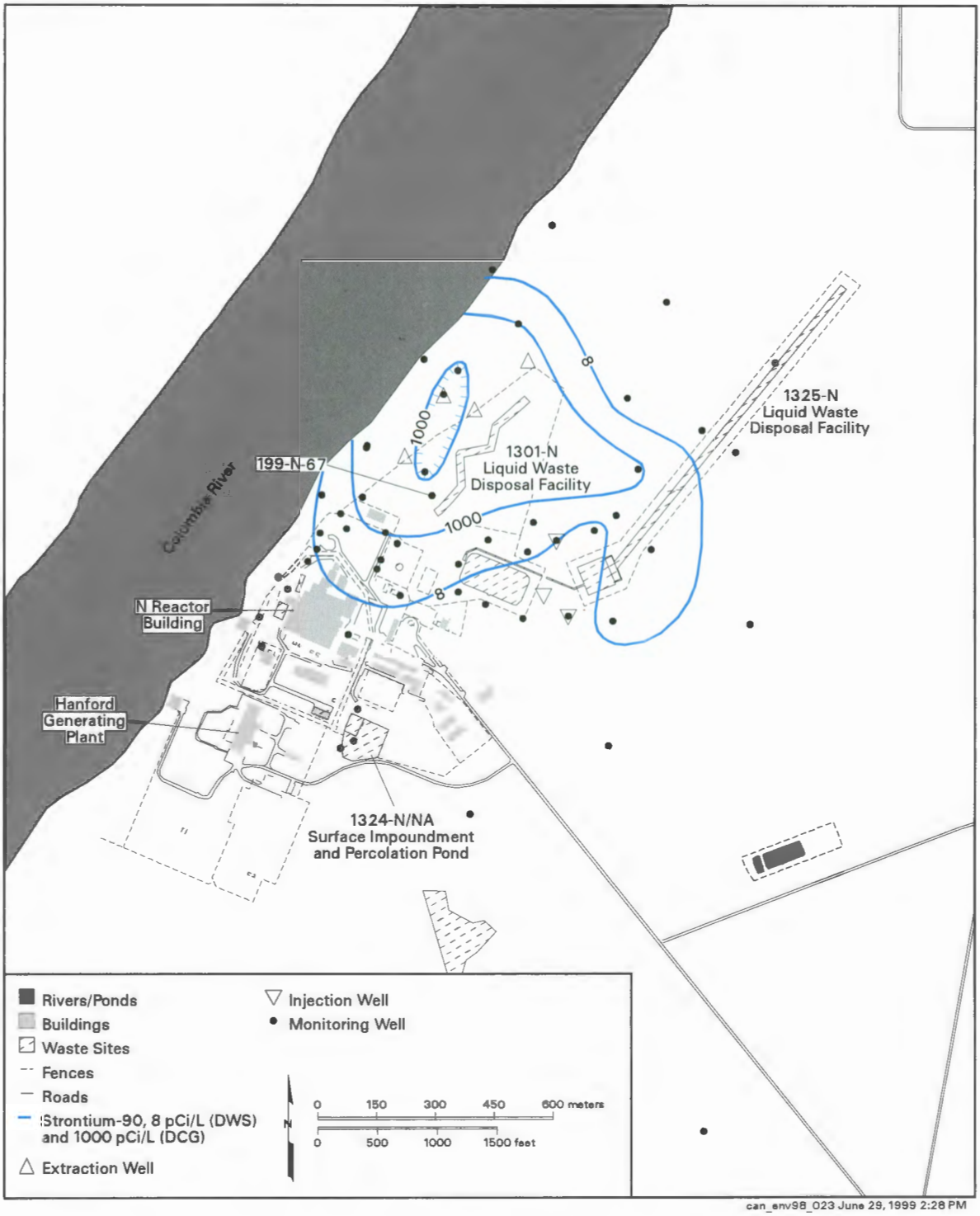

Figure 6.1.25. *Average Strontium-90 Activities in the Unconfined Aquifer in the 100-N Area, 1998*

interim drinking water standard in one well near the Plutonium-Uranium Extraction Plant cribs in the 200-East Area and in one well near the Reduction-Oxidation Plant cribs in the 200-West Area.

Strontium-90 in the 600 Area. In the 600 Area, the highest strontium-90 activities were detected in four wells in the former Gable Mountain Pond area (see Figure 6.1.21). In three of the wells, levels exceeded the derived concentration guide and reached a maximum of 1,350 pCi/L in 1998. Strontium-90 contamination in this area resulted from the discharge of radioactive liquid waste to the former Gable Mountain Pond during its early use.

Carbon-14. Carbon-14 activities are widely distributed in the 100-K Area and exceed the 2,000-pCi/L interim drinking water standard in two plumes near the KE and KW Reactors (Figure 6.1.26). The sources of the carbon-14 were the 116-KE-1 and 116-KW-1 Cribs, respectively. The maximum in 1998 was 35,000 pCi/L near the 116-KW-1 Crib. The derived concentration guide for carbon-14 is 70,000 pCi/L. Carbon-14 has a half-life of 5,730 yr.

Cesium-137. Cesium-137, which has a half-life of 30 yr, is produced as a high-yield fission product and is present in waste streams associated with fuel processing. Former reactor operations also may have resulted in the release of some cesium-137 associated with fuel element breaches. Cesium-137 is normally strongly sorbed on soil and, thus, is very immobile in Hanford Site groundwater. The interim drinking water standard for cesium-137 is 200 pCi/L; the derived concentration guide is 3,000 pCi/L.

Cesium-137 was detected in three wells located near the inactive 216-B-5 Injection Well in the 200-East Area. The injection well received cesium-137 bearing wastes from 1945 to 1947. The maximum cesium-137 in 1998 was 1,840 pCi/L, which is greater than the interim drinking water standard. Cesium-137 appears to be restricted to the immediate vicinity of the former injection well by its extremely low mobility in groundwater.

Cobalt-60. Cobalt-60 in groundwater is typically associated with wastes generated by reactor effluent. Cobalt-60 is normally present as a divalent transition metal cation and, as such, tends to be highly immobile in groundwater. However, complexing agents may mobilize it. All groundwater samples analyzed for cobalt-60 in 1998 were below the 100-pCi/L interim drinking water standard. The derived concentration guide for cobalt-60 is 5,000 pCi/L.

Cobalt-60 activities were less than the interim drinking water standard in the northwestern part of the 200-East Area and the adjacent 600 Area north of the 200-East Area, which are the same areas where the technetium-99 contamination associated with the BY Cribs is found. Apparently, cobalt in this plume is mobilized by reaction with cyanide or ferrocyanide in the waste stream, forming a dissolved cobalt species. The maximum measured in 1998 was 66 pCi/L at the BY Cribs. Because of its relatively short half-life (5.3 yr), much of the cobalt-60 in groundwater in this area has decayed to lower activities.

Plutonium. Plutonium has been released to the soil column in several locations in both the 200-West and 200-East Areas. Plutonium is generally considered to sorb strongly to sediments and, thus, has limited mobility in the aquifer. The derived concentration guide for both plutonium-239 and plutonium-240 is 30 pCi/L. Analytical detection is incapable of distinguishing between plutonium-239 and plutonium-240; thus, the results are expressed as a concentration of plutonium-239,240. There is no explicit drinking water standard for plutonium-239,240; however, the gross alpha drinking water standard of 15 pCi/L would be applicable at a minimum. Alternatively, if the derived concentration guide that is based on a 100-mrem dose standard is converted to the 4-mrem dose equivalent used for the drinking water standard, 1.2 pCi/L would be the relevant guideline. The half-lives of plutonium-239 and plutonium-240 are 24,000 and 6,500 yr, respectively.

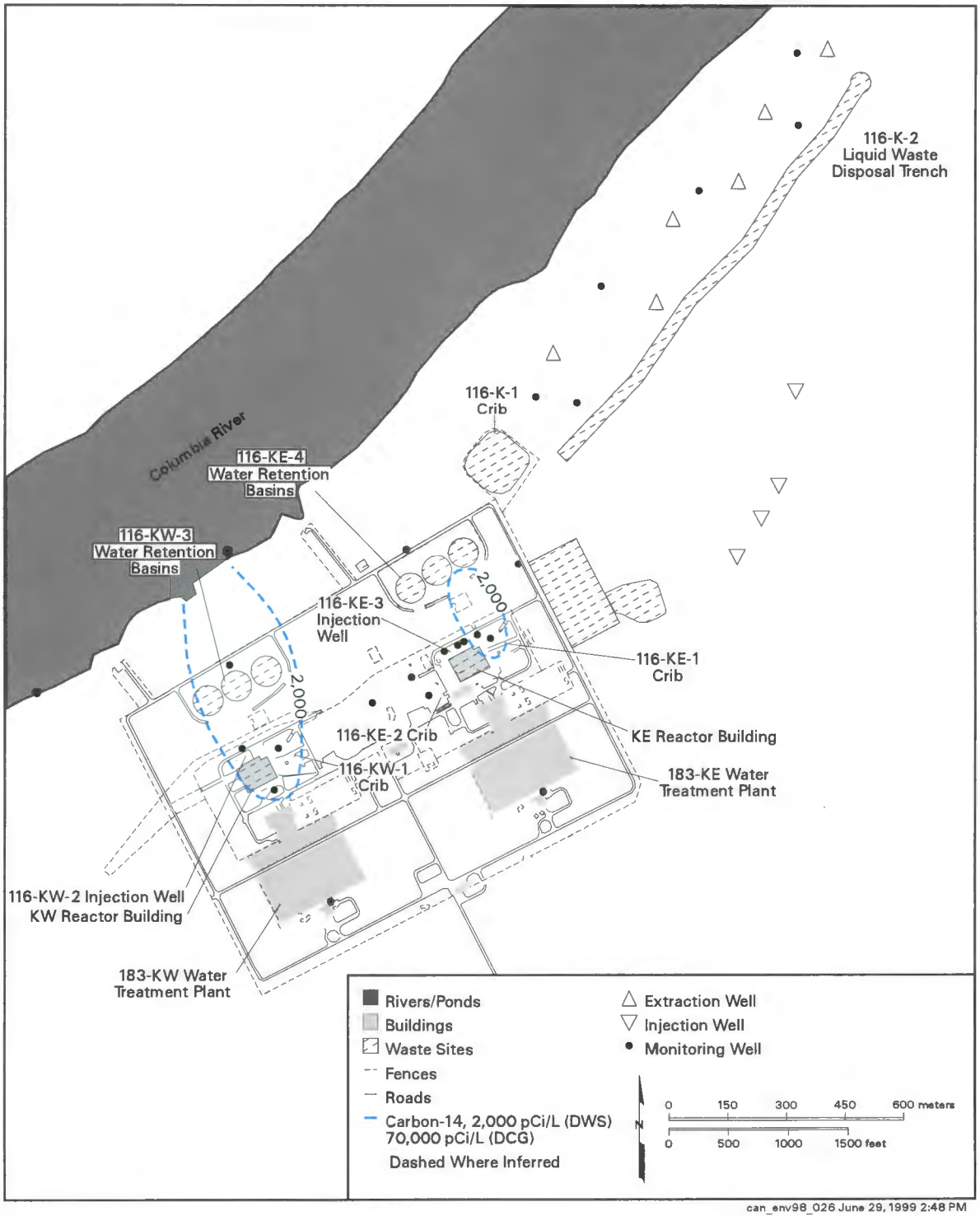

Figure 6.1.26. *Average Carbon-14 Activities in the 100-K Area, 1998*

The only location where plutonium isotopes were detected in groundwater was near the inactive 216-B-5 Injection Well in the 200-East Area. Groundwater sampled during 1998 at wells located near this injection well ranged up to 66 pCi/L of plutonium-239,240. Because plutonium is strongly adsorbed to sediments and may have been injected into the aquifer as suspended particles, it is likely that the values measured result in part from solid rather than dissolved material. The injection well received an estimated 244 Ci of plutonium-239,240 during its operation from 1945 to 1947 (PNL-6456).

6.1.6.2 Chemical Monitoring Results for the Unconfined Aquifer

In recent years, chemical analyses performed by various monitoring programs at the Hanford Site have identified several hazardous chemicals in groundwater at concentrations greater than their respective drinking water standards. Nitrate, chromium, and carbon tetrachloride are the most widely distributed of these hazardous chemicals and have the highest concentrations in groundwater at the Hanford Site. Chemicals that are less widely distributed and have lower concentrations in groundwater include chloroform, trichloroethylene, tetrachloroethylene, cis-1,2-dichloroethylene, cyanide, and fluoride.

A number of parameters such as pH, specific conductance, total carbon, total organic carbon, and total organic halides are used as indicators of contamination. These are mainly discussed in Section 6.1.7, "RCRA Summary." Other chemical parameters listed in Table 6.1.3 are indicators of the natural chemical composition of groundwater and are usually not contaminants from operations at the Hanford Site. These include alkalinity, aluminum, calcium, iron, magnesium, manganese, potassium, silica, and sodium. Chloride and sulfate occur naturally in groundwater and can also be introduced as contaminants from site operations. There is no primary drinking water standard for chloride or sulfate. The secondary standard for each is 250 mg/L and is based on aesthetic rather than health considerations; therefore, they will not be discussed in detail. The analytical technique used to determine the concentration of metals in groundwater provides results for a number of constituents such as antimony, barium, beryllium, boron, cadmium, copper, nickel, silver, strontium, vanadium, and zinc that are rarely observed at greater than background concentrations.

The following presents a summary of the chemical constituents in groundwater at concentrations greater than existing or proposed drinking water standards (40 CFR 141 and EPA 822-R-96-001; see Appendix C).

Nitrate. Many groundwater samples collected in 1998 were analyzed for nitrate. Nitrate was measured at concentrations greater than the drinking water standard (45 mg/L as nitrate ion) in wells in all operational areas. Nitrate is associated primarily with process condensate liquid wastes, though 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 reprocessing operations. However, additional sources of nitrate are located off the site to the south, west, and southwest. The distribution of nitrate on the Hanford Site is shown in Figure 6.1.27; this distribution is similar to previous evaluations. Although nitrate contamination can be detected over large areas of the site, the areas impacted by levels greater than the drinking water standard are small. The widespread distribution of nitrate below the drinking water standard is shown in Figure 5.2-2 of PNNL-12086.

Nitrate in the 100 Areas. A plume containing slightly elevated levels of nitrate occurs in the northeastern part of the 100-B,C Area. In 1998, the maximum nitrate concentration in this area was 49 mg/L, which exceeded the drinking water standard.

Nitrate is found at levels greater than the drinking water standard in much of the 100-D Area. The highest nitrate level found in the 100-D Area in 1998

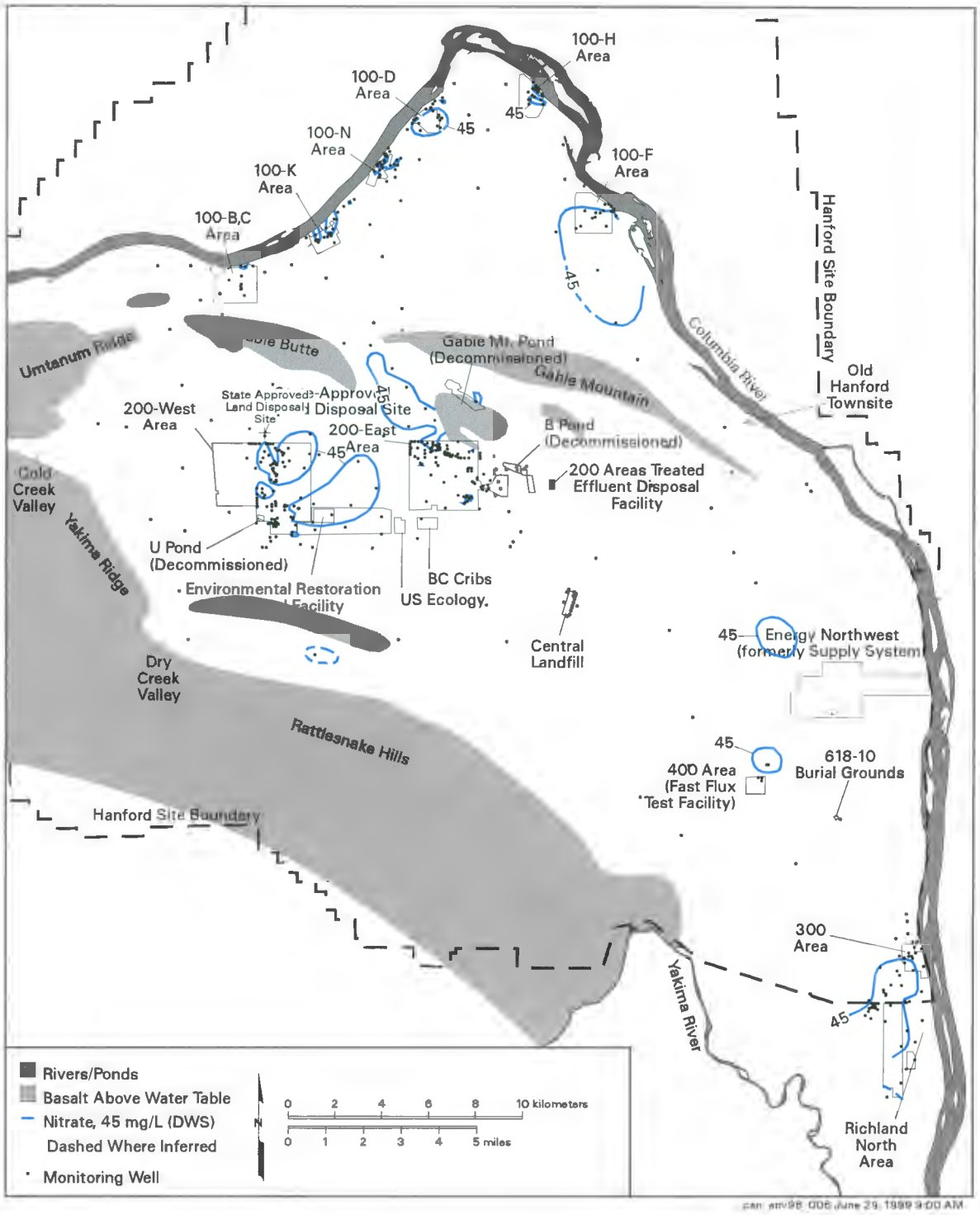

Figure 6.1.27. Average Nitrate Concentrations in the Unconfined Aquifer, 1998

was 103 mg/L, the same as in 1997, in the southwestern part of the area. Slightly lower levels were found in the northeastern part of the 100-D Area.

The central and southern portions of the 100-F Area contain nitrate in groundwater at levels greater than the drinking water standard. This plume appears to extend to the south and southeast into the 600 Area from upgradient sources near F Reactor. In the vicinity of the reactor, groundwater flow was to the south and southeast in 1998. The maximum nitrate detected in the 100-F Area in 1998 was 198 mg/L in the southwestern part of the 100-F Area.

Nitrate above the drinking water standard in the 100-H Area is restricted to a small area downgradient of the former 183-H Solar Evaporation Basins. The concentrations in this area have been some of the highest on the site; however, levels decreased in 1998. The maximum nitrate detected was 273 mg/L. The levels of nitrate exhibited in this area are related to the groundwater levels and Columbia River stage.

Nitrate at levels greater than the drinking water standard in the 100-K Area are found downgradient of both the KE and KW Reactors and appear to reach the Columbia River. The maximum concentration detected in 1998 was 175 mg/L in a well adjacent to the KE Reactor.

Although detected over most of the 100-N Area, nitrate contamination above the drinking water standard occurs at isolated locations in the 100-N Area. The areas where concentrations exceed the drinking water standard grew in size in 1998. The maximum was 280 mg/L in a well located between the 1301-N Liquid Waste Disposal Facility and the Columbia River.

Nitrate in the 200-East Area. The nitrate plume in the 200-East Area covers a nearly identical area to that of the tritium plume. However, the area with nitrate exceeding the drinking water standard is smaller than the area with tritium exceeding its drinking water standard. Nitrate exceeds the drinking water standard near the Plutonium-Uranium Extraction Plant and near cribs in the northern part of the 200-East Area. In 1998, the highest concentrations were reported in several wells near the 216-B-8 and BY Cribs. The maximum concentration in the 200-East Area was 491 mg/L in a well adjacent to the inactive 216-B-8 Crib. High nitrate concentrations in the 600 Area north of the 200-East Area, ranging up to 119 mg/L, are apparently related to past disposal practices at the BY Cribs.

High nitrate concentrations continued to be found near liquid waste disposal facilities that received effluent from Plutonium-Uranium Extraction Plant operations. Nitrate concentrations in wells near the inactive 216-A-10 and 216-A-36B Cribs generally have tended to decrease in the past few years but remained greater than the drinking water standard, even though these facilities were removed from service in 1987. The maximum nitrate concentration detected in this vicinity was 192 mg/L adjacent to the 216-A-36B Crib.

Nitrate is also elevated in a few wells near the former Gable Mountain Pond north of the 200-East Area. The highest measured concentration in this area in 1998 was 127 mg/L.

Nitrate in the 200-West Area. Nitrate concentrations greater than the drinking water standard were widespread in groundwater beneath the 200-West Area and adjacent parts of the 600 Area. The major nitrate plumes were found in wells east of U Plant and wells in the north-central part of the 200-West Area. Some of the highest nitrate concentrations across the site continued to be found in wells southeast of U Plant, where the maximum detected in 1998 was 1,673 mg/L adjacent to the inactive 216-U-17 Crib. This was the highest nitrate concentration observed on the Hanford Site in 1998. The presence of nitrate in wells near this crib was observed before February 1988 when the crib went into operation. The source of nitrate is believed to be wastes

disposed of in the 216-U-1 and 216-U-2 Cribs southwest of U Plant. These cribs received >1,000,000 kg (2,200,000 lb) of nitrate bearing chemicals during their operation from 1951 to 1967 (PNL-6456). As of September 1998, a pump-and-treat system near the 216-U-17 Crib has removed 7,910 kg (17,442 lb) of nitrate from approximately 338 million L (89 million gal) of extracted groundwater (DOE/RL-99-02).

Nitrate concentrations (maximum of 238 mg/L) continued to be elevated above the drinking water standard near other inactive cribs to the south that are associated with the U Plant and Reduction-Oxidation Plant. These elevated levels represent nitrate plumes that coalesce with the plume emanating from the U Plant area. A small, isolated plume of elevated nitrate occurs west of the Reduction-Oxidation Plant near the inactive 216-S-25 Crib and S and SX Tank Farms, where the maximum concentration was 121 mg/L.

A large area, encompassing the northern half of the 200-West Area, continued to contain nitrate in groundwater at concentrations much greater than the drinking water standard. Wells showing the highest concentrations are located near several inactive liquid waste disposal facilities that received waste from early T Plant operations. A large amount of nitrate was disposed to these cribs (e.g., approximately 2,300,000 kg [5,100,000 lb] of nitrate to the 216-T-7 Crib). Maximum concentrations in these wells in 1998 ranged up to 726 mg/L west of T Plant near the inactive T, TX, and TY Tank Farms. High concentrations of nitrate (306 mg/L) were also found in 1998 at the northeastern boundary of the 200-West Area.

A smaller area of elevated nitrate concentrations above the drinking water standard is located in the vicinity of the Plutonium Finishing Plant in the central part of the 200-West Area. The highest reported concentration was 483 mg/L near the 216-Z-9 Crib. This crib had received an estimated 1,300,000 kg (2,900,000 lb) of nitrate bearing chemicals during its operation from 1955 to 1962.

Nitrate in Other Areas. Nitrate concentrations near the city of Richland and in the former 1100 Area, Richland North Area, and adjacent parts of the 600 Area along the southern boundary of the Hanford Site are also apparently affected by offsite nitrate sources. These sources may include agriculture, food processing, urban horticulture, and nuclear fuel manufacturing at offsite commercial facilities. The part of this plume with nitrate concentrations greater than the drinking water standard extends from off the site, south of the former Horn Rapids Landfill, to the 300 Area to the northeast. The area of the nitrate plume at levels greater than the drinking water standard expanded in the southern part of the Hanford Site in 1998. The maximum nitrate concentration in 1998 was 174 mg/L on the northeastern edge of the Horn Rapids Landfill.

Although most nitrate observed on the site is the result of Hanford Site operations, elevated nitrate concentrations in wells in the western part of the site appear to be the result of increasing agricultural activity in offsite areas (e.g., Cold Creek Valley). There is no known source of nitrate in these areas associated with site operations, and the groundwater flow is from the west toward the Hanford Site facilities to the east. Nitrate levels have fluctuated considerably in wells upgradient of the 200 Areas over the past 30 yr. In Cold Creek Valley, nitrate levels have been near or greater than the drinking water standard in one well since 1985. A maximum nitrate concentration of 54 mg/L was found in a well located just north of the Rattlesnake Hills.

Nitrate was detected at levels exceeding the drinking water standard in a well downgradient of the 400 Area process ponds. These levels were attributed to a former sanitary sewage lagoon west of the process ponds. The maximum concentration observed was 97 mg/L.

High nitrate concentrations have been reported off the site in parts of Grant, Adams, and Franklin Counties to the east and north of the Hanford Site. Ryker and Jones (1995) reported that 28% of the wells sampled in this area had nitrate concentrations above the drinking water standard. The nitrate is related, in general, to fertilizer and water usage and has been increasing since the 1950s. This nitrate may impact surface-water quality (see Section 4.2, "Surface Water and Sediment Surveillance") and groundwater in the northern part of the Hanford Site north of the Columbia River.

Chromium. Use of chromium on the Hanford Site has been extensive. In the 100 Areas, sodium dichromate was added to cooling water as a corrosion inhibitor, and some residual chromium remains from that use. Chromium was used for decontamination in the 100, 200, and 300 Areas and also was used for oxidation state control in the Reduction-Oxidation Plant process. In the hexavalent form, chromium is present in an anionic state. Thus, hexavalent chromium is freely mobile in the groundwater. The drinking water standard for chromium is 100 µg/L.

Both filtered and unfiltered samples were collected for analyses of chromium and other metals from several of the wells onsite. Unfiltered samples may contain metals present as particulate matter, whereas filtered samples are representative of the more-mobile, dissolved metals. Filtered samples also may contain some colloidal particles that are fine enough to pass through the filter. Drinking water standards are based on unfiltered concentrations; however, differences in well construction and pumping practices between monitoring wells and water supply wells make it difficult to predict potential drinking water concentrations from monitoring well data when the metals are present as particulate matter. In general, filtered samples provide the best indication of groundwater contamination levels for chromium because unfiltered samples are subject to greater variability introduced by the sampling process. Chromium concentrations in filtered samples, which are considered to be representative of dissolved hexavalent chromium, will be used to describe the level of contamination in the discussion below.

Chromium in the 100 Areas. Chromium has been detected above the drinking water standard in the 100-B,C, 100-D, 100-H, 100-K, and 100-N Areas. Groundwater pump-and-treat systems continued to operate in 1998 to reduce the amount of hexavalent chromium entering the Columbia River at the 100-D, 100-H, and 100-K Areas. The purpose of the pump-and-treat systems is to prevent discharge of hexavalent chromium into the Columbia River at concentrations exceeding 11 µg/L, which is the EPA's standard for protection of freshwater aquatic life.

Chromium exceeded the drinking water standard from a filtered sample in the 100-B,C Area in 1998. The maximum concentration was 113 µg/L downgradient of former water treatment facilities, where sodium dichromate may have leaked from storage tanks and transfer facilities.

The chromium distribution in the 100-D Area is shown in Figure 6.1.28. An area of chromium concentrations greater than the drinking water standard extends from northeast to southwest across the 100-D Area near the Columbia River. The source of chromium in groundwater is sodium dichromate released to the ground at former facilities near D Reactor. Leakage from inactive retention basins and liquid waste disposal trenches north of D Reactor may also have contributed to the chromium plume. In 1998, the maximum chromium concentration from filtered samples was 2,200 µg/L in a well in the vicinity of a chromium hot spot in the southwestern portion of the 100-D Area. The source of this hot spot is unknown. In situ redox manipulation technology is currently being demonstrated in the hot spot area to address hexavalent chromium contamination in groundwater. This technology immobilizes hexavalent chromium by reducing the soluble chromate ion to highly insoluble chromium hydroxide or iron chromium hydroxide. In 1998, results of a

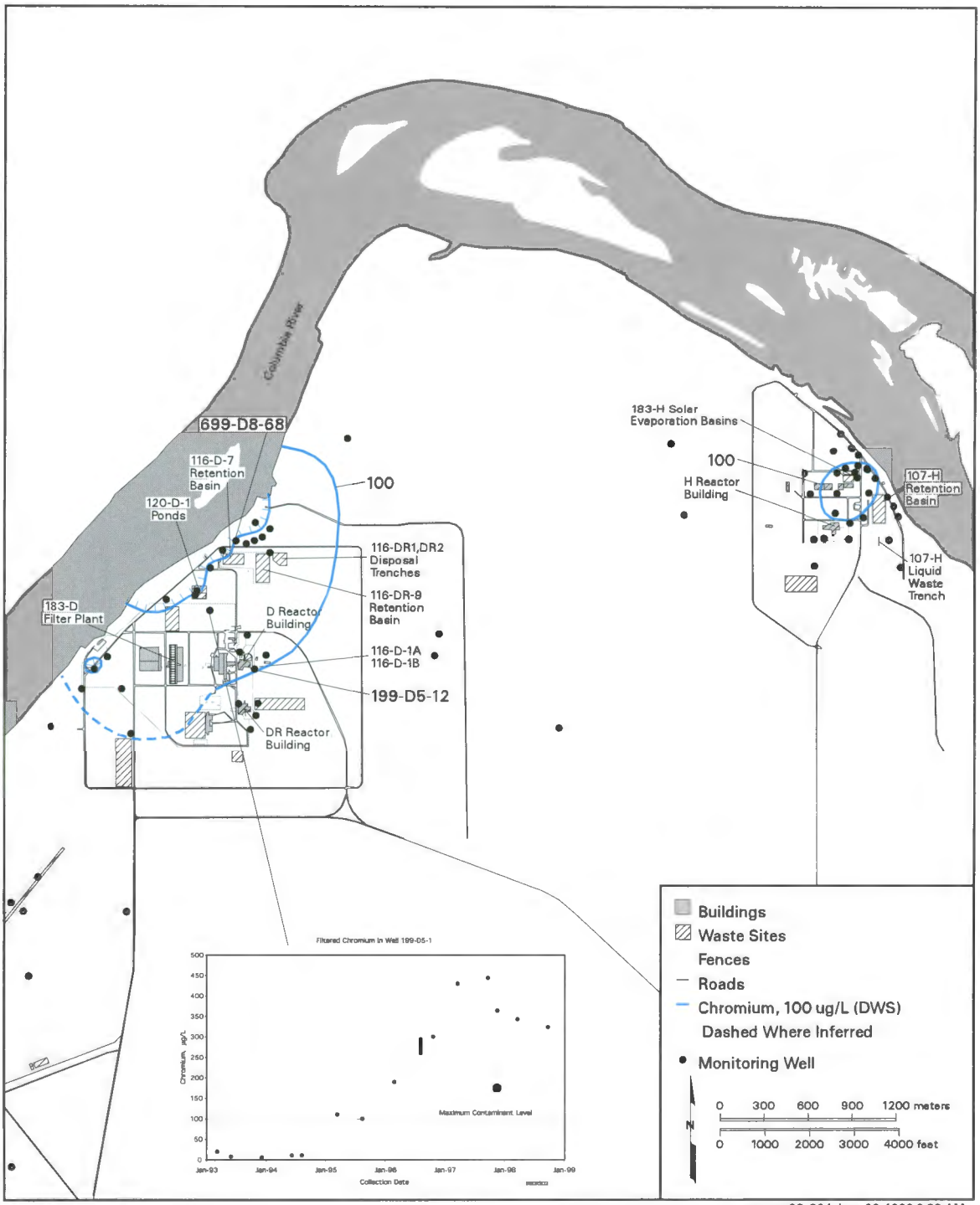

Figure 6.1.28. *Average Filtered Chromium Concentrations in the 100-D and 100-H Areas, 1998, and Concentration Trends for Selected Wells*

treatability study indicated that hexavalent chromium concentrations were decreased from ~1,000 µg/L to less than detection limits (7 µg/L) within the treatment zone. In the area near the inactive 120-D-1 Ponds, chromium concentrations increased in response to ceased discharges of noncontaminated water to the ponds in 1994, as shown by the trend plot for well 199-D5-13 in Figure 6.1.28. Chromium concentrations decreased in late 1997 through 1998.

Many samples from 100-H Area wells contained chromium at levels greater than the drinking water standard (see Figure 6.1.28). In 1998, the maximum chromium concentration from filtered samples collected from the shallow parts of the unconfined aquifer was 259 µg/L in a well near the former 183-H Solar Evaporation Basins. Chromium was also found at levels above the drinking water standard in one well monitoring the deeper part of the unconfined aquifer. Filtered samples from this well, located near the former 183-H Basins, contained 201 µg/L of chromium in 1998. Potential sources include past disposal of sodium dichromate near H Reactor, disposal to the inactive 107-H Liquid Waste Disposal Trench, and chromium in acid wastes stored in the former 183-H Basins (Peterson and Connelly 1992). Chromium was also detected above the drinking water standard in the 600 Area west of the 100-H Area. The maximum concentration in this area in 1998 was 102 µg/L. The primary sources of the chromium plume west of 100-H Area were former 100-D Area liquid waste disposal facilities. Effluent releases at the 100-D Area during operations produced groundwater mounding, which altered flow conditions. This contributed to the spreading of chromium contamination into the 600 Area.

A groundwater remediation pump-and-treat system to decrease the amount of hexavalent chromium entering the Columbia River from the aquifer continued to operate in the 100-D and 100-H Areas in 1998. Groundwater extracted from the 100-D Area wells downgradient of the inactive retention basins is piped to the 100-H Area for treatment. Groundwater extracted from the 100-D and 100-H Area wells is treated using ion-exchange technology and then reinjected into the aquifer in the southwestern part of the 100-H Area. Performance of the interim action to pump and treat has shown that hydraulic containment, resulting from the operation of the extraction wells, has reduced the amount of chromium entering the river from the aquifer in both the 100-D and 100-H Areas (DOE/RL-97-96, DOE/RL-99-13). By the end of December 1998, approximately 53 kg (116 lb) of chromium were removed from >401.5 million L (106.1 million gal) of groundwater extracted from these areas since pump-and-treat operations began in July 1997.

Chromium in the 100-K Area occurs in groundwater near or at levels greater than the drinking water standard (Figure 6.1.29). Two localized areas of chromium contamination occur near the KW Reactor and the water treatment basins southeast of the KE Reactor. The maximum concentration in 1998 was 443 µg/L near the KW Reactor. By late 1998, chromium concentrations reached a maximum of 249 µg/L in a well (199-K-36) adjacent to the 183-KE Water Treatment Basins and inactive sodium dichromate storage tanks. A much wider area of chromium contamination is found in the vicinity of the former 116-K-2 Liquid Waste Disposal Trench to the northeast. A pump-and-treat system for treating chromium in groundwater between the trench and the Columbia River, which began operating in October 1997, continued to operate in 1998. Groundwater extracted from a network of wells is treated using ion-exchange technology and then returned to the aquifer upgradient of the 116-K-2 Trench. By the end of December 1998, approximately 42 kg (93 lb) of chromium have been removed from >311 million L (82 million gal) of extracted groundwater (DOE/RL-99-13).

In the 100-N Area, chromium contamination is not widespread in groundwater. However, filtered samples in one well that monitors a locally confined

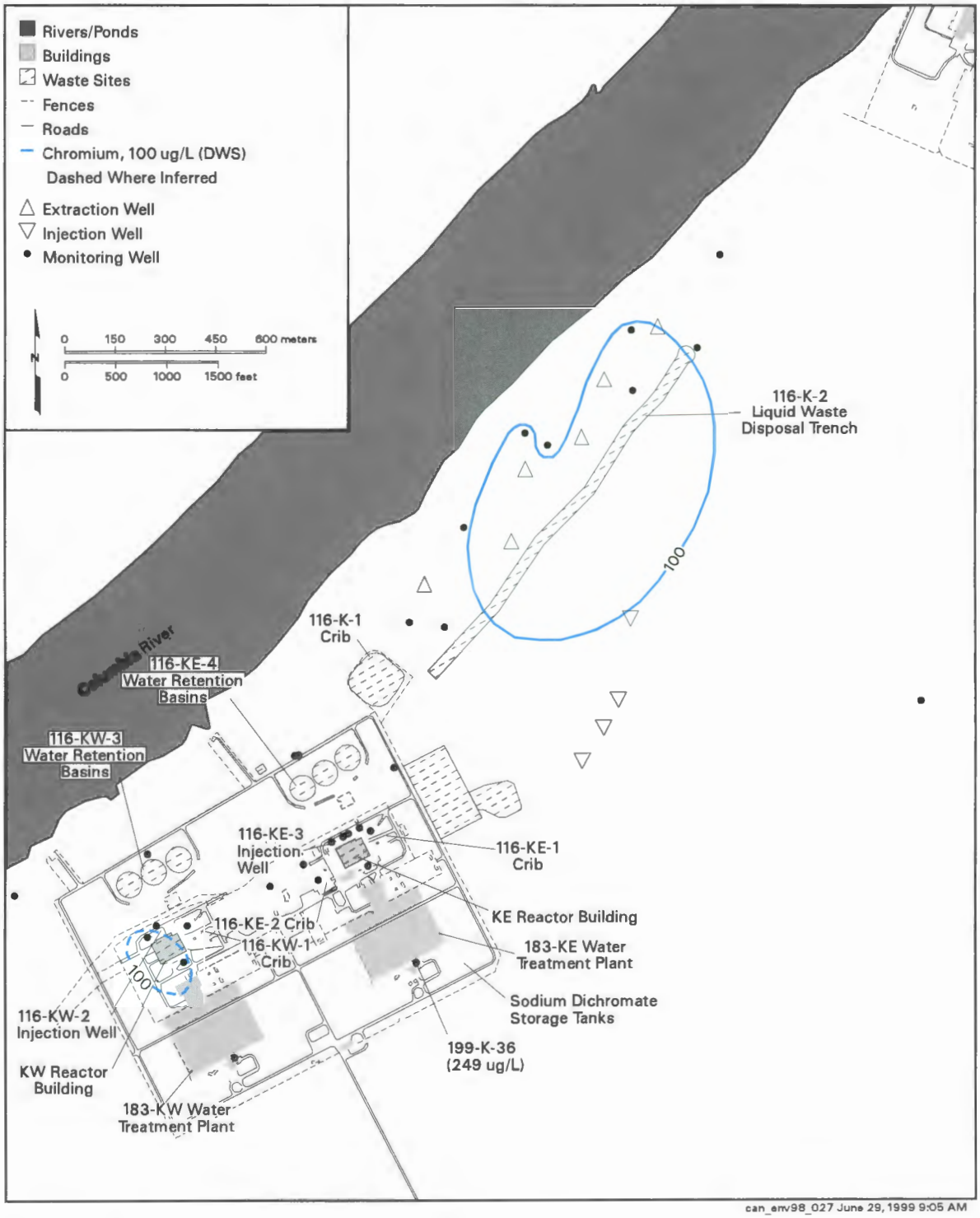

Figure 6.1.29. *Average Filtered Chromium Concentrations in the 100-K Area, 1998*

unit within the Ringold Formation have consistently shown concentrations greater than the drinking water standard northwest of the 1301-N Liquid Waste Disposal Facility. A filtered sample from a well upgradient of the inactive 1301-N facility contained a concentration of 124 µg/L, which exceeded the drinking water standard in this well for the first time. The source for the contamination at these locations is unknown.

Chromium in the 200 Areas. Chromium at concentrations greater than the drinking water standard in the 200-East Area was found in one well on the southern boundary of the A and AX Tank Farms. The maximum concentration detected in the sample was 2,820 µg/L. Concentrations in this well have been sporadic, and the source of the chromium is unknown.

Chromium contamination has been found at several locations in the 200-West Area. Areas where concentrations exceeded the drinking water standard in 1998 include the T, TX, and TY Tank Farms and 216-S-10 Pond. Filtered samples from a new well monitoring the TX and TY Tank Farms showed a maximum concentration of 180 µg/L, the highest filtered chromium concentration in the 200-West Area. The highest concentration found in the vicinity of T Tank Farm was 172 µg/L. The highest concentration near the former 216-S-10 Pond was 175 µg/L.

Chromium in Other Areas. Filtered chromium concentrations above the drinking water standard have been known to occur downgradient of the 200-West Area (located southwest of the 200-East Area). However, the sampling frequency of wells in this area was changed from annual to every 3 yr in 1998 because historical trends showed that chromium concentrations were steady in this area. The maximum concentration in this area in 1997 was 226 µg/L. The extent of chromium contamination in this area is poorly defined, and the source has not been determined.

Carbon Tetrachloride. The carbon tetrachloride contamination that occurs above the 5-µg/L drinking water standard in much of the 200-West Area represents one of the most significant contaminant plumes at the Hanford Site (Figure 6.1.30). The plume covers an area that is >10 km^2 (4 mi^2). However, the overall carbon tetrachloride distribution has changed slowly since the plume was first identified in 1987.

The bulk of the contamination is believed to be from waste disposal operations associated with the Plutonium Finishing Plant in the west-central part of the 200-West Area. Carbon tetrachloride was used as the carrier solvent for tributyl phosphate in the final purification of plutonium. Carbon tetrachloride was also used in the same facility as a nonflammable thinning agent while machining plutonium. A minor source of carbon tetrachloride is a former waste disposal crib near T Plant. Carbon tetrachloride is immiscible in water but exhibits a relatively high solubility (805,000 µg/L at 20°C [68°F]). Carbon tetrachloride has been found to have a relatively high degree of mobility in groundwater. Mobilization above the water table can also occur through vapor transport.

Wells in the vicinity of the Plutonium Finishing Plant showed the highest concentrations in the plume, with levels exceeding the drinking water standard by more than two orders of magnitude. The maximum concentration was near 7,000 µg/L in one pump-and-treat extraction well just north of the plant. Pump-and-treat operations, which began in 1994, have influenced the distribution of carbon tetrachloride. The plume center continues to move in a northerly and easterly direction toward the extraction wells, as evidenced by increased concentrations in several extraction and monitoring wells (DOE/RL-99-02). The extraction wells are located north and east of the Plutonium Finishing Plant. Carbon tetrachloride concentrations in the vicinity of the injection wells southwest of the plant continue to decline as a result of injection of the treated water. As of September

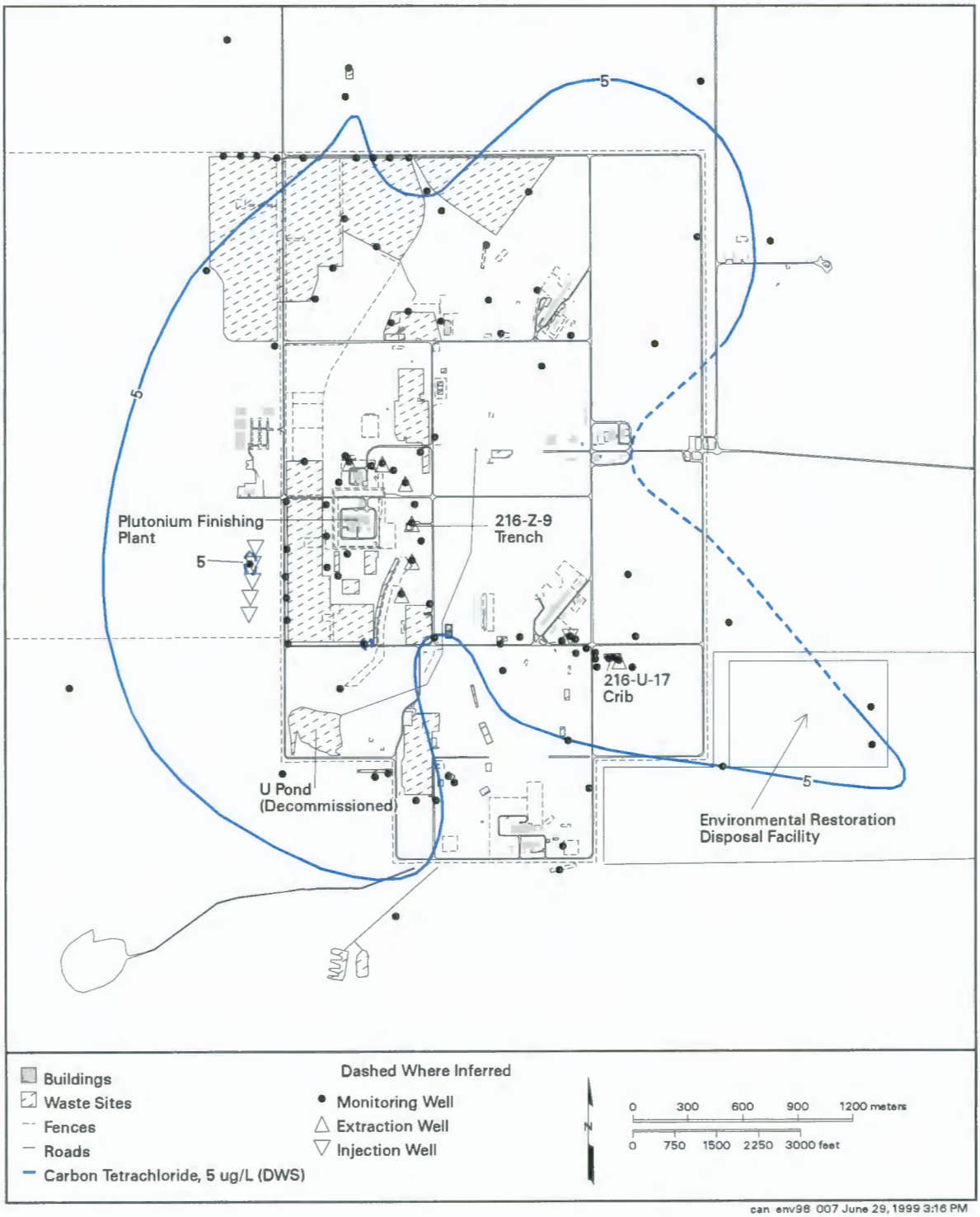

Figure 6.1.30. *Average Carbon Tetrachloride Concentrations in the Unconfined Aquifer in the 200-West Area, 1998*

1998, approximately 615 million L (162 million gal) of extracted groundwater have been treated, resulting in the removal of 2,099 kg (4,637 lb) of carbon tetrachloride (DOE/RL-99-02).

Near the 216-U-17 Crib in the southeastern part of the 200-West Area, the pump-and-treat system removed 13.8 kg (30.3 lb) of carbon tetrachloride from approximately 338 million L (89 million gal) of extracted groundwater as of September 1998 (DOE/RL-99-02).

The extent of carbon tetrachloride contamination in deeper parts of the aquifer is uncertain because of the limited amount of concentration data from depths below the water table. The limited amount of data indicates that the concentrations are highest at the top of the aquifer and decline with depth at most locations within the plume. In 1998, carbon tetrachloride was found at a level of 12 µg/L at a depth of ~58 m (190 ft) below the water table near the Plutonium Finishing Plant.

Changes in groundwater flow since decommissioning U Pond may be influencing the plume configuration and the concentrations at particular locations. Another potential influence is the continued spreading of carbon tetrachloride above the water table, in either the liquid or vapor phase. Free-phase, liquid, carbon tetrachloride above and possibly below the water table provides a continuing source of contamination. Therefore, lateral expansion of the carbon tetrachloride plume is expected to continue.

Chloroform. A chloroform plume appears to be associated with, but not exactly coincident with, the carbon tetrachloride plume in the 200-West Area (Figure 6.1.31). The highest chloroform concentrations were measured in the vicinity of the Plutonium Finishing Plant, where the maximum level was 120 µg/L. The drinking water standard for chloroform is 100 µg/L (total trihalomethanes), which is 20 times higher than that for carbon tetrachloride. The origin of chloroform is unknown, but is suspected to be a degradation product of carbon tetrachloride or an anaerobic degradation product associated with septic drain fields.

Trichloroethylene. A commonly used organic solvent, trichloroethylene has a drinking water standard of 5 µg/L. In 1998, trichloroethylene was detected at levels greater than the drinking water standard in some wells in the 100, 200, 300, and 600 Areas. The most widespread area of contamination occurred in the 200-West Area.

Trichloroethylene in the 100 Areas. Trichloroethylene was detected at levels greater than the drinking water standard in the southwestern corner of the 100-F Area and in the adjacent 600 Area. The maximum concentration detected in this area was 18 µg/L in the adjacent 600 Area. No specific sources of this contamination have been identified.

In the 100-K Area, two wells sampled contained trichloroethylene at levels above the drinking water standard, representing a localized area of contamination near the KW Reactor complex. The maximum concentration was 24 µg/L in monitoring well 199-K-106A.

Trichloroethylene in the 200 Areas. Trichloroethylene was detected at levels greater than the drinking water standard in several parts of the 200-West Area (Figure 6.1.32). The most significant area extends from the Plutonium Finishing Plant to the west of T Plant and past the northern boundary of the 200-West Area. The source of the contamination is presumably past disposal in these plant areas. The highest concentration was 23 µg/L northeast of the Plutonium Finishing Plant. A smaller, isolated area of contamination occurs downgradient of the U Plant cribs, where the maximum concentration was 15 µg/L.

Trichloroethylene in the 300 Area. Trichloroethylene was detected at one well in 1998 in the 300 Area at concentrations above the drinking water

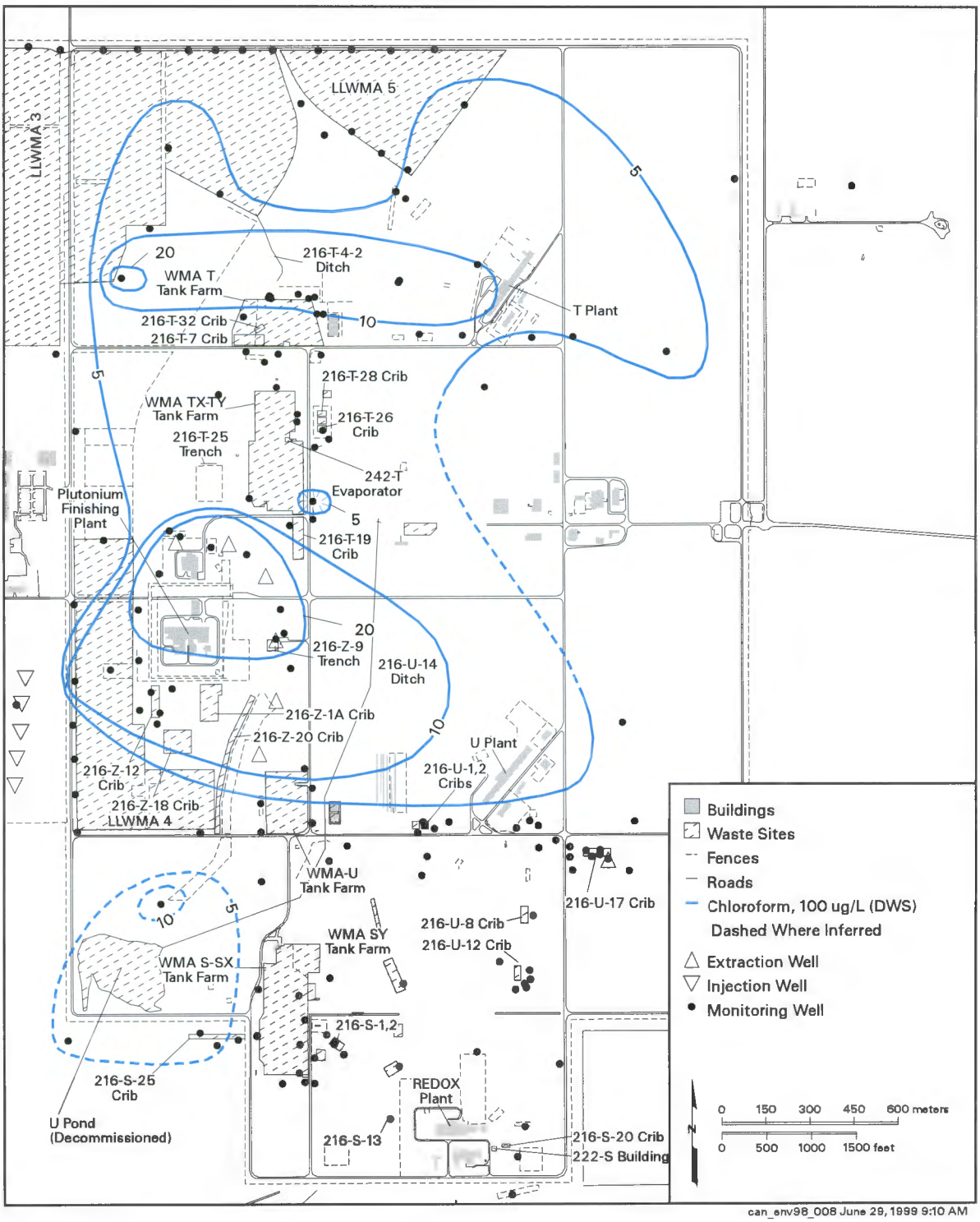

Figure 6.1.31. *Average Chloroform Concentrations in the Unconfined Aquifer in the 200-West Area, 1998*

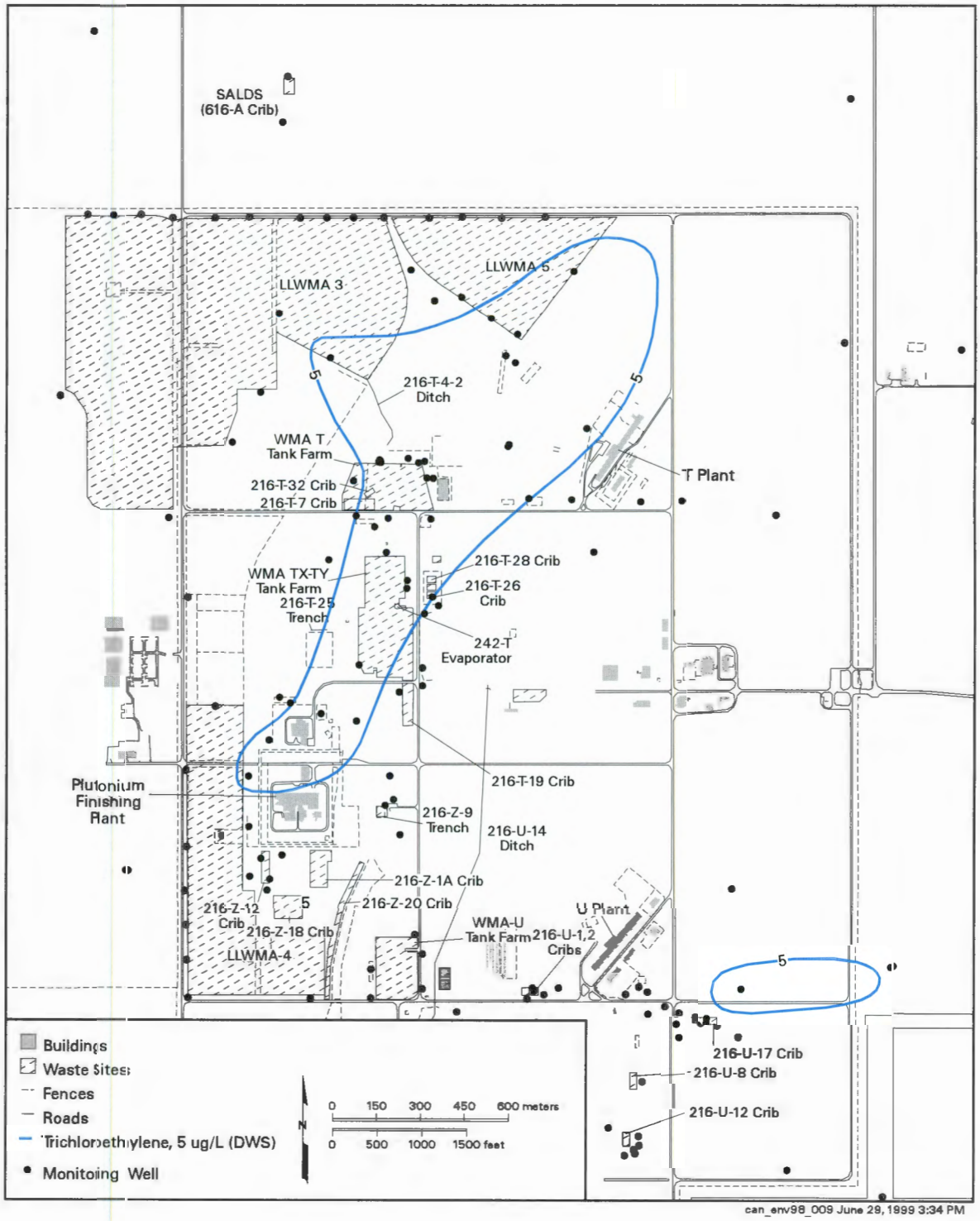

Figure 6.1.32. *Average Trichloroethylene Concentrations in the Unconfined Aquifer in the 200-West Area, 1998*

standard. The maximum concentration was 8 µg/L at well 399-1-16B. This well monitors the base of the unconfined aquifer downgradient of the former 316-5 process trenches.

Trichloroethylene in the 600 Area. Trichloroethylene was found at levels above the drinking water standard in a number of wells in the vicinity of the former Horn Rapids Landfill in the southern part of the site (Richland North Area). This contamination forms an elongated plume that extends from an area just south of the landfill to near the southwestern corner of the 300 Area and has an origin off the Hanford Site (Figure 6.1.33). The maximum contamination detected in this plume in 1998 was approximately 10 µg/L on the northeastern side of the landfill.

Tetrachloroethylene. Also referred to as perchloroethylene (or PCE), tetrachloroethylene was detected at levels above the 5-µg/L drinking water standard in the 300 Area during 1998. In the 300 Area, a new plume of tetrachloroethylene was discovered between the former process trenches and ponds and the Columbia River during 1998 (Figure 6.1.34). The maximum concentration detected was 38 µg/L near the southern end of the process trenches. However, by the end of 1998, concentrations decreased to levels near the drinking water standard. One possible source of the contamination was vadose zone residuals that were mobilized by the high-river levels in 1996 and 1997. Tetrachloroethylene was commonly used as a degreasing solvent.

cis-1,2-Dichloroethylene. Concentrations of cis-1,2-dichloroethylene, a biodegradation product of trichloroethylene, remain elevated in well 399-1-16B, located near the former process trenches and ponds in the 300 Area. This well is completed in the deeper part of the unconfined aquifer and is the only well on the site where this constituent is found at levels above the 70-µg/L drinking water standard. In 1998, a maximum of 180 µg/L was detected in this well.

Cyanide. Waste fractionation activities performed in the late 1950s used large quantities of sodium and nickel ferrocyanide to recover cesium-137. Large volumes of aqueous supernatant waste containing excess ferrocyanide were disposed to the ground in both the northern and southern portions of the 200-East Area. Smaller quantities were also disposed to former cribs in the 200-West Area. Procedures used to analyze for cyanide do not distinguish between ferrocyanide and free cyanide. Cyanide results reported here are, thus, normally assumed to be residual ferrocyanide associated with the discharges from the waste fractionation activities performed >30 yr ago. A chemical speciation study performed in 1988 indicated that approximately one-third of the cyanide in groundwater is present as free cyanide and the rest may be present as ferrocyanide (Section 4.1 in PNL-6886 and Section 3.2.2 in PNL-7120). The drinking water standard for cyanide is 200 µg/L.

The highest cyanide levels were detected in samples collected from wells in the northwestern part of the 200-East Area and in the 600 Area north of the 200-East Area. Only samples collected from one well near the inactive BY Cribs showed concentrations above the drinking water standard in 1998. The maximum concentration (347 µg/L) was a significant increase compared to levels in 1997 and correlates with cobalt-60 levels. Wells containing cyanide often contain several radionuclides, including cobalt-60. Although cobalt-60 is normally immobile in the subsurface, it appears to be chemically complexed by cyanide or ferrocyanide. The complexed chemical species is more soluble and more mobile in groundwater.

Fluoride. At this time, fluoride has a primary drinking water standard of 4 mg/L and a secondary standard of 2 mg/L. Secondary standards are based primarily on aesthetic rather than health considerations. Fluoride was detected above the primary drinking water standard at three wells near T Tank Farm in the 200-West Area in 1998. The new well

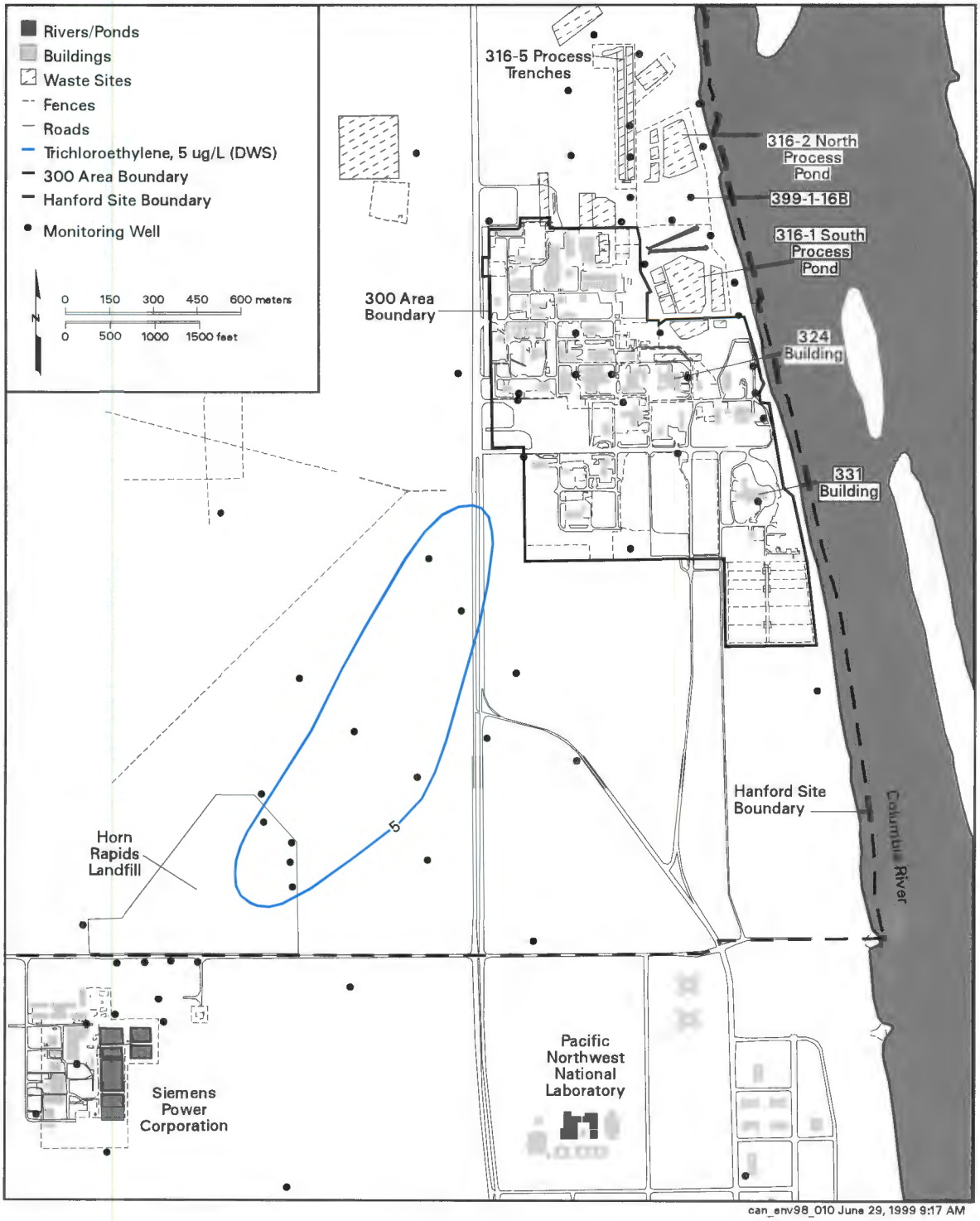

Figure 6.1.33. *Average Trichloroethylene Concentrations in the Vicinity of the Former Horn Rapids Landfill and Richland North Area, 1998*

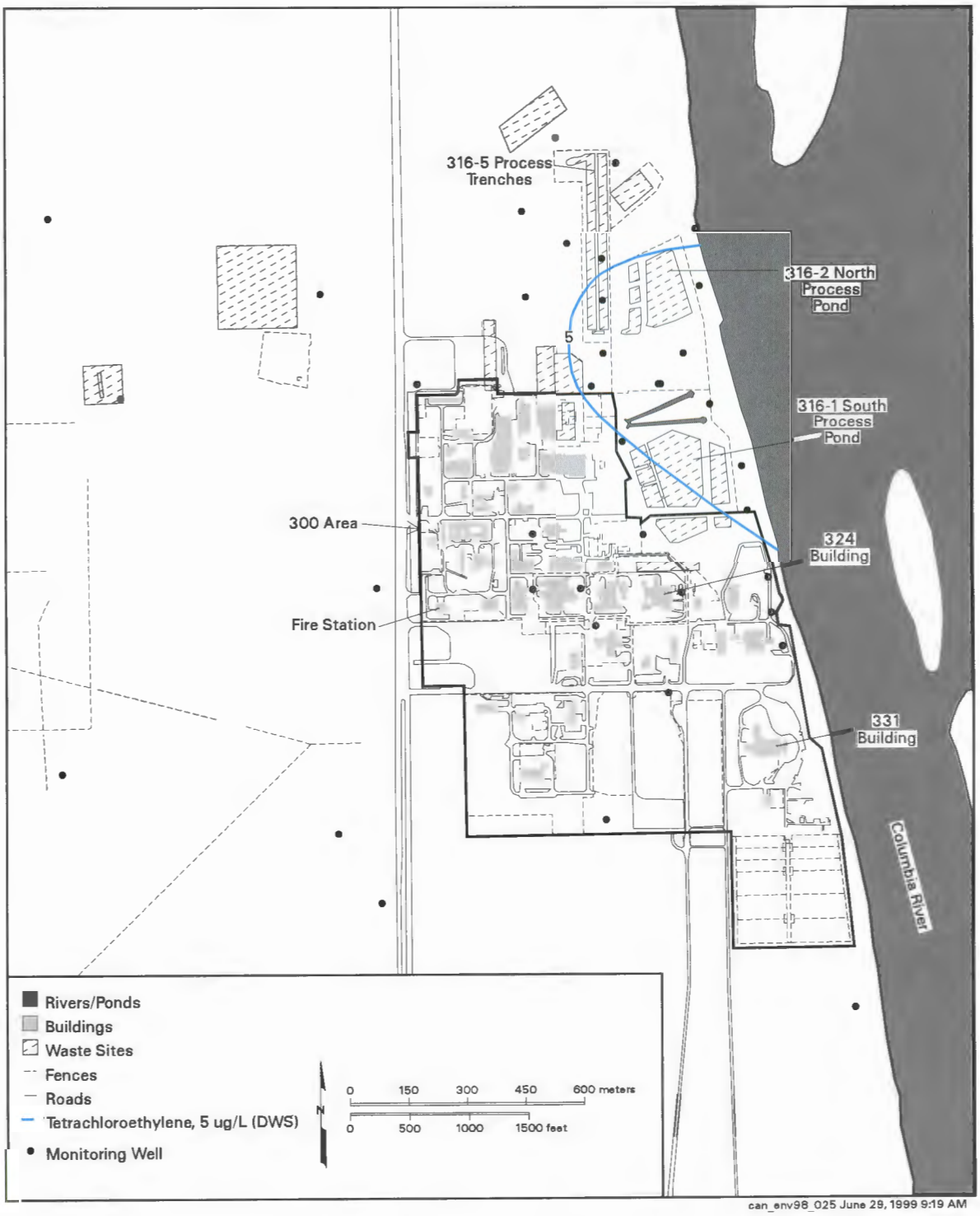

Figure 6.1.34. *Average Tetrachloroethylene Concentrations in the 300 Area, 1998*

(299-W10-24) showed a maximum fluoride concentration of 5 mg/L. A few wells near the T Tank Farm showed concentrations above the secondary standard. Aluminum fluoride nitrate used in the past 200-West Area processes is the probable source of the fluoride contamination.

6.1.6.3 Radiological and Chemical Monitoring Results for the Basalt-Confined Aquifer

Aquifers confined below the uppermost basalt layers show much less impact from Hanford Site contamination than the unconfined aquifer system within the overlying sediments. The minor contamination found in the basalt-confined aquifers may be attributed to several factors. These factors include areas where the confining layers of basalt have been eroded away, areas where disposal of large amounts of water resulted in downward gradients, and areas where wells penetrating to the confined aquifers provided pathways for contaminant migration. These factors produced intercommunication between the aquifers, meaning they permitted the flow of groundwater from the unconfined aquifer to the underlying confined aquifer, thereby increasing the potential to spread contamination. Because fewer wells are available to evaluate contamination in the confined aquifer, it is important to consider contamination in the confined aquifer even where the levels are well below drinking water standards. The distribution of tritium and other detected contaminants in the upper basalt-confined aquifer are shown in Figure 6.1.35.

Intercommunication between the unconfined and basalt-confined aquifers in the vicinity of the northern part of the 200-East Area has been identified previously in RHO-BWI-ST-5 and RHO-RE-ST-12 P. The hydrochemical and hydrogeologic conditions within the upper basalt-confined aquifer system and the potential for offsite migration of contaminants through confined aquifer pathways were evaluated in PNL-10817.

Several confined aquifer wells north and east of the 200-East Area that show evidence of intercommunication with the overlying unconfined aquifer were identified in PNL-10817. Intercommunication between the unconfined and confined aquifers in the area north and east of the 200-East Area has been attributed to erosion of the upper Saddle Mountains Basalt and downward vertical gradients that result from groundwater mounding associated with waste disposal. Groundwater chemical data from most confined aquifer wells in other areas of the Hanford Site do not exhibit evidence of contamination, with the exception of wells that were previously open to both the unconfined and confined aquifers, thus providing conduits 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 warranted continued annual monitoring. Consequently, the number of wells sampled during 1998 was reduced to include only those with groundwater contamination or those downgradient from areas with historical indications of contamination. Prominent analytical results and trends arising from 1998 sampling are discussed below. The locations of wells used for monitoring confined aquifer groundwater chemistry were given in Figure 6.1.11.

Contamination has also been identified in the confined aquifer in the northern part of the 200-East Area and adjacent parts of the 600 Area. The highest levels of contamination detected in the confined aquifer in this vicinity were in well 299-E33-12. Contamination in this well is attributed to migration of high-salt waste down the borehole during construction when it was open to both the unconfined and confined aquifers (RHO-RE-ST-12 P). Contaminant concentrations continue to be elevated in this well. During 1998, technetium-99 was detected in well 299-E33-12 at 1,810 pCi/L, which is above the 900-pCi/L interim drinking water standard. Cobalt-60 was detected in this well (21.8 pCi/L) in 1998.

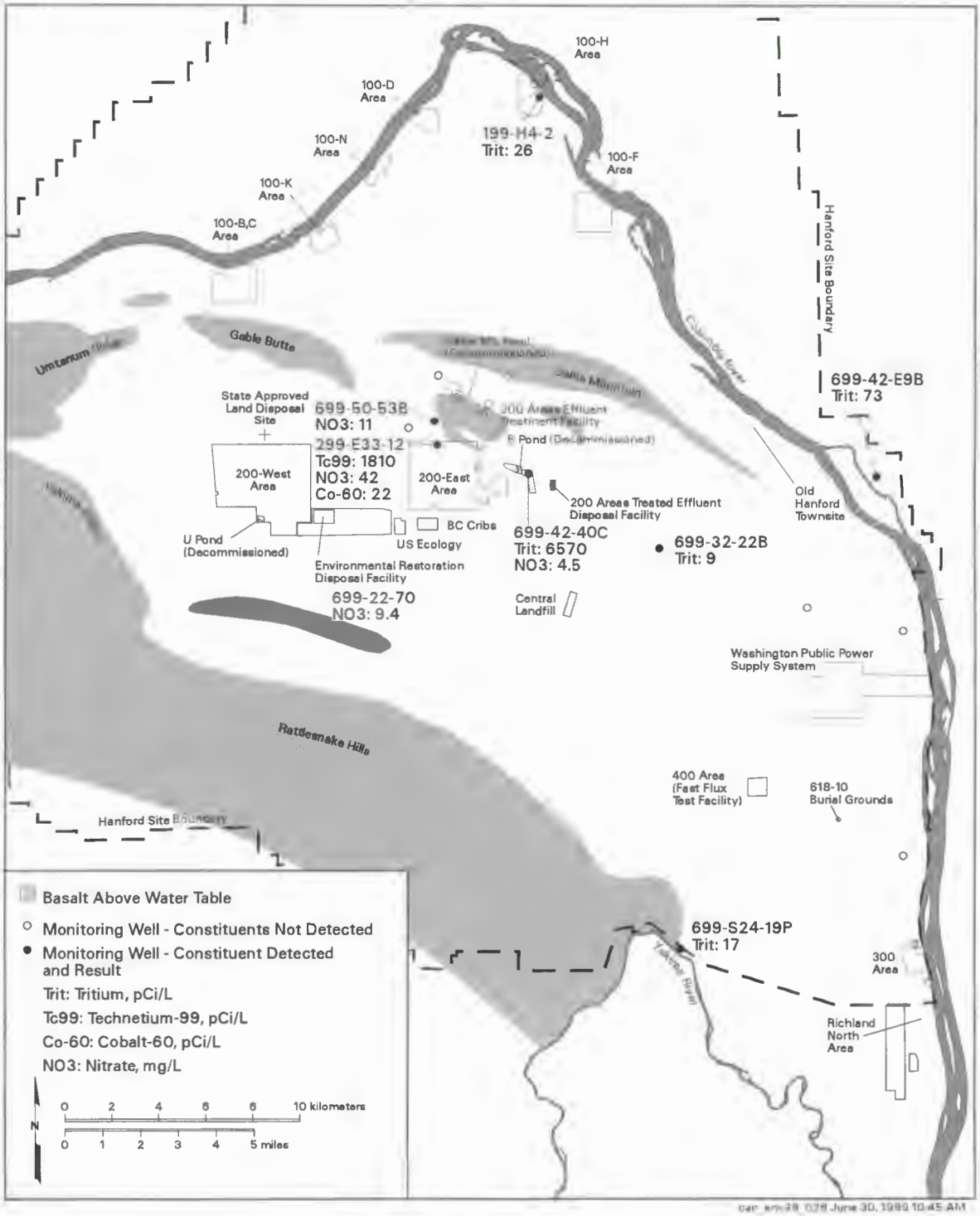

Figure 6.1.35. *Tritium and Other Contaminants Detected in Confined Aquifer Wells, 1998*

Well 699-42-40C monitors the confined aquifer adjacent to the former B Pond. Tritium in this well was 6,570 pCi/L, the highest level observed in the confined aquifer in 1998. Tritium in this well is believed to have originated from downward migration from the overlying, unconfined aquifer.

Wells are completed in the basalt-confined aquifer near the base of the Rattlesnake Hills in an area where pervasive downward flow from the unconfined aquifer recharges the upper portion of the confined aquifer (PNL-10817). Samples from one well contained up to 9.4 mg/L of nitrate in 1998, well below the 45-mg/L drinking water standard. Nitrate in the overlying unconfined aquifer in the Dry Creek Valley area and in wells near the base of the Rattlesnake Hills may result from agricultural sources to the south and west and is not believed to originate from sources on the Hanford Site.

6.1.7 RCRA Summary

More than 60 treatment, storage, and disposal units are recognized under the RCRA permit for the Hanford Site. Of these, 26 required groundwater monitoring during 1998. Locations of these groundwater monitoring sites were given in Figure 6.1.12. This section provides a summary of groundwater monitoring activities and results for these sites. Additional information, including RCRA groundwater monitoring and complete listings of radioactive and chemical constituents measured in monitoring wells from October 1997 through September 1998, is available in PNNL-12086. Any significant changes that occurred from October through December 1998 are noted below.

RCRA groundwater monitoring is conducted under one of three phases: 1) indicator parameter/detection, 2) groundwater quality assessment/compliance, or 3) corrective action. Initially, a detection program is developed to monitor the impact of facility operations on groundwater. During the indicator parameter/detection phase, groundwater parameters established for the particular site are measured in wells upgradient and downgradient from the site. Statistical tests are applied to the monitoring results to calculate "critical mean" values for each monitoring parameter. These values represent the background water quality for the site. Subsequent monitoring data are compared to the critical mean values to determine if there has been a statistically significant increase (or pH decrease) in the concentrations of key indicator parameters or dangerous waste constituents in the groundwater. The statistical methods used to calculate critical means and compare with monitoring data are described in Appendix B in PNNL-12086. If a statistically significant change from the "critical mean" is observed, then a groundwater quality assessment/compliance phase of monitoring and investigation is initiated. During this phase, groundwater monitoring is designed to determine if groundwater protection standards have been exceeded. If the source of the contaminants is determined to be the treatment, storage, and disposal unit and concentrations exceed maximum contaminant levels defined in the monitoring plan or permit, then the Washington State Department of Ecology may require corrective action to reduce the contaminant hazards to the public and environment. Groundwater monitoring during the corrective action phase is designed to assess the effectiveness of the corrective action. Table 2.2.2 in Section 2.2, "Compliance Status," listed the phase pertaining to each of the RCRA groundwater monitoring projects at the end of 1998.

6.1.7.1 100 Areas Facilities

120-D-1 Ponds. These ponds were constructed in 1977 for disposal of nonradioactive effluent derived from operating facilities in the 100-D,DR Area. This facility is located in the former 188-D Ash

Disposal Basin and includes settling and percolation ponds separated by a dike. 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, sodium hydroxide, and sulfuric acid. 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 (5 lb) of mercury to have been discharged to the ponds. Between 1986 and 1994, the effluent discharged to the ponds included chlorine and flocculating agents such as aluminum sulfate. Effluent discharge to the ponds ceased in 1994. Contaminated soils were removed from the ponds in 1996.

Recharge from the ponds diluted ambient groundwater, but did not degrade groundwater quality. In 1998, specific conductance, pH, total organic carbon, and total organic halide in downgradient wells continued to be below the background critical mean values. Mercury is the only listed waste that may have been discharged to these ponds but it has never been detected in any of the downgradient monitoring wells. The 100-D Ponds will be clean-closed when modification D of the RCRA permit is signed in 1999, and no further groundwater monitoring will be required. Until then, the site remains in indicator parameter monitoring.

183-H Solar Evaporation Basins. This facility, now remediated, consisted of four separate concrete basins surrounded by an earthen berm. Between 1973 and 1985, the basins were used to store liquid waste, 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. The solutions included chromic, hydrofluoric, nitric, and sulfuric acids and also contained various metallic and radioactive constituents. Groundwater in the vicinity of these basins is characterized by elevated levels of chromium, nitrate, technetium-99, and uranium. All of these constituents were present in waste discharged to the basins when they were in use.

The basins are subject to final-status monitoring. Concentration limits for chromium, nitrate, technetium-99, and uranium were exceeded in one or more downgradient wells in 1996 and 1997, and a corrective-action groundwater monitoring plan was released in 1997 (PNNL-11573). The monitoring plan was implemented in early 1998 after the corrective-action plan was incorporated into a revision of the RCRA permit. The monitoring plan takes into account the effects of a pump-and-treat system that began operation in 1997. Four wells are sampled annually for the constituents of concern to monitor concentration trends. Although the concentrations decreased several orders of magnitude in this area since the basins ceased operation, nitrate, chromium, and uranium remained above their respective drinking water standards in 1998.

1301-N and 1325-N Liquid Waste Disposal Facilities. These facilities contaminated groundwater with radionuclides, most notably strontium-90 and tritium, as discussed in Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer." A pump-and-treat system is active as a CERCLA interim action to reduce the amount of strontium-90 flowing into the river at the 100-N Area. RCRA monitoring focuses on the hazardous (nonradioactive) constituents discharged to the facilities.

The 1301-N facility was the primary liquid waste disposal site for N Reactor from 1963 until 1985. Discharges were primarily radioactive fission and activation products. Minor amounts of dangerous waste and other constituents may also have been discharged, including ammonium hydroxide, cadmium, diethylthiourea, lead, morpholine, phosphoric acid, and sodium dichromate. The facility consists of a concrete basin with an unlined, zigzagging extension trench, covered with concrete panels.

The 1325-N facility was constructed in 1983 and also received effluent from N Reactor. 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.

Total organic carbon (the indicator parameter) exceeded the critical mean value at 1301-N downgradient well 199-N-3 in September 1998. The well was resampled and the value was verified. However, no organic constituents of concern were identified in 1301-N waste or sediments (DOE/RL-96-39), and the contamination is believed to have originated at one of several petroleum waste sites nearby (DOE/RL-95-111). The Washington State Department of Ecology was notified of the exceedance and its probable cause, and the site remains in a detection monitoring program. No other indicator parameters exceeded critical mean values at the 1301-N or 1325-N facilities. Groundwater at these facilities is also analyzed for other constituents that were discharged to them, including cadmium, chromium, lead, nitrate, and phosphate. Cadmium, chromium, lead, and phosphate were not detected in groundwater at these facilities in significant concentrations; however, nitrate continued to be detected at levels greater than the EPA maximum contaminant level in 1998, but the sources are uncertain.

1324-N and 1324-NA Ponds. The 1324-N Pond was a treatment facility that was in service from May 1986 to November 1988. This facility is a double-lined pond that was used for neutralizing high- and low-pH waste from a demineralization plant. The 1324-NA Pond is unlined and was used for treating waste from August 1977 to May 1986 and for disposing of treated waste from May 1986 to August 1990. The effluent to both facilities contained sulfuric acid and sodium hydroxide, and the pH was occasionally high or low enough to classify the effluent as a dangerous waste.

Specific conductance measured in wells downgradient from these ponds remained higher than the background critical mean value in 1998. This indicator parameter is high because the 1324-NA Pond introduced nondangerous constituents (e.g., sodium, sulfate) to groundwater. Total organic carbon was detected above the background critical mean value in one downgradient well in September 1997, and the value was confirmed in January 1998. No organic contaminants were present in the waste discharged to the facility (DOE/RL-96-39), and the Washington State Department of Ecology agreed that a groundwater quality assessment is not required. The contamination is believed to have originated at one of several petroleum waste sites nearby. Downgradient measurements of pH and total organic halide were below critical mean values.

6.1.7.2 200 Areas Single-Shell Tank Farms

Single-shell tanks are located in the A, AX, B, BX, BY, C, S, SX, T, TX, TY, and U Tank Farms, which have been designated as parts of RCRA Waste Management Areas A-AX, B-BX-BY, C, S-SX, T, TX-TY, and U, respectively. Waste Management Areas A-AX, B-BX-BY, and C are located in the 200-East Area; Waste Management Areas S-SX, T, TX-TY, and U are in the 200-West Area. Each waste management area includes tanks and associated ancillary systems (e.g., pipelines). The single-shell tanks store a mixture of dangerous chemical and radioactive wastes generated by reprocessing fuel irradiated in Hanford Site reactors. The single-shell tanks received mixtures of organic and inorganic liquids that contain radionuclides, solvents, and metals that were originally discharged to the tanks as alkaline slurries. Subsequent waste management operations have combined waste streams from different processes. In many tanks, wastes have been concentrated by removing water through evaporation.

Waste Management Area A-AX. Critical mean values for pH, specific conductance, total

organic carbon, and total organic halide (the indicator parameters) were not exceeded during 1998. Iodine-129 exceeded the 1-pCi/L drinking water standard in the monitoring wells because of a plume extending through this area from other sources. Chromium, manganese, and nickel exceeded drinking water standards in one of the network wells, and may be related to corrosion of the well screen.

Waste Management Area B-BX-BY. The results of the first phase of a groundwater quality assessment program were published in 1998 (PNNL-11826). It was concluded that the waste management area was most likely the cause of the elevated specific conductance that had triggered the assessment.

There appear to be two centers of technetium-99 contamination near the waste management area. Levels continued to exceed the 900-pCi/L interim drinking water standard in 1998 in several wells. This contamination was discussed in Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer," and its distribution was shown in Figure 6.1.21.

Nitrate concentrations continued to rise across the waste management area and exceeded the 45-mg/L drinking water standard in most of the monitoring network (see Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer"). There are two local centers of nitrate contamination that approximately correspond with the technetium-99 distribution.

Uranium concentrations exceeded the 20-mg/L proposed drinking water standard in four wells, but its source is not known. In late 1997 and early 1998, two high, rapid spikes of uranium were observed in one well (299-E33-41). Similar spikes in technetium-99 were observed in this well in 1997.

One new monitoring well was installed in 1998 to support the assessment program.

Waste Management Area C. Critical mean values for pH, specific conductance, total organic carbon, and total organic halide (the indicator parameters) were not exceeded during 1998. Iodine-129 showed levels above the 1-pCi/L drinking water standard in the monitoring wells because of a plume extending through this area from other sources.

Waste Management Area S-SX. The results of the first phase of a groundwater quality assessment program were released in 1998 and showed that the S and SX Tank Farms contributed to groundwater contamination (PNNL-11810). A second phase assessment is being conducted to determine the nature, extent, and source(s) of groundwater contamination attributed to Waste Management Area S-SX.

Mobile contaminants from the waste management area include chromium, nitrate, and technetium-99. All of these constituents were highest in well 299-W22-46 in 1998. Lower, but sharply increasing, levels of contaminants were observed in well 299-W22-45. Past spills or leaks from transfer lines or diversion boxes are potential sources of this contamination.

Waste Management Areas T and TX-TY. The results of the first phase of assessment monitoring were released in 1998 (PNNL-11809). There is evidence that Waste Management Area T has contaminated groundwater in well 299-W11-27. The source of contamination at Waste management Area TX-TY could not be determined, but a source within the waste management area could not be ruled out, so assessment will continue.

Specific conductance in Waste Management Area T well 299-W11-27 has declined slowly since a peak in 1996. This pulse of specific conductance was caused by increases in calcium, magnesium, nitrate, and sulfate and was accompanied by increases in chromium, cobalt-60, technetium-99, and tritium. Technetium-99 is the major contaminant present, reaching a peak in 1997 (21,700 pCi/L) and declining in 1998 (average = 7,390 pCi/L). The contaminants

affecting groundwater quality in well 299-W11-27 represent a very narrow plume, indicating a nearby source.

Specific conductance in Waste Management Area TX-TY well 299-W10-17 remained elevated in 1998 and is principally a result of elevated nitrate and sodium. Gross beta, nitrate, and tritium exceeded their drinking water standards during the year and represent a regional contaminant plume. Specific conductance also was elevated in well 299-W14-12 in 1998. The high specific conductance is a result of elevated calcium, magnesium, nitrate, and sulfate and is distinctly different from the regional sodium/nitrate signature.

Monitoring wells for these waste management areas are rapidly going dry because of a declining water table. Two new wells were installed in 1998 at Waste Management Area T to replace those that were dry. Four new wells were drilled at Waste Management Area TX-TY.

Waste Management Area U. This waste management area is under a detection-level monitoring program. Three indicator parameters (pH, specific conductance, and total organic carbon) remained below their background critical mean values. Total organic halides exceeded the critical mean value in well 299-W19-31 as a result of carbon tetrachloride contamination flowing into the area from upgradient sources. The Washington State Department of Ecology was informed of the exceedance and its source, and the waste management area remains in a detection monitoring program.

Technetium-99 remained slightly elevated in downgradient wells. Levels are below the interim drinking water standard but higher than upgradient wells. The highest value was in well 299-W19-31, where the annual average was 320 pCi/L.

Two new wells were installed in 1998 to replace wells that are nearly dry because of the declining water table.

6.1.7.3 200 Areas Liquid Effluent Disposal Facilities

216-A-10, 216-A-36B, and 216-A-37-1 Cribs. These inactive cribs received liquid waste from the Plutonium-Uranium Extraction Plant. The waste stream at the 216-A-10 Crib was characteristically acidic and contained concentrated salts, hydrocarbon compounds, organic complexants, plutonium, uranium, and other radionuclides. The 216-A-36B Crib received ammonia scrubber distillate 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, cobalt-60, strontium-90, ruthenium-106, iodine-129, cesium-137, and uranium. The 216-A-37-1 Crib received process condensate from the 242-A Evaporator. The process condensate contained radionuclides, spent halogenated and nonhalogenated solvents, and ammonia. The radionuclides included cobalt-60, strontium-90, ruthenium-106, cesium-137, uranium, and plutonium.

These three cribs are monitored as a single waste management area under an assessment program because they have similar hydrogeology and waste constituents. The cribs have contributed to the large nitrate, iodine-129, and tritium plumes downgradient of the 200-East Area (see Section 6.1.6.1, "Radiological Monitoring Results for the Unconfined Aquifer"). These constituents remained above drinking water standards in 1998. Strontium-90 also exceeded the interim drinking water standard in well 299-E17-14, adjacent to the 216-A-36B crib, with an annual average of 16 pCi/L.

216-A-29 Ditch. This is an inactive earthen ditch approximately 2 km (1.2 mi) long that conveyed Plutonium-Uranium Extraction Plant chemical waste to the 216-B-3 Pond from 1955 to 1986. The ditch received effluents that contained dangerous

chemical and radioactive contaminants. Of primary concern for RCRA regulations were discharges of sodium hydroxide and sulfuric acid, which occurred daily as a result of ion-exchange regeneration at the Plutonium-Uranium Extraction Plant.

Assessment monitoring between 1990 and 1995 concluded that the ditch contaminated groundwater with the nondangerous constituents calcium, sodium, and sulfate, which contributed to elevated specific conductance. Because the contaminants are nondangerous, the site reverted to detection monitoring. Specific conductance subsequently declined, and in 1998, all indicator parameters were below the critical mean values.

216-B-3 Pond. This former pond consisted of a main pond and three expansion ponds (216-B-3A, 216-B-3B, and 216-B-3C). The main pond began operating in 1945 and the expansions were built in the 1980s. In 1994, the main pond ceased operating, and the waste streams were rerouted to the 216-B-3C Expansion Pond and the 200 Areas Treated Effluent Disposal Facility. The main pond was filled with clean soil, and the expansion ponds were clean-closed (i.e., deemed free of dangerous waste and no longer regulated under RCRA). In August 1997, waste streams received by the expansion pond were diverted to the 200 Areas Treated Effluent Disposal Facility, thus ending operation of the B Pond system. In the past, B Pond received liquid waste from B Plant and the Plutonium-Uranium Extraction Plant, consisting of chemical sewer waste, cooling water, and steam condensate. These waste streams contained aluminum nitrate, nitric acid, potassium hydroxide, sulfuric acid, tritium, and other acids. In its later years, B Pond received nondangerous, nonradioactive effluent primarily from the Plutonium-Uranium Extraction Plant and B Plant.

During 1998, B Pond was monitored under an interim-status detection program. Critical mean values of the indicator parameters were not exceeded. The only contaminants consistently detected in groundwater that could be attributed to B Pond operations were nitrate and tritium; however, these constituents have shown downward trends since monitoring began at B Pond.

216-B-63 Trench. This trench received liquid effluent from the B Plant chemical sewer from March 1970 to February 1992. The liquid effluent consisted of a mixture of steam condensate and raw water. Past releases to the trench also included sulfuric acid and sodium hydroxide solutions. Radioactive soils were dredged from the trench in August 1970, but no records exist of radioactive waste disposal to the trench.

Groundwater monitoring continues to show no evidence that dangerous nonradioactive constituents entered the groundwater from this trench. No indicator parameters (pH, specific conductance, total organic carbon, or total organic halide) were exceeded in 1998.

216-U-12 Crib. This crib received wastewater containing dangerous chemical wastes and radionuclides from April 1960 until February 1988. This facility has been in the groundwater quality assessment phase of monitoring since 1993. Site-specific waste indicators include gross alpha, gross beta, iodine-129, nitrate, technetium-99, and tritium. Iodine-129, nitrate, technetium-99, and tritium are detected consistently in groundwater. The findings of the first two phases of the assessment monitoring program indicate that the crib is a source of nitrate and technetium-99 detected in the downgradient wells (PNNL-11574). Nitrate concentrations downgradient of the crib are >10 times the average background value in the upgradient well.

One new well was installed in 1998 to replace a well that is nearly dry as a result of the declining water table.

216-S-10 Pond and Ditch. The facility consisted of an open, unlined ditch and an open, unlined percolation pond. The pond and ditch

received radioactive and dangerous chemical waste from the Reduction-Oxidation Plant from 1951 until 1985, when the pond and the lower part of the ditch were decommissioned and backfilled. The upper part of the ditch continued to receive nondangerous, unregulated wastewater from 1985 through 1991.

All indicator parameters (pH, specific conductance, total organic carbon, and total organic halide) were below their respective critical mean values in 1998.

Chromium continued to be elevated in well 299-W26-7, reaching 576 mg/L in December 1997 (there are no 1998 chromium data). This well is upgradient of the pond, but may have been affected by artificial recharge when the pond was active. The source of the chromium contamination is uncertain, but is possibly related to the pond or to earlier disposal to upgradient facilities.

6.1.7.4 200 Areas Low-Level Burial Grounds

The low-level burial grounds are divided into five low-level waste management areas in the 200 Areas (see Figure 6.1.12). However, Low-Level Waste Management Area 5 has not been monitored for groundwater since 1996 because the burial ground never received waste. The remaining low-level waste management areas are in the indicator parameter phase of RCRA groundwater monitoring.

Low-Level Waste Management Area 1. This waste management area consists of the 218-E-10 Burial Ground. Disposal activities began in 1960 and continue today. Materials placed in this facility are primarily failed equipment and mixed industrial waste from the Plutonium-Uranium Extraction Plant B Plant, and N Reactor.

Specific conductance exceeded the critical mean value in one downgradient well in December 1998. The higher-conductivity groundwater is believed to have originated in other 200-East Area facilities. The Washington State Department of Ecology was notified of the exceedance and its probable source, and the waste management area remains in detection monitoring. No other indicator parameters exceeded background values, and there is no evidence of any contaminant contribution from this area.

Low-Level Waste Management Area 2. This waste management area includes all of the 218-E-12B Burial Ground, which has been in use since 1968. The waste consists primarily of miscellaneous dry waste and submarine reactor compartments. Parts of two trenches contain transuranic waste.

In 1998, specific conductance exceeded the critical mean established for this area as a result of increases in calcium, nitrate, and sulfate, which are not regulated constituents in groundwater. Because the increase occurred in an upgradient well, assessment monitoring is not required. Total organic halides exceeded the critical mean in a downgradient well in November 1998, but the high value is believed to be erroneous and is being investigated. Values for iodine-129 were above the 1-pCi/L drinking water standard in several wells along the southern boundary of this area. However, this is related to the widespread iodine-129 plume beneath the 200-East Area, and there is no evidence of groundwater contamination from this waste management area.

Low-Level Waste Management Area 3. The 218-W-3A, 218-W-3AE, and 218-W-5 burial grounds make up this area. The 218-W-3A Burial Ground began accepting waste in 1970 and received primarily ion-exchange resins and failed equipment (e.g., tanks, pumps, ovens, agitators, heaters, hoods, vehicles, accessories). The 218-W-3AE Burial Ground began operation in 1981 and contains low-level and mixed waste, including rags, paper, rubber gloves, tools, and industrial waste. The 218-W-5 Burial Ground first received waste in 1986, and contains low-level and low-level-mixed waste, including lead bricks and shielding.

Carbon tetrachloride and nitrate are consistently above their drinking water standards of 5 µg/L and 45 mg/L, respectively, in monitoring wells in this waste management area. However, the elevated values can be attributed to contaminant plumes originating to the south of the area. There appears to be no groundwater contamination directly attributable to this waste management area, and the critical mean values for indicator parameters were not exceeded in 1998.

Low-Level Waste Management Area 4. This area consists of the 218-W-4B and 218-W-4C Burial Grounds. The 218-W-4B Burial Ground first received waste in 1968 and contains mixed and retrievable transuranic waste in trenches and caissons. One caisson is believed to contain mixed waste. Wastes were first deposited in the 218-W-4C Burial Ground in 1978 and were classified as transuranic, mixed, or low-level and included contaminated soil, decommissioned equipment, and remote-handled transuranic waste.

Groundwater near this waste management area is being remediated as part of the 200-ZP-1 Operable Unit. Water is pumped from wells located east of this waste management area, treated, and injected into wells located west of the waste management area. Consequently, the direction of groundwater flow is now from west to east across the site. The groundwater monitoring network was revised in 1998 to reflect the current flow direction. Network modifications also were needed to accommodate declining water levels beneath the area. Statistical evaluation of the upgradient/downgradient comparison values has been suspended until the flow regime stabilizes following pump-and-treat activities. Semiannual sampling continues during this time to determine when stabilization occurs and to maintain continuity in the database.

6.1.7.5 Liquid Effluent Retention Facility

This facility consists of three, lined, surface impoundments (basins) located east of the 200-East Area and serves as temporary storage for condensate from the 242-A Evaporator. Constituents detected in the effluent stream from the 242-A Evaporator were acetone, aluminum, ammonium, 1-butanol, 2-butanone, tritium, strontium-90, ruthenium-106, and cesium-137.

The facility is subject to final-status monitoring. Until the final-status monitoring plan is approved by the regulators, the site continues to operate under the existing interim-status plan. The indicator parameters (pH, specific conductance, total organic carbon, and total organic halide) were not exceeded in 1998. However, in January 1999, specific conductance exceeded its critical mean in one downgradient well. Tritium, which is present in site effluent, is not elevated in downgradient wells, so the source of the high conductivity is not this facility. The Washington State Department of Ecology was notified of the exceedance, and the site remains in detection monitoring.

6.1.7.6 300 Area Process Trenches

The 316-5 Process Trenches are two unlined trenches that were used for the disposal of liquid wastes generated in the 300 Area, beginning in 1975, and received uranium and other radioactive and chemical constituents. From 1985 through 1991, the trenches received nondangerous effluent, and all discharges ceased in 1991.

The site is monitored under a final-status corrective-action program. Until the corrective-action plan is approved, the final-status compliance

monitoring program remains in effect. In 1998, monitoring continued to show elevated levels of uranium downgradient of the trenches. Trichloroethylene exceeded the drinking water standard in two deep downgradient wells, and cis-1,2-dichloroethylene exceeded the drinking water standard in one deep well. A plume of tetrachloroethylene appeared in 1998, with concentrations increasing and decreasing rapidly. The highest concentration was 38 mg/L in well 399-1-17A in July 1998. Levels declined rapidly and the concentration was only 3 mg/L in December 1998. Wells farther downgradient of the trenches reached peak concentrations somewhat later in the year. Although tetrachloroethylene was accidentally discharged to the trenches in 1982 and 1984, the trenches have not been used since 1994. Therefore, the 1998 plume was not due to a recent discharge. Furthermore, the sudden and wide lateral extent of the plume indicates it did not originate at a point source. The most likely source is residual vadose-zone contamination near the trenches that was mobilized by high-river levels in 1996 and 1997.

6.1.7.7 Nonradioactive Dangerous Waste Landfill

The former Nonradioactive Dangerous Waste Landfill (Central Landfill) in the 600 Area southeast of the 200-East Area received waste from 1975 through 1985 that included asbestos, miscellaneous laboratory waste, solvents, paints, sewage, sulfamic and other acids, batteries, battery acid, and mercury. The site is in the indicator parameter phase of groundwater monitoring. None of the indicator parameters (pH, specific conductance, total organic carbon, or total organic halide) exceeded critical mean values during 1998. Chlorinated hydrocarbons were detected in a few wells at concentrations below their respective drinking water standards. Some constituents (e.g., 1,1,1-trichloroethane, trichloroethylene) are thought to be the result of vadose zone vapor transport from the adjacent Solid Waste Landfill, while others (e.g., carbon tetrachloride, chloroform) may have originated in the Nonradioactive Dangerous Waste Landfill. Iodine-129, nitrate, and tritium contamination is also present in some wells, but is part of large plumes originating in the 200-East Area.

6.2 Vadose Zone Characterization and Monitoring

The vadose zone is the region in the subsurface between the ground surface and the top of the water table. In the Hanford 200 Areas, the vadose zone is >61 m (200 ft) thick. As a result of past Hanford Site operations, the vadose zone has become contaminated from spills, leaks, and intentional discharges. There are three programs/projects involved in vadose zone characterization and monitoring. This section provides descriptions of each and summarizes the 1998 results.

6.2.1 Tank Farms Vadose Zone Baseline Characterization Project

S. E. Kos and R. G. McCain

Contamination was released to the near-surface and subsurface environment at the Hanford Site single-shell tank farms as the result of tank leaks, spills of radioactive effluent on the ground surface, pipeline leaks, and airborne releases of particulate matter through tank ventilation and access ports.

RCRA specifies the requirements to identify sources of contamination and to determine the nature and extent of the contamination that has leaked from the single-shell tanks. In 1994, the Tank Farms Vadose Zone Baseline Characterization Project was initiated to perform a baseline characterization of the gamma-emitting contamination in the vadose zone under the tank farms and to satisfy RCRA requirements in a limited way. The technical plan for this baseline characterization is documented in P-GJPO-1786.

Under this project, approximately 800 preexisting monitoring boreholes surrounding the Hanford Site single-shell tanks are being logged with passive spectral gamma-ray logging methods. These methods were developed at the Hanford Site in the late 1980s and early 1990s to identify specific gamma-emitting radionuclides in the subsurface and to determine their concentrations.

Borehole logging is used for the initial characterization because it is an economical means of obtaining information about conditions in the subsurface, using existing boreholes, and it helps to identify the locations and sizes of the contamination plumes. For comprehensive characterizations or special investigations, follow-up drilling and sampling must be conducted to identify specific contaminants, to better define observed contaminant distributions, and to collect geologic samples as needed.

Once a baseline is established for a particular tank, that tank can be monitored over time for either short-term or long-term changes. Long-term monitoring over a 5- to 10-yr period can provide information on migration rates of gamma emitters that can be used to verify models used for predictive risk assessments. Short-term monitoring is useful for identifying recent changes in the vadose zone that result from current operations or tank leaks.

A plan view of a typical tank farm is presented in Figure 6.2.1. Each tank farm consists of a collection of between 2 and 18 underground waste storage tanks. Most of the tanks are surrounded by monitoring boreholes that provide access to the subsurface with

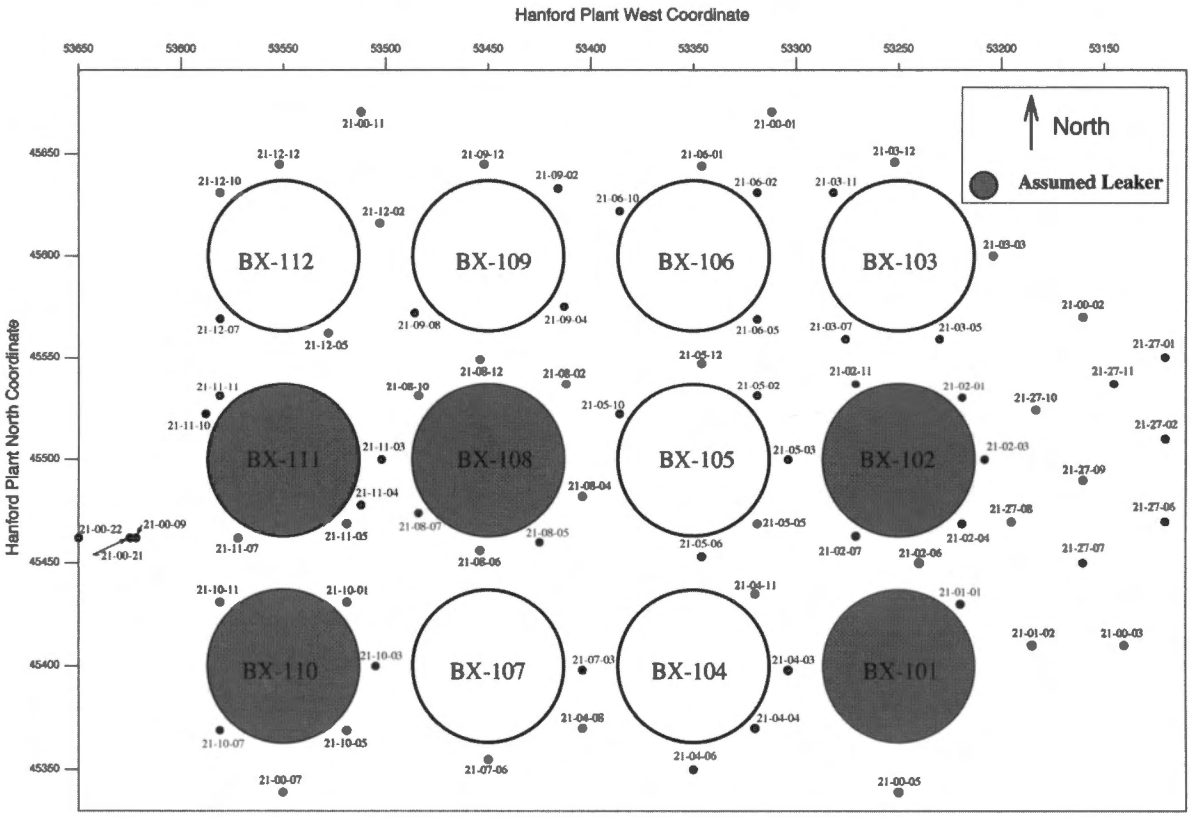

***Figure 6.2.1**. Plan View of BX Tank Farm with Monitoring Boreholes*

geophysical logging probes. There are 12 single-shell tank farms at Hanford that contain a total of 149 tanks.

The baseline characterization project involves logging the boreholes surrounding the single-shell tanks and analyzing the data to produce logs of the radionuclide concentrations. Figure 6.2.2 presents an example of a radionuclide concentration log. The logs for all of the boreholes surrounding a tank are interpreted and reported in a tank summary data report for each tank. The reports also provide summaries of the tank histories and any other tank-specific information.

After completion of a summary data report for each tank, a more comprehensive tank farm report is prepared. Each tank farm report provides a correlation of the contamination across the farm and includes computer-generated, three-dimensional visualizations of the contamination. Correlations between boreholes help to determine contamination sources and define the three-dimensional contamination distributions. The visualizations are based strictly on an empirical geostatistical correlation of the data and are used to help identify the general location and distribution of the contamination so that more complete analyses can be assembled to develop more realistic and quantitative contamination distribution models. The visualizations are an effective means of identifying regions in specific tank farms where additional characterization is necessary.

6.2.1.1 Data Collection and Analysis

All data acquisition is accomplished with spectral gamma-ray logging systems that are automated

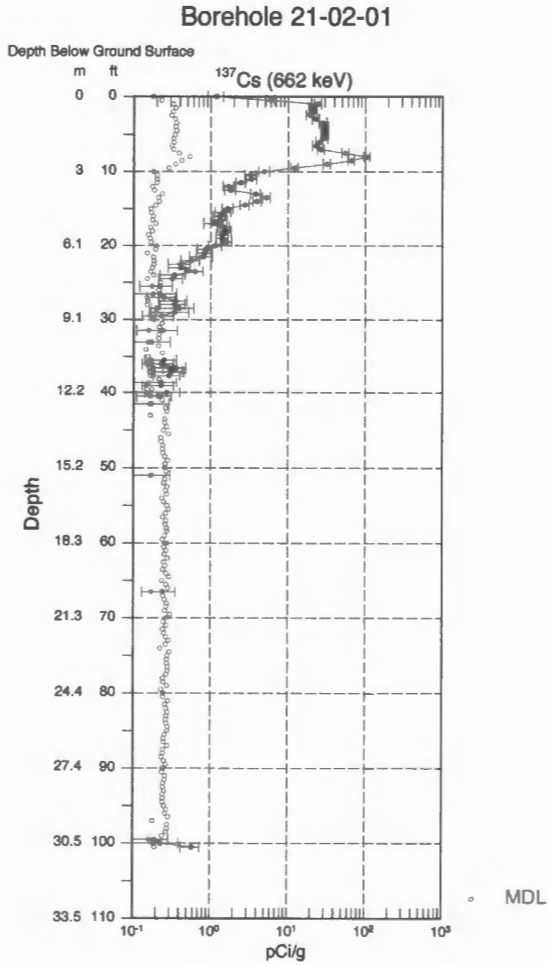

Figure 6.2.2. *Example of a Radionuclide Concentration Log (MDL = minimum detection level)*

and configured to deliver a germanium detector down a borehole. Data acquisition operations are specified by logging procedures provided in MAC-VZCP-1.7.10-1 (Rev. 2) and governed by quality assurance procedures specified in a project management plan MAC-VZCP-1.7.2 (Rev. 1). All data are managed as quality records governed by the current revision of the Hanford Tank Farms Vadose Zone Working File Index, which is used in conjunction with Section 3.0, "Records Management," of the *General Administrative Procedures Manual* (MAC-1000).

The spectral gamma-ray logging system equipment was calibrated by conducting a comprehensive baseline calibration and biannual field calibrations as specified in a calibration plan (MAC-VZCP-1.7.3, Rev. 1). The baseline calibration was conducted using borehole model standards constructed at the DOE Grand Junction Office specifically for borehole logging. The results of the calibration are reported in GJPO-HAN-1. Biannual field calibrations were conducted using borehole calibration models installed at the Hanford Site, and the results were reported in biannual calibration reports. The results of the fifth and most current recalibration report are presented in GJO-98-41-TAR, GJO-HAN-20. Based on the observed stability of the logging system from the biannual recalibrations, a

decision was made in 1998 to revise the calibration frequency from biannually to annually.

Data analysis involves identifying the specific isotopes detected in the gamma-ray spectra and then calculating the concentrations of those isotopes. Once the isotope concentrations are determined, the data are collated into isotope-specific logs of the radionuclide concentration versus depth, and the data are plotted as logs. Logs of man-made and naturally occurring radionuclides are produced routinely. Details of the data analysis process are documented in MAC-VZCP-1.7.9 (Rev. 1).

Data are interpreted by reviewing all of the spectral gamma logs from a single borehole and correlating the data with information on the geology, tank history, and historical gross gamma-ray logs. The intent of the individual borehole interpretations is to quantify contamination plumes, identify potential contamination sources, and relate contamination distribution patterns to the geology or tanks.

6.2.1.2 Activities for 1998

Baseline Logging, Tank Summary Data Reports, and Tank Farm Reports. During 1998, spectral gamma data were acquired from 79 boreholes surrounding tanks in the B and T Tank Farms in the 200-East and 200-West Area, respectively.

Tank summary data reports were completed for 25 tanks in the A, B, BX, C, and T Tank Farms. The tank summary data reports that were completed are tanks A-101 through A-106; tanks B-101 and B-103; tank BX-101 and tanks BX-103 through BX-112; tanks C-222 and C-112; and tanks T-108, T-109, T-111, and T-112. The borehole log plots and interpretation of results are presented in each of the tank summary data reports (GJ-HAN-93 through GJ-HAN-112, GJ-HAN-114, and GJ-HAN-121 through GJ-HAN-124).

During 1998, tank farm reports were prepared for the BX, C, and S Tank Farms (GJO-98-40-TAR, GJO-HAN-19; GJO-98-39-TAR, GJO-HAN-18; and GJO-97-31-TAR, GJO-HAN-17, respectively). Much of the preparation of the A Tank Farm Report was conducted in 1998, and the report was published in 1999 (GJO-98-64-TAR, GJO-HAN-23). The results of the A Tank Farm vadose zone characterization will be reported in next year's environmental report.

Enhancements to Spectral Shape Factor Analysis. At the recommendation of the independent SX Tank Farm expert panel, activities were conducted in 1998 to enhance the applicability of shape factor analysis. Shape factor analysis is a data analysis method that provides insights into the distribution of gamma-emitting radionuclides relative to the detector based on the ratio of count rates in various portions of the gamma-ray spectrum (GJO-96-13-TAR, GJO-HAN-7; GJO-97-25-TAR, GJO-HAN-15). To provide these insights, spectral shape factor analysis takes advantage of 1) the spectral gamma-ray logging system's ability to record the specific energies of detected gamma rays and 2) the Compton downscattering caused by the interaction of gamma rays with matter between the gamma-ray source and the detector. The enhancement activities conducted in 1998 were based on a combination of computer and physical modeling to simulate the effects of various contaminants.

The computer modeling expanded on work previously performed (GJO-97-25-TAR, GJO-HAN-15) and modeled three types of cesium-137 distributions that had not been performed previously. The three types of distributions modeled were 1) cesium-137 distributed uniformly in a cylindrical configuration of various diameters around a central borehole coincident with the cylinder's axis; 2) a cesium-137 source distributed uniformly in a thick, horizontal tabular zone; and 3) a cesium-137 source distributed uniformly in a thin, horizontal tabular zone. The results of the modeling are provided in GJO-99-80-TAR, GJO-HAN-24.

The physical modeling activities also expanded on previous work (GJO-97-25-TAR, GJO-HAN-15). The physical modeling was performed using a sand-filled tank with a central, steel-cased borehole (15-cm [6-in.] diameter). Tubes were provided in the sand-filled tank at various radii from the central borehole to allow the placement of cobalt-60 and cesium-137 point sources. The borehole was logged with the point sources located at various distances from the borehole to examine the effect of source distance on the shape factor analysis results. Examination of the data from the physical modeling is ongoing, and the results are scheduled to be reported in next year's environmental report.

Reassessment of Vadose Zone Contamination at Tank SX-104. In late 1997, moisture measurements acquired from the liquid observation well in tank SX-104 indicated a possible decrease in the tank's liquid level. At the request of DOE, Richland Operations Office, MACTEC-ERS relogged the boreholes surrounding tank SX-104 to identify regions of increased gamma-ray activity that would indicate increasing contaminant concentration in the sediments surrounding the boreholes. The boreholes were relogged with a spectral gamma logging system in January 1998, and the data were compared to those acquired during the baseline logging conducted between April and June 1995. Each borehole was also logged with a neutron-neutron logging system to evaluate the moisture content in the sediments surrounding tank SX-104.

The results of the 1998 relogging of the SX-104 monitoring boreholes indicated there was no increase or other changes in the concentrations and distributions of contaminants observed in the baseline logging. The moisture data showed variations in volumetric moisture content that were related to soil properties and not to specific contamination intervals that were detected in the boreholes. Consequently, there was no evidence from the log data acquired in 1998 in the SX-104 boreholes that indicated the tank had leaked. The results of the 1998 spectral gamma and neutron-neutron logging and comparisons between the 1998 and the baseline data are presented in GJO-98-48-TAR, GJO-HAN-21.

SX Tank Farm Borehole 41-09-39 Extension. Borehole 41-09-39 was installed to evaluate deep cesium-137 contamination that was detected around tank SX-109 during the initial spectral gamma logging in the SX Tank Farm in 1995. The borehole was terminated at a depth of 40 m (130 ft), and log data collected during installation were analyzed. The results were reported in GJO-97-4-TAR, GJO-HAN-9. The borehole was deepened in the fall of 1997, and the spectral gamma-ray system was used to log borehole 41-09-39 periodically during extension activities. The purposes of the logging were to estimate gamma-emitting radionuclide concentrations and to assess whether contamination was being dragged down during drilling operations. The spectral gamma-ray logging system was operated in both the spectral and total gamma modes during these logging operations.

Drag down relates to the contamination, generally cesium-137, that adheres to the outside of the casing and is carried down as the casing is advanced (i.e., the casing becomes contaminated as it passes through a contaminated zone). The drag-down contamination is later detected by the spectral gamma logging system, and every effort is made to identify and eliminate the drag-down data from the interpretation.

The spectral data from certain depths showed contaminant concentration changes from one log run to the next (Figure 6.2.3). On the basis of these data, and corroboration by the results of a spectral shape factor analysis process where applicable, it was shown that drag-down contamination was occurring during the deepening of borehole 41-09-39. Because of this drag-down contamination, it was not possible to determine to what depth contamination plumes exist. If an actual contaminant plume exists in the interval from approximately 40 to 49 m (133 to

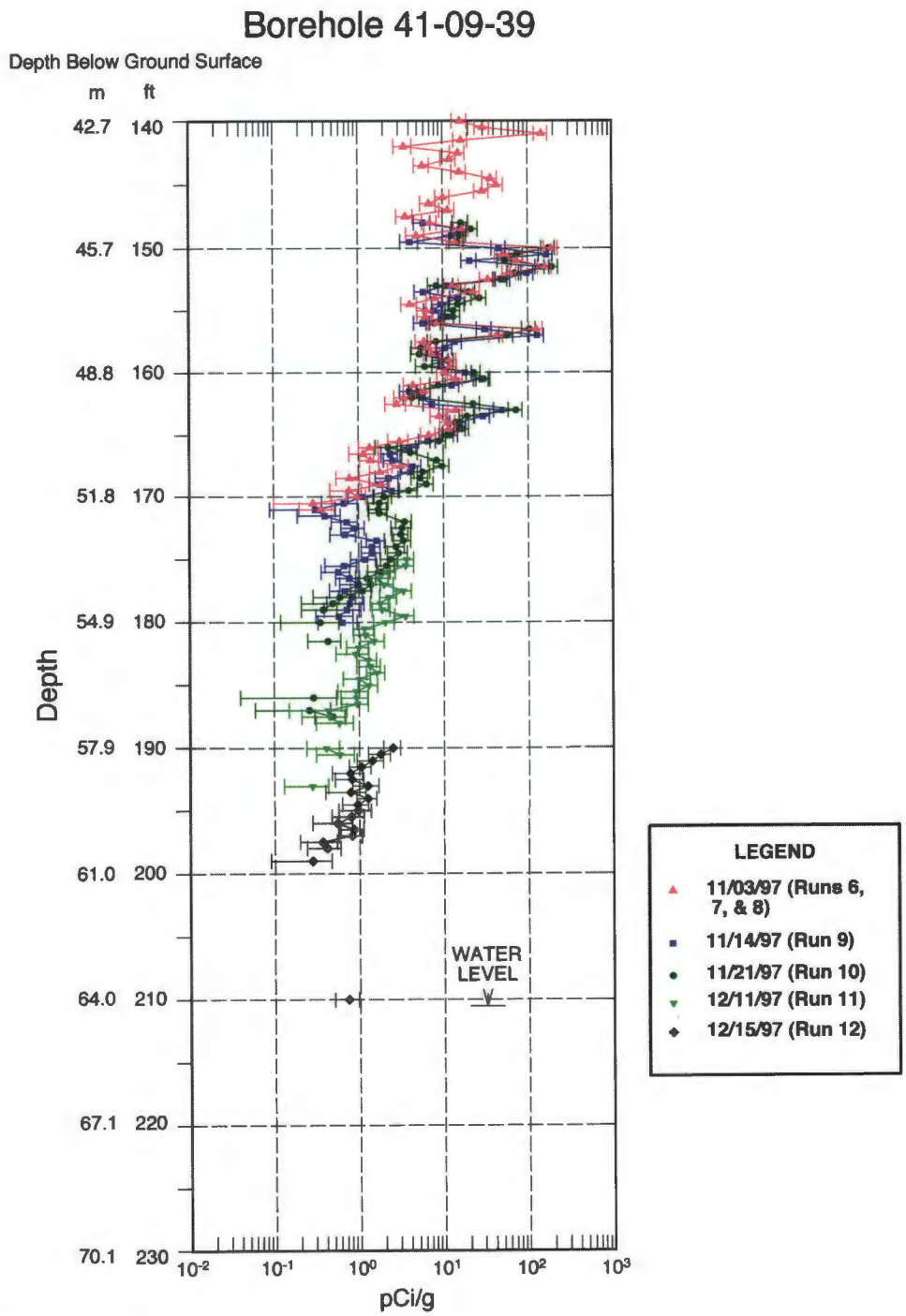

Figure 6.2.3. *Comparison of Cesium-137 Concentrations from Log Runs 6 through 12 in Borehole 41-09-39, 200-West Area*

160 ft), it could be masked by a false plume caused by contamination dragged down from higher in the borehole. Below approximately 49 m (160 ft), no zones of highly elevated activity were detected during the first log run in those intervals, suggesting that the existence of contaminant plumes in those intervals is very unlikely. On the basis of a comparison of the driller's logs and the gamma logs, it was postulated that the one mechanism of the drag down was that contamination had been smeared on the inside of the outer borehole casing and was being knocked loose and collected at the bottom of the borehole during drilling, logging, and sampling activities.

In addition to the spectral and total gamma logging, neutron-neutron moisture log data were collected at the conclusion of borehole drilling. Increases in moisture content identified in the neutron-neutron moisture log data correlated to water additions during drilling.

BX Tank Farm Vadose Zone Characterization. Details of the results of the spectral gamma logging in boreholes surrounding tank BX-102, where most of the vadose zone contamination in the BX Tank Farm was found, were presented in PNNL-11795 (Section 6.2.3.4). Some of the information discussed in that report are presented again in this section, along with the information for the rest of the tank farm, to provide a complete description of the BX Tank Farm vadose zone contamination.

The 74 existing boreholes surrounding the 12 single-shell tanks in the BX Tank Farm were logged with the spectral gamma logging system from May to August 1997. Figure 6.2.1 is a plan view of the BX Tank Farm, showing the locations of the monitoring boreholes. The final tank summary data report for the BX Tank Farm was completed in May 1998, and the BX Tank Farm report (GJO-98-40-TAR, GJO-HAN-19) was completed in August 1998.

Cobalt-60, antimony-125, cesium-137, europium-152, europium-154, uranium-235, and uranium-238 were the major gamma-emitting contaminants detected in the BX Tank Farm vadose zone. Occurrence of these radionuclides was detected around and below all tanks that are designated as leakers (BX-101, -102, -108, -110, and -111); however, the vadose zone contamination in the tank farm was not limited to these tanks. Figure 6.2.4 shows the vadose zone contamination at the BX Tank Farm that was detected with spectral gamma logging. The contamination shown in the figure is limited to the depth extent of the existing monitoring boreholes.

Cesium-137 was detected at ground surface throughout most of the BX Tank Farm area, and most of this contamination is associated with surface spill and/or piping leaks. This contamination decreased below the detection limits of the logging equipment at depths of approximately 3 m (10 ft).

The majority of the contamination in the BX Tank Farm was detected in its eastern area, where cobalt-60, antimony-125, cesium-137, europium-152, europium-154, uranium-235, and uranium-238 were detected throughout the 46-m (150-ft) depths of the monitoring boreholes (the majority of the monitoring boreholes surrounding the tanks are 30 m [100 ft] deep). This contamination is associated with leakage from tanks BX-101 and -102, which are designated as leakers, and the plumes originating from these tanks have commingled to create a complex distribution of contamination in this region of the tank farm. Because the monitoring boreholes surrounding tanks BX-101 and -102 are only 30 m (100 ft) deep, the presence of these radionuclides below the tanks, as well as the westward extent of the contaminant plumes, could not be determined.

Monitoring of groundwater in the well network surrounding the B, BX, and BY Tank Farms indicates contamination of groundwater has occurred. Remobilization of waste leaked from tanks BX-101 and -102 has been identified as the source of contamination in monitoring well 299-E33-41, which is located approximately 46 m (150 ft) northeast of

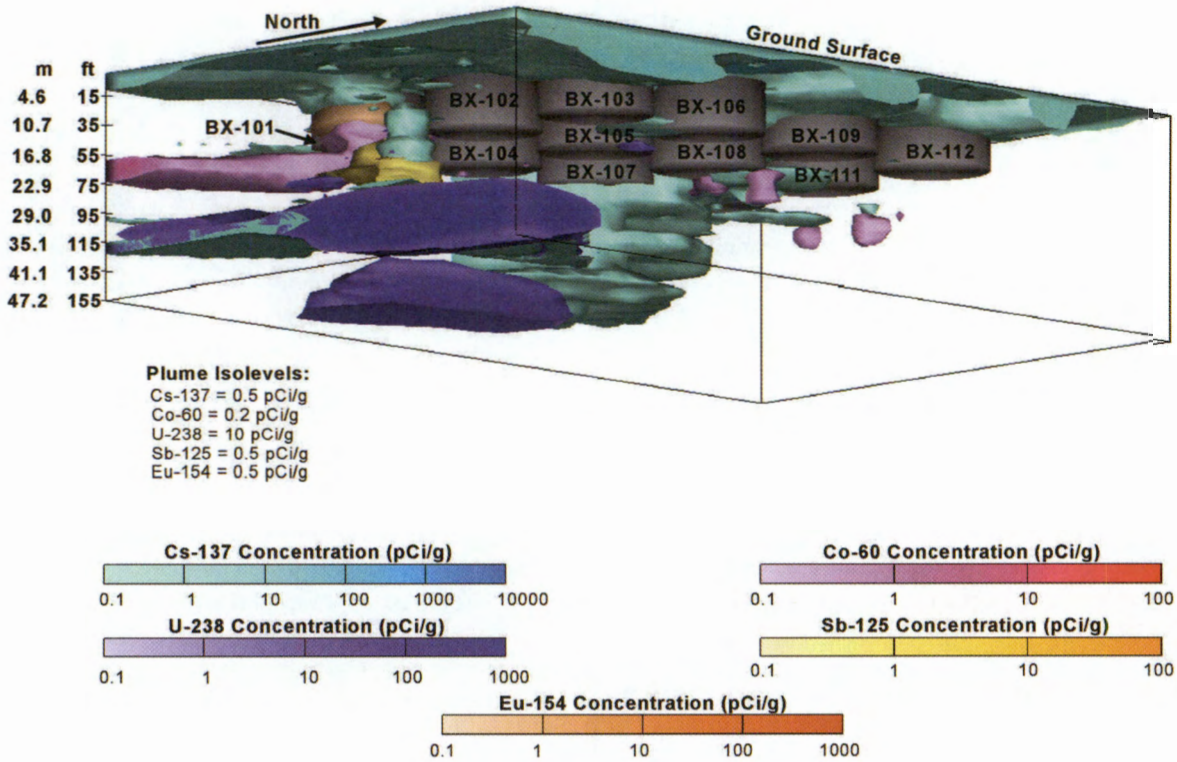

Figure 6.2.4. *Vadose Zone Contamination at the BX Tank Farm, 200-East Area*

tank BX-102 (PNNL 11826). Man-made uranium was detected in sediments at the depth of groundwater (which is approximately 78 m [255 ft]) and at the capillary fringe in this well.

An isolated plume of antimony-125, cesium-137, uranium-235, and uranium-238 occurs along the side of tank BX-106, which is designated as sound. The isolated nature of this plume and its spatial position relative to the tank location suggest that tank BX-106 may have leaked.

A thick accumulation of cesium-137 contamination occurs along the southern side of tank BX-107 and in the area between tanks BX-107 and -110 (see Figure 6.2.4). Several boreholes in this area have high-cesium-137 concentrations along most of their lengths. There are no documented spills and/or leaks for this area of the BX Tank Farm to account for the contamination that was detected with the spectral gamma logging systems.

C Tank Farm Vadose Zone Characterization. The 70 existing boreholes surrounding the 12 single-shell tanks in the C Tank Farm, 200-East Area, were logged with the spectral gamma logging system from January to April 1997. The final tank summary data report was completed in January 1998, and the C Tank Farm report (GJO-98-39-TAR, GJO-HAN-18) was completed in July 1998.

Cobalt-60 and cesium-137 were the major radionuclides detected in the vadose zone at the C Tank Farm; europium-152, europium-154, and uranium-235 were also detected, but their occurrences were limited to thin zones or single encounters near ground surface. Three-dimensional visualizations were created only for the cobalt-60 and cesium-137

distributions, and the plumes of these radionuclides are shown in Figure 6.2.5. The contamination detected in the C Tank Farm is limited to the depths of the existing C Tank Farm monitoring boreholes.

The majority of the contamination detected by the spectral gamma logging in the C Tank Farm cannot be directly associated to documented leaks from tanks or subsurface pipelines. The contamination distributions in some cases appear to indicate that tanks designated as sound (C-104, -105, -106, -107, and -108) may, in fact, have leaked. Conversely, there was minimal evidence of contamination detected in boreholes surrounding tanks that are designated as leakers (C-110 and -111). Contamination leaking from these tanks may not have migrated laterally to the extent to reach the vadose zone penetrated by the monitoring boreholes.

The contamination detected beneath tanks C-104, -105, and -106 may have resulted from leakage from cascade lines between these tanks as a result of overfilling tank C-105 or possible leakage from the tank itself. A 91-cm (36-in.) liquid-level drop in tank C-105 between 1963 and 1967 may be indicative of tank leakage. An investigation of this liquid-level drop identified evaporation as the cause; however, there was no positive support to this conclusion.

An extensive plume of cobalt-60 and cesium-137 was detected in boreholes between and around tanks C-108 and -109, which are designated as sound. This contamination may have resulted from leaks from tanks C-108 and/or -109, from a leak in the cascade line between these tanks, or from a leak over the dome of either tank. The leak over the dome may

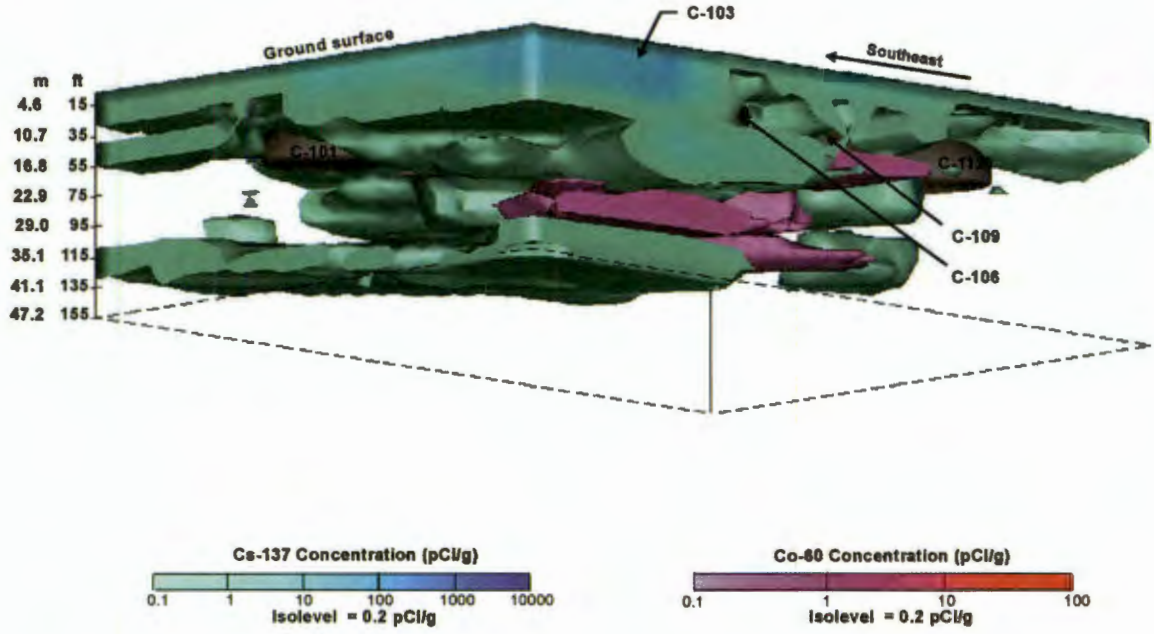

Figure 6.2.5. Vadose Zone Contamination at the C Tank Farm, 200-East Area

have migrated downward along the tank sides and may have accumulated at the interface of the backfill materials and undisturbed Hanford formation sediments. The source(s) of this contamination was not positively identified.

Tanks C-201, -202, -203, and -204 are designated as leakers. There are no monitoring boreholes around these tanks; therefore, the vadose zone in this region of the C Tank Farm cannot be characterized. The contamination from the relatively small volume of leakage (6,624 L [1,750 gal]) from these tanks is probably minimal.

There is no indication from published groundwater monitoring data that waste from tanks in the C Tank Farm has reached groundwater.

S Tank Farm Vadose Zone Characterization. The 68 existing boreholes surrounding the 12 single-shell tanks in the S Tank Farm, 200-West Area, were logged with the spectral gamma logging system from May to June 1996. The final tank summary data report was completed in August 1997, and the S Tank Farm report (GJO-97-31-TAR, GJO-HAN-17) was completed in February 1998.

Cobalt-60 and cesium-137 were the major radionuclides detected in the S Tank Farm vadose zone monitoring boreholes. Europium-154 was detected in one borehole in a thin interval near ground surface. Because of the limited occurrence of cobalt-60 contamination relative to the distribution of cesium-137, three-dimensional visualizations of only the cesium-137 contamination were prepared. Figure 6.2.6 shows the cesium-137 contamination in the S Tank Farm that was detected with spectral gamma logging; the characterization of the S Tank Farm vadose zone contamination is limited to the depths of the tank monitoring boreholes.

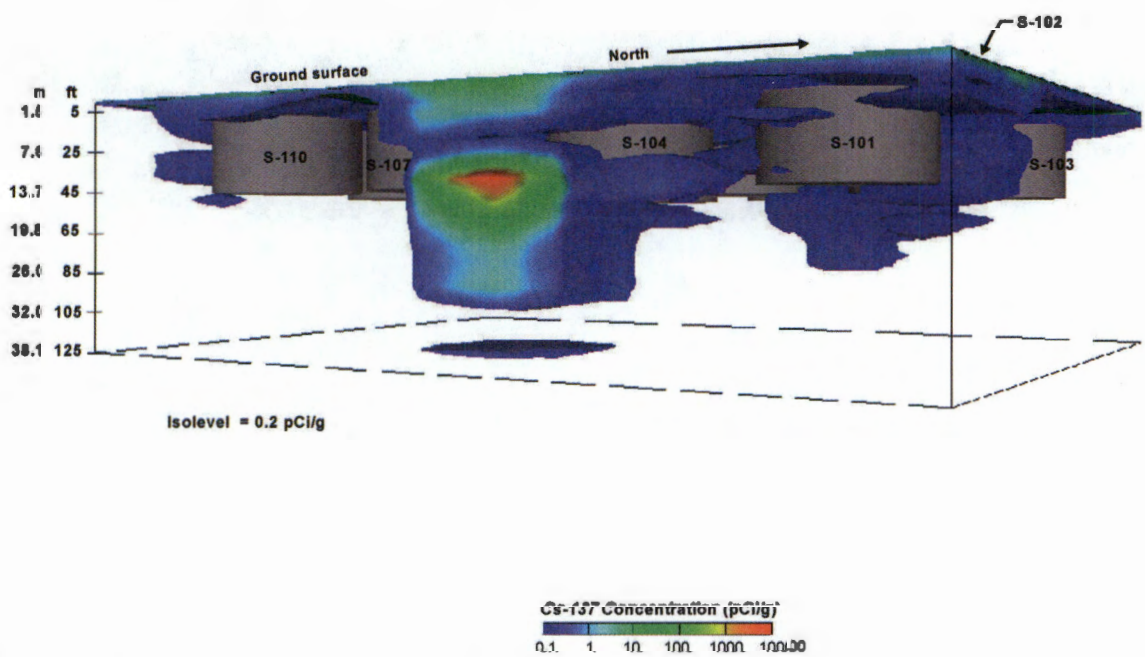

Figure 6.2.6. Vadose Zone Contamination at the S Tank Farm, 200-West Area

Two major regions of contamination were detected in the S Tank Farm: one beneath and to the east of tank S-104 and the other around tanks S-101, -102, and -103. Cesium-137 contamination beneath tank S-104 resulted from leakage from that tank and extends to a depth of approximately 29 m (95 ft) (approximately 17 m [55 ft] beneath the tank base).

Cobalt-60 and cesium-137 contamination was detected around tanks S-101, -102, and -103. This plume of contamination resulted from a large surface spill that occurred in this region of the tank farm in 1973. The surface spill appears to have migrated through the backfill materials, cascaded over tank domes, and collected at the base of the tank farm excavation to depths of approximately 22 m (73 ft).

Data indicate that contaminants may be entering the groundwater beneath the S Tank Farm; however, a positive source of the contamination could not be determined from this initial vadose zone characterization. Waste disposal facilities adjacent to the S Tank Farm, as well as the S Tank Farm itself, may be sources of the groundwater contamination (WHC-SD-EN-AP-191).

6.2.2 Vadose Zone Monitoring at Waste Disposal Facilities

D. G. Horton, R. J. Serne, and V. J. Rohay

Radioactive and hazardous waste in the soil column from past intentional liquid waste disposals, accidental spills, and leachate from solid waste burial grounds at the Hanford Site are potential sources of groundwater contamination. Subsurface source characterization and vadose zone monitoring, using spectral gamma logging and soil-gas monitoring were conducted during 1998. Also in 1998, physical, chemical, and hydraulic properties were measured from samples obtained from characterization boreholes at the Immobilized Low-Activity Waste site in the 200-East Area, which is the site for activities associated with retrieval and processing of tank waste, to support performance assessment modeling; at the borehole 41-09-39 extension site in the 200-West Area, to support SX Tank Farm remediation/closure; and at the 216-B-2-2 ditch in the 200-East Area to support 200 Areas soils remediation. Further, soil-vapor monitoring in the 200-West Area continued in 1998, and the summary of those activities is provided in this section.

6.2.2.1 Subsurface Characterization and Vadose Zone Monitoring

During 1998, in situ spectral gamma logging was performed by Waste Management Federal Services, Inc., Northwest Operations in support of Pacific Northwest National Laboratory RCRA groundwater monitoring in 21 boreholes (Figure 6.2.7) at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, all associated with the Plutonium Finishing Plant in the 200-West Area. These facilities were logged to determine whether recent movement of transuranic radionuclides had occurred beneath the facilities as a result, in part, of infiltration of precipitation. The surface of the 216-Z-1A facility is approximately 2 m (6.6 ft) below the surrounding grade and is covered with gravel. Thus, infiltration at this facility could be expected to be enhanced.

Spectral Gamma Logging Results. All borehole logs and a full discussion of the logging results at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib can be found in PNNL-11978.

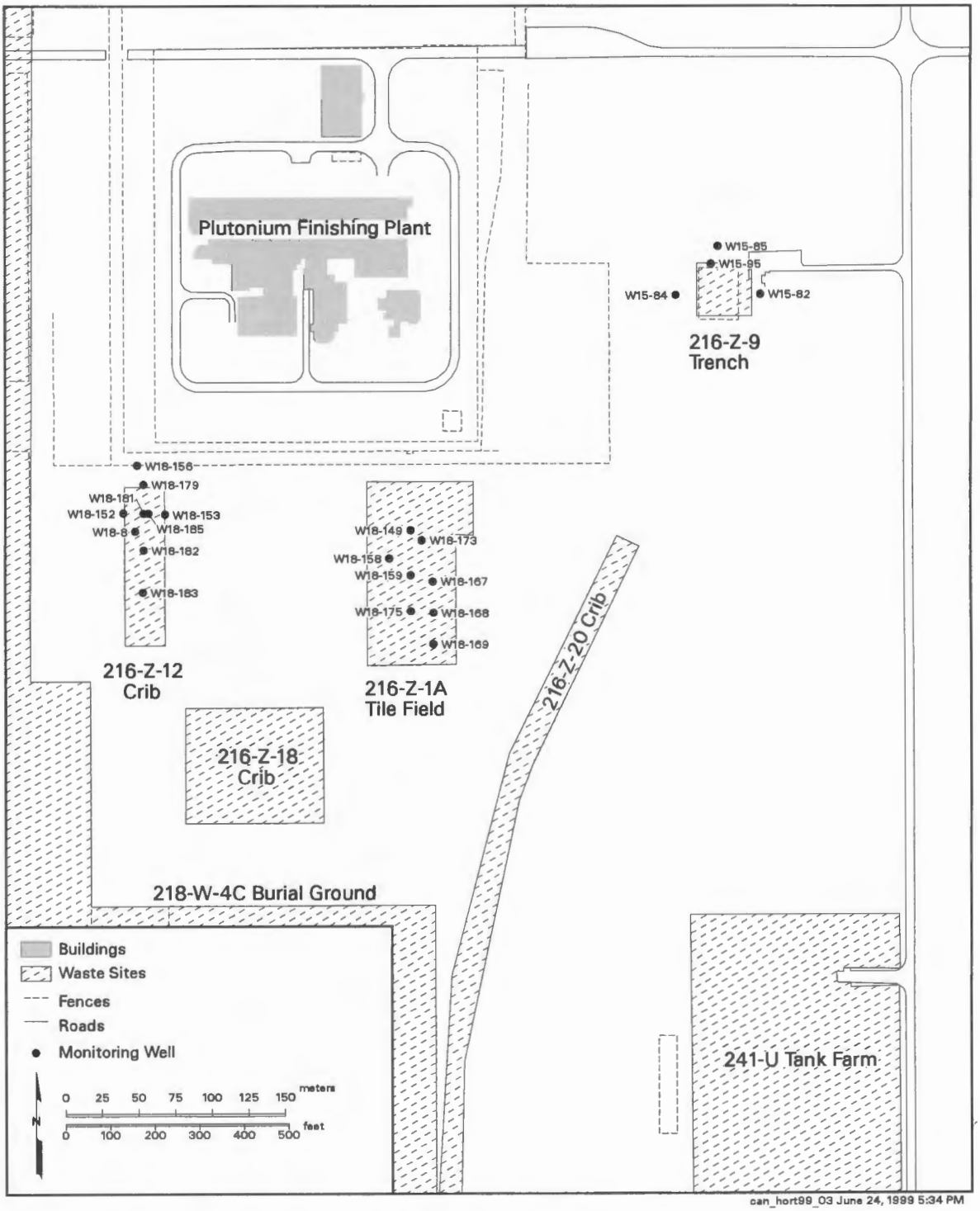

Figure 6.2.7. *Location of Boreholes Logged at the 216-Z-1A Tile Field, 216-Z-9 Trench, and 216-Z-12 Crib, 200-West Area*

The discussion below summarizes those results. All depths referred to in this section are relative to ground surface.

Cesium-137, protactinium-233, plutonium-239, and americium-241 were identified in the logs from the tile field and the crib. The maximum activities found at the tile field were in borehole 299-W18-159, which is located along the centerline/central distributor pipe of the tile field (cesium-137, 23 pCi/g at 3.3 m [10.8 ft]; protactinium-233, 63 pCi/g at 16.5 m [54.1 ft]; plutonium-239, 25,000,000 pCi/g at 3.3 m [10.8 ft]; americium-241, 2,500,000 pCi/g at 4.3 m [14.1 ft]). The distributor pipes are at the approximate 4.6-m (15-ft) depth (RHO-ST-17). This high-activity, shallow zone has been attributed to particulate plutonium dioxide that was filtered out of the liquid effluent by the sediments. Grab samples obtained in 1979 during drilling of borehole 299-W18-159 were found to contain a maximum of 1,500,000 pCi/g plutonium-239,240 at 4 m (13.1 ft) (RHO-ST-17). The difference between the maximum activities found from the 1979 laboratory results and the 1998 logging results probably reflects differences in the two analytical methods, coupled with the potential for discrete particulate plutonium dioxide at the level of the distributor pipe.

The deepest depth at which contamination was found at the 216-Z-1A Tile Field was approximately 30 m (98.4 ft) in borehole 299-W18-175, which is located along the centerline/central distributor pipe, where protactinium-233 was ~21 pCi/g, plutonium-239 was near 28,000 pCi/g, and americium-241 was near 80,000 pCi/g. Significant activities (≥100,000 pCi/g) of plutonium-239 were found as deep as 16 m (52.3 ft) in one borehole and approximately 14 m (46 ft) in another. Significant activities (≥100,000 pCi/g) of americium-241 were found as deep as 15 to 18 m (49 to 59 ft) in two boreholes. Whereas the shallow, high-activity zone can be attributed, in part, to particulate plutonium dioxide that was filtered out of the effluent by the sediments, the deeper, more widely distributed zones of contamination probably resulted from dissolved transuranics in aqueous and/or organic phases.

The only man-made radionuclide identified at the 216-Z-9 Trench was cesium-137, at <1 pCi/g near the surface in borehole 299-W15-95. However, only four wells were logged, and radionuclide contamination almost certainly exists beneath the trench.

At the 216-Z-12 Crib, boreholes 299-W18-179, -181, -182, and -185 showed the highest activities of man-made radionuclides. The maximum plutonium-239 activity was 3,000,000 pCi/g at 7 m (22.9 ft) in borehole 299-W18-181. The maximum americium-241 activity was 2,100,000 pCi/g at 7 m (22.9 ft) in borehole 299-W18-182. The maximum cesium-137 activity was 900 pCi/g at 5.8 m (19 ft) in borehole 299-W18-179. The distributor pipe is ~5.2 m (17 ft) below ground surface at this facility. The deepest contamination was found ~10 to 11 m (32.8 to 36 ft) at borehole 299-W18-181, where plutonium-239 was ~110,000 pCi/g, americium-241 was ~40,000 pCi/g, and cesium-137 was ~6 pCi/g. These boreholes all lie along the central distributor pipe near the headend of the crib. Protactinium-233 was the only man-made radionuclide found in boreholes near the crib boundary.

Comparisons of log data collected in 1998 with past logging event data suggest that some changes have occurred in radionuclide activity around two boreholes in the 216-Z-1A Tile Field and around one borehole in the 216-Z-12 Crib.

In borehole 299-W18-159 at the 216-Z-1A Tile Field, there was an apparent decrease in protactinium-233 activity to approximately one-third of 1991 values between 13.4 and 15 m (43.9 to 49.2 ft), with no apparent change above or below that zone. This suggests a lateral, not a vertical, change in protactinium-233 activity. Also, between 13 and 16 m (42.6 and 52.5 ft), cesium-137 activity decreased by a factor of approximately three, compared to the 1991 log.

In borehole 299-W18-175 at the 216-Z-1A Tile Field, a 51% increase in protactinium-233 activity was found between 6 and 16 m (19.7 and 52.5 ft) and a 22% increase between 28 and 29 m (91.9 and 95.1 ft), compared to activities from a 1993 log. Also in this borehole, there was an increase in the intensity of the americium-241 60-keV photopeak but no change in the intensity of the americium-241 208-keV photopeak at the 12.5-m depth, which compared with the 1993 log data. This suggests either a decrease in the casing thickness, such as from corrosion, leading to less attenuation of the less-energetic photon, or small amounts of americium-241 inside the borehole casing.

Only borehole 299-W18-179 at the 216-Z-12 Crib suggested that there were changes in subsurface distribution of radionuclides at that facility. Protactinium-233 showed an apparent 16% increase, and plutonium-239 showed an apparent 123% increase over the 4.6- to 5.5-m (15- to 18-ft) depth interval since the last logging in 1993. This depth is within the crib backfill material.

There is significance to the occurrence and the changes in protactinium-233 activity found in the three boreholes. Protactinium-233 has a 27-d half-life, so its occurrence must be supported by a long-lived parent isotope. Alpha decay of neptunium-237, with a half-life of 2.2 million years, is the most probable parent for protactinium-233. One probable origin for the neptunium-237 is alpha decay of americium-241, which was a significant contaminant in the waste stream sent to the Plutonium Finishing Plant cribs. A second possible origin for neptunium-237 is uranium-238 (n,2n) uranium-237, which beta decays to neptunium-237. Regardless of the origin of the neptunium-237, it is considered to be rather mobile in oxidizing environments (see PNL-10379, SUP. 1). Thus, the changes in activity of protactinium-233 probably reflect movement of neptunium-237, and the distribution of protactinium-233 can be considered a surrogate for neptunium-237.

Finally, the 1998 logging found large amounts of transuranics around boreholes 299-W18-149 and -159 that produced a large neutron flux, resulting in activation of elements in the soil column and in the borehole casing. This phenomenon was not investigated further.

Migration of Transuranics. The mobility of transuranics that are complexed with organic molecules in acidic waste streams discharged to past-practice disposal facilities near the Plutonium Finishing Plant were discussed in Section 4.4.5 of PNNL-11793 and by Johnson and Hodges (1997). The mechanism suggested by Johnson and Hodges might account for the distribution of high-activity transuranics to the 20- to 30-m (65.6- to 98.4-ft) depth in the 216-Z-1A Tile Field as found in earlier soil-column characterizations (RHO-ST-17). It is also suggested that transuranics could be adsorbed by the soil column after degradation of the organic complexing agents, resulting in stabilization of the contaminants. Alternatively, other soil-chemical reactions may have occurred (RHO-ST-17, NUREG/CR-6124).

In 1993, a logging team produced prompt fission neutron logs of four boreholes at the 216-Z-1A Tile Field and one each at the 216-Z-9 Trench and 216-Z-12 Crib. The prompt fission neutron tool measures undifferentiated, fissionable isotopes (primarily uranium-235, plutonium-239, and plutonium-241). The results of the prompt fission neutron logging were not published, but a draft report states that all the boreholes at the 216-Z-1A Tile Field and one borehole at the 216-Z-12 Crib showed large activities of fissionable isotopes. Two of the boreholes at the tile field had been logged previously with the prompt fission neutron tool in 1978 and again in 1984. The distribution of contaminants, as seen from the 1993 log, agreed well with the previous logs, indicating that fissionable radionuclides, including plutonium, had not moved substantially over the span of 15 yr at the two boreholes. The general

conclusion is that transuranics were relatively mobile at the time of discharge to the tile field but have been fairly stable since.

The 1998 logging found that the subsurface distribution of plutonium had changed around only one borehole at the 216-Z-12 Crib. "Particulate" plutonium, with discrete 2- to 24-micron particle sizes (>79 wt% plutonium dioxide) at and immediately below the distribution pipe at the 216-Z-1A Tile Field was documented in Price and Ames (1976). Although it is possible that particulate plutonium has been remobilized at the 5-m (16.4-ft) depth at the crib, further investigation is needed to determine both the nature and the reasons for plutonium remobilization.

Comparing the distribution of transuranics beneath the 216-Z-1A Tile Field and the 216-Z-12 Crib shows a much deeper penetration of transuranics beneath the tile field. This agrees with past characterizations at the two facilities (RHO-ST-17, RHO-ST-44) and can be explained by the processes described in Section 4.4.5 of PNNL-11793 or in Johnson and Hodges (1997). Unlike the acidic, organics-containing waste stream disposed to the tile field, the waste stream sent to the crib was neutral to basic and contained little organic-complexing agents (though sufficient carbon tetrachloride was found beneath the crib to include it in the vapor-extraction project). The initial mobility of transuranics is expected to be greater in the former waste stream than in the latter. After the disposal occurred, both the acidic and organic complexes are expected to have diminished via soil pH neutralization and biodegradation processes, and transuranics, especially americium and plutonium, would be expected to adsorb strongly to the sediments. There has been no obvious increased americium or plutonium migration deeper into the sediment profile at these facilities, but the protactinium-233 distribution may be interpreted as showing some migration of neptunium-237.

6.2.2.2 Immobilized Low-Activity Waste Site

The Tank Waste Remediation System program is focusing on resolving tank safety issues, planning for waste retrieval, developing waste pretreatment and treatment facilities, and evaluating waste storage and disposal needs for single-shell tank wastes. Vitrification and onsite disposal of low-activity waste from single-shell tanks are embodied in the strategy described in the Hanford Site federal facility agreement and consent order (commonly known as the Tri-Party Agreement; Ecology et al. 1989). The pretreatment and immobilization operations for both the low-activity and high-level wastes have been contracted to private organizations. The current plan is to dispose of immobilized, low-activity, tank waste in new facilities in the south-central part of the 200-East Area and in four existing vaults (unused, reinforced concrete structures remaining at the former Grout Treatment Facility) along the eastern side of the 200-East Area (DOE/RL-97-69).

Boreholes 299-E17-21, B8501, and B8502 were drilled in April 1998 at the southwestern corner of the Immobilized Low-Activity Waste disposal site (Figure 6.2.8) in support of the performance assessment activities for the disposal options. The boreholes were drilled using an air-lift, driven-casing method, and continuous soil samples were collected through the vadose zone. A complete description of the drilling project is presented in PNNL-11957.

Geologic logging of the drill cores showed that the vadose zone beneath the southwestern portion of the Immobilized Low-Activity Waste disposal site consists of the upper few meters (feet) of Ringold Formation Unit E gravels overlain by the Hanford formation (PNNL-11957). The careful drilling and near-continuous core recovery allowed geologists to identify for the first time three paleosols (layers) in a single borehole (299-E17-21). The three paleosols represent significant time intervals when soil development took place and are interpreted to be the tops

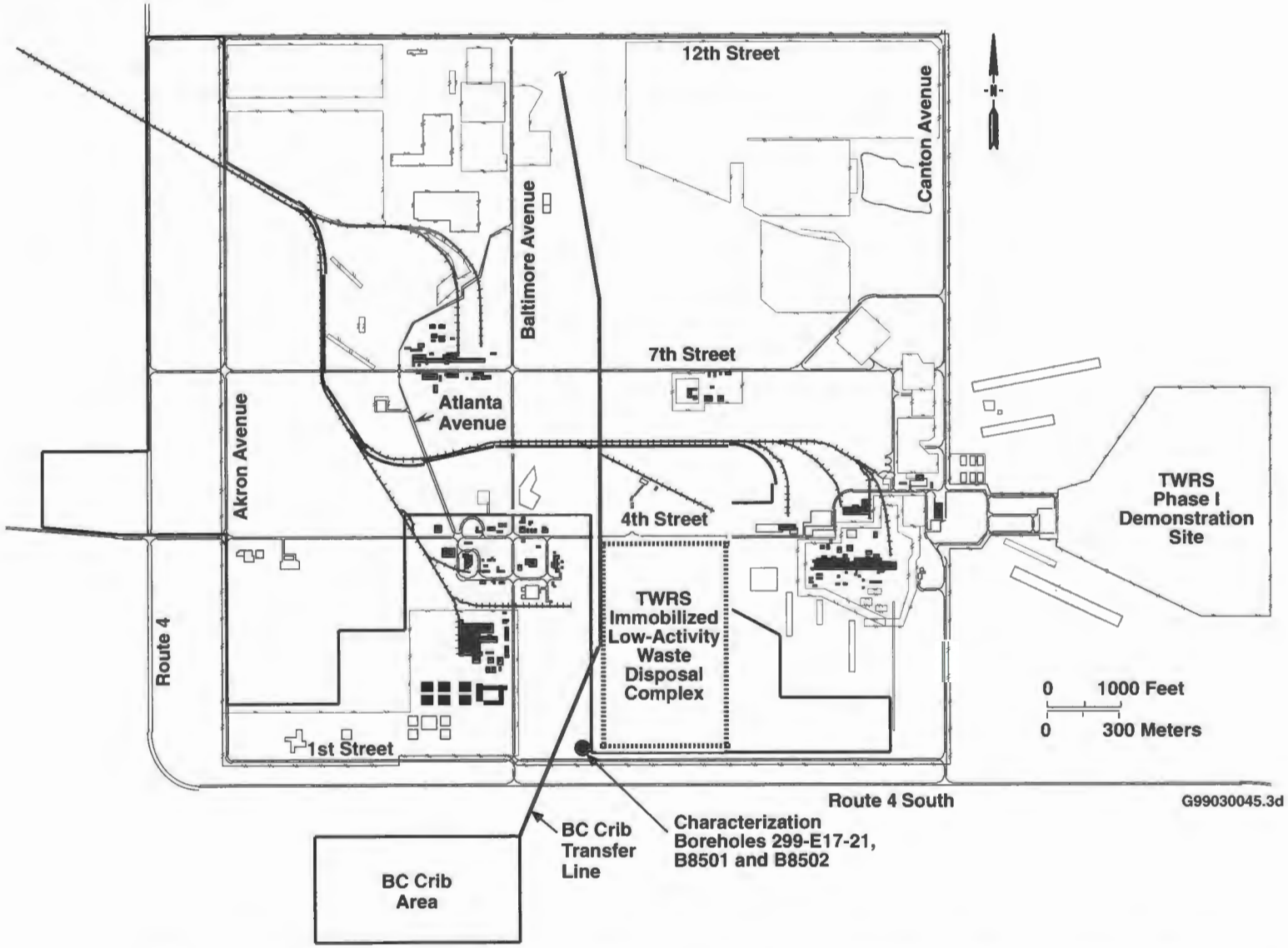

Figure 6.2.8. *Locations of the Immobilized Low-Activity Waste Site and Characterization Boreholes 299-E17-21, B8501, and B8502, 200-East Area*

of three Missoula flood deposits. The three flood events have been mapped at the Hanford Site (Reidel and Fecht 1994a, 1994b) but they have not been encountered in a single borehole. The detailed stratigraphy from the borehole sets a good background for the subsequent chemical transport, physical properties, and estimation of recharge tests.

All three boreholes were logged with a high-purity germanium detector to determine whether man-made, gamma-emitting radionuclides were present and to provide analyses of naturally occurring isotopes for stratigraphic purposes. No man-made radionuclides were identified. The boreholes were also logged with a neutron probe to determine moisture content. The moisture logging showed higher moisture content in the upper part of the borehole, consistent with higher-than-normal precipitation over the past several years. Comparison of the neutron probe moisture data with the stratigraphy indicated good agreement between high-moisture zones and fine-grained stratigraphic units.

Twenty intact cores from borehole 299-E17-21 were analyzed for physical and hydraulic properties. The 20 cores are from the Hanford formation sandy sequence. The cores were found to be fairly uniform as were the data generated, reflecting the high percentage of medium to fine sand. The variability among the hydrologic and physical data collected was within the range reported by WHC-EP-0883 for sediments of the 200 Areas. This increases confidence that existing data sets are representative of the range of physical and hydrologic properties present in the uncontaminated portions of the 200 Areas and may be representative of many of the contaminated portions of the 200 Areas. The data represent the most complete set of physical properties (i.e., particle size, particle density, bulk density, porosity) and hydrologic properties (i.e., saturated and unsaturated hydraulic conductivity, water retention) measured on undisturbed cores (split-spoon samples) at the Hanford Site.

In two samples, thin zones were observed with finer texture and lower hydraulic conductivities than were seen in the other 18 samples. These two thin zones could impact flow and contaminant transport by increasing lateral spreading. These observations, in concert with others, will be used to formulate a vadose zone conceptual model for the Immobilized Low-Activity Waste disposal site. Additional boreholes are planned in future years to help verify whether the two, thin, fine-textured layers are continuous across the disposal site. An unexpected feature found during coring activities was a relatively thick, open-framework, gravel sequence below 76.2 m (250 ft). No physical or hydrologic data are available for this sequence. Plans are in place to gather samples that are as undisturbed as possible during the future drilling activities.

Specific Distribution Coefficient Data. Radionuclide distribution coefficients (K_d) are a measure of the ratio of the amount of radionuclide adsorbed onto soil or rock and the amount remaining in solution (i.e., groundwater). K_ds are usually obtained by contacting soil with groundwater that has been spiked with a known amount of a specific radionuclide. The quantity of radionuclide adsorbed on the soil and the quantity remaining in the water are then measured. The higher the K_d, the greater the amount of contaminant on the soil relative to the amount remaining in the groundwater.

Radionuclide K_d measurements for cesium, iodine, selenium, strontium, technetium, and uranium were made on 20 samples from borehole 299-E17-21. Results of the measurements are summarized below. A more complete description of the tests is given in PNNL-12086 (Section 4.4). The results of the testing serve as input to performance assessment modeling of the Immobilized Low-Activity Waste Site.

Two sets of K_d values were calculated: conservative and best estimate. The conservative and best estimates of K_d values are given in Table 6.2.1,

Table 6.2.1. Conservative and Best Estimates of Distribution Coefficient (K_d) Values of Units 1, 2, and 3[a,b] at Borehole 299-E17-21, 200-East Area

Radionuclide	Units 3 and 2 K_d, mL/g		Unit 1 K_d, mL/g	
	Conservative[c]	Best[d]	Conservative[c]	Best[d]
Cesium	1,370	2,050 ± 440	1,370	2,050 ± 440
Iodine	0	0 ± 0	0	0.1 ± 0.1
Selenium	3.8	6.7 ± 1.9	3.8	6.7 ± 1.9
Strontium	12.0	14.3 ± 1.6	12.0	16.5 ± 1.9
Technetium	0	0 ± 0	0	0 ± 0
Uranium	0.5	0.6 ± 0.1	0.5	0.6 ± 0.1

(a) Different K_d values were assigned to each unit when statistical analyses determined that they differed at the 5% level of confidence. Otherwise, the same K_d values were assigned for all three units.
(b) Units represent depths within the Hanford formation: unit 3, 1.5 to 17.7 m (5 to 58 ft); unit 2, 17.7 to 49.7 m (58 to 163 ft); and unit 1, 49.7 to 75.3 m (163 to 247 ft).
(c) Conservative estimates were based on the minimum value.
(d) Best estimates were based on the median ± standard deviation.

assuming that performance assessment modeling will divide the Hanford formation into three geologic units separated by the paleosols described above, and in Table 6.2.2, assuming that the Hanford formation will be treated as a single modeling unit. Which of these two conceptual models will ultimately be used in future performance assessments will depend on these as well as other characterization data. Presumably, if significant differences in other parameter values such as hydraulic conductivity are observed among the three units, then it may be decided that introducing the added complexity of three units is warranted. Otherwise, the most conservative estimate of the combined units may be used for the performance assessment.

Overall, the estimates appearing in Tables 6.2.1 and 6.2.2 are consistent with those used for past performance assessments, with some notable exceptions. The older, conservative values for cesium, selenium, and strontium used in past calculations were 100, 0, and 5 mL/g, respectively, and were appreciably more conservative than necessary. The new K_d estimates for technetium and uranium in Tables 6.2.1 and 6.2.2 are approximately the same as those used for past calculations. The iodine K_d value from this new work is appreciably less than that used in the most recent performance assessment (3 mL/g) (DOE/RL-97-69), which was based on a literature review of K_d values measured using generic Hanford Site sediments (PNL-10379, SUP. 1). The cause for the new, measured, lower, iodine K_d values is not known, though the sediments used in this study clearly had appreciably lower amounts of fine-grained material than the previously used Hanford Site sediments. These differences in values underscore the importance of basing K_d estimates for the more-mobile major dose contributors on measurements using site-specific sediments.

Ideally, all K_d experiments should be conducted using site-specific sediments because the science of

Table 6.2.2. Conservative and Best Estimates of Distribution Coefficient (K_d) Values for the Hanford Formation at Borehole 299-E17-21, 200-East Area

Radionuclide	Conservative K_d Value,[a] mL/g	Best K_d Value,[b] mL/g
Cesium	1,370	2,030 ± 597
Iodine	0	0 ± 0
Selenium	3.8	6.7 ± 1.9
Strontium	12.0	14.3 ± 1.6
Technetium	0	0 ± 0
Uranium	0.5	0.6 ± 0.1

(a) Conservative K_d value estimates are based on the lowest value for each radionuclide (except uranium, which used the second-lowest measured K_d value.
(b) Best K_d value estimates are the median ± standard deviation from the 20 samples studied.

geochemistry is not yet advanced enough to permit estimating the geochemical behavior of a radionuclide in one sediment based on its behavior in another. However, site-specific sediments are generally expensive to collect, and the volume of material available usually is limited. The newly determined iodine K_d data suggest that the most technically defensible way to quantify radionuclide sorption is through experiments conducted with site-specific sediments and pore water or waste leachate, but the new results for the other contaminants studied are quite similar to past results using generic Hanford Site sediments not proximal to the proposed Immobilized Low-Activity Waste disposal complex.

6.2.2.3 Borehole 41-09-39 Extension to Groundwater

Borehole 41-09-39 was drilled in 1996 in the SX Tank Farm, 200-West Area, to a depth of 40 m (131 ft) in response to the determination that cesium-137 might reside in the soil column at depths >30.4 m (100 ft). Closed-end casing was driven to ascertain whether the contamination was an artifact of transport down the outside of an adjacent borehole or was disseminated in the soil formation. Geophysical logging of this borehole in late 1996 confirmed that cesium-137 dissemination within the formation was plausible and that contamination was still present at a depth of 40 m (131 ft).

Concern was raised that if relatively immobile cesium-137 was present at that depth, then more-mobile, long-lived, tank-waste constituents such as technetium-99 might be at or near the water table at approximately 64 m (210 ft). In response to a recommendation of the independent expert panel brought together to address these early findings (DOE/RL-97-49), borehole 41-09-39 was extended to groundwater in 1998 and samples were collected for laboratory analysis of tank waste components.

The closed-end casing was removed by milling with a rotary drilling machine, and the borehole was extended by sequentially driving a split-spoon sampler into the formation ahead of the drill casing, then cleaning the bore to the depth sampled, driving the drill casing to that depth, and finally cleaning out the drill casing again. This process was then repeated for

subsequent samples. Geologic conditions resulted in excessive friction against the drill pipe, effectively stopping progress. The drill casing was removed from the bore, and the drill shoe was replaced to over-ream the hole, reducing friction and allowing the casing to be advanced. The over-reaming drill shoe created a small annular space that may have contributed to drag down of contamination.

Sediment samples were collected in a near-continuous manner throughout the vadose zone, except where geologic conditions required use of a drilling method that resulted in unrepresentative samples. All sediment returned to the surface was preserved for potential analysis. Samples from seven selected locations within the borehole were analyzed for radionuclides, chemical constituents, cation-exchange capacity, and particle-size distribution.

Periodic geophysical logging of the borehole was used to indicate the occurrence of contaminant drag down and to provide additional data used to select sample locations. Gamma logging techniques were used throughout the drilling effort. On completion of the borehole, a neutron-neutron moisture log was run. Geophysical logging indicated that some contaminated material was following the casing as it was advanced. It should be noted that the indicated contaminant levels were low.

Screening analyses of the samples showed that the upper portion of the split-spoon sampler often exhibited low levels of contamination while the lower portion did not. The regularity of this occurrence resulted in its being interpreted as cross-contamination, either from material dragged along the outside of the casing or from material smeared along the inside of the casing that was deposited as the drill tools and samplers were inserted or extracted from the bore. Samples from the upper split-spoon sleeves were excluded from analysis when there was evidence of such possible cross-contamination.

Detailed geochemical analyses of the seven samples from this borehole showed that tank waste constituents are predominantly held within or above the Plio-Pleistocene sediments. Nonradiological constituents (calcium, nitrate, sodium) point to the leading edge of tank waste components being at a depth of approximately 47 m (154 ft) in borehole 41-09-39. This leading edge may be from natural percolation or drag down; however, the determination of which process is most likely cannot be made at this time.

Analyses for cesium-137, the radionuclide originally recognized as being deeper than expected in the vadose zone, were conducted on all samples via gamma energy analysis. Cesium-137 activity in the soils of the extended borehole was highest in the Plio-Pleistocene sediments at the 40-m (131-ft) depth. Activity dropped off rapidly and was at or below detection levels from 48.8 m (160 ft) to the water table at 64.3 m (210 ft).

Distribution of technetium-99, the most mobile of the long-lived radionuclides found in tank wastes, was sporadic, with most occurrences above the method detection level being above the Plio-Pleistocene unit. A single, deep occurrence was noted at 56.3 m (185 ft); this is the location postulated to be the highest level reached by groundwater during operation of U Pond (now decommissioned) located west of the SX Tank Farm. It is possible that technetium-99 was brought to this sediment sample by horizontal migration from disposal facilities outside the tank farm boundaries. If the technetium source was the SX tanks, it would have been expected that near-continual detection would have been noted throughout the shallower sediments. Figure 6.2.9 shows the distribution of cesium-137, technetium-99, and water extractable nitrate concentrations in the vadose zone sediments from borehole 41-09-39.

K_d tests were run on sediment samples for both technetium-99 and cesium-137. These tests showed that cesium-137 is strongly bound to the fine-grained sediments. The tests for technetium-99 showed positive K_d values, but the uncertainty associated with those values was significant.

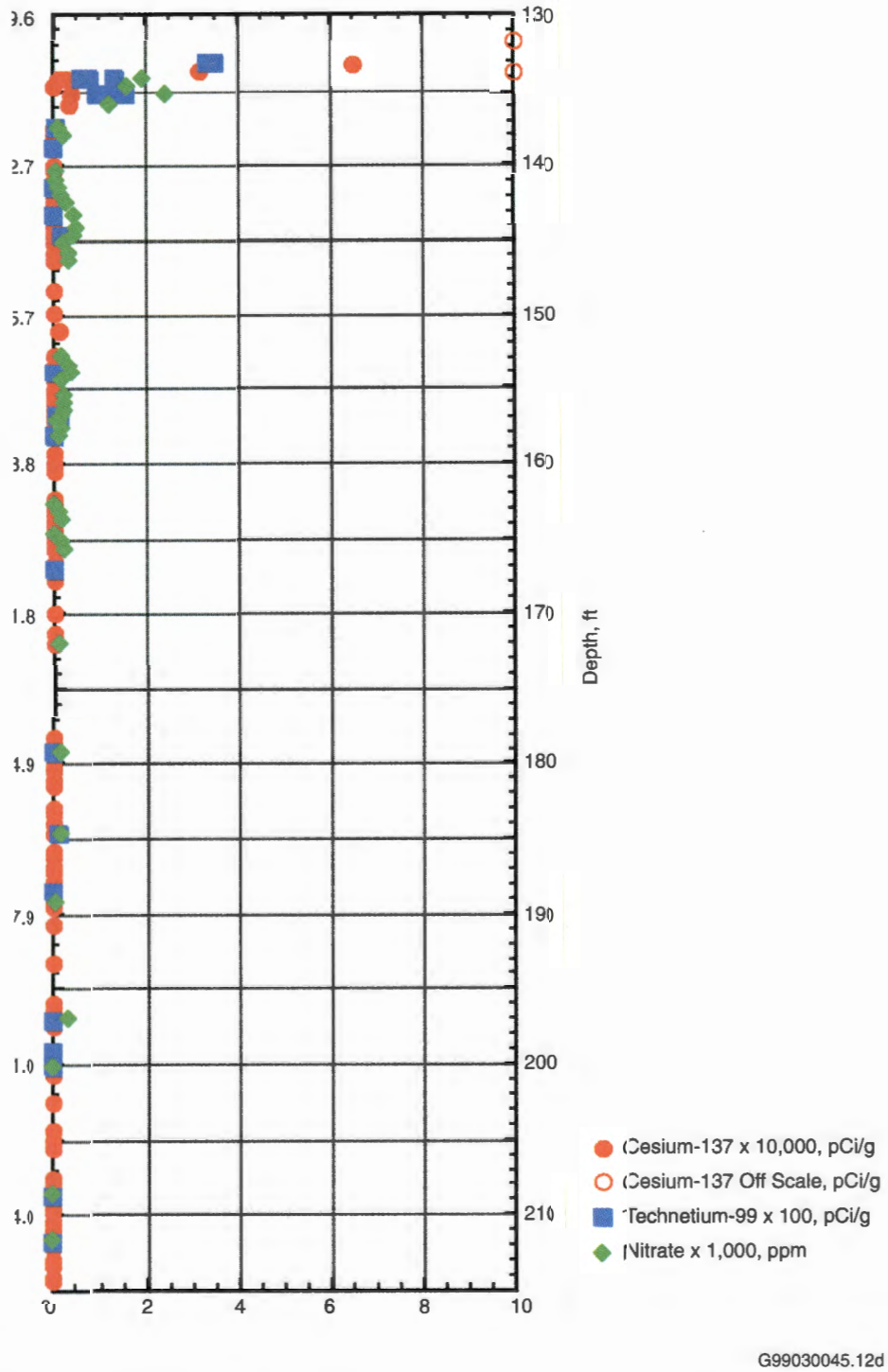

Figure 6.29. *Distribution of Technetium-99 and Cesium-137 in the Vadose Zone Sediments from Depth and the Water Extractable Nitrate Concentrations from Borehole 41-09-39, SX Tank Farm, 200-West Area*

Groundwater samples were collected from 0.02, 0.6, and 3 m (0.06, 2, and 10 ft) below the water table. Analyses of these samples showed technetium-99 and tritium activities indicative of an upgradient source. Analytical results for chromium were consistently below the method detection limit. These analyses indicate that groundwater contamination at this specific location is due to non-tank farm sources. More sampling of vadose zone sediments under the SX Tank Farm at additional locations is needed to determine whether the contaminants in downgradient monitoring wells may have originated from the single-shell tanks or from non-tank-related liquid discharge facilities nearby.

The results of the investigation of the borehole 41-09-39 extension point to a need to ascertain the disposition and distribution of the mobile, long-lived, waste constituents in the vadose zone. Complete details of the borehole extension findings can be found in HNF-2855. The geochemistry of tank wastes and the possible interactions of mobile species with sediments of the vadose zone are major gaps in the Hanford Site vadose zone information base for addressing tank remediation/closure.

6.2.2.4 200 Areas Assessment

A characterization borehole (299-E33-333) was drilled through the 216-B-2-2 Ditch, 200-East Area, (Figure 6.2.10) to groundwater during late December 1997 and early January 1998. This ditch was selected for characterization based on the criteria in DOE/RL-96-81, which identified this ditch as a representative site for the 200-CW-1 Gable Mountain Pond/B Pond and Ditches Cooling Water Group (formerly the 200-BP-11 Operable Unit). The 216-B-2-2 Ditch was selected as a representative site because 1) it was operationally typical of a ditch and contains a representative inventory of contaminants; 2) it is expected to contain typical to higher levels of contamination at the headend of the ditch system; and 3) it lies in the middle of the 216-B-2 Ditch system, providing composite data for all three 216-B-2 ditches at depth. The 216-B-2-2 Ditch received 49,700,000 L (13,100,000 gal) of effluent containing 147 Ci of strontium-90 as the major contaminant (DOE/RL-96-81). The purpose of drilling the borehole was to refine the preliminary physical conceptual models of contaminant distribution and hydrogeology, to assess the nature and extent of subsurface contaminants, and to support remedial action/closure decisions for the 200-CW-1 group (BHI-01052). The characterization activities, sampling and analysis plan, and data quality objectives are described in the description of work (BHI-01052). The characterization results are found in the borehole summary report (BHI-01177).

Characterization borehole 299-E33-333 was drilled at the influent end of the 216-B-2-2 Ditch because it was the location considered the most likely to have the highest concentration of contaminants along the ditch. The borehole was extended to a depth of 77.4 m (254 ft), which is below the water table, to investigate the extent of contamination throughout the vadose zone. The borehole was drilled using cable-tool techniques and was abandoned following characterization. Soil samples for chemical and radiological analyses and/or physical property testing were collected at 13 depths using a split-spoon sampler.

Geophysical surveys of borehole 299-E33-333 included both spectral gamma logging and neutron-neutron logging (BHI-01177). Spectral gamma logging was conducted to characterize the vertical profile of gamma-emitting radionuclides in the vadose zone. Neutron-neutron logging was conducted to characterize the vertical profile of the moisture content of the vadose zone.

Volatile organic analyses were conducted on all chemical samples, with the exception of the uppermost sample from 1.2 to 1.8 m (4 to 6 ft) below ground surface, which had insufficient sample volume. Three target volatile organic contaminants (acetone, methylene chloride, toluene) were detected at

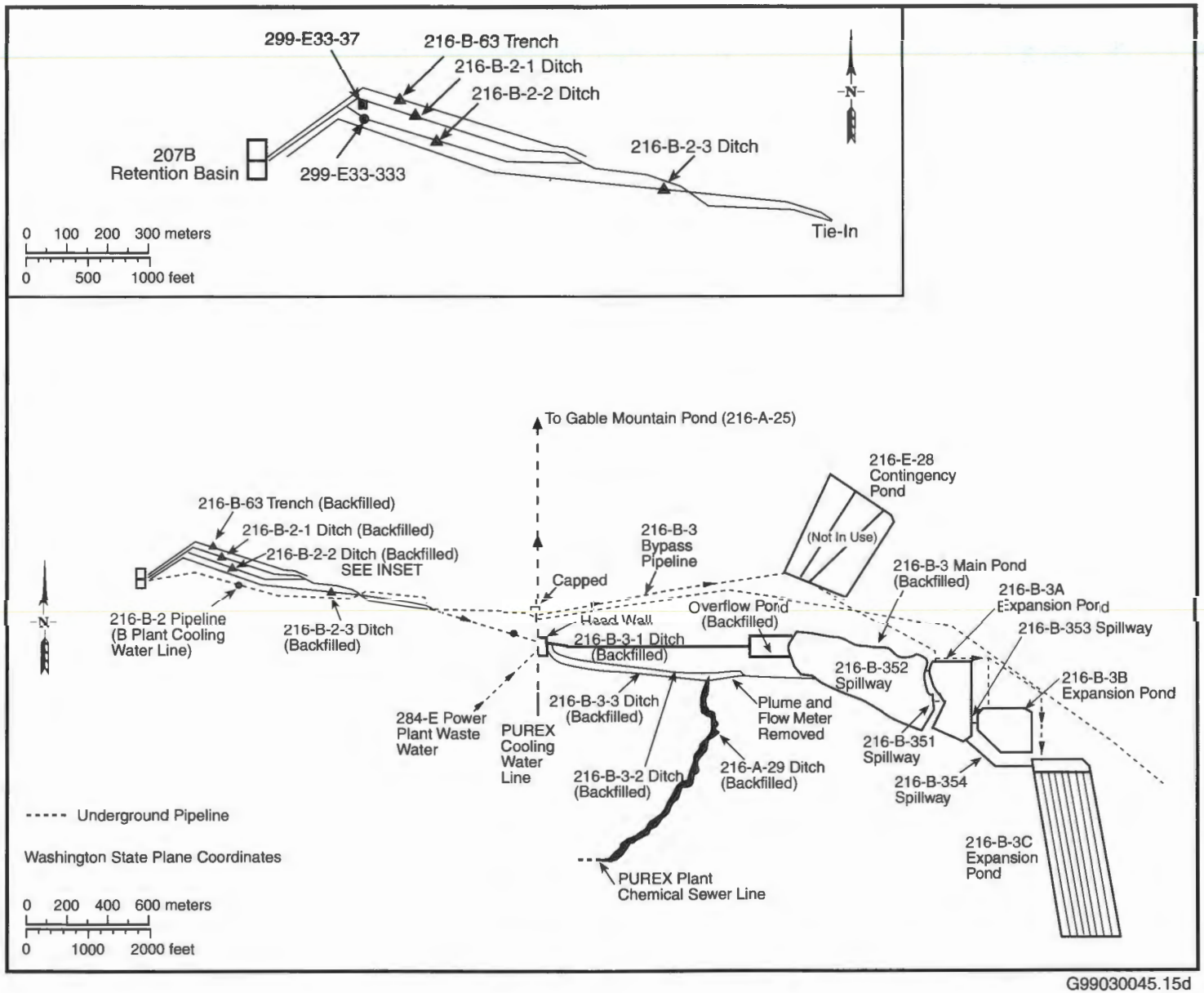

Figure 6.2.10. Location of the 216-B-2 Ditch System, 200-East Area

concentrations below the limit of quantification. One nontarget volatile organic (total xylenes) was detected at 8 µg/kg in the 45.7- to 46.5-m (150- to 152.5-ft) interval.

Semivolatile organic analyses were conducted on all chemical samples. The only polychlorinated biphenyl detected was aroclor-1260, which was found in the 2.4- to 4.7-m (8- to 15.5-ft) interval, with a maximum concentration of 9,200 µg/kg between 2.4- and 3.2-m (8 and 10.5 ft). Two nontarget semivolatile organic contaminants (butyl benzyl phthalate, di-n-octyphthalate) were detected at concentrations below the limit of quantification.

Chemical analyses for ammonia, cyanide, nitrate, nitrite, and sulfate were conducted on all samples, with one exception: cyanide was not analyzed in the uppermost sample from 1.2 to 1.8 m (4 to 6 ft) because a sufficient sample volume was not available. Cyanide was not detected in any sample. The maximum ammonia, nitrate, nitrite, and sulfate concentrations were 0.553, 35.8, 0.38, and 43.3 mg/kg, respectively, and all were detected in the 1.2- to 3.2-m (4- to 10.5-ft) interval. Ammonia and elevated nitrate were detected in only the uppermost sample from 1.2 to 1.8 m (4 to 6 ft).

Inorganic (metal) analyses were conducted on all chemical samples. For 12 of the 17 target metals detected, the maximum concentration was found in the 2.4- to 4.7-m (7.9- to 15.4-ft) interval. Cadmium and tin were the only 2 of the 17 target metals not detected in any samples.

Radiochemical analyses were conducted on all samples for both man-made and naturally occurring radionuclides. The primary man-made radionuclides detected were strontium-90, cesium-137, and europium-154 at maximum activities of 4,710, 100, and 1.29 pCi/g, respectively. The activities were one to two orders of magnitude higher in the intervals from 2.4 to 3.0 and 4.0 to 4.6 m (8 to 10 and 13 to 15 ft) than in the intervening sample interval from 3.2 to 4.0 m (10 to 13 ft). No man-made radionuclides were detected below 4.6 m (15 ft).

Cobalt-60, cesium-137, and europium-154 were detected in borehole 299-E33-333 by spectral gamma-ray logging methods. Cesium-137 was detected from the ground surface to a depth of 0.7 m (2.3 ft) and at depths between 1.8 and 3.3 m (6 and 11 ft). The maximum cesium-137 activity was approximately 400 pCi/g measured at 2.7 m (8.8 ft). Analysis of the data indicates that, within the zone of highest cesium-137 activity, the contamination is uniformly distributed in the formation as a thin, 0.15- to 0.3-m-thick (0.5- to 1-ft) layer (BHI-01177). Cobalt-60 was detected at the ground surface and at a depth of 0.15 m (0.5 ft). The maximum cobalt-60 activity was approximately 0.15 pCi/g. Europium-154 was detected at three points at depths between 2.6 and 2.9 m (8.5 and 9.5 ft) within the interval of highest cesium-137 activity. The maximum europium-154 activity was 2.0 pCi/g. The spectral gamma logging and sediment radiochemical analyses agree, except that the spectral gamma logging estimates the maximum cesium-137 activity at 400 versus 100 pCi/g for the laboratory analyses. Strontium-90, a beta emitter, was not detectable using the spectral gamma logging instrument.

For both data sets, man-made radionuclides are found within the upper 4.6 m (15 ft) of the soil column. One zone of high activity was found at a depth of 2.4 to 3.2 m (7.9 to 10.5 ft) in both data sets. The laboratory analytical data also indicated a zone of high activity from 4.0 to 4.6 m (13.1 to 15.1 ft). The distribution of man-made radionuclides underlying the 216-B-2-2 Ditch is consistent with the conceptual model developed for the 200-CW-1 group (DOE/RL-96-81). The conceptual model for this group is that the highest activity of the primary contaminants of concern (e.g., strontium-90) will be directly underlying the headend of the ditch. Furthermore, according to the conceptual model, most of the contaminants were expected to be within the

uppermost gravel unit, which at this site extends to a depth of 9.1 m (29.8 ft). The data indicate that, in fact, the radionuclide contamination does not extend below 4.6 m (15.1 ft).

6.2.2.5 Soil-Vapor Monitoring

Soil-vapor extraction is being used to remove the carbon tetrachloride from the vadose zone as part of the 200-West Area expedited response action being conducted by Bechtel Hanford, Inc. This section summarizes 1998 activities. For a more complete description of 1998 activities, see Section 4.5 of PNNL-12086. For descriptions of past work, see BHI-00720 (Rev. 2) and Section 4.4 in PNNL-11793.

To track the effectiveness of the remediation effort, measurements of soil-vapor concentrations of chlorinated hydrocarbons were made at the inlet to the soil-vapor-extraction system, at individual, on-line (i.e., operating), extraction wells, and at individual, off-line (i.e., standby), wells and probes throughout the soil-vapor-extraction sites during 1998. One soil-vapor-extraction system was operated from April through September 1998. Soil-vapor monitoring at off-line wells and probes was conducted from October 1997 through September 1998.

Soil-vapor samples were collected from approximately 25 off-line wells and probes once per month. Soil-vapor samples were analyzed primarily to monitor for carbon tetrachloride; however, the samples collected from off-line wells and probes were also analyzed for chloroform, methylene chloride, methyl ethyl ketone, and water vapor.

In 1998, 46 drilled wells were available for on-line extraction or monitoring (BHI-00720, Rev. 2) (Figure 6.2.11). 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. Of the 46 wells, 17 have two, separated open intervals in the well. The soil-vapor-extraction system extracts simultaneously from multiple wells open either above and/or below the Plio-Pleistocene unit. The mix of on-line wells is adjusted periodically to optimize contaminant removal.

There are 125 subsurface monitoring probes at >2 m (6.6 ft) below ground surface. A cone penetrometer was used to install 11 extraction, or monitoring, wells (denoted by + on Figure 6.2.11) and 104 subsurface monitoring probes at 33 locations (denoted by D on Figure 6.2.11). Up to five monitoring probes were installed per location at various depths. The deepest monitoring probe installed at the vapor-extraction sites is 36 m (118 ft) below ground surface. Ten stainless-steel tubes were strapped to the outside of the casing of 4 of the 13 wells during installation to enable monitoring above and below the screened intervals.

There are up to 73 shallow, soil-vapor probes at depths ranging from 1.2 to 1.8 m (4 to 6 ft) (Figure 6.2.12). The network was installed between 1991 and 1995. Some of the probes have since been destroyed, primarily as a result of other near-surface construction activities or prolonged exposure to weather conditions.

Based on the results of the 1997 rebound study (BHI-01105) and the declining rate of carbon tetrachloride removal during continuous extraction operations (BHI-00720, Rev. 2), the operating strategy for 1998 was modified. Rather than operating all three soil-vapor-extraction systems continuously, only the 14.2-m^3/min (500-ft^3/min) system was used for carbon tetrachloride removal during 1998. The 14.2-m^3/min (500-ft^3/min) system was modified so that it could be moved between the well fields surrounding the 216-Z-1A Tile Field, 216-Z-9 Trench, 216-Z-12 Crib, and 216-Z-18 Crib. The 28.3- and

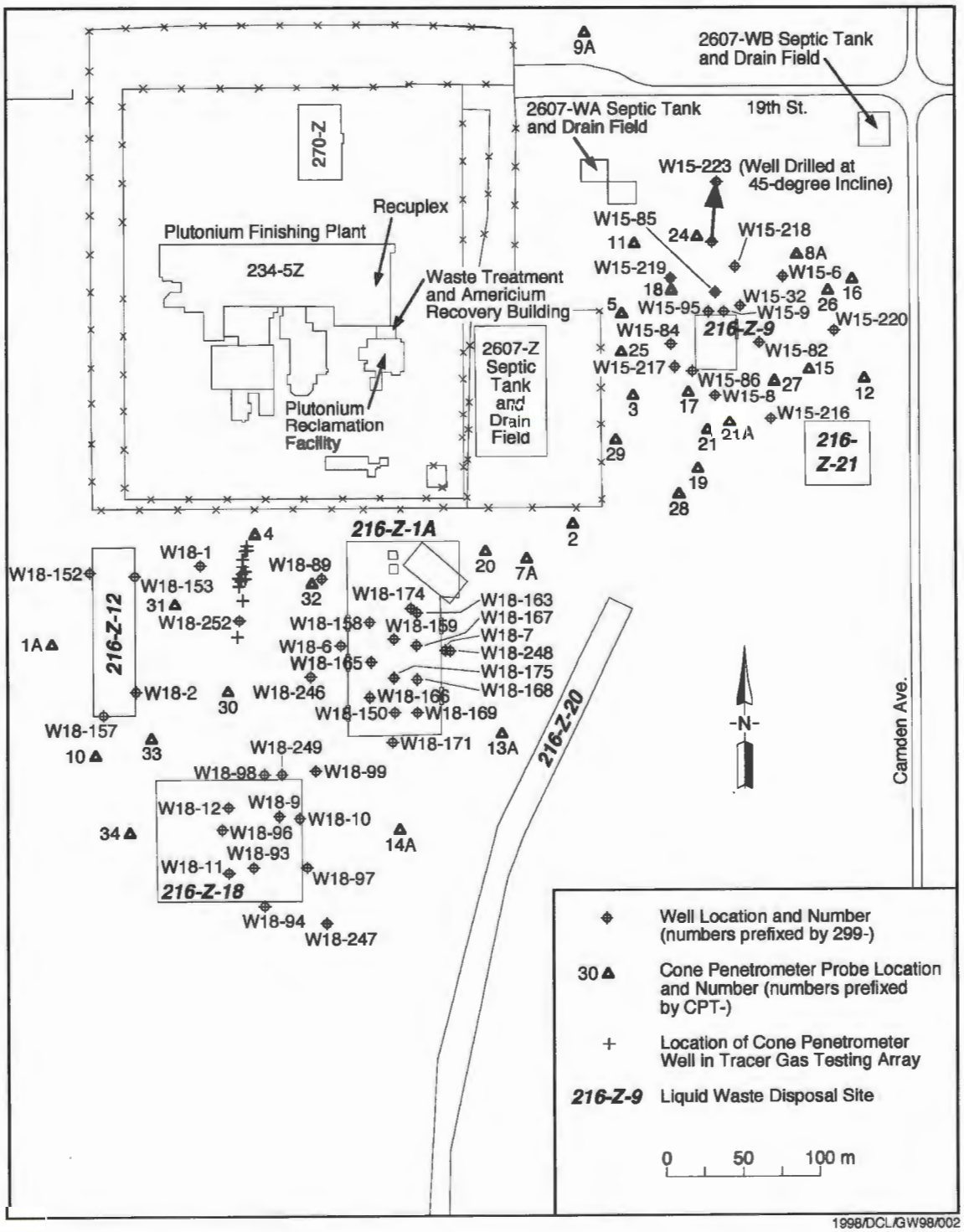

Figure 6.2.11. Location of Wells and Deep Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area

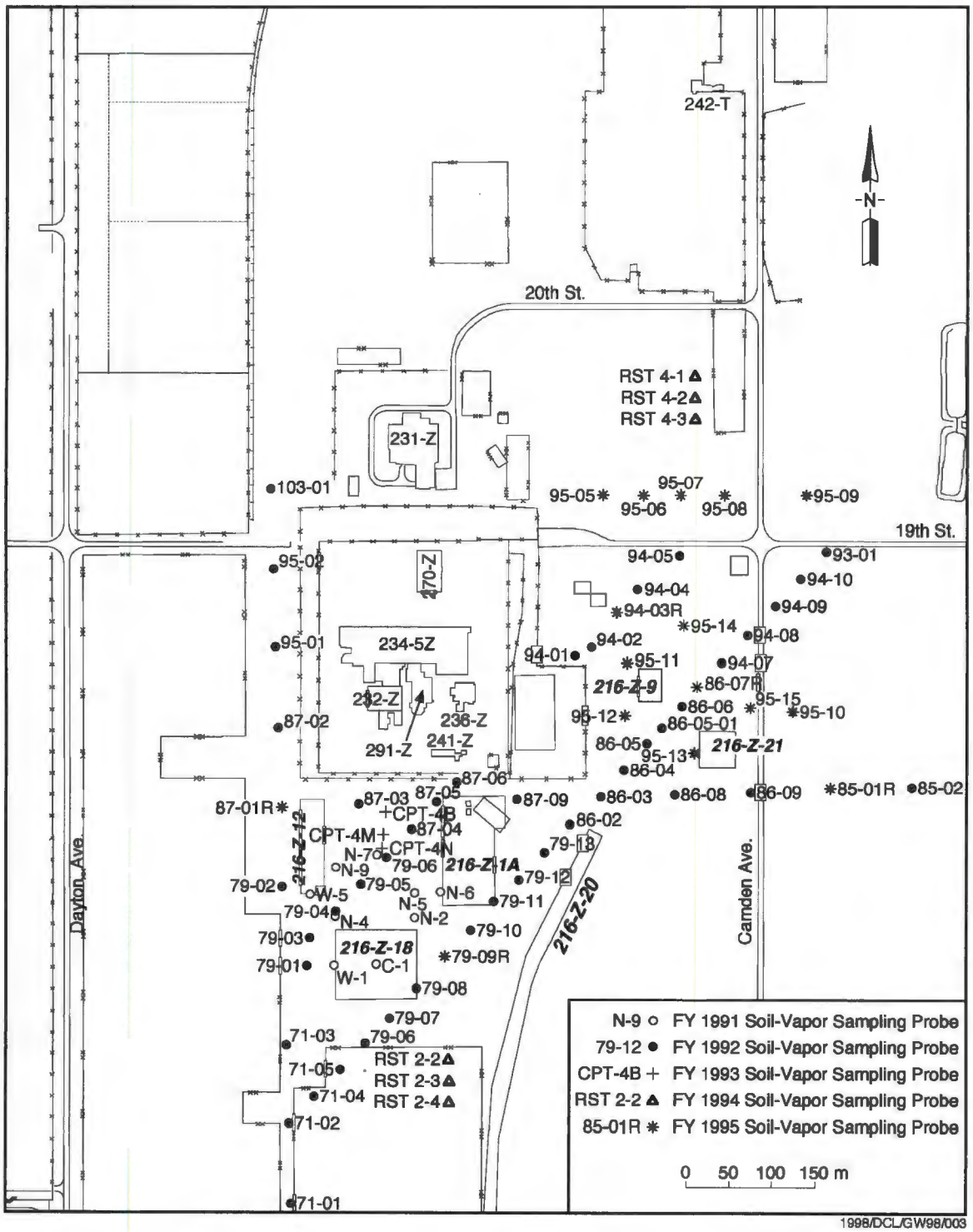

***Figure 6.2.12**. Locations of Shallow Soil-Vapor Monitoring Probes at the Carbon Tetrachloride Vapor-Extraction Site, 200-West Area*

42.5-m^3/min (1,000- and 1,500-ft^3/min) soil-vapor-extraction systems were maintained in standby mode during 1998.

The 14.2-m^3/min (500-ft^3/min) soil-vapor-extraction system was operated from March 30 through June 30, 1998 at the combined 216-Z-1A/-12/-18 well field and from July 7 through September 30, 1998 at the 216-Z-9 well field. The system was shut down for the winter (October 1, 1997 through March 29, 1998).

For the 6 mo that the system was shut down, the rebound in carbon tetrachloride concentrations was monitored at 25 wells and probes at both well fields. For the 3 mo that the system was operated at 216-Z-1A/-12/-18, carbon tetrachloride concentrations were monitored at 25 wells and probes primarily at the 216-Z-9 well field; for the 3 mo that the system was operated at the 216-Z-9 well field, carbon tetrachloride concentrations were monitored at 25 wells and probes primarily at the 216-Z-1A/-12/-18 well field.

Soil-Vapor Remediation. Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed on March 30, 1998 at the 216-Z-1A/-12/-18 well field, using the 14.2-m^3/min (500-ft^3/min) system, which is on the northern side of the 216-Z-18 Crib. Fifteen extraction wells distributed throughout the well field were selected to optimize both protection of groundwater and mass removal of contaminant. Initial characterization of the 15 on-line wells indicated that the system was extracting soil vapor effectively from only the closest wells and that the applied vacuum at the distant wells was insufficient to produce flow. Tests showed that the system could, however, extract soil vapor effectively from isolated, distant wells. Therefore, the mix of on-line extraction wells was periodically switched among one set of seven relatively nearby wells and various sets of four relatively distant wells. Each set included wells open near the groundwater and wells open near the less-permeable Plio-Pleistocene unit. As a result, the system was extracting from wells primarily associated with the 216-Z-18 Crib for the first 7 wk (March 30 through May 17) and from wells primarily associated with the 216-Z-1A Tile Field for the following 6 wk (May 18 through June 30). Comparison of the changes in inlet concentrations to the changes in the sets of on-line wells indicated that the higher concentrations observed from May 18 through June 30 tended to be associated with the 216-Z-1A wells (Figure 6.2.13).

Soil-vapor extraction to remove carbon tetrachloride from the vadose zone resumed on July 7, 1998 at the 216-Z-9 well field, using the 14.2-m^3/min (500-ft^3/min) system. Initial on-line wells were selected close to the 216-Z-9 Trench. As extraction continued, wells farther away from the trench were brought on line. Each selection of on-line wells included those with openings near the groundwater and those with openings near the less-permeable Plio-Pleistocene unit. The daily mass-removal rate increased significantly twice during the 3 mo of extraction as a result of changes in extraction wells: two additional wells were brought on line on July 29, 1998 (the mass-removal rate increased, despite a continued decline in concentrations, because the flow rate increased [see Figure 6.2.13]); and the mix of on-line wells was changed again on September 1, 1998 (the mass-removal rate increased, despite a constant flow rate, because the inlet concentrations increased [see Figure 6.2.13]).

During a total of 178 d of soil-vapor extraction in 1998, 777 kg (1,700 lb) of carbon tetrachloride were removed from the vadose zone. Of this total, 254 kg (560 lb) were removed from the 216-Z-1A/-12/-18 well field during 91 d of operation and 523 kg (1,150 lb) were removed from the 216-Z-9 well field during 86 d of operation.

As of September 1998, approximately 75,000 kg (165,000 lb) of carbon tetrachloride had been removed from the subsurface since extraction operations started in 1992 (Table 6.2.3). Since initiation, the extraction systems are estimated to

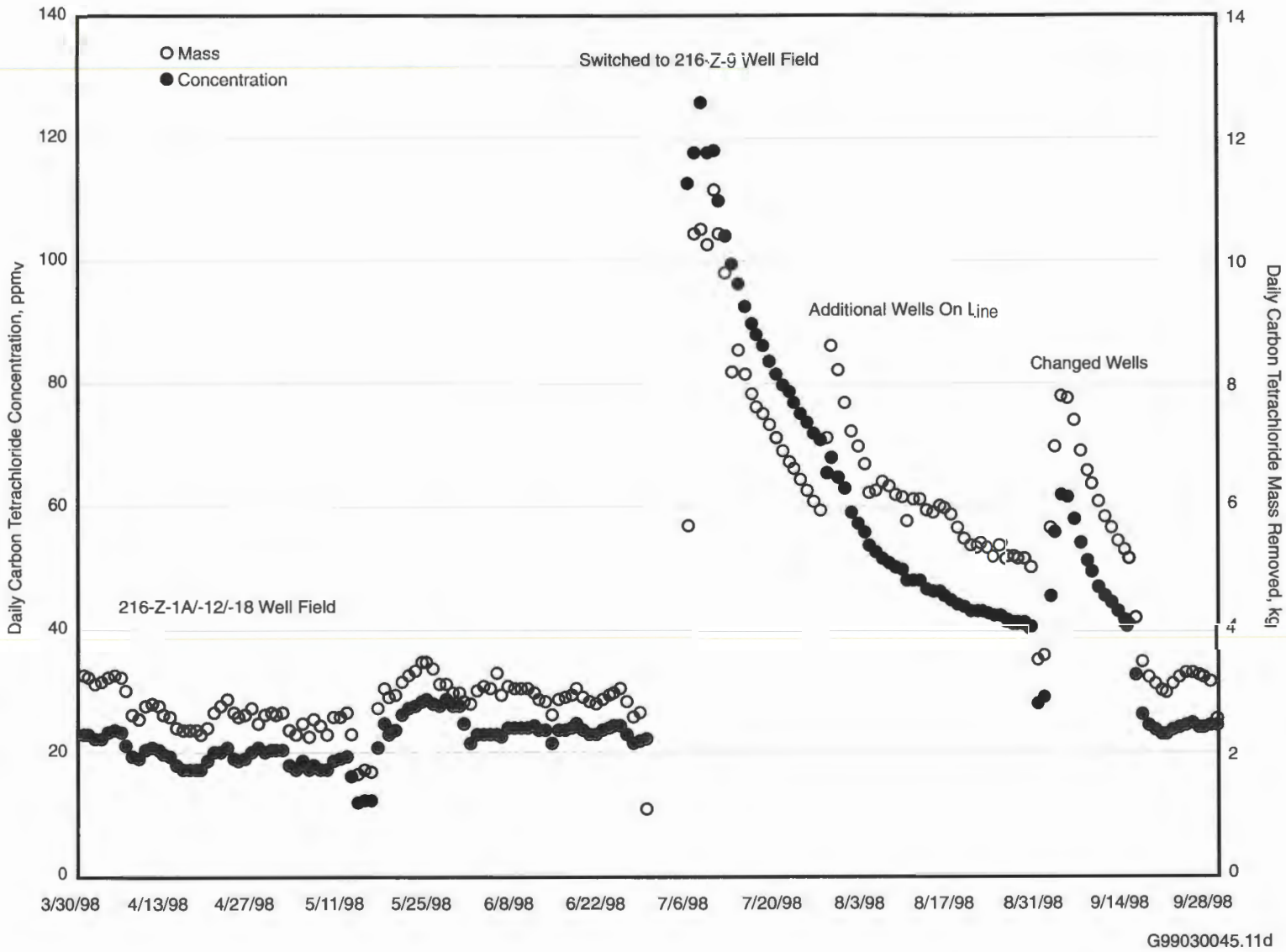

Figure 6.2.13. *Time-Series Concentration of Carbon Tetrachloride in Soil Vapor Extracted from the 216-Z-1A/-12/-18 Well Fields, 200-West Area*

Table 6.2.3. Carbon Tetrachloride Inventory in Primary Disposal Sites, 200-West Area

Well Field	Estimated Mass Discharged, 1955 to 1973,[a] kg (lb)	Estimated Mass Lost to Atmosphere, 1955 to 1990,[b] kg (lb)	Mass Removed Using Soil-Vapor Extraction, 1992 to 1998, [c] kg (lb)
216-Z-1A	270,000 (595,000)	56,700 (125,000)	22,983[d] (50,500)
216-Z-18	170,000 (375,000)	35,700 (78,700)	
216-Z-9	130,000 to 480,000 (287,000 to 1,060,000)	27,300 to 100,800 (60,200 to 222,000)	52,507 (115,500)
Total	570,000 to 920,000 (1,260,000 to 2,030,000)	119,700 to 196,800 (264,000 to 434,000)	75,490 (166,000)

(a) Based on DOE/RL-91-32 (Draft B).
(b) Based on WHC-SD-EN-TI-101.
(c) Based on BHI-00720 (Rev. 2).
(d) Includes mass removed from 216-Z-18 well field; reported as a combined value because the well fields overlap.

have removed 7% of the residual mass at the 216-Z-1A/-12/-18 well field and 22% of the mass at the 216-Z-9 well field. This estimate assumes that all of the mass that has not been lost to the atmosphere (21% of the original inventory) or dissolved in groundwater (2% of the original inventory) is still available in the vadose zone as "residual" mass (BHI-00720, Rev. 2; WHC-SD-EN-TI-101).

Soil-Vapor Monitoring. During October 1997 through March 1998, soil-vapor concentrations were monitored near the groundwater and near the ground surface to assess whether nonoperation of the soil-vapor-extraction system was allowing carbon tetrachloride to migrate out of the vadose zone. The maximum concentration detected between 1.5 and 4.5 m (5 and 15 ft) below ground surface was 1 ppm (by volume); the maximum concentration detected between 7.6 and 18.3 m (25 and 60 ft) was 43 ppm (by volume). Near the groundwater, at depths ranging from 56.0 to 63.4 m (184 to 208 ft), maximum concentrations ranged from 14.6 to 31.3 ppm (by volume). These results, after 6 mo of rebound, are similar to those obtained during the 8-mo rebound study conducted in 1997 (BHI-01105).

During April through June 1998, soil-vapor monitoring was continued at the shallow and deep locations at the 216-Z-9 well field. Monitoring locations were added near the less-permeable Plio-Pleistocene unit at 216-Z-9 to provide an indication of concentrations that could be expected during restart of soil-vapor extraction in July 1998. Concentrations detected in the near-surface and near-groundwater zones during these additional 3 mo of rebound were similar to those observed during the previous 6 mo. Nearer the Plio-Pleistocene layer, at depths ranging from 18.3 and 36.0 m (60 and 118 ft), maximum concentrations ranged from 0 to 630 ppm (by volume). The highest concentration was detected in well 299-W15-217 (35.1 m [115 ft] deep), the well at which the highest concentration was detected during the 1997 rebound study. These results were obtained after 9 mo of rebound and are similar to

those obtained during the 8-mo rebound study conducted in 1997 (BHI-01105).

During July through September 1998, soil-vapor monitoring was resumed at the 216-Z-1A and -18 sites. Monitoring was conducted in the near-surface, near-Plio-Pleistocene, and near-groundwater zones. The maximum concentration detected was 143 ppm (by volume) in well 299-W18-158L (37.5 m [123 ft] deep) in the 216-Z-1A Tile Field. This result was obtained after only 3 mo of rebound.

Samples were collected initially from well 299-W15-217 at the wellhead before the downhole sampling tube was installed to evaluate the effect of an installed sampling tube. In March and April, these wellhead samples contained 65 and 25 ppm (by volume) of carbon tetrachloride, respectively. Samples collected in May and June, using the downhole sampling tube, contained 630 and 504 ppm (by volume) of carbon tetrachloride, respectively. Other wells sampled without the sampling tube had anomalously low to nondetectable carbon tetrachloride concentrations.

Because carbon tetrachloride concentrations did not increase significantly at the shallow probes monitored in 1998, temporarily suspending operation of the soil-vapor-extraction system for 6 to 9 mo appears to have caused minimal, detectable, vertical transport of carbon tetrachloride through the soil surface to the atmosphere. Because carbon tetrachloride concentrations did not increase significantly near the water table during this time, temporarily suspending operation of the soil-vapor-extraction system appears to have had no negative impact on groundwater quality.

Carbon Tetrachloride Migration. A schematic representation, or conceptual model, of the subsurface behavior of carbon tetrachloride beneath the 216-Z-9 Trench is shown in Figure 6.2.14. A numerical model was developed (BHI-00459) to simulate the primary transport processes shown in Figure 6.2.14, using local stratigraphy and published parameters for the source term and soil properties. Results of initial simulations suggested that over two-thirds of the discharged carbon tetrachloride would have been retained in the soil column and that a dense, nonaqueous-phase liquid would continue to drain slowly through the vadose zone into the underlying aquifer for years into the future. Although additional modeling is needed to assess the influence of effective porosity and groundwater velocity, the modeling results support the liquid-phase transport concept illustrated on the model in Figure 6.2.14. The vapor-phase results were less definitive but suggested that vapor-phase transport is secondary to dense, nonaqueous-phase liquid transport as a groundwater contamination pathway.

Field measurements of carbon tetrachloride vapor concentrations are not completely consistent with numerical modeling results. Soil-vapor monitoring of rebound carbon tetrachloride concentrations conducted in 1997 and 1998 within the vadose zone at the 216-Z-9 Trench did not exceed 60 ppm (by volume). Vapor-extraction concentrations >12,000 ppm (by volume) of carbon tetrachloride are needed to indicate that the soil near the extraction well is saturated with nonaqueous-phase liquid. The low, measured, vapor concentrations indicate less nonaqueous-phase liquid remaining in the vadose zone below the Plio-Pleistocene unit than predicted; however, these measurements were not taken directly under the 216-Z-9 Trench or at depth-discrete, narrow zones above the water table. Although carbon tetrachloride volatilizing from a residual, nonaqueous-phase, liquid source may have been diluted by the time the vapor reached the sampling locations, the data suggest that soil-vapor extraction may have removed much of the remaining source in the area of the 216-Z-9 Trench and that the continuing groundwater source may now be within the aquifer (BHI-01105).

Vertical and areal distribution of dissolved carbon tetrachloride in groundwater is consistent with a dense, nonaqueous-phase, liquid transport mechanism for transport of carbon tetrachloride to groundwater. Maps and profiles of carbon tetrachloride

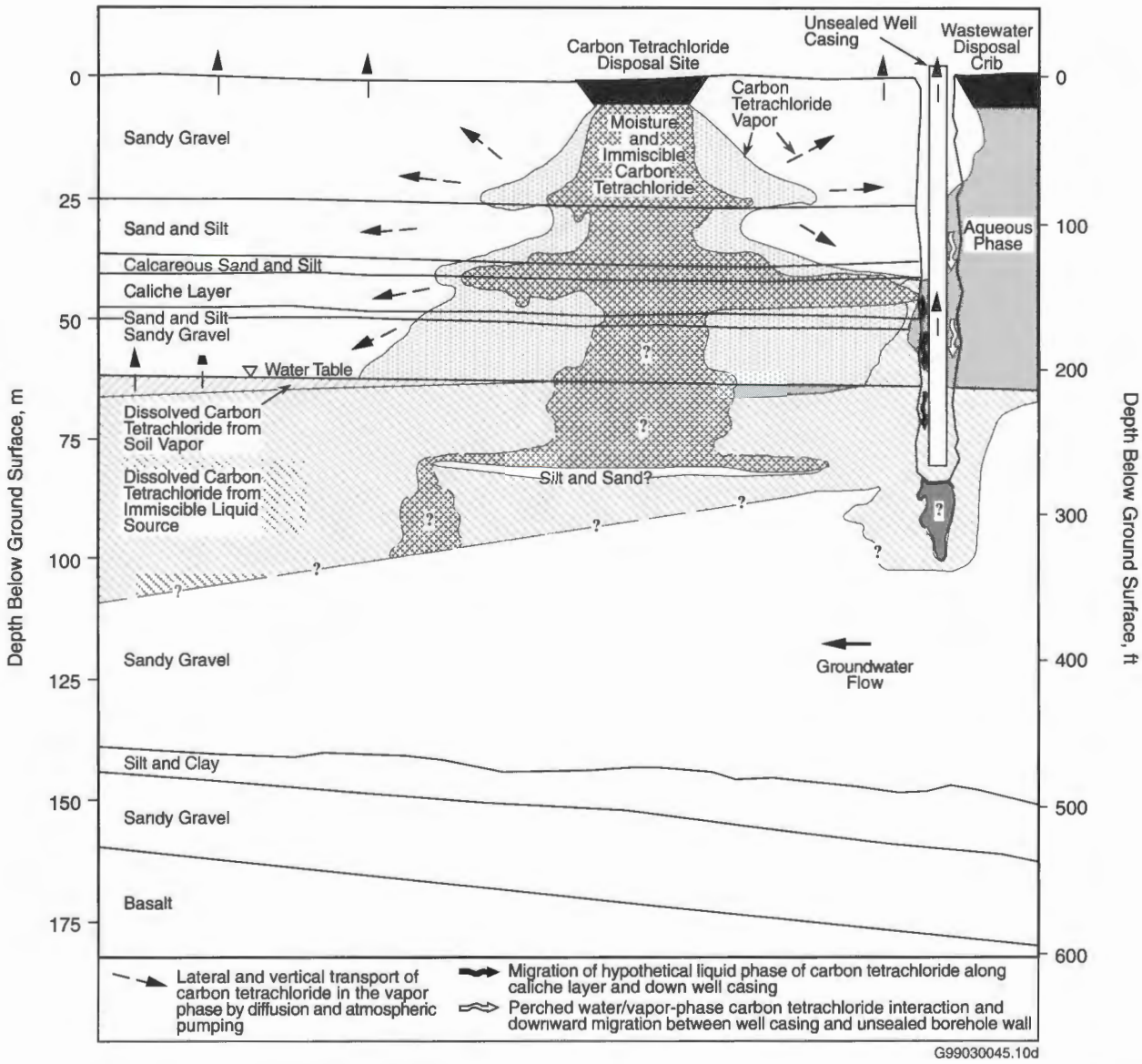

Figure 6.2.14. *Conceptual Model of Carbon Tetrachloride and Wastewater Migration Beneath 216-Z-9 Trench, 200-West Area*

distribution in groundwater suggest there is a continuing groundwater source that produces somewhat uniform carbon tetrachloride concentrations with depth in the aquifer. A dense, nonaqueous-phase liquid that drained from the vadose zone into the aquifer and is slowly dissolving could produce such a pattern. An 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-vapor carbon tetrachloride could absorb this slightly soluble, chlorinated hydrocarbon and carry it into the aquifer under saturated flow conditions.

The continuing presence of relatively high, dissolved, carbon tetrachloride concentrations in groundwater in the immediate vicinity of the 216-Z-9 Trench, 35 yr after termination of disposal operations, suggests that a dense, nonaqueous-phase liquid is

slowly dissolving within the aquifer. Although this liquid phase may be slowly draining from the vadose zone to groundwater, the soil-vapor concentrations monitored deep within the vadose zone during 1997 and 1998 suggest that soil-vapor-extraction remediation may have removed much of the vadose-zone source and that the continuing groundwater source resides within the aquifer. Carbon tetrachloride concentrations in the soil vapor and underlying groundwater do not appear to be in equilibrium, and the expected direction of carbon tetrachloride migration is from the groundwater to the vadose zone (BHI-01105).

Carbon tetrachloride rebound concentrations indicate that in many areas much of the readily accessible mass has been removed during soil-vapor-extraction operations and that the supply of additional carbon tetrachloride is limited by desorption and/or diffusion from contaminant sources (e.g., lower-permeability zones such as the lower Hanford formation silt and/or Plio-Pleistocene unit). Under these conditions, the removal rate of the additional carbon tetrachloride using soil-vapor extraction is controlled by the desorption and diffusion rates of the contaminant.

6.2.3 Historical Gross Gamma-Ray Log-Time Series

R. R. Randall, D. A. Myers, D. G. Horton

The single-shell tank farm borehole logging surveillance program was established as one of several methods used to identify leaking tanks and operated until 1994. In 1975, borehole logging within this program was upgraded to a digital system. Under the upgraded program, gross gamma-ray logs were captured in digital form and reviewed to identify large leaks of radioactive liquid from the underground tanks. In 1998, Waste Management Federal Services, Inc., Northwest Operations and Three Rivers Scientific reanalyzed the January 1975 through 1993/1994 gross gamma-ray logs to look for mobile changes in subsurface contamination not found under the original program. During 1998, the tank data for the BX, BY, SX, and TY Tank Farms were reanalyzed. The results of these analyses were available in 1998, but only those for the SX Tank Farm were published (WMNW/TRS-ES-VZMA-002). The remaining results are scheduled to be published in 1999.

This section summarizes the methods of analysis and the general observations for the borehole data analyzed during 1998. A more-complete description of this work is found in PNNL-12086 (Section 4.3) and in WMNW/TRS-ES-VZMA-002.

The strategy for analysis of the surveillance log data was to preserve as much of the raw data as possible by limiting the amount of processing. All historical log surveys for one borehole were analyzed as a group for each radioactive zone in a well, allowing statements to be made about the stability of any given contaminated interval.

Integral to the analysis of the gross gamma-ray data was the use of information provided by the spectral gamma logging system (DOE/ID/12584-268, GJPO-HAN-4). The spectral gamma logging system employs a high-resolution germanium detector to obtain data that lead to the identity and depth of radionuclides. Knowledge of the isotopes present in the subsurface was invaluable in the interpretation of the tank farm surveillance logs. By integrating the spectral gamma logging data with historical surveillance data, the behavior of radionuclides in the vadose zone over time was examined. The analysis performed on the gross gamma-ray data makes evident the usefulness of the historical data for the purpose of evaluating the presence of gamma-emitting radionuclides in the vadose zone beneath the tank farms.

Data were represented graphically to illustrate trends in subsurface contamination. Figure 6.2.15 shows an example analysis for borehole 41-00-08 in the SX Tank Farm, 200 West Area. The plot shows gamma-ray data by depth over the period for which data were available. The log profiles in Figure 6.2.15 represent quarterly logging events selected from more frequently collected data for most years between 1975 and 1994. Between 1980 and 1984, log data were collected approximately once per year. This example illustrates zones of anthropogenic gamma-ray activity at 20.7 and 23.8 m (68 and 78 ft). The activity at 23.8 m (78 ft) is first identifiable around 1985 and increases with survey date from that time to the end of data collection in 1993. The zone at 20.7 m (68 ft) is a clear case of lateral contaminant migration into the region surrounding the borehole.

The analysis of the 98 SX Tank Farm boreholes indicates that 45 were free of identifiable contamination, 31 exhibited zones of contamination interpreted to have been stable over the period of records analyzed, 9 exhibited zones that are interpreted to have increasing activity at the end of the period of records analyzed, and 13 exhibited zones of contamination that could not be readily interpreted. A total of 37,210 records were analyzed.

The analysis of the 74 BX Tank Farm boreholes indicates that 25 were free of identifiable contamination, 27 exhibited zones of contamination interpreted to have been stable over the period of the records analyzed, 8 exhibited zones interpreted to have been increasing at the end of the record period, 8 had contamination interpreted to be from tank

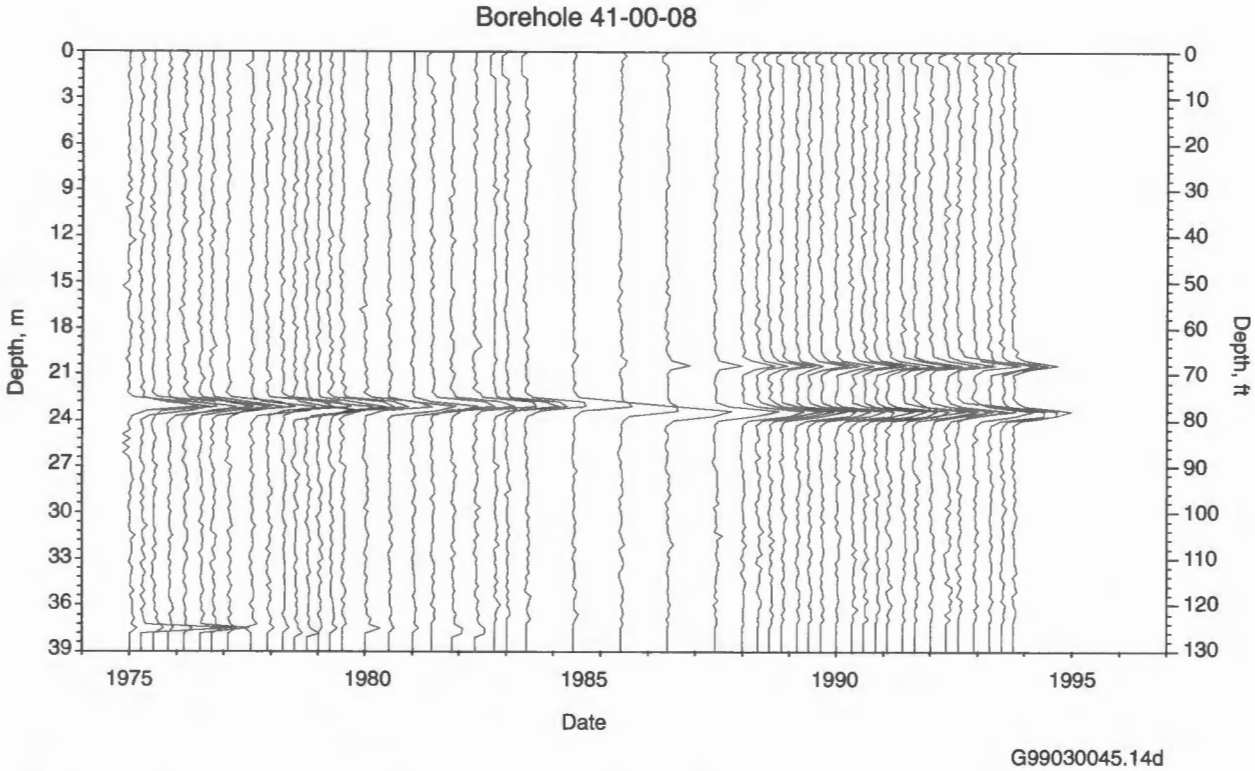

***Figure 6.2.15**. Example Analysis of Historical Gross Gamma-Ray Logs from Borehole 41-00-08 in the SX Tank Farm*

farm activities such as waste transfers, and 6 exhibited zones of contamination that could not be readily interpreted. A total of 20,021 records were analyzed.

The analysis of the 71 BY Tank Farm boreholes indicates that 5 were free of identifiable contamination, 8 were interpreted to be stable at the end of the period of record analyzed, 10 were interpreted to be unstable or increasing at the end of the record period, 43 had contamination interpreted to be from tank farm activities such as waste transfers, and 4 exhibited zones of contamination that could not be readily interpreted. There was one borehole for which there were no available data. A total of 30,882 records were analyzed.

Boreholes may exhibit one or more characteristics, so the above summations reflect the most conservative status.

The results of these analyses show that detailed examination of historical gross gamma-ray logs can reveal changes in subsurface contamination at the tank farms that was not previously identified.

6.3 References

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7.0 Other Hanford Site Environmental Programs

At the Hanford Site, a variety of environmental activities are performed to comply with laws and regulations, to enhance environmental quality, and to monitor the impact of environmental pollutants from site operations.

This section summarizes activities conducted in 1998 to monitor the climatology and meteorology, to assess the status of the ecosystem, to monitor and manage cultural resources, to actively involve the public in environmental surveillance activities, and to control noxious weeds on the Hanford Site.

7.1 Climate and Meteorology

D. J. Hoitink

Meteorological measurements are taken to support Hanford Site emergency preparedness and response, operations, and atmospheric dispersion calculations for dose assessments (Appendix D, Tables D.5 and D.7 through D.9). Support is provided through weather forecasting and maintenance and distribution of climatological data. Forecasting is provided to help manage weather-dependent operations. Climatological data are provided to help plan weather-dependent activities and are used as a resource to assess the environmental effects of site operations.

Local data to support the Hanford Meteorology Station operations are provided via the Hanford Meteorological Monitoring Network. This network consists of 30 remote monitoring stations that transmit data to the Hanford Meteorology Station via radio telemetry every 15 min. There are 27 10-m (30.5-ft) towers and 3 60-m (182.9-ft) towers. Meteorological parameters collected at these stations include wind speed, wind direction, temperature, precipitation, atmospheric pressure, and relative humidity; however, not all parameters are collected at all stations. Figure 7.1.1 shows the wind roses (diagrams showing direction and frequencies of wind) measured at a height of 10 m (30.5 ft) for the network.

The Cascade Range to the west of Yakima, Washington greatly influences the climate of the Hanford Site. These mountains create a rain shadow effect and also serve as a source of cold air drainage, which significantly affects the wind regime.

The Hanford Meteorology Station is located on the 200 Areas plateau, where the prevailing wind direction is from the northwest during all months of the year. The secondary wind direction is from the southwest. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during winter and summer. During spring and fall, the frequency of southwesterly winds increases, with a corresponding decrease in the northwesterly flow. Monthly average wind speeds are lowest during winter months, averaging 10 to 11 km/h (6 to 7 mi/h), and highest during summer, averaging 13 to 15 km/h (8 to 9 mi/h). Wind speeds that are well above average are usually associated with southwesterly winds. However, summertime drainage winds are generally northwesterly and frequently reach 50 km/h (30 mi/h). These winds are most prevalent over the northern portion of the site.

Atmospheric dispersion is a function of wind speed, wind duration and direction, atmospheric stability, and mixing depth. Dispersion conditions are generally good if winds are moderate to strong, the atmosphere is of neutral or unstable stratification, and there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist approximately 57% of the time during summer. Less-favorable conditions may occur when wind speed is light and the mixing layer is shallow. These conditions are most common during winter, when moderately to extremely stable stratification exists approximately 66% of the time. Occasionally, there are extended periods of poor dispersion conditions, primarily during winter, which are associated with stagnant air in stationary high-pressure systems.

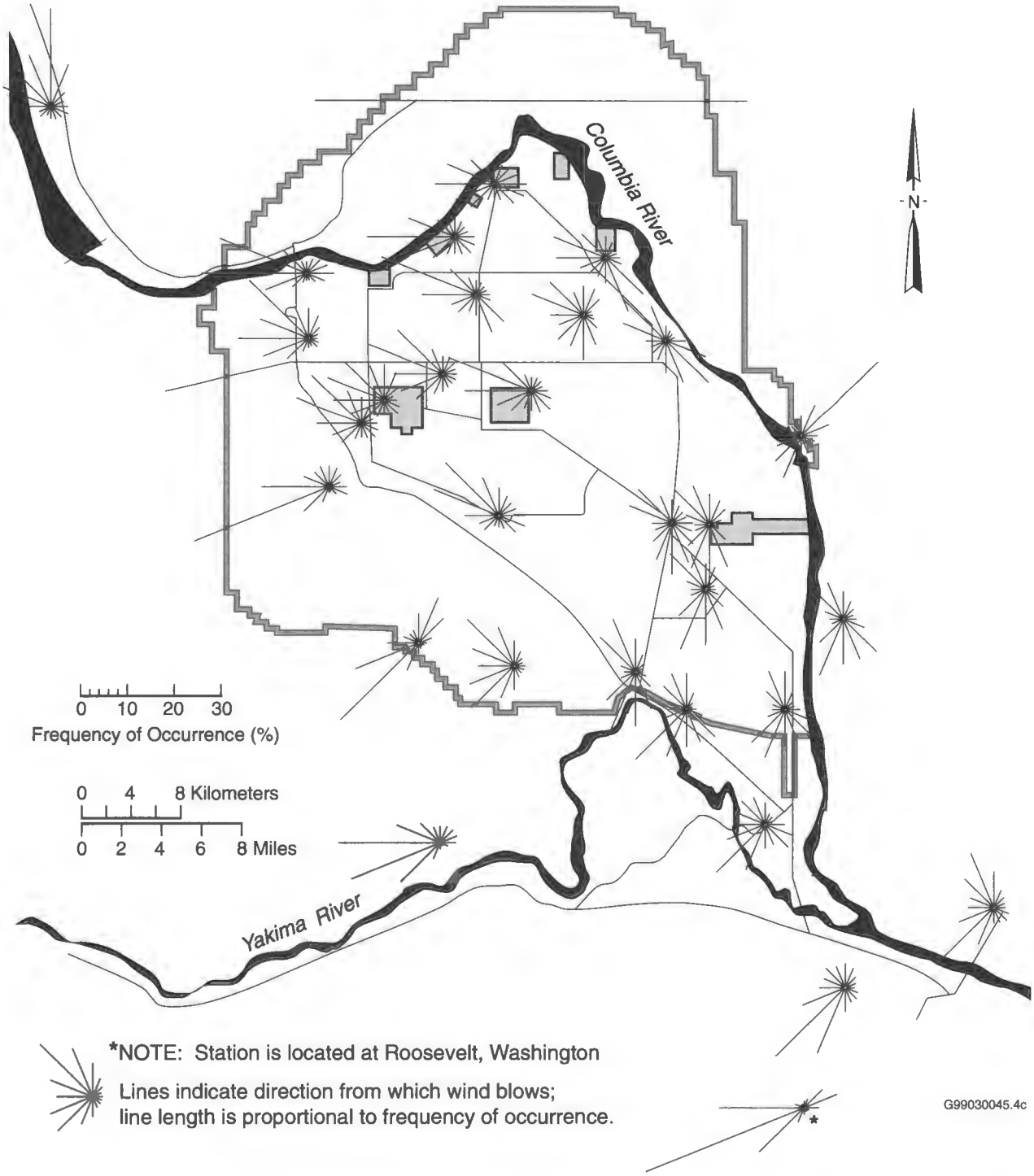

Figure 7.1.1. *Hanford Meteorological Monitoring Network Wind Roses (measured at a height of 10 m [30.5 ft]), 1998. Individual lines indicate direction from which wind blows. Length of line is proportional to frequency of occurrences from a particular direction.*

7.1.1 Historical Information

Daily and monthly averages and extremes of temperature, dew point temperature, and relative humidity for 1945 through 1998 are reported in PNNL-12087. From 1945 through 1998, the record maximum temperature was 45°C (113°F) recorded in August 1961, and the record minimum temperature was -30.6°C (-23°F) in February 1950. Normal monthly average temperatures ranged from a low of -0.4°C (31.3°F) in January to a high of 24.6°C (76.2°F) in July. During winter, the highest monthly average temperature at the Hanford Meteorology Station was 6.9°C (44.5°F) in February 1991, and the record lowest was -11.1°C (12.1°F) in January 1950. During summer, the record maximum monthly average temperature was 27.9°C (82.2°F) in July 1985, and the record minimum was 17.2°C (63.0°F) in June 1953. The average annual relative humidity at the Hanford Meteorology Station is 54%. Humidity is highest during winter, averaging approximately 76%, and lowest during summer, averaging approximately 36%. Average annual precipitation at the Hanford Meteorology Station is 15.9 cm (6.26 in.). The wettest year on record, 1995, received 31 cm (12.3 in.) of precipitation; the driest, 1976, received 8 cm (2.99 in.). Most precipitation occurs during late autumn and winter, with more than half of the annual amount occurring from November through February. The snowiest winter on record, 1992-1993, received 142.5 cm (56.1 in.) of snow.

7.1.2 Results of 1998 Monitoring

1998 was warmer than normal, with nearly normal precipitation. The average temperature for 1998 was 13.6°C (56.4°F), which was 1.7°C (3.1°F) above normal (11.8°C [53.3°F]), and tied 1992 as the warmest year on record. Eleven months during 1998 were warmer than normal, and one month was cooler than normal. July had the highest positive departure, 3.2°C (5.8°F); October, at 0.3°C (0.5°F) below normal, had the only negative departure. The maximum temperature of 44.4°C (112°F) on July 27, 1998 was the hottest temperature ever recorded during the month of July. For the year, there were 73 d with maximum temperature ≥32.2°C (90°F), the third highest day-total on record. The summer (June, July, and August) and autumn (September, October, and November) of 1998 were the fourth warmest on record.

Precipitation for 1998 totaled 16.4 cm (6.45 in.), 103% of normal (15.9 cm [6.26 in.]), with 18.3 cm (7.2 in.) of snow (compared to an annual normal snowfall of 35.1 cm [13.8 in.]). There were eight thunderstorms recorded at the Hanford Meteorological Station in July 1998, tying 1983 for the most thunderstorms in July.

The average wind speed for 1998 was 12.7 km/h (7.9 mi/h), which was 0.3 km/h (0.2 mi/h) above normal. The peak gust for the year was 90 km/h (56 mi/h) on November 21. November 1998 had a record number of days (10) with wind gusts ≥64 km/h (40 mi/h). Figure 7.1.1 shows the 1998 wind roses (diagrams showing direction and frequencies of wind) measured at a height of 10 m (30.5 ft) for the 30 meteorological monitoring stations on and around the Hanford Site.

Table 7.1.1 provides monthly climatological data from the Hanford Meteorology Station for 1998.

Table 7.1.1. Monthly Climatological Data from the Hanford Meteorology Station, 1998

Hanford Meteorology Station, 40 km (25 mi) northwest of Richland, Washington, latitude 46° 34'N, longitude 119° 35'W, elevation 223 m (733 ft)

Month	Temperatures, °C								Precipitation (cm)				Relative Humidity (%)		15-m Wind[a]				
	Averages				Extremes						Snowfall						Peak Gusts		
	Daily Maximum	Daily Maximum	Monthly	Departure[b]	Highest	Date	Lowest	Date	Total	Departure[b]	Total	Departure[b]	Average	Departure[b]	Average Speed, km/h	Departure[b]	Speed, km/h	Direction	Date
J	6.7	-2.1	2.3	+2.7	13.9	19[c]	-13.9	13	3.1	+1.1	16.0	+6.1	76.3	-0.1	12.6	+2.1	69	SW	24
F	10.9	0.4	5.7	+2.3	14.4	21	-5.6	27	2.9	+1.3	T[d]	-5.1	74.4	+4.1	11.7	+0.2	80	S	21
M	15.7	2.5	9.1	+1.6	22.2	13	-5.0	5	1.3	+0.1	T	-0.8	58.4	+2.5	11.7	-1.6	63	WSW	26
A	20.4	4.5	12.4	+0.9	33.3	30	-1.7	12	0.2	-0.9	0	T	49.4	+2.2	12.2	-2.3	60	W	24
M	24.6	9.2	16.9	+0.6	33.9	6[c]	3.9	15	1.3	0.0	0	0	53.2	+10.5	12.9	-1.8	88	WNW	21
J	29.8	13.6	21.7	+0.7	37.2	30	8.3	27	1.2	+0.3	0	0	41.0	+2.2	15.8	+1.0	80	WNW	15
J	36.3	19.3	27.8	+3.2	44.4	27	14.4	20[c]	0.9	+0.4	0	0	33.6	+0.1	13.0	-1.1	76	WSW	27
A	34.7	16.3	25.5	+1.6	43.3	4	10.0	24	0.1	-0.6	0	0	33.0	-2.8	13.0	+0.3	80	NW	15
S	30.6	12.8	21.7	+2.9	39.4	1	6.1	27	0.3	-0.5	0	0	42.6	-0.1	10.8	-1.1	56	WSW	17
O	18.7	3.9	11.3	-0.3	28.9	1	-3.9	30	0.7	-0.3	0	-0.2	56.7	+1.5	11.3	+0.8	74	SW	8
N	12.1	3.0	7.6	+3.0	19.4	25[c]	-2.8	19[c]	3.3	+1.0	0	-4.6	72.8	-0.6	14.2	+3.9	90	SSW	21
D	5.4	-4.3	0.6	+0.9	15.6	29	-18.3	21	1.1	-1.5	2.3	-12.2	72.3	-8.0	12.6	+3.1	88	WSW	26
Y[e]	20.5	6.6	13.6	+1.7	44.4	Jul 27	-18.3	Dec 21	16.4	+0.5	18.3	-16.8	55.3	+1.0	12.7	+0.3	90	SSW	Nov 21

NOTE: See Table H.2, Conversion Table in "Helpful Information" for unit conversion information.
(a) Measured on a tower 15 m (50 ft) above the ground.
(b) Departure columns indicate positive or negative departure of meteorological parameters from 30-yr (1961-1990) climatological normals.
(c) Latest of several occurrences.
(d) Trace.
(e) Yearly averages, extremes, and totals.

7.2 Ecosystem Monitoring (Plants and Wildlife)

L. L. Cadwell, D. D. Dauble, J. L. Downs, M. A. Simmons, and B. L. Tiller

The Hanford Site is a relatively large, undisturbed area of shrub-steppe that contains a rich, natural diversity of plant and animal species adapted to the region's semiarid environment. Terrestrial vegetation on the site consists of 10 major plant communities: 1) sagebrush/ bluebunch wheatgrass, 2) sagebrush/cheatgrass or sagebrush/Sandberg's bluegrass, 3) sagebrush-bitterbrush/cheatgrass, 4) grease wood/cheatgrass-saltgrass, 5) winterfat/Sandberg's bluegrass, 6) thyme buckwheat/Sandberg's bluegrass, 7) cheatgrass-tumble mustard, 8) willow or riparian, 9) spiny hopsage, and 10) sand dunes (PNNL-6415, Rev. 10). Nearly 600 species of plants have been identified on the site (WHC-EP-0054). Recent work by The Nature Conservancy of Washington has further delineated 36 distinct plant community types (Soll and Soper 1996) from within those 10 major communities.

There are two types of natural aquatic habitats on the Hanford Site. One is the Columbia River and associated wetlands and the second includes upland aquatic sites. The upland sites include small spring streams and seeps located mainly on the Fitzner/ Eberhardt Arid Lands Ecology Reserve on Rattlesnake Mountain (e.g., Rattlesnake Springs, Dry Creek, Snively Springs) and West Lake, which is a small, natural pond near the 200 Areas.

More than 1,000 species of insects (Soll and Soper 1996), 3 species of reptiles and amphibians (PNNL-6415, Rev. 10), 44 species of fish (Gray and Dauble 1977; PNNL-6415, Rev. 10), 214 species of birds (Soll and Soper 1996), and 39 species of mammals (PNNL-6415, Rev. 10) have been found on the Hanford Site. Deer and elk are the major large mammals, coyotes are plentiful, and the Great Basin pocket mouse is the most abundant mammal. Waterfowl are numerous on the Columbia River, and the bald eagle is a regular winter visitor along the river. Salmon and steelhead are the fish species of most interest to sport fishermen and are commonly consumed by local Native American tribes.

Although no Hanford Site plant species have been identified from the federal list of threatened and endangered species (Title 50, Code of Federal Regulations, Part 17, Section 12 [50 CFR 17.12]), recent biodiversity inventory work conducted by The Nature Conservancy of Washington identified 100 populations of 30 different rare plant taxa (Hall 1998). The U.S. Fish and Wildlife Service lists the peregrine falcon as endangered and the bald eagle and Aleutian Canada goose as threatened (50 CFR 17.11). The peregrine falcon and Aleutian Canada goose are rare migrants through the site, and the bald eagle is a common winter resident and has initiated nesting on the site but has never successfully produced offspring. Several plant species, mammals, birds, molluscs, reptiles, and invertebrates occurring on the site are candidates for formal listing under the Endangered Species Act of 1973. Appendix F lists special-status species that could occur on the site.

7.2.1 Chinook Salmon

Chinook salmon are an important resource in the Pacific Northwest; they are caught commercially and for recreation. Salmon are also of cultural importance to Native American tribes. Today, the

most important natural spawning area in the mainstem Columbia River for the fall chinook salmon is found in the free-flowing Hanford Reach. In the early years of the Hanford Site, there were few spawning nests (redds) in the Hanford Reach (Figure 7.2.1). Between 1943 and 1971, a number of dams were constructed on the Columbia River, their reservoirs eliminating most mainstem spawning areas, resulting in increased numbers of salmon spawning in the Hanford Reach. Fisheries management strategies aimed at maintaining spawning populations in the mainstem Columbia River also have contributed to the observed increases. The number of fall chinook salmon redds counted in the Hanford Reach increased through the decades of the 1960s, 1970s, and 1980s until reaching a high in 1989 of nearly 9,000 (see Figure 7.2.1). In the early 1990s, redd counts declined to approximately one-third of the 1989 peak, but they appear to have rebounded in recent years. In 1998, approximately 5,370 redds were observed, or approximately 70% of the 1996 and 1997 totals. It should be noted that aerial surveys do not yield absolute counts of redds because visibility varies, depending on water depth and other factors, and because the number of redds in high-density locations cannot be counted accurately. However, redd survey data generally agree well with adult escapement figures obtained by counting migrating adult fish at fish ladders on the Columbia River.

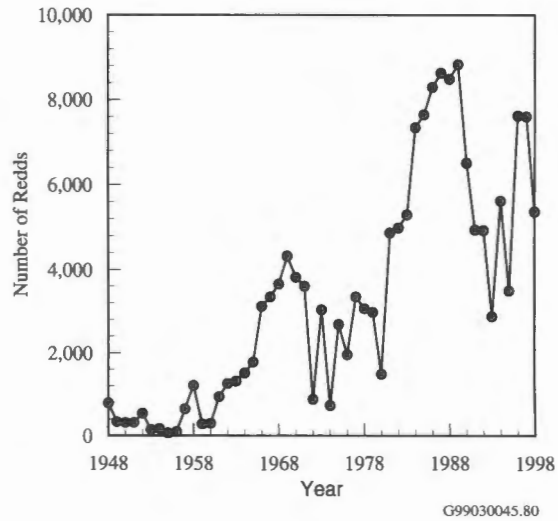

Figure 7.2.1. *Chinook Salmon Spawning Redds in the Hanford Reach, 1948 Through 1998*

7.2.2 Bald Eagle

The bald eagle is listed as a federally threatened species (50 CFR 17.11) and also a Washington State threatened species (Washington State Department of Wildlife 1994). Protection for bald eagles on the Hanford Site is guided by the management plan contained in DOE/RL-94-150 and coordinated with representatives of the U.S. Fish and Wildlife Service.

Historically, bald eagles have wintered along the Hanford Reach of the Columbia River. The wintering eagles originate from various places, including interior Alaska, British Columbia, Northwest Territories, Saskatchewan, and even possibly Manitoba. However, when monitoring began in the early 1960s, numbers were low (Figure 7.2.2). Following the passage of the Endangered Species Act, the number of wintering bald eagles has generally increased. Primary reasons for the observed increase are 1) reduced persecution in Alaska, 2) protection of bald eagles at nesting locations, and 3) nationwide elimination of dichlorodiphenyltrichloroethane (DDT) as an agricultural pesticide in 1972.

The number of nesting eagles was estimated approximately 25,000 in the lower 48 states when the bird was adopted as our national symbol in 1782. From fewer than 450 nesting pairs in the early 1960s, there are now >4,000 nesting pairs in the lower 48 states. When eagles were federally listed as endangered, recovery goals included at least 800 nesting pairs collectively in California, Idaho, Montana, Oregon, Utah, and Washington (i.e., the Pacific

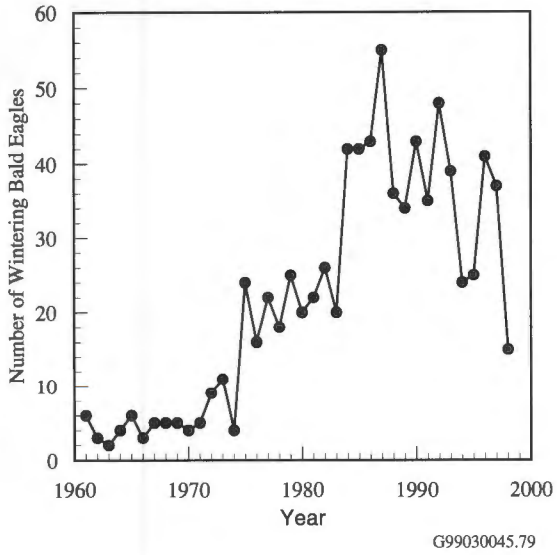

Figure 7.2.2. *Bald Eagles Observed Along the Hanford Reach, 1948 Through 1998*

states). In 1997, the wildlife experts estimated >1,200 nesting pairs in the Pacific states region. Only three pairs of nesting eagles are known to occur in eastern Washington. One of these pairs occurs on the Hanford Reach of the Columbia River.

Several nest-building attempts by bald eagles have been observed on the Hanford Site. In 1998, a pair of adult eagles built two separate nests in the vicinity of the White Bluffs (see Figure 1.0.1). All Hanford-related activities were prohibited from occurring within 800 m (2,600 ft) of either nest site. Nest tending activities and territorial displays were documented at these two sites in late December 1998 and continued through April 1999.

A single maximum count of only 15 bald eagles was documented on the Hanford Reach and typically only 5 were observed in the winter of 1998. Wintering eagle numbers similar to those observed in 1998 along the Hanford Reach were last seen in the 1970s (see Figure 7.2.2). The low counts observed on the Hanford Reach this winter are consistent with reports from the upper Columbia River at Rocky Reach and Rock Island Reservoirs, the Clearwater River in Idaho, and the lower Snake and Columbia Rivers of Oregon and Washington. A wildlife researcher working for the Washington State Department of Fish and Wildlife noted that many of the eagles fitted with satellite transmitters did not move their typical 1,200-km (745-mi) distance for the wintering period but, rather, stayed near their nesting territories in Alaska, British Columbia, and the Northwest Territories (Watson, personal communication 1999). The underlying cause(s) for reduced winter migration of eagles during the winter of 1998-1999 have not been fully examined. However, availability of food sources for eagles may have played a major role. Chum salmon (a major food of wintering eagles) were so abundant along the Fraser River (British Columbia) that wintering eagles may have elected to use the Fraser River area and tributaries rather than the mid-Columbia River. Also, an atypically high snow fall occurred in some portions of Alaska, resulting in an increase in winter-killed big game (another major food source for eagles that typically migrate south for the winter). Recent studies conducted along the Skagit River in northwestern Washington indicate increased recreational activities negatively affect the number of wintering eagles there (Stalmaster and Kaiser 1998).

Changes in the number of eagles on the Hanford Site have generally corresponded to changes in the number of returning fall chinook salmon, a major fall and winter food source for eagles (compare Figures 7.2.1 and 7.2.2 to see similarity in the patterns of salmon redd counts and bald eagle counts).

7.2.3 Hawks

The undeveloped land of the semiarid areas of the Hanford Site provides nest sites and food for three species of migratory buteo hawks: Swainson's, red-tailed, and ferruginous. Under natural conditions,

these hawks nest in trees, on cliffs, or on the ground. Power-line towers and poles also can serve as nest sites, and these structures are used extensively by nesting hawks on the site because of the relative scarcity of trees and cliffs. The ferruginous hawk is a Washington State threatened species (Washington State Department of Wildlife 1994) as well as a U.S. Fish and Wildlife Service candidate species for listing as threatened or endangered (50 CFR 17.11). Approximately one quarter of the state's ferrguinous hawk nesting territories are located on the site.

In recent years, the number of ferruginous hawks nesting on the Hanford Site has remained stable (10 active nests in 1998, range of 7 to 12 since 1995). The site continues to provide hawk nesting habitats that are administratively protected from public intrusion. An evaluation of selected aspects of ferruginous hawk ecology on the site and adjacent lands was completed in 1996 (Leary 1996). That work suggested that ferruginous hawks nest on the site because of suitable, disturbance-free habitat, but that much of the foraging for prey species occurred on adjacent, privately owned, agricultural fields. Male ferruginous hawks were observed to travel up to 15 km (9.3 mi) from their Hanford Site nests to hunt, making several trips each day to deliver prey to their mates and offspring. These results showed that small rodents such as northern pocket gophers, which can be serious agricultural pests, are the primary prey of ferruginous hawks.

7.2.4 Rocky Mountain Elk

Rocky Mountain elk did not inhabit the Hanford Site when it was established in 1943. Elk were first observed on the Fitzner/Eberhardt Arid Lands Ecology Reserve in the winter of 1972. A few animals stayed and reproduced. Since that time, the herd has grown and now occupies portions of the Hanford Site, the United States Army's Yakima Training Center, and private land along Rattlesnake Ridge. Herd size was estimated from census data at 742 animals prior to the 1998 hunting season (Figure 7.2.3). Although accurate counts of elk harvest on adjacent private lands are not available, the harvest appears to be small, with <5% of the herd being harvested and the majority of the harvest consisting of bulls. The 1998 harvest consisted of approximately 18 adult bulls and 15 cows. Thus, growth of the herd is largely unconstrained, and increasing damage to natural plant communities on the site and to crops on adjacent private land is likely. Several observations were made in 1996 and 1997 of elk having crossed to the northern side of State Highway 240. Four vehicle collisions with elk were documented near Hanford in 1998 alone. As the herd continues to grow, there are two safety-related concerns that will increase. The first is the potential for an increase in vehicle-elk collisions on local highways; the second is the possibility that elk will range into the recently enlarged radiologically controlled area (BC Cribs) immediately south of the 200-East Area.

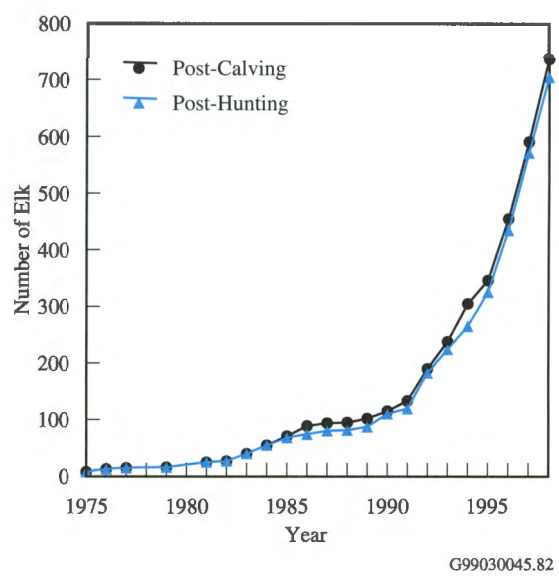

Figure 7.2.3. *Elk on the Hanford Site: Post-Calving (August through September) and Post-Hunting (December through January) Periods, 1975 Through 1998*

7.2.5 Mule Deer

Mule deer are a common resident of the Hanford Site and are important because of the recreational (offsite hunting) and aesthetic values they provide. Because mule deer have been protected from hunting on the site for approximately 50 yr, the herd has developed a number of unique population characteristics different from most other herds in the semiarid region of the northwest. These characteristics include a large proportion of old-age animals (older than 5 yr) and large-antlered males.

Because mule deer are often hunted and eaten, they can contribute to the radiation dose received by members of the public that consume game animals (PNL-7539, MacLellan et al. 1993). On the Hanford Site, deer are also of interest to environmental monitoring programs because they can provide useful information that can be used in contaminant cleanup efforts (Eberhardt and Cadwell 1983, PNL-10711, PNNL-11518).

The onsite deer population was estimated in 1996 by marking several Hanford Site deer and counting the ratio of marked to unmarked animals along the Columbia River. In addition, relative deer densities were determined throughout the remainder of the site by comparing the frequency of fecal pellet groups found within each region. Approximately 330 deer were estimated to reside in the region of the site bordering the Columbia River, and the total site mule deer population, exclusive of the lands lying north of the Columbia River, was estimated at 650.

Age and sex classes of deer that reside along the Columbia River of the Hanford Site have been monitored yearly since 1993. Roadside surveys have been conducted on an established route that is >64 km (40 mi) long. The route is driven several times during the post-fawning season (July-September) and the post-hunting season (December-February) to get a precise estimate of the ratio of bucks (antlered deer) to adult females (adult antlerless deer) and the ratio of fawns to adult female deer. The buck-to-doe ratios seen in this region have remained relatively stable since 1993 (20 to 40 bucks per 100 does) and are higher than ratios typically observed throughout the northwest (10 to 30 bucks per 100 does). Fawn-to-doe ratios demonstrated a significant downward trend through 1997 (Figure 7.2.4); however, in 1998, the fawn ratio appeared to be increasing again (20 fawns to 100 does). Although the causes of fluctuating fawn numbers are not known on the site, several factors that may play a role include neonatal losses, unhealthy newborns, and predation. Coyote predation on fawns is known to occur on the site and is likely a primary regulating factor for population growth.

7.2.6 Plant Biodiversity Inventories

Surveys and mapping efforts conducted by The Nature Conservancy of Washington and Pacific Northwest National Laboratory Ecosystem Monitoring Project document the occurrence and extent of rare plant populations and plant community types on the Hanford Site (Soll and Soper 1996, Hall 1998). These populations include taxa listed by Washington State as endangered, threatened, or sensitive and the locations of populations of taxa that are listed as review group 1 (i.e., taxa in need of additional field work before status can be determined) (Washington Natural Heritage Program 1997). The data provide information that is critical to site planning processes and land-use policy development.

Figure 7.2.5 delineates the known locations of more than 100 rare plant populations of 30 different taxa (Caplow and Beck 1996, Hall 1998). Five of these 30 taxa (including the two new species,

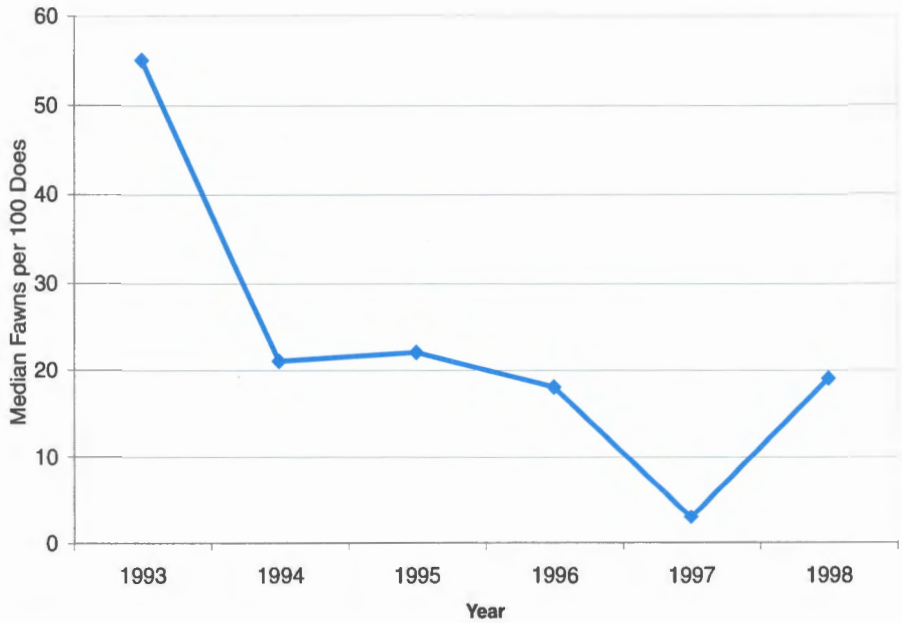

Figure 7.2.4. *Median Number of Fawns Observed per 100 Adult Does During Roadside Surveys, 1993 Through 1998*

Eriogonum codium and *Lesquerella tuplashensis*) have been designated as species of concern in the Columbia River Basin Ecoregion by the U.S. Fish and Wildlife Service. In addition to the rare plant populations, several areas on the Hanford Site are designated as special habitat types with regard to potential occurrence of plant species of concern. These include areas that could support populations of rare annual forbs found in adjacent habitat. The degree of protection from disturbance afforded to the site over the past 50 yr has resulted in an "island of biodiversity" for plant resources (Caplow and Beck 1998).

Populations of another species of concern in the Columbia River Basin Ecoregion, *Rorippa columbiae* (persistent sepal yellowcress), may be declining as a result of the high river flow levels over the past 3 yr. *Rorippa columbiae* is a rhizomatous perennial found in moist soils along the Columbia River within the Hanford Site. This species is often inundated by river flows, but little is known concerning long-term survival under continuous inundation. Surveys in 1998 identified far fewer stems at several locations on the Hanford Reach than previously documented (Table 7.2.1).

7.2.7 Sagebrush Die-Off

Big sagebrush (*Artemisia tridentata* subspecies *wyomingensis*) is the most common shrub component of shrub-steppe vegetation associations on the Hanford Site. These sagebrush stands represent an important resource for sagebrush-obligate wildlife species such as black-tailed jackrabbits, sage sparrows, sage thrashers, and loggerhead shrikes. Since 1993, site biologists have documented areas of sagebrush die-off in stands near the 100-D Area, the cause of which is not known. Shrub die-offs are not uncommon in the intermountain west and such episodes have been reported from British Columbia, Idaho, Nevada, Utah, and Wyoming (Dobrowolski and Ewing 1990). Die-off of shrubs has been attributed to severe rootlet

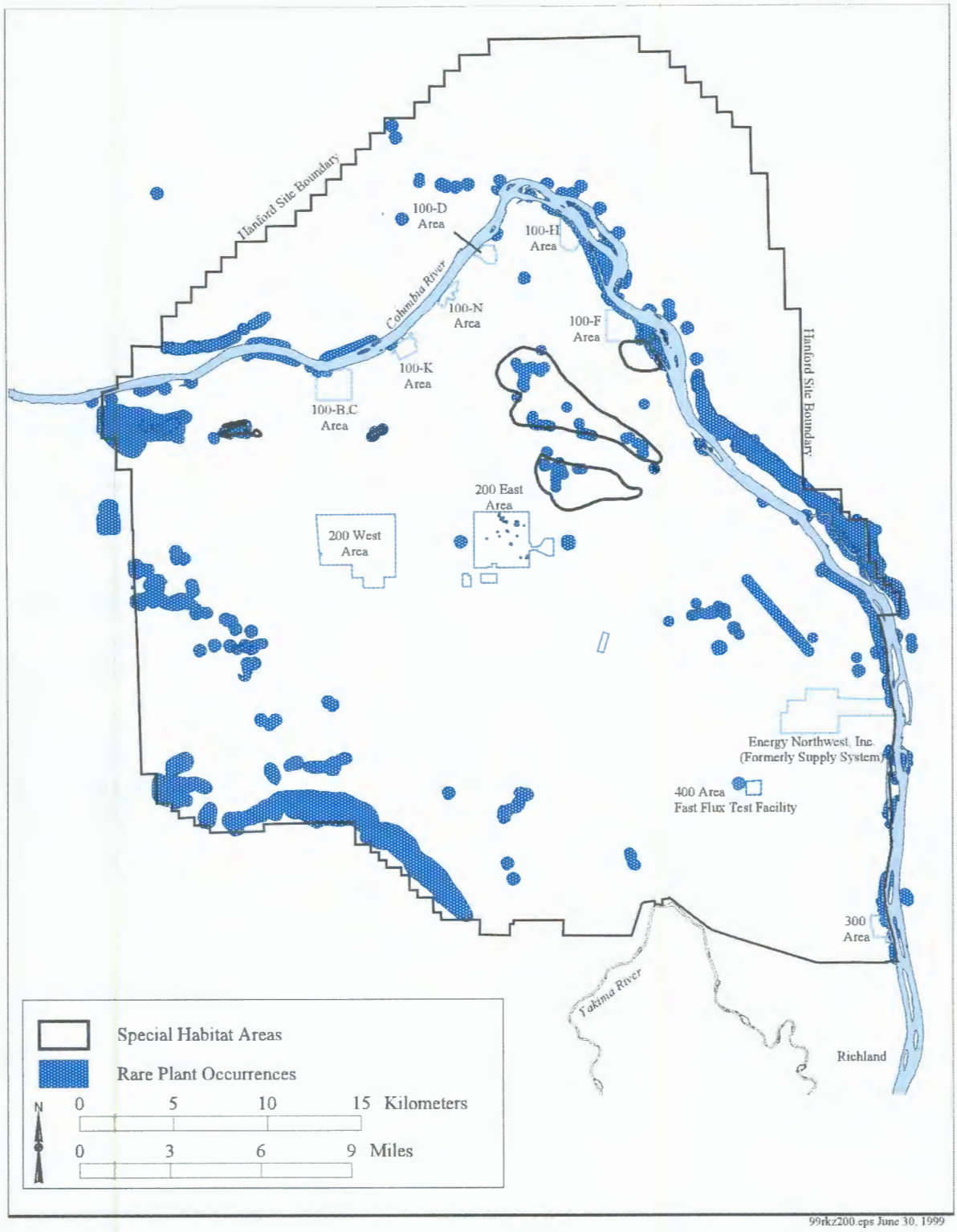

***Figure 7.2.5**. Rare Plant Locations on the Hanford Site Based on 1994, 1995, 1997, and 1998 Surveys Conducted by The Nature Conservancy of Washington*

Table 7.2.1. Numbers of *Rorippa Columbiae* Stems Counted Along the Hanford Reach of the Columbia River, 1994 and 1998

Survey Location	1994 Counts	1998 Counts
100-F beach	>15,000	70
Locke Island	>10,000	117
Island 18[a]	>10,000	0

(a) Located in the Columbia River at the 300 Area.

mortality, root rot, soil salinity and anaerobiosis, and vascular shoot wilt induced by fungal pathogens (Nelson et al. 1989, Weber et al. 1989).

The extent of the die-off on the Hanford Site was mapped and survey data were collected in 1996 and 1997 to establish a baseline for monitoring future expansion of the die-off (PNNL-11700). That report indicated that a total area of 1,776 ha (4,388 acres) showed evidence of sagebrush decline, with a central portion of 280 ha (692 acres) where shrub death was estimated to be approximately 80% or greater. Surveys in 1997 and 1998 of shrubs within the die-off areas indicate that sagebrush plants are continuing to decline. Observations of shrub vigor (percent canopy defoliation) show continuing declines in shrub health in the die-off areas and along the boundary of the die-off area.

The cause of sagebrush die-off on the Hanford Site remains undetermined. Possible causes of shrub death that have been evaluated include insect infestation, rodent damage, and high levels of soil salinity. Repeated surveys and observations have failed to document any obvious and consistent level of insect damage across the die-off areas. Field observations do not document any rodent damage or removal of sagebrush bark from plant stems at and below ground level. Limited soil analyses show no evidence of increased soil salinity or differences in nutrient levels in die-off areas versus similar soils outside the die-off areas. Although previous observations documented the presence of fungal rust species on leaf material from sagebrush in the die-off area, rust infestation does not appear to be the cause of shrub death. Consultations with the shrub pathologist at the U.S. Department of Agriculture Shrub Sciences Laboratory (part of the U.S. Forest Service Intermountain Research Station), Provo, Utah, indicate that the most likely pathogen is a soil fungus or virus. These pathogens are difficult to isolate and sample and often contribute to an overall decline in shrub health that may lead to death.

Pathological tests of sagebrush samples from the die-off area produced 29 fungal isolates from the upper root zone and base of the shrubs. Isolates included *Fusaria* sp., *Sclerocium* sp., and *Altenaria* sp.; all fungal isolates previously observed on sagebrush. Fungal pathogens are common in the soil and the air but may not have the ability to penetrate shrub defenses and impact shrub health until the shrub is weakened by another stress or stresses brought on by drought and/or cold temperatures. Continuing pathological investigation will reveal whether the fungal isolates can successfully infect sagebrush in the absence of secondary stress. These tests may help identify the agent or agents responsible for the sagebrush decline on the Hanford Site.

To understand whether and how sagebrush may recolonize the die-off areas, seedling growth and survival were examined by transplanting 133 container-grown seedlings (averaging 3.5 cm [1.4 in.] in height) into the field. One-half of the plants were transplanted in the central die-off area (80% or greater shrub mortality) and one-half in the control plot distant from the die-off area (south of the Wye Barricade). Seedlings were planted in mid-March 1998 on north-facing slopes in sandy loam soils and watered with a dilute nutrient solution. Heights and diameters were recorded after planting.

The seedlings were measured in August 1998, January and April 1999 to determine survival and growth. Approximately 50% of the transplanted shrubs in the central die-off area and in the control area distant from the die-off area died within the first 6 mo. After 1 yr, transplanted shrub survival in the central die-off area was 39%, while survival at the control plot was 51%. Growth measurements after 1 yr reveal an overall increase in shrub height of 3 cm (1.2 in.) at the control plot (average shrub height = 7.0 cm [2.9 in.]) and a 3.7-cm (1.48-in.) increase at the die-off plot (average shrub height = 7.3 cm [2.92 in.]). There was no significant difference in seedling growth between the areas, and no differences in shrub vigor were observed for shrubs in either area.

Shrubs were classified by the amount of canopy: dead, <50% live, 50%-90% live, and >90% live. These measurements indicated that, though few shrubs actually died along each measured transect (Table 7.2.2), 10% to 35% of shrubs measured declined by at least one category.

Table 7.2.2. Decline of Shrub Conditions Measured Along Six Transects Within and Along the Boundaries of the Sagebrush Die-Off Area on the Hanford Site

Transect	% Dead at First Measurement	% Dead at Last Measurement	% Canopy >90% Live at First Measurement	% Canopy >90% Live at Last Measurement	Percentage of Shrubs Declining
1 (n=27)	95.0	95.0	5.0	0.0	5.0
2 (n=34)	18.0	18.0	41.0	35.0	35.3
3 (n=31)	81.0	84.0	10.0	0.0	12.9
4 (n=50)	48.0	48.0	14.0	4.0	10.0
5 (n=61)	15.0	16.0	43.0	15.0	28.0
6 (n=51)	18.0	19.0	54.0	9.0	27.9

Number of shrubs measured in parentheses.

7.3 Cultural Resources

M. K. Wright and D. W. Harvey

The U.S. Department of Energy (DOE), Richland Operations Office, established a cultural resources program in 1987 that has been managed by the Hanford Cultural Resources Laboratory as part of Pacific Northwest National Laboratory (PNL-6942). Pacific Northwest National Laboratory, Bechtel Hanford, Inc., and CH2M Hill Hanford, Inc. provided support to DOE for the cultural resources program on the Hanford Site throughout 1998. Thus, management of archaeological, historical, and traditional cultural resources at the Hanford Site was provided in compliance with the National Historic Preservation Act of 1966, Native American Graves Protection and Repatriation Act of 1990, Archaeological Resources Protection Act of 1979, and American Indian Religious Freedom Act of 1978.

7.3.1 Native American Involvement

Members of the Confederated Tribes of the Umatilla Indian Reservation, Yakama Indian Nation, Nez Perce Tribe, and Wanapum Band were actively involved in the cultural resources program during 1998. Monthly cultural resource issues meetings provided a venue for the exchange of information between DOE, tribal staff members, and site contractors about projects and activities on the Hanford Site. These meetings included discussions of sitewide projects dealing with a wide range of topics: the groundwater/vadose zone, 1100 Area land transfer, a new boat launch at Vernita Bridge, Office of River Protections Project W-519, and Hanford's native plants. Tribal staff and site contractors worked together during the completion of several field surveys to identify and record cultural features, sites, and landscapes in advance of new construction (an excavation at the 100-KR-4 Operable Unit pump-and-treat project) and monitoring of numerous projects requiring excavation during the year. Bechtel Hanford, Inc. contracted with the Nez Perce Tribe for the identification and propagation of traditional plants and with the Confederated Tribes of the Umatilla Indian Reservation for a native plant nursery. In addition, one Wanapum Band member was hired by Pacific Northwest National Laboratory and trained to work as an archaeological technician and assist DOE with cultural resources management activities.

Several other activities involving tribes and tribal expertise were conducted during 1998. These activities included a technical exchange held for members in each of four tribes to present summarizations of their overall involvement in cultural resources efforts at Hanford, a tour of the Hanford Site's environmental restoration projects for Nez Perce Elders and Tribal Council members, a Traditional Places Visitation led by Wanapum Elders for regional tribes, and an Archaeological Resources Protection Act training workshop conducted by the Confederated Tribes of the Umatilla Indian Reservation for law enforcement personnel.

7.3.2 Public Involvement

The cultural resources staff of the Pacific Northwest National Laboratory, Bechtel Hanford, Inc., and CH2M Hill Hanford, Inc. assisted DOE in organizing and conducting public meetings for reviewing the implementation of DOE's programmatic agreement for building mitigation activities (DOE/RL-96-77) and the sitewide treatment plan (DOE/RL-97-56, Rev. 1). There were discussions of the future uses of

historic buildings at the Hanford Site; one meeting specifically focused on the reuse of historic structures in the 300 Area to preserve a selected number to maintain the integrity of the Manhattan Project/ Cold War Era Historic District. Additional meetings focused on assessing historic buildings for the purpose of identifying those suitable for public interpretation and educational/museum purposes.

Discussions were held at public issues exchange workshops on a variety of cultural resources issues, including National Landmark approach for the Hanford Site, transition of the 1100 Area from DOE to the Port of Benton, and potential of heritage tourism at the Hanford Site (i.e., a tour program that envisioned utilization of the defunct Hanford Site railroad). These discussions broadened to include strong support for the use of B Reactor as a publicly accessible museum, including the rehabilitation of the nearby historic cobblestone structure known as Bruggeman's Warehouse into an interpretive center for the site's cultural resources.

Public involvement activities are important components of a cultural resources management program. To accomplish this goal, DOE developed mechanisms that allow the public access to cultural resources information and the ability to comment and make recommendations concerning the management of cultural resources on the Hanford Site. In 1998, these mechanisms were woven into a draft involvement plan that includes input provided by the public and Hanford Site staff over the past several years.

7.3.3 Section 106 Activities

Pursuant to Section 106 of the National Historic Preservation Act, cultural resources reviews must be conducted before each proposed ground disturbance or building alteration/demolition project can take place. Cultural resources reviews are required to identify properties that may be eligible for or listed in the National Register of Historic Places within the proposed project area and evaluate the effect the proposed project may have on any such property.

During 1998, 150 cultural resources reviews were requested (Figure 7.3.1). A majority of the reviews involved project areas that had been previously surveyed or were located in previously disturbed ground. Of the projects reviewed, 6 were also monitored during the construction phase, 7 required archaeological surveys, and 18 involved building modification or demolition. The surveys covered a total of 584 ha (1,444 acres) and resulted in the discovery of 5 isolated finds and 23 archaeological sites (Figure 7.3.2).

A survey of 256 ha (632 acres) was done in preparation for the land transfer of the 1100 Area from DOE to the Port of Benton. A total of 20 archaeological sites were recorded, including sites relating to homesteading and farming (1905 to 1943) and sites related to development of the Hanford Site (post 1943). Fields, irrigation canals, and roadways related to the early twentieth century Richland, Washington farming community are apparent in 1948 aerial photographs (Figure 7.3.3), as is the encroaching development related to the Hanford Site.

7.3.4 Section 110 Activities

Section 110 of the National Historic Preservation Act requires that federal agencies undertake a program to identify, evaluate, and nominate historic properties and consider the use and reuse of historic buildings or structures. Staff of DOE, Bechtel Hanford, Inc., and Pacific Northwest National Laboratory applied for a "Save America's Treasures" Millennium Grant to fund renovation of the historic B Reactor as

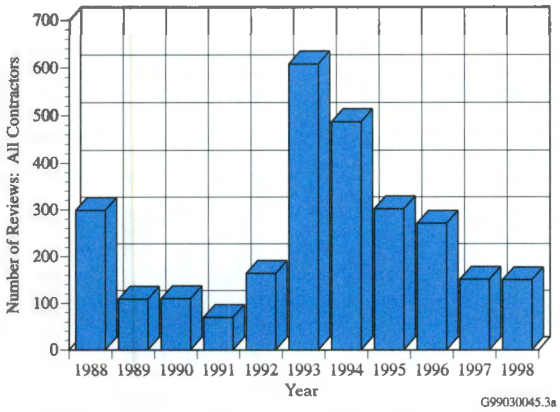

Figure 7.3.1. *Cultural Resources Reviews Requested Each Calendar Year*

Figure 7.3.2. *Historic Sites are Commonly Found During Surveys Conducted at the Hanford Site*

a publicly accessible museum and the historic Bruggeman Warehouse as an interpretive center. Agencies are required to maintain and manage historic properties in a way that considers preservation of their values and ensures that preservation-related activities are completed in consultation with other agencies, the tribes, and the general public.

In 1998, management activities conducted to fulfill Section 110 requirements included continual implementation of the programmatic agreement for the built environment (DOE/RL-96-77) and application of the Hanford Site curation strategy for the purpose of identifying, evaluating, and preserving Manhattan Project and Cold War era artifacts

Figure 7.3.3. *1948 Aerial Photograph of the Former 1100 Area Showing Irrigated Farms and Hanford Development*

(DOE/RL-97-71). Since the initiation of Section 110 activities on the Hanford Site, 495 buildings/structures have been documented on historic property inventory forms and are on file at the Hanford Cultural Resources Laboratory (Figure 7.3.4).

The Vernita Section 110 Survey, conducted in 1998, resulted in an intensive survey of 744 ha (1,838 acres) of the Hanford Site and documentation of 48 archaeological sites and 19 isolated finds associated with historic farmsteads and prehistoric lithic scatters. This survey represented a cooperative approach to investigations of previously unsurveyed lands on the site. The Yakama Indian Nation, Wanapum Band, Nez Perce Tribe, DOE, Bechtel Hanford, Inc., CH2M Hill, Inc., and Pacific Northwest National Laboratory each contributed staff time to the project.

National Register sites were also monitored in a continuing effort to assess impacts caused by erosion associated with high water levels along the Columbia River.

7.3.4.1 Historic District

During 1998, implementation of the building mitigation project continued to carry out the stipulations of the programmatic agreement (DOE/RL-96-77) and as outlined in the sitewide treatment plan (DOE/RL-97-56, Rev. 1). The plan is stipulated in the programmatic agreement and directs the production of a mitigation document that chronicles the history of the Hanford Site during the Manhattan Project and Cold War periods.

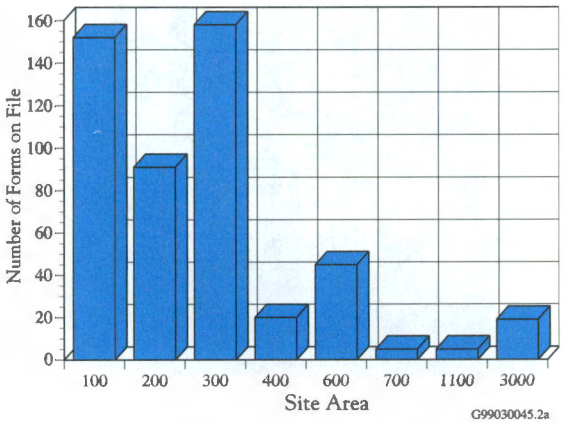

Figure 7.3.4. *Hanford Buildings and Structures Documented with a Washington State Historic Property Inventory Form*

In 1996, the Hanford Site Manhattan Project and Cold War Era Historic District was established, and 185 buildings, structures, and complexes were identified as contributing properties recommended for mitigation. Subsequent public meetings and staff evaluations resulted in additional properties in the 600, 700, and former 1100 Areas, including the Hanford Site railroad, being identified as contributing properties within the historic district and recommended for mitigation, bringing the total to 190 (Figure 7.3.5). Of the buildings, structures, and complexes recommended for mitigation, 139 have been documented according to mitigation standards identified in the sitewide treatment plan (DOE/RL-97-56, Rev. 1). Four historic properties, including B Reactor, have been documented at the Historic American Engineering Record level, 29 have been documented with Expanded Historic Property Inventory Forms, while standard Historic Property Inventory Forms have been prepared for the remaining 106 buildings and structures.

Approximately 900 buildings and structures have been identified as either contributing properties with no individual documentation requirement (not selected for mitigation) or as noncontributing/exempt buildings and structures and will be documented in a database maintained by DOE. According to the programmatic agreement (DOE/RL-96-77), certain property types such as mobile trailers, modular buildings, storage tanks, towers, wells, and structures with minimal or no visible surface manifestations are exempt from the identification and evaluation requirement.

Figure 7.3.5. *105-C Reactor, One of Several Structures Included in the Hanford Site Manhattan Project and Cold War Era Historic District*

7.3.4.2 Hanford Curation Strategy

The application of the curation strategy for artifacts and records associated with the Hanford Site Manhattan Project and Cold War Era Historic District continued in 1998. The strategy is stipulated in the programmatic agreement (DOE/RL-96-77), which directs DOE to assess the contents of Hanford's historic buildings and structures prior to the commencement of deactivation, decontamination, or decommissioning activities. The purposes of these assessments are to identify and preserve any artifacts (e.g., control panels, signs, scale models, machinery) that may have interpretive or educational value as exhibits within national, state, or local museums. The assessments are accomplished by conducting walkthroughs of the contributing properties within the historic district by teams made up of cultural resources specialists, historians, archivists/curators, and facility experts. Fifteen assessments/walkthroughs were conducted in 1998, including several facilities in the Plutonium Finishing Plant, DR and F Reactors, and five buildings in the former 1100 Area. Staff of Pacific Northwest National Laboratory and DOE participated in the assessment process that contributed to the transfer of the 1100 Area and the railroad.

In 1998, DOE and the Columbia River Exhibition of History, Science, and Technology assembled a team of historians, curators, cultural resources specialists, and Hanford retirees for the purposes of evaluating the makeup and condition of the Manhattan Project/Cold War era artifact collection and DOE's curation strategy and developing a new collection management policy.

DOE's archaeological collections and associated records continued to be housed in Pacific Northwest National Laboratory's repository during 1998. A draft management plan that deals specifically with archaeological collections was developed in 1998 to guide access to and uses of the collections and to provide guidelines for acquisition and deaccessioning processes.

7.3.4.3 Locke Island Monitoring

Locke Island, in the Hanford Reach of the Columbia River, contains some of the best-preserved evidence of prehistoric village sites extant in the Columbia Basin and is included within the Locke Island National Register Archaeological District. Since 1995, field monitoring of this large island continues. The erosion along the northeastern shoreline of Locke Island and also along the entire Hanford Reach was substantial as a result of sustained high waters during the spring floods of 1997. The monitoring includes the rates of erosion and associated impacts to archaeological features. During 1998, the highest loss recorded at any one monitoring transect was 3.1 m (10.4 ft). A summary of monitoring efforts at Locke Island was published in PNNL-11970 and documents the geologic history of the island, the erosional history of the past few years, and the cultural materials recorded during monitoring trips.

7.3.5 Education and Research

Educational activities associated with the cultural resources program in 1998 included presenting lectures to groups, ranging from public school classrooms to civic groups, colleges, and professional societies. Several symposia were organized throughout the Pacific Northwest region to present DOE's cultural resources management techniques to professional groups and societies. The annual cultural resources forum, sponsored by the DOE Federal Preservation Office, was held at a professional conference in Seattle, Washington, and was attended by staff of Pacific Northwest National Laboratory, Bechtel Hanford, Inc., and DOE. Washington's Archaeology Month provided educational opportunities in the form of tours, lectures, social gatherings, and workshops for residents of the Tri-Cities' area through the efforts of staff and professionals from the East Benton County Historical Society; Columbia River Exhibition of History, Science, and Technology; Confederated Tribes of the Umatilla Reservation; City of Richland; DOE; Pacific Northwest National Laboratory; CH2M Hill, Inc.; and Bechtel Hanford, Inc.

Pacific Northwest National Laboratory participated in the Associated Western Universities, Inc., Northwest program by hosting a student intern involved in field and laboratory work with Hanford Cultural Resources Laboratory staff.

Research activities continued as part of compliance work. Research in the field of archaeology and history focused on archaeological site preservation and protection and documentation of the built environment of the Manhattan Project and Cold War periods.

7.4 Community-Operated Environmental Surveillance Program

R. W. Hanf

Since 1991, citizens living near the Hanford Site have been actively participating in site environmental surveillance activities through the Community-Operated Environmental Surveillance Program. During 1998, nine radiological air sampling stations were operated by local teachers at selected locations around the site perimeter. These stations are located in Basin City, Richland, Pasco, Kennewick, north Franklin County, Othello, Mattawa, Toppenish, and Benton City, Washington (see Figure 4.1.1). Each station consists of equipment for collecting air samples and for monitoring ambient radiation levels. Four of the nine stations also include large, lighted, informational displays that provide real-time meteorological and radiological information as well as general information on station equipment, sample types, and analyses (Figure 7.4.1). The station managers' names and telephone numbers are provided on the four displays for anyone desiring additional information about the purpose of the station, station equipment, or analytical results.

***Figure 7.4.1**. Community Members See Environmental Surveillance in Action at a Community-Operated Environmental Surveillance Station in Richland*

Two teachers from schools located near the stations were selected to operate each station. Each pair of teachers is responsible for collecting a variety of air samples, preparing the samples and collection records for submission to the analytical laboratory, monitoring the performance of station equipment, performing minor station maintenance, and participating in scheduled training. They also serve as spokespersons for the Community-Operated Environmental Surveillance Program and are points of contact for local citizens. Pacific Northwest National Laboratory staff worked closely with the teachers to provide training, maintain station equipment and displays, and coordinate sampling and analytical efforts with other Hanford environmental surveillance activities. Analytical results for samples collected at these stations in 1998 are discussed in Section 4.1, "Air Surveillance." Results of gamma radiation measurements are discussed briefly in Section 4.7, "External Radiation Surveillance."

7.5 Noxious Weed Control Program

R. C. Roos

The noxious weed control program on the Hanford Site was developed in response to federal, state, and local laws requiring eradication or control of noxious weeds. Developed in an effort to satisfy agreements made in the federal interagency memorandum of understanding (1994), the noxious weed control program has been designated as a model for other DOE sites.

The four counties surrounding the Hanford Site (Adams, Benton, Franklin, and Grant Counties) have active noxious weed control programs to protect their important agricultural industries, native ecology, and other interests. The Hanford Site is viewed with great interest and concern as a potential source for invasion of noxious weeds into these counties.

7.5.1 Background

A noxious weed is defined as any plant that, when established, is highly destructive, competitive, or difficult to control by cultural or chemical practices. Typically, noxious weeds are non-native (alien) species that invade and displace native species, reduce habitat for fish and wildlife, and contribute to the extinction of sensitive species.

Priorities for control of noxious weeds on the Hanford Site are based primarily on 1) the potential for a weed species to spread and cause ecological damage, 2) the potential for a weed species to spread into radiological control areas and serve as a biological vector of contamination (take up stabilized radioactive elements and bring them to the surface), 3) the potential for a weed species to cause financial harm to neighboring landowners, and 4) the control effort activities of neighboring counties.

Planning and field control for the noxious weed control program at Hanford is closely coordinated with the Washington State Department of Agriculture and Adams, Benton, Franklin, and Grant Counties. Weed control plans and progress of ongoing field control activities are reviewed in quarterly meetings. Other agencies and groups attending the quarterly meetings and assisting in the technical review of the program include Washington State University Agricultural Extension Service, U.S. Fish and Wildlife Service, Washington Department of Fish and Wildlife, U.S. Bureau of Reclamation, and South Columbia Irrigation District.

7.5.2 1998 Noxious Weed Control Activities

Nine plant species are on a high-priority list for control at the Hanford Site. These species are listed below, with a summary of the 1998 control activities.

Yellow starthistle (*Centaurea solstitialis*) represents the most rapidly expanding weed infestation in the western United States. Hanford is at a critical point in the infestation cycle. Over 800 ha (2,000 acres) of the site have been heavily infested, and a large seed bank has been established in the soil. Many additional acres have scattered starthistle infestation. In the absence of control, starthistle will take over additional acres in the next few years, multiplying the size of the current infestation. Pioneer populations have begun in areas widely scattered from the

main infestation. Pioneer populations expand rapidly in size and serve as seed source for even wider distribution.

Efforts to control yellow starthistle were concentrated in three major areas in 1998: spot treatment of pioneer populations; control and maintenance on roadways; and aerial application of herbicide to a portion of the main infestation, including both the core population and the invasion zone. Approximately 320 ha (800 acres) were aerially treated. This constituted approximately one-third of the area of major infestation. An application is planned for the spring of 1999 to cover the remaining portion of the major infestation. It is expected that, with the aerial applications and a vigorous, timely control campaign in 1999, flowering and seed set for yellow starthistle will be dramatically reduced. Biological control organisms have been released in the major population of yellow starthistle over the past 3 yr. As chemical controls reduce the number and size of populations, it is hoped that biocontrols will assist in reducing seed production in scattered plants and isolated populations.

Rush skeletonweed (*Chondrilla juncea)* is widely scattered across the Hanford Site. Included are four populations of one or more acres where skeletonweed is either the dominant or codominant species. The remainder of the site has plants or small patches scattered many to hundreds of meters (feet) apart. Each of the four large populations of skeletonweed were treated with herbicide in 1998. Additionally, approximately one-fourth of the area known to harbor scattered skeletonweed was surveyed, and the plants were treated with herbicide as they were located.

Rush skeletonweed has a deep, extensive root system and minimal leaf area. These characteristics make it very difficult to control. Although initial chemical control of individual plants have appeared very effective, sprouts from deep roots that were not killed by the herbicide occasionally appear at the surface within 2 to 3 yr. Treated skeletonweed populations are monitored for several years to identify and re-treat sprouts before the plants fully recover from previous control efforts. Biological controls for rush skeletonweed have been introduced at Hanford. Effectiveness of controls vary widely from population to population and from year to year. In 1998, as in most other years, some populations were highly affected by the biocontrols and flowering was eliminated. Other populations were less affected and some were not significantly impacted by the biocontrol agents. On the site, biocontrol agents available for rush skeletonweed rarely, if ever, prove lethal to plants. Nevertheless, under good conditions, individual populations can be prevented from flowering and setting seed during a year.

A number of babysbreath (*Gypsophila paniculata)* control methods were tested, including several chemical combinations; in 1996 and 1997, none proved effective. A new treatment tried in 1998 was very successful in killing the aerial portions of the plant. After positive results in trial plots, this treatment was implemented on approximately 80% of the Hanford population before the plants matured to the point that controls were no longer effective. Flowering and seed set were prevented in virtually 100% of the plants treated. However, mortality of the perennial root was only 10% to 20%. Although the treatments killed only the aerial portions of the plant, by destroying the leaves and stems, photosynthesis was curtailed, preventing plants from storing energy reserves for winter and spring 1999 sprouting.

Plants not killed by the 1998 treatments have been weakened. With consistent, follow-up treatment, it is expected that the plants will ultimately be weakened to the point of death. The babysbreath invasion is relatively small, and control by attrition is a practical alternative.

Three small populations of dalmation toadflax (*Linaria genistifolia ssp. Dalmatica)* have been found on the Hanford Site. All sites were treated in 1998 and will be monitored and treated in the future if resprouting occurs.

Five populations of spotted knapweed (*Centaurea maculosa)* are identified on the Hanford Site. All known individuals were treated in 1998. Follow-up monitoring has identified resprouting from seeds and roots that were not completely killed by initial herbicide treatments. Populations were inconsistent in response to treatment. Treatment of some populations appeared to be 100% successful, while other populations, given the same treatment, showed considerable resprouting. Spotted knapweed is a prolific seed producer and seeds remain viable in the soil for 10 yr or more. All populations will be monitored in subsequent years to check for resprouting and follow-up control.

Diffuse knapweed (*Centaurea diffusa)* has become established in several locations on the Hanford Site and is rapidly invading and expanding in many areas. Invasion of this weed threatens much of the site. 1998 was the first year that an aggressive attempt at control of diffuse knapweed had been made; approximately 20% of the population was treated. Control efforts are expected to increase in 1999. Major populations of diffuse knapweed were sprayed with herbicide to reduce overall seed production. A special effort was made to treat roadways to prevent seed production. Vehicle traffic is a major vector for dispersal of diffuse knapweed. Isolated populations can serve as seed sources to infest large areas and were spot sprayed. By controlling these pioneer populations, relatively large areas can be kept free of knapweed. Diffuse knapweed is a prolific seed producer and seeds remain viable in the soil for 10 yr or more. All populations will be monitored in subsequent years to check for resprouting and to coordinate additional control measures.

Treatment of Russian knapweed (*Acroptilon repens)* was delayed until 1999 to focus attention on the more-invasive species.

Several individual plants of saltcedar (*Tamarix spp.)* are found on the Hanford Site, south and west of the Columbia River. Most remain from ornamental plantings around homes in the early part of this century. These plants are being controlled to prevent seed dispersal to sensitive habitats where uncontrolled populations may establish. A few populations are the result of natural seed dispersal; all plants were treated in 1998.

Saltcedar has an extensive root system that is very difficult to eliminate. Most plants on the Hanford Site have been treated for 3 yr; however, some continue to sprout new growth. Monitoring and annual treatment will continue until saltcedar is eradicated.

Actively reproducing populations of saltcedar have also established on DOE-owned land north and east of the Columbia River. These lands are leased and managed by the U.S. Fish and Wildlife Service and the Washington State Department of Fish and Wildlife. An active program is in place by these agencies, and the associated counties, to control saltcedar on these lands.

Portions of Hanford's riparian areas were monitored for purple loosestrife (*Lythrum salicaria)* in 1998. A single plant was identified and destroyed.

7.6 References

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8.0 Quality Assurance

B. M. Gillespie

Quality assurance and quality control practices encompass all aspects of Hanford Site environmental monitoring and surveillance programs. Samples are collected and analyzed according to documented standard analytical procedures. Analytical data quality is verified by a continuing program of internal laboratory quality control, participation in interlaboratory crosschecks, replicate sampling and analysis, submittal of blind standard samples and blanks, and splitting samples with other laboratories.

Quality assurance/quality control for the Hanford Site environmental monitoring program also includes procedures and protocols for 1) documenting instrument calibrations, 2) conducting program-specific activities in the field, 3) maintaining wells to ensure representative samples are collected, and 4) using dedicated well sampling pumps to avoid crosscontamination.

This section discusses specific measures taken to ensure quality in project management, sample collection, and analytical results.

8.0.1 Environmental Surveillance and Groundwater Monitoring

Comprehensive quality assurance programs, including various quality control practices, are maintained to ensure the quality of data collected through the Surface Environmental Surveillance Project and the Hanford Groundwater Monitoring Project. Quality assurance plans are maintained for all program activities and define the appropriate controls and documentation required by the U.S. Environmental Protection Agency (EPA) and/or the U.S. Department of Energy (DOE) for the project-specific requirements.

8.0.1.1 Project Management Quality Assurance

Site environmental surveillance, groundwater monitoring, and related programs such as processing of thermoluminescent dosimeters and performing dose calculations are subject to an overall quality assurance program. This program implements the requirements of DOE Order 5700.6C.

The site surveillance and groundwater monitoring projects have quality assurance plans that describe the specific quality assurance elements that apply to each project. These plans are approved by a quality assurance organization that conducts surveillances and audits to verify compliance with the plans. Work performed through contracts such as sample analysis must meet the same quality assurance requirements. Potential equipment and services suppliers are audited before service contracts or material purchases that could have a significant impact on quality within the project are approved and awarded.

8.0.1.2 Sample Collection Quality Assurance/Quality Control

Surface Environmental Surveillance Project samples are collected by staff trained to conduct sampling according to approved and documented procedures (PNL-MA-580, Rev. 2). Continuity of all sampling location identities is maintained through careful

documentation. Field duplicates are collected for specific media and a summary of the results is provided in Table 8.0.1. The percentage of acceptable field duplicate results for 1998 was very high at 91%.

Samples for the Hanford Groundwater Monitoring Project are collected by trained staff according to approved and documented procedures (ES-SSPM-001). Chain-of-custody procedures are followed (SW-846) that provide for the use of evidence tape in sealing sample bottles to maintain the integrity of the samples during shipping. Full trip blanks and field duplicates are obtained during field operations. Summaries of the 1998 groundwater field quality control sample results are provided in Appendix D of PNNL-12086. The percentages of acceptable field blank and duplicate results in fiscal year 1998 were very high, 93% for blanks and 95% for field duplicates.

8.0.1.3 Analytical Results Quality Assurance/Quality Control

Routine hazardous and nonhazardous chemical analyses for environmental and groundwater surveillance and monitoring water samples are performed primarily by the Quanterra Laboratory, St. Louis, Missouri. Some routine analyses of hazardous and nonhazardous chemicals for the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) groundwater program were also performed by Recra Environmental, Inc., Lionsville, Pennsylvania. Each laboratory participates in the EPA Water Pollution and Water Supply Performance Evaluation Studies. Each laboratory maintains an internal quality control program that meets the requirements in SW-846, which is audited and reviewed internally and by Pacific Northwest

Table 8.0.1. Summary of Surface Environmental Surveillance Project Field Duplicate Results, 1998

Medium	Radionuclides	Number of Results Reported	Number Within Control Limits[a]
Air filters	Gross alpha	28	24
	Gross beta	28	27
	^{3}H	13	8
	^{7}Be, ^{40}K, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu	36	36
Water	Gross alpha	1	0
	Gross beta	1	1
	^{3}H	2	2
	^{7}Be, ^{40}K, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu	9	9
	^{90}Sr	3	3
	^{99}Tc	1	1
	^{234}U, ^{235}U, ^{238}U	3	3
Milk	^{40}K	2	0
	^{7}Be, ^{60}Co, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{154}Eu, ^{155}Eu	16	16

(a) Control limit of ±30% for sample and duplicate results above the detection limit or minimum detectable concentration.

National Laboratory. Pacific Northwest National Laboratory submits additional quality control double-blind spiked samples for analysis.

Routine radiochemical analyses on samples for the Surface Environmental Surveillance Project and the Hanford Groundwater Monitoring Project are performed primarily by Quanterra's Richland, Washington laboratory. Data from Thermo NUtech, Richmond, California were also used in the fiscal year 1998 groundwater evaluations. Each laboratory participates in DOE's Quality Assessment Program, Environmental Measurements Laboratory, New York, and EPA's Laboratory Intercomparison Studies at the National Exposure Research Laboratory, Characterization Research Division, Las Vegas, Nevada. An additional quality control blind spiked sample program is conducted for each project. Each laboratory also maintains an internal quality control program, which is audited and reviewed internally and by Pacific Northwest National Laboratory. Additional information on these quality control efforts is provided in the following sections.

8.0.1.4 DOE and EPA Comparison Studies

Standard water samples are distributed blind to participating laboratories. These samples contain specific organic and inorganic analytes that have concentrations unknown to the analyzing laboratories. After analysis, the results are submitted to the EPA for comparison with known values and results from other participating laboratories. Summaries of the results for 1998 are provided in Table 8.0.2 for the primary laboratory, Quanterra, St. Louis, Missouri. The percentage of EPA-acceptable results is high for the laboratory, indicating acceptable performance.

The DOE Quality Assessment Program and EPA's Laboratory Intercomparison Studies provide standard samples of environmental media (e.g., water, air filters, soil, vegetation) that contain specific amounts of one or more radionuclides that were unknown by the participating laboratory. After analysis, the results are forwarded to DOE or EPA for

Table 8.0.2. Summary of Performance on EPA Water Pollution and Water Supply Studies, 1998

Laboratory	Water Supply Study March 1998 % Acceptable	Water Pollution Study May 1998 % Acceptable	Water Supply Study September 1998 % Acceptable	Water Pollution Study November 1998 % Acceptable
Quanterra Laboratory, St. Louis, Missouri	94[a]	95[b]	91[c]	83[d]

(a) Unacceptable results were for vinyl chloride, 1,1-dichloroethylene, dichloromethane, and pH.
(b) Unacceptable results were for total hardness, nitrate-nitrogen, orthophosphate, and oil and grease.
(c) Unacceptable results were for orthophosphate, bromoform, chlorodibromomethane, total trihalomethane, dichloromethane, and total cyanide.
(d) Unacceptable results were for alkalinity, nitrogen (Kjeldahl), polychlorinated biphenyl in oil 1016/1232, polychlorinated biphenyl in oil 1254, benzene, ethylbenzene, toluene, 1,2-dichlorobenzen, 1,4-dichlorobenzen, and total phenolics.

comparison with known values and results from other laboratories. Both DOE and EPA have established criteria for evaluating the accuracy of results (EPA-600/4-81-004, EML-596, EML-600). Summaries of the 1998 results are provided in Tables 8.0.3 and 8.0.4.

Table 8.0.3. Summary of Performance on DOE Quality Assessment Program Samples, 1998

Medium	Radionuclides	Number of Results Reported for Each Analyte	Number Within Acceptable Control Limits[a]
Quanterra Environmental Services, Richland, Washington			
Air filter particulate	^{54}Mn, ^{60}Co, ^{137}Cs, ^{234}U, ^{238}Pu, ^{238}U, ^{239}Pu, ^{241}Am, gross alpha, gross beta, total uranium	2	2
	^{57}Co, ^{134}Cs, ^{144}Ce, total uranium	1	1
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, ^{239}Pu, ^{241}Am, total uranium	2	2
	^{208}Tl, ^{210}Pb, ^{212}Bi, ^{212}Pb, ^{214}Bi, ^{214}Pb, ^{226}Ra, ^{228}Ac, ^{228}Th, ^{234}Th, ^{238}Pu, total uranium	1	1
Vegetation	^{241}Am, ^{244}Cm	2	2
	^{90}Sr	1	1
Water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}Pu, ^{238}U, ^{239}Pu, ^{241}Am, gross alpha, gross beta, total uranium	2	2
	Total uranium	1	1
Thermo NUtech, Richmond, California			
Water	^{55}Fe, ^{234}U, ^{238}U, ^{241}Am, gross alpha, gross beta, total uranium	2	2
	^{54}Mn, ^{60}Co, ^{137}Cs, ^{238}Pu, ^{239}Pu	2	1
	^{3}H, ^{63}Ni	1	1

(a) Control limits are from EML-596 and EML-600.

Table 8.0.4. Summary of Performance on EPA Laboratory Intercomparison Studies Samples, 1998

Medium	Radionuclides	Number of Results Reported for Each Analyte	Number Within Control Limits for Each Analyte[a]
Quanterra Environmental Services, Richland, Washington			
Water	^{3}H, ^{65}Zn, ^{131}I, ^{133}Ba	2	2
	^{89}Sr, ^{90}Sr	3	3
	^{137}Cs	4	4
	^{134}Cs	4	3
	Gross alpha, gross beta, ^{226}Ra, ^{228}Ra, total uranium	5	5
Thermo NUtech, Richmond, California			
Water	^{3}H	1	1
	^{65}Zn, ^{131}I, ^{133}Ba	2	2
	^{60}Co, ^{89}Sr, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{226}Ra, ^{228}Ra, total uranium	4	4
	Gross alpha, gross beta	5	5

(a) Control limits are from EPA-600/4-81-004.

8.0.1.5 Pacific Northwest National Laboratory Evaluations

In addition to DOE and EPA interlaboratory quality control programs, Pacific Northwest National Laboratory maintains a quality control program to evaluate analytical contractor precision and accuracy and to conduct special intercomparisons. This program includes the use of blind spiked samples. Blind spiked quality control samples and blanks were prepared and submitted to check the accuracy and precision of analyses at Quanterra. In 1998, blind spiked samples were submitted for groundwater (Table 8.0.5) and for air filters, vegetation, soil, and surface water (Table 8.0.6). For all water samples, 72% of nonradiochemistry blind spiked determinations were within control limits (see discussion of results in Appendix D of PNNL-12086). For all media, 92% of Quanterra's radiochemistry blind spiked determinations were within control limits, which indicates acceptable results.

Pacific Northwest National Laboratory also participates in a Quality Assurance Task Force, a program conducted by the Washington State Department of Health. Public and private organizations from Idaho, Oregon, and Washington participate in analyzing the intercomparison samples. Samples from a Hanford Site well were collected for the 1998 intercomparison sample exchange. Ten of the Quality Assurance Task Force participants analyzed the sample.

The intercomparison sample was chosen to be representative of the type of sample that may be

Table 8.0.5. Summary of Hanford Groundwater Monitoring Project Double-Blind Spike Determinations, 1998[a]

Constituent	Number of Results Reported[b]	Number Within Control Limits[c]	Control Limits, %
General Chemical Parameters			
Total organic carbon spiked with potassium phthalate	15	8	±25
Total organic halides spiked with 2,4,6-trichlorophenol	14	11	±25
Total organic halides spiked with carbon tetrachloride, chloroform, and trichloroethene	14	7	Determined each quarter
Ammonia and Anions			
Cyanide	12	3	±25
Fluoride	12	9	±25
Nitrate	12	12	±25
Volatile Organic Compounds			
Carbon tetrachloride	12	10	Determined each quarter
Chloroform	12	8	Determined each quarter
Trichloroethene	12	11	Determined each quarter
Metals			
Chromium	12	12	±20
Radiological Parameters			
Gross alpha (spiked with ^{239}Pu)	12	10	±25
Gross beta (spiked with ^{90}Sr)	13	9	±25
Cobalt-60	12	12	±30
Strontium-90	12	12	±30
Technetium-99	12	12	±30
Iodine-129	12	12	±30
Cesium-137	12	12	±30
Plutonium-239,240	12	10	±30
Tritium	12	12	±30
Uranium	12	12	±30

(a) The Hanford Groundwater Monitoring Project reporting requirements are by fiscal year (October 1 through September 30).
(b) Blind standards were submitted in triplicate or quadruplicate each quarter and compared to actual spike values.
(c) Quality control limits are given in the Hanford Groundwater Monitoring Project's quality assurance plan.

Table 8.0.6. Summary of Surface Environmental Surveillance Project Blind Spiked Determinations, 1998

Medium	Radionuclides	Number of Results Reported	Number Within Control Limits[a]
Air filters	^{54}Mn, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{241}Am	16	11
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{238}U, ^{238}Pu, ^{239}Pu	13	11[b]
Surface water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{234}U, ^{238}Pu, ^{238}U, ^{239}Pu	18	18
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{238}Pu, ^{239}Pu	9	9

(a) Control limit of ±30%.
(b) Uranium isotopic results were determined using a different preparation method than was used to determine the standard value.

encountered in this region. The sample was analyzed for gross alpha, gross beta, technetium-99, tritium, iodine-129, uranium alpha-emitting isotopes, and total uranium. Table 8.0.7 provides the Pacific Northwest National Laboratory results with respect to the grand mean of the study. The results fell within the ±2 standard error of the mean of the concentration of the other participating laboratories and were acceptable, except for the gross beta results. The sample for gross beta was reanalyzed by the laboratory, but the difference in the results between the grand mean and the laboratory remains unresolved.

8.0.1.6 Laboratory Internal Quality Assurance Programs

The analyzing laboratories are required to maintain an internal quality assurance and control program. Periodically, the laboratories are audited internally for compliance to the quality assurance and control programs. At Quanterra St. Louis, the quality control programs meet the quality assurance and control criteria in SW-846. The laboratories are also required to maintain a system for reviewing and analyzing the results of the quality control samples to detect problems that may arise from contamination, inadequate calibrations, calculation errors, or improper procedure performance. Method detection levels are determined at least annually for each analytical method.

The internal quality control program at Quanterra Richland involves routine calibrations of counting instruments, yield determinations of radiochemical procedures, frequent radiation check sources and background counts, replicate and spiked sample analyses, 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 are used for radiochemical calibrations. Calculation of minimum detectable activities involves the use of factors such as the average counting efficiencies and background for detection instruments, length of time for background and sample counts, sample volumes, radiochemical yields, and a predesignated uncertainty multiplier (EPA 520/1-80-012).

Periodically, inspections of services are performed, which document conformance with contractual requirements of the analytical facility and provide the framework for identifying and resolving

Table 8.0.7. Comparison[a] of the Quality Assurance Task Force Intercomparison Well Water Sample, 1998

Radionuclide	Number of Sample Results	Intercomparison Sample Concentration, pCi/L
Gross Alpha		
Grand mean	21	129 ± 41
PNNL (Quanterra)	2	122 ± 17
Gross Beta		
Grand mean	21	993 ± 311
PNNL (Quanterra)	2	390 ± 3
Tritium		
Grand mean	22	587 ± 86
PNNL (Quanterra)	1	433 ± 223[b]
Technetium-99		
Grand mean	18	1,831 ± 252
PNNL (Quanterra)	2	1,470 ± 113
Iodine-129		
Grand mean	7	1.8 ± 2.1
PNNL (Quanterra)	1	-0.06 ± 0.3[b]
Total Uranium		
Grand mean	13	183 ± 36
PNNL (Quanterra)	1	158 ± 51[b]
Uranium-234		
Grand mean	12	85 ± 10
PNNL (Quanterra)	1	78 ± 12[b]
Uranium-235		
Grand mean	14	5 ± 1
PNNL (Quanterra)	1	3 ± 1[b]
Uranium-238		
Grand mean	14	84 ± 11
PNNL (Quanterra)	1	79 ± 12[b]

(a) Pacific Northwest National Laboratory (PNNL) analyses by Quanterra, Richland, Washington, are compared against grand mean (±2 standard error of the mean) of all participating laboratories.
(b) ±2 sigma total analytical uncertainty.

potential performance problems. Responses to assessment and inspection findings are documented by written communication, and corrective actions are verified by follow-up audits and inspections. Assessments of Quanterra St. Louis and Quanterra Richland were conducted in 1998 by the Hanford Site's Integrated Contractor Assessment Team, consisting of representatives from Bechtel Hanford, Inc., Pacific Northwest National Laboratory, and Waste Management Federal Services of Hanford, Inc. The purpose of the assessment of services was to evaluate the continued capability of the laboratories to analyze and process samples for the Hanford Site as specified in the statement of work between the DOE contractors and the laboratories.

Internal laboratory quality control program data are summarized by the laboratories in monthly or quarterly reports. The results of the quality control sample summary reports and the observations noted by each laboratory indicated an acceptably functioning internal quality control program.

8.0.1.7 Media Audits and Comparisons

Additional audits and comparisons are conducted on several specific types of samples. The Washington State Department of Health routinely cosampled various environmental media and measured external radiation levels at multiple locations during 1998. Media that were cosampled and analyzed for radionuclides included groundwater from 32 wells, water from 11 Columbia River locations along and across the river, water from 5 riverbank springs, water from 2 onsite drinking water locations, sediment from 9 Columbia River sites, surface soil samples from 4 locations, samples from 3 air monitoring stations, thermoluminescent dosimeters from 14 sites, pheasant, deer, and carp. Also cosampled and analyzed for radionuclides were upwind and downwind samples of leafy vegetables, fruit, perennial vegetation, potatoes, and wine. Results will be published in the Washington State Department of Health 1998 annual report.

The U.S. Food and Drug Administration also cosampled and analyzed sugar beets, cabbage, and potatoes for radionuclides from upwind and downwind sampling locations. The data are presented in Table 8.0.8.

Quality control for environmental thermoluminescent dosimeters includes the audit exposure of three environmental thermoluminescent dosimeters per quarter to known values of radiation (between 17 and 28 mR). A summary of 1998 results is shown in Table 8.0.9. On average, the thermoluminescent dosimeter measurements were biased 1.6% higher than the known values.

8.0.2 Effluent Monitoring and Near-Facility Environmental Monitoring

The Effluent Monitoring and Near-Facility Environmental Monitoring Programs are subject to the quality assurance requirements specified in the Hanford Analytical Services Quality Assurance Requirements Document (DOE/RL-96-68). These quality assurance programs comply with DOE Order 5700.6C, using standards from the American Society of Mechanical Engineers (ASME NQA-1-1997 Edition) as their basis. The programs also adhere to the guidelines and objectives in EPA/005/80 and EPA QA/R-5.

The monitoring programs each have a quality assurance project plan describing applicable quality assurance elements. These plans are approved by contractor quality assurance groups, who conduct surveillances and audits to verify compliance with

Table 8.0.8. Comparison of U.S. Food and Drug Administration Cosampling, 1998

Medium	Area[a]	Organization	Potassium-40, pCi/g[b]	Strontium-90, pCi/g[b,c]	Cesium-137, pCi/g[b,c]	Ruthenium-106, pCi/g[c]
Leafy vegetables	Riverview	FDA[d]	3.6 ± 1.1	0.0038 ± 0.0012	<0.01	<0.01
		PNNL[e]	œ4.4 ± 0.49	0.021 ± 0.0042	0.0055 ± 0.0043	<0.038
	Sunnyside	FDA	2.7 ± 0.8	0.0043 ± 0.0011	<0.01	<0.01
		PNNL	1.2 ± 0.31	<0.0045	<0.0081	<0.071
Potatoes	Sunnyside	FDA	6.0 ± 0.8	<0.002	<0.01	<0.01
		PNNL	3.8 ± 0.51	<0.0034	0.011 ± 0.0086	<0.079

(a) Locations are identified in Figure 4.4.1.
(b) ±2 sigma total propagated analytical uncertainty.
(c) < values are ±2 sigma total propagated analytical uncertainties.
(d) FDA = U.S. Food and Drug Administration.
(e) PNNL = Pacific Northwest National Laboratory.

Table 8.0.9. Comparison of Thermoluminescent Dosimeter Results with Known Exposure, 1998

	Quarter/ Exposure	Known Exposure, mR[a]	Determined Exposure, mR[b]	Determined/ Known Exposure, %
1st	February 17, 1998	19 ± 0.70	19.88 ± 1.12	105
	February 17, 1998	24 ± 0.89	23.69 ± 0.25	99
	February 17, 1998	26 ± 0.96	26.66 ± 0.02	103
2nd	May 15, 1998	17 ± 0.63	16.60 ± 0.39	98
	May 15, 1998	20 ± 0.74	19.70 ± 0.15	99
	May 15, 1998	27 ± 1.00	26.89 ± 0.29	100
3rd	August 17, 1998	21 ± 0.78	20.69 ± 0.24	99
	August 17, 1998	25 ± 0.93	25.39 ± 0.80	102
	August 17, 1998	28 ± 1.04	28.99 ± 1.50	104
4th	November 13, 1998	17 ± 0.63	17.51 ± 0.71	103
	November 13, 1998	22 ± 0.81	22.63 ± 0.68	103
	November 13, 1998	26 ± 0.96	27.05 ± 0.73	104

(a) ±2 sigma total propagated analytical uncertainty.
(b) ±2 times the standard deviation.

the plans. Work such as sample analysis performed through contracts must meet the requirements of these plans. Suppliers are audited before the contract selection is made for equipment and services that may significantly impact the quality of a project.

8.0.2.1 Sample Collection Quality Assurance

Samples for the Effluent Monitoring and Near-Facility Environmental Monitoring Programs are collected by staff trained for the task in accordance with approved procedures. Established sampling locations are accurately identified and documented to ensure continuity of data for those sites and are described in DOE/RL-91-50, Rev. 2.

8.0.2.2 Analytical Results Quality Assurance

Samples for the Effluent Monitoring and Near-Facility Environmental Monitoring Programs are analyzed by two different analytical laboratories. The use of these laboratories depends on the Hanford contractor collecting the samples and contract(s) established between the contractor and the analytical laboratory(s). Table 8.0.10 provides a summary of the Hanford Site's analytical laboratories used for effluent monitoring and near-facility monitoring samples.

The quality of the analytical data is ensured by several means. Counting room instruments, for

Table 8.0.10. Hanford Site Laboratories Used by Contractor and Sample Type, 1998

	Effluent Monitoring Samples					Near-Facility Environmental Monitoring Samples		
	Fluor Daniel Hanford, Inc.		Pacific Northwest National Laboratory	Bechtel Hanford, Inc.		Fluor Daniel Hanford, Inc.		
Analytical Laboratory	Air	Water	Air	Air	Water	Air	Water	Other
Waste Sampling and Characterization Facility[a]	X	X		X	X	X	X	X
222-S Analytical Laboratory[a]								X
Quanterra Environmental Services, Richland	X	X	X	X	X			
Analytical Chemistry Laboratory[b]	X	X	X					

(a) Operated by Waste Management Federal Services of Hanford, Inc.
(b) Operated by Pacific Northwest National Laboratory.

instance, are kept within calibration limits through daily checks, the results of which are stored in computer databases. Radiochemical standards used in analyses are regularly measured and the results are reported and tracked. Formal, written, laboratory procedures are used in analyzing samples. Analytical procedural control is ensured through administrative procedures. Chemical technologists at the laboratory qualify to perform analyses through formal classroom and on-the-job training.

The participation of the Hanford Site analytical laboratories in DOE and EPA laboratory intercomparison programs also serves to ensure the quality of the data produced. Laboratory intercomparison program results for 1998 can be found in Tables 8.0.11 through 8.0.14 for the Waste Sampling and Characterization Facility and the 222-S Analytical Laboratory. Laboratory intercomparison results for Quanterra were previously provided in Tables 8.0.3 and 8.0.4.

Table 8.0.11. Waste Sampling and Characterization Facility[a] Performance on DOE Quality Assessment Program Samples, 1998

Medium	Radionuclide	Number of Results Reported	Number Within Control Limits
Air filters	^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	27	26
Soil	^{40}K, ^{90}Sr, ^{137}Cs, ^{234}U, ^{239}Pu, ^{241}Am	12	11
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{241}Am, ^{244}Cm	14	14
Water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	24	23

(a) Onsite laboratory operated by Waste Management Federal Services of Hanford, Inc.

Table 8.0.12. 222-S Analytical Laboratory[a] Performance on DOE Quality Assessment Program Samples, 1998

Medium	Radionuclide	Number of Results Reported	Number Within Control Limits
Air filters	^{54}Mn, ^{57}Co, ^{60}Co, ^{90}Sr, ^{125}Sb, ^{134}Cs, ^{137}Cs, ^{144}Ce, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	23	21
Soil	^{40}K, ^{90}Sr, ^{137}Cs	6	4
Vegetation	^{40}K, ^{60}Co, ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{241}Am, ^{244}Cm	14	12
Water	^{3}H, ^{54}Mn, ^{60}Co, ^{90}Sr, ^{134}Cs, ^{137}Cs, ^{238}Pu, ^{239}Pu, ^{241}Am, total uranium	18	15

(a) Onsite "high-level" radiological laboratory operated by Waste Management Federal Services of Hanford, Inc. (Note: these samples are "low-level" environmental activity samples.)

Table 8.0.13. Waste Sampling and Characterization Facility[a] Performance on EPA Laboratory Intercomparison Studies Samples, 1998

Category	Radionuclide	Number of Results Reported	Number Within Control Limits
Gross alpha-beta in water	Gross alpha	4	4
Gamma in water	^{60}Co, ^{65}Zn, ^{133}Ba, ^{134}Cs, ^{137}Cs	10	9
Uranium-radium in water	Uranium (natural)	9	8
Tritium in water	^{3}H	2	1
Blind A[b]	Gross alpha, uranium (natural)	8	7
Blind B[c]	Gross beta, ^{60}Co, ^{134}Cs, ^{137}Cs	8	7

(a) Onsite laboratory operated by Waste Management Federal Services of Hanford, Inc.
(b) Blind A samples are liquid samples with unknown quantities of alpha emitters analyzed for gross alpha and each radionuclide component.
(c) Blind B samples are liquid samples with unknown quantities of beta emitters analyzed for gross beta and each radionuclide component.

Table 8.0.14. 222-S Analytical Laboratory[a] Performance on EPA Laboratory Intercomparison Studies Samples, 1998

Category	Radionuclide	Number of Results Reported	Number Within Control Limits
Gamma in water	^{60}Co, ^{65}Zn, ^{133}Ba, ^{134}Cs, ^{137}Cs	10	8
Gross alpha-beta in water	Gross alpha	1	1
Uranium-radium in water	Uranium (natural)	3	3
Tritium in water	^{3}H	2	2
Blind A[b]	Gross alpha, uranium (natural)	3	3
Blind B[c]	^{60}Co, ^{134}Cs, ^{137}Cs	3	3

(a) Onsite "high-level" radiological laboratory operated by Waste Management Federal Services of Hanford, Inc. (Note: these samples are "low-level" environmental activity samples.)
(b) Blind A samples are liquid samples with unknown quantities of alpha emitters analyzed for gross alpha and each radionuclide component.
(c) Blind B samples are liquid samples with unknown quantities of beta emitters analyzed for gross beta and each radionuclide component.

8.0.3 References

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Appendix A
Additional Monitoring Results for 1998

G. W. Patton and T. M. Poston

This appendix contains additional information on 1998 monitoring results, supplementing the data summarized in the main body of the report. More detailed information is available in PNNL-12088, APP. 1.

Table A.1. Radionuclide Activities in Columbia River Water at Priest Rapids Dam, 1998 Compared to Previous 5 Years

Radionuclide[a]	1998 No. of Samples	1998 Activity,[b] pCi/L Maximum	1998 Activity,[b] pCi/L Average	1993-1997 No. of Samples	1993-1997 Activity,[b] pCi/L Maximum	1993-1997 Activity,[b] pCi/L Average	Ambient Surface Water Quality Standard, pCi/L
Composite System							
Tritium	10	62[c] ± 12	36 ± 7.2	60	51 ± 9.4	34 ± 1.7	20,000[d]
Alpha (gross)	12	1.6 ± 0.83	0.49 ± 0.26	60	1.2 ± 0.86	0.41 ± 0.088	15[e,f]
Beryllium-7	12	17 ± 15	0.74 ± 5.0	60	18 ± 15	1.6 ± 2.0	6,000[d]
Beta (gross)	12	2.3 ± 1.5	1.1 ± 0.36	60	3.5 ± 2.4	0.93 ± 0.30	50[e,f]
Potassium-40	12	120 ± 58	38 ± 28	60	280 ± 54	48 ± 12	--[g]
Cobalt-60	12	3.0 ± 1.9	0.21 ± 0.76	60	1.6 ± 0.99	0.016 ± 0.22	100[d]
Strontium-90	12	0.11 ± 0.038	0.080 ± 0.0076	60	0.14 ± 0.0049	0.086 ± 0.0060	8[e,f]
Technetium-99	12	0.21 ± 0.49	0.026 ± 0.076	60	1.6 ± 0.69	0.026 ± 0.072	900[d]
Iodine-129[h]	3	0.000020 ± 0.0000027	0.000015 ± 0.0000094	21	0.00013 ± 0.000013	0.000014 ± 0.000012	1[d]
Ruthenium-106	12	20 ± 22	6.5 ± 4.4	43	12 ± 22	-0.70 ± 2.2	30[d]
Antimony-125	12	4.3 ± 6.2	-0.74 ± 1.5	43	6.4 ± 5.6	-0.50 ± 0.64	300[d]
Cesium-134	12	2.6 ± 2.1	0.075 ± 0.68	60	2.8 ± 2.4	0.030 ± 0.22	20,000[d]
Cesium-137	12	3.5 ± 2.4	0.64 ± 0.76	60	2.0 ± 2.3	0.15 ± 0.18	200[d]
Europium-154	12	5.5 ± 6.6	-1.2 ± 2.2	60	5.2 ± 2.9	0.035 ± 0.64	200[d]
Europium-155	12	4.8 ± 3.9	-0.52 ± 1.5	60	5.8 ± 4.7	0.097 ± 0.46	600[d]
Uranium-234	12	0.38 ± 0.068	0.26 ± 0.030	60	0.44 ± 0.13	0.24 ± 0.014	--
Uranium-235	12	0.024 ± 0.014	0.0082 ± 0.0048	60	0.032 ± 0.039	0.0091 ± 0.0020	--
Uranium-238	12	0.32 ± 0.062	0.22 ± 0.028	60	0.35 ± 0.11	0.19 ± 0.012	--
Uranium (total)	12	0.71 ± 0.14	0.48 ± 0.056	60	0.83 ± 0.28	0.43 ± 0.026	--
Continuous System							
Plutonium-230,240 P	4	0.00028 ± 0.00011	0.000099 ± 0.00012	21	0.00015 ± 0.000098	0.000036 ± 0.000016	--
D	4	0.000040 ± 0.000060	0.000015 ± 0.000018	21	0.00063 ± 0.00021	0.000055 ± 0.000064	--

(a) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on unfiltered samples collected by the composite system (see Section 4.2, "Surface Water and Sediment Surveillance").
(b) Maximum values are ± total propagated analytical uncertainty (2 sigma). Averages are ±2 standard error of the calculated mean.
(c) Excludes one result of 200 ± 22 pCi/L.
(d) WAC 173-201A-050 and EPA-570/9-76-003.
(e) WAC 246-290.
(f) 40 CFR 141.
(g) Dashes indicate no concentration guides available.
(h) From 1993 through 1995, iodine-129 activities were obtained from the dissolved fraction of the continuous system.

Table A.2. Radionuclide Activities in Columbia River Water at the Richland Pumphouse, 1998 Compared to Previous 5 Years

Radionuclide[a]		1998 No. of Samples	1998 Activity,[b] pCi/L Maximum	1998 Activity,[b] pCi/L Average	1993-1997 No. of Samples	1993-1997 Activity,[b] pCi/L Maximum	1993-1997 Activity,[b] pCi/L Average	Ambient Surface Water Quality Standard, pCi/L
Composite System								
Tritium		10	150 ± 18	76 ± 21	60	160 ± 19	79 ± 7.4	20,000[c]
Alpha (gross)		12	0.86 ± 0.61	0.47 ± 0.12	60	2.2 ± 1.1	0.60 ± 0.12	15[c,d]
Beryllium-7		12	26 ± 26	1.4 ± 7.0	60	20 ± 12	1.5 ± 2.0	6,000[e]
Beta (gross)		12	2.2 ± 2.0	0.68 ± 0.50	60	3.4 ± 1.7	1.0 ± 0.24	50[c,d]
Potassium-40		12	200 ± 52	67 ± 42	60	240 ± 61	48 ± 9.4	--[f]
Cobalt-60		12	4.1 ± 2.2	-0.44 ± 1.1	60	1.7 ± 2.1	0.059 ± 0.22	100[e]
Strontium-90		12	0.098 ± 0.036	0.077 ± 0.0092	60	0.30 ± 0.081	0.088 ± 0.0092	8[c,d]
Technetium-99		12	0.53 ± 0.52	0.12 ± 0.12	60	0.31 ± 0.56	0.019 ± 0.040	900[e]
Iodine-129[g]		4	0.00016 ± 0.000020	0.00012 ± 0.000042	18	0.00016 ± 0.000013	0.00010 ± 0.000020	1[e]
Ruthenium-106		12	19 ± 20	1.0 ± 6.2	43	13 ± 18	0.46 ± 2.2	30[e]
Antimony-125		12	5.0 ± 5.5	1.7 ± 1.4	43	6.0 ± 4.7	0.17 ± 0.56	300[e]
Cesium-134		12	1.4 ± 2.2	-0.88 ± 1.1	60	1.1 ± 0.89	-0.10 ± 0.18	20,000[e]
Cesium-137		12	3.1 ± 2.2	0.23 ± 0.82	60	3.7 ± 2.1	0.34 ± 0.20	200[e]
Europium-154		12	8.8 ± 5.4	1.4 ± 2.4	60	4.1 ± 3.4	-0.20 ± 0.50	200[e]
Europium-155		12	3.4 ± 4.2	1.2 ± 0.84	60	3.4 ± 4.6	-0.020 ± 0.40	600[e]
Uranium-234		12	0.37 ± 0.070	0.29 ± 0.024	60	0.50 ± 0.13	0.27 ± 0.020	--
Uranium-235		12	0.024 ± 0.015	0.010 ± 0.0048	60	0.048 ± 0.022	0.0098 ± 0.0022	--
Uranium-238		12	0.30 ± 0.060	0.23 ± 0.026	60	0.53 ± 0.14	0.22 ± 0.0022	--
Uranium (total)		12	0.68 ± 0.14	0.53 ± 0.040	60	1.0 ± 0.30	0.50 ± 0.036	--
Continuous System								
Plutonium-239,240	P	4	0.00017 ± 0.000087	0.000066 ± 0.000068	18	0.00015 ± 0.000051	0.000034 ± 0.000017	--
	D	4	0.000052 ± 0.000058	0.000038 ± 0.000011	18	0.00020 ± 0.00012	0.000050 ± 0.000024	--

(a) Radionuclides measured using the continuous system show the particulate (P) and dissolved (D) fractions separately. Other radionuclides are based on unfiltered samples collected by the composite system (see Section 4.2, "Surface Water and Sediment Surveillance").
(b) Maximum values are ± total propagated analytical uncertainty (2 sigma). Averages are ±2 standard error of the calculated mean.
(c) 40 CFR 141.
(d) WAC 246-290.
(e) WAC 173-201A-050 and EPA-570/9-76-003.
(f) Dashes indicate no concentration guides available.
(g) From 1993 through 1995, iodine-129 activities were obtained from the dissolved fraction of the continuous system.

Table A.3. Radionuclide Activities Measured in Columbia River Water Along Transects of the Hanford Reach, 1998

Transect/Radionuclide	No. of Samples	Activity,[a] pCi/L Maximum	Minimum	Mean
Vernita Bridge				
Tritium	12	85 ± 13	26 ± 7.9	49 ± 11
Strontium-90	16	0.15 ± 0.052	0.045 ± 0.029	0.080 ± 0.011
Uranium (total)	16	0.60 ± 0.15	0.33 ± 0.083	0.44 ± 0.034
100-N Area				
Tritium	7	61 ± 12	33 ± 10	45 ± 5.4
Strontium-90	10	0.088 ± 0.034	0.053 ± 0.042	0.072 ± 0.0068
Uranium (total)	10	0.45 ± 0.11	0.34 ± 0.083	0.40 ± 0.024
100-F Area				
Tritium	10	96 ± 14	39 ± 9.7	52 ± 11
Strontium-90	10	0.11 ± 0.037	0.020 ± 0.021	0.076 ± 0.015
Uranium (total)	10	0.46 ± 0.099	0.33 ± 0.084	0.40 ± 0.026
Old Hanford Townsite				
Tritium	10	4,100 ± 350	53 ± 10	730 ± 910
Strontium-90	10	0.086 ± 0.034	0.055 ± 0.027	0.072 ± 0.0070
Uranium (total)	10	0.58 ± 0.12	0.30 ± 0.086	0.42 ± 0.050
300 Area				
Tritium	10	63 ± 11	34 ± 8.4	42 ± 5.6
Strontium-90	10	0.11 ± 0.053	-0.22 ± 0.33	0.046 ± 0.060
Uranium (total)	8	0.77 ± 0.25	0.26 ± 0.15	0.43 ± 0.11
Richland Pumphouse				
Tritium	30	99 ± 13	23 ± 7.6	52 ± 3.7
Strontium-90	42	0.11 ± 0.056	0.042 ± 0.030	0.074 ± 0.0050
Uranium (total)	42	0.88 ± 0.16	0.34 ± 0.094	0.50 ± 0.034

(a) Maximum and minimum values are ± total propagated analytical uncertainty (2 sigma). Mean values are ±2 standard error of the mean.

Table A.4. Selected U.S. Geological Survey Columbia River Water Quality Data,[a] 1998

Analysis	Units	Vernita Bridge (upstream) No. of Samples	Median	Maximum	Minimum	Richland Pumphouse (downstream) No. of Samples	Median	Maximum	Minimum	Washington Ambient Surface Water Quality Standard[b]
Temperature	°C	10	12	20	4.0	4	11	20	5.5	20 (maximum)
Dissolved oxygen	mg/L	10	12	13	9.3	4	11	13	9.1	8 (minimum)
Turbidity	NTU[c]	10	0.50	1.6	0.30	4	0.8	1.8	0.6	5 + background
pH	pH units	10	8.0	8.1	7.8	4	7.9	8.1	7.8	6.5 - 8.5
Suspended solids, 105°C (221°F)	mg/L	10	2.0	4	<0.5	4	4.0	10	2.0	--[d]
Dissolved solids, 180°C (356°F)	mg/L	10	81	97	72	4	84	92	80	--
Specific conductance	µS/cm	10	140	150	110	4	150	150	130	--
Total hardness, as $CaCO_3$	mg/L	10	63	69	50	4	64	71	59	--
Phosphorus, total	mg/L	10	<0.05	0.02	<0.01	4	<0.03	0.01	<0.01	--
Chromium, dissolved	µg/L	8	<1	2	<1	4	<1	<1	<1	--
Dissolved organic carbon	mg/L	10	1.3	2.1	1.1	4	1.2	1.8	1.1	--
Iron, dissolved	µg/L	10	<10	24	<10	4	<10	<10	<10	--
Ammonia, dissolved, as N	mg/L	10	<0.002	0.002	<0.002	4	<0.02	0.06	<0.02	--
Nitrogen, total Kjeldahl, as N	mg/L	10	<0.1	0.2	<0.1	4	<0.1	0.1	<0.1	--
Nitrite + nitrate, dissolved, as N	mg/L	10	0.092	0.17	0.033	4	0.14	0.17	0.090	--

(a) Provisional data from U.S. Geological Survey National Stream Quality Accounting Network (NASQAN), subject to revision.
(b) From WAC 173-201A.
(c) NTU = nephelometric turbidity units.
(d) Dashes indicate no standard available.

Table A.5. Radionuclide Activities in Sediments from the Columbia and Snake Rivers and from Columbia River Shoreline Springs, 1998 Compared to Previous 5 Years

		1998			1993-1997		
		No. of	Activity, pCi/g		No. of	Activity, pCi/g	
Location	Radionuclide	Samples	Median[a]	Maximum[b]	Samples	Median[a]	Maximum[b]
River Sediment							
100-F Slough	Cobalt-60	1		0.023 ± 0.010	6	0.026	0.033 ± 0.011
	Cesium-137	1		0.36 ± 0.042	6	0.43	0.49 ± 0.054
	Europium-155	1		0.028 ± 0.030	6	0.028	0.061 ± 0.033
	Plutonium-239,240	1		0.0017 ± 0.00038	6	0.0018	0.0024 ± 0.00082
	Strontium-90	1		0.0052 ± 0.0037	6	0.0034	0.013 ± 0.0052
	Uranium-235	1		0.0022 ± 0.0052	6	0.022	0.064 ± 0.068
	Uranium-238	1		0.10 ± 0.022	6	0.94	1.4 ± 0.41
Hanford Slough	Cobalt-60	1		0.011 ± 0.011	6	0.14	0.32 ± 0.046
	Cesium-137	1		0.13 ± 0.021	6	0.41	0.59 ± 0.068
	Europium-155	1		0.067 ± 0.036	6	0.080	0.16 ± 0.075
	Plutonium-239,240	1		0.0014 ± 0.00039	6	0.0047	0.0076 ± 0.0014
	Strontium-90	1		0.0036 ± 0.0036	6	0.0084	0.017 ± 0.0052
	Uranium-235	1		0.0090 ± 0.0068	6	0.064	0.24 ± 0.16
	Uranium-238	1		0.27 ± 0.044	6	1.2	2.4 ± 0.88
McNary Dam	Cobalt-60	6	0.048	0.063 ± 0.035	24	0.058	0.26 ± 0.033
	Cesium-137	6	0.36	0.81 ± 0.090	24	0.46	1.0 ± 0.11
	Europium-155	6	0.056	0.085 ± 0.058	24	0.055	0.13 ± 0.069
	Plutonium-239,240	6	0.0084	0.013 ± 0.0019	24	0.0081	0.014 ± 0.0026
	Strontium-90	6	0.020	0.039 ± 0.010	24	0.024	0.049 ± 0.011
	Uranium-235	6	0.028	0.030 ± 0.011	24	0.066	0.21 ± 0.10
	Uranium-238	6	0.62	0.67 ± 0.086	24	1.5	2.3 ± 0.71
Priest Rapids Dam	Cobalt-60	6	-0.0011	0.026 ± 0.015	23	0.0020	0.038 ± 0.049
	Cesium-137	6	0.32	0.52 ± 0.065	23	0.41	1.0 ± 0.14
	Europium-155	6	0.061	0.076 ± 0.043	23	0.049	0.10 ± 0.050
	Plutonium-239,240	6	0.0081	0.013 ± 0.0032	23	0.0082	0.018 ± 0.0032
	Strontium-90	6	0.015	0.019 ± 0.0074	23	0.014	0.025 ± 0.0068
	Uranium-235	6	0.016	0.028 ± 0.012	23	0.079	0.32 ± 0.17
	Uranium-238	6	0.44	0.70 ± 0.087	23	0.99	2.2 ± 0.71

Table A.5. (contd)

Location	Radionuclide	1998 No. of Samples	1998 Activity, pCi/g Median[a]	1998 Activity, pCi/g Maximum[b]	1993-1997 No. of Samples	1993-1997 Activity, pCi/g Median[a]	1993-1997 Activity, pCi/g Maximum[b]
Ice Harbor Dam (Snake River)	Cobalt-60	3	-0.016	-0.0022 ± 0.014	0		
	Cesium-137	3	0.23	0.29 ± 0.044	0		
	Europium-155	3	0.079	0.081 ± 0.044	0		
	Plutonium-239,240	3	0.0085	0.0087 ± 0.0019	0		
	Strontium-90	3	0.018	0.019 ± 0.0095	0		
	Uranium-235	3	0.018	0.027 ± 0.011	0		
	Uranium-238	3	0.66	0.73 ± 0.090	0		
Richland	Cobalt-60	1		0.012 ± 0.013	5	0.051	0.074 ± 0.019
	Cesium-137	1		0.086 ± 0.018	5	0.30	0.34 ± 0.042
	Europium-155	1		0.028 ± 0.037	5	0.059	0.066 ± 0.034
	Plutonium-239,240	1		0.0014 ± 0.00061	5	0.0020	0.0034 ± 0.00073
	Strontium-90	1		0.0041 ± 0.0042	5	0.0027	0.0050 ± 0.0035
	Uranium-235	1		0.014 ± 0.0080	5	0.053	0.14 ± 0.080
	Uranium-238	1		0.24 ± 0.039	5	1.1	2.1 ± 0.54
White Bluffs Slough	Cobalt-60	1		0.11 ± 0.024	6	0.081	0.20 ± 0.031
	Cesium-137	1		0.60 ± 0.067	6	0.80	0.97 ± 0.11
	Europium-155	1		0.10 ± 0.034	6	0.051	0.065 ± 0.034
	Plutonium-239,240	1		0.0050 ± 0.0012	6	0.0040	0.0073 ± 0.0017
	Strontium-90	1		0.0082 ± 0.0049	6	0.0055	0.017 ± 0.0055
	Uranium-235	1		0.0087 ± 0.0063	6	0.019	0.16 ± 0.12
	Uranium-238	1		0.26 ± 0.041	6	1.2	1.9 ± 0.52
Riverbank Springs Sediment							
100-B Spring	Cobalt-60	1		0.021 ± 0.015	3	0.029	0.051 ± 0.024
	Cesium-137	1		0.10 ± 0.023	3	0.079	0.095 ± 0.015
	Europium-155	1		0.11 ± 0.072	3	0.065	0.074 ± 0.036
	Strontium-90	1		0.0041 ± 0.0083	3	0.0027	0.0041 ± 0.0050
	Uranium-235	1		0.029 ± 0.016	3	0.10	0.20 ± 0.10
	Uranium-238	1		0.26 ± 0.055	3	1.2	1.2 ± 0.38

Table A.5. (contd)

Location	Radionuclide	1998 No. of Samples	1998 Activity, pCi/g Median[a]	1998 Activity, pCi/g Maximum[b]	1993-1997 No. of Samples	1993-1997 Activity, pCi/g Median[a]	1993-1997 Activity, pCi/g Maximum[b]
100-F Spring	Cobalt-60	1		0.016 ± 0.0071	3	0.040	0.044 ± 0.024
	Cesium-137	1		0.14 ± 0.019	3	0.19	0.32 ± 0.040
	Europium-155	1		0.024 ± 0.025	3	0.037	0.055 ± 0.031
	Strontium-90	1		0.0041 ± 0.0071	3	0.0087	0.0096 ± 0.010
	Uranium-235	1		0.022 ± 0.0095	3	0.16	0.17 ± 0.13
	Uranium-238	1		0.43 ± 0.059	3	1.2	1.4 ± 0.54
100-K Spring	Cobalt-60	(c)			2	0.011	0.015 ± 0.021
	Cesium-137	(c)			2	0.17	0.19 ± 0.046
	Europium-155	(c)			2	0.084	0.13 ± 0.066
	Strontium-90	(c)			2	0.0049	0.0085 ± 0.0048
	Uranium-235	(c)			2	0.17	0.20 ± 0.14
	Uranium-238	(c)			2	1.2	1.5 ± 0.54
300 Area Spring	Cobalt-60	(d)			5	0.013	0.016 ± 0.0076
	Cesium-137	(d)			5	0.074	0.15 ± 0.026
	Europium-155	(d)			5	0.045	0.13 ± 0.14
	Strontium-90	(d)			5	0.0073	0.012 ± 0.0060
	Uranium-235	(d)			5	0.12	0.41 ± 0.16
	Uranium-238	(d)			5	3.2	5.2 ± 1.1
Hanford Spring	Cobalt-60	(c)			5	0.059	0.090 ± 0.021
	Cesium-137	(c)			5	0.25	0.29 ± 0.032
	Europium-155	(c)			5	0.062	0.068 ± 0.034
	Strontium-90	(c)			5	0.0068	0.0086 ± 0.011
	Uranium-235	(c)			5	0.023	0.23 ± 0.14
	Uranium-238	(c)			5	1.3	1.9 ± 0.54

(a) Median values are not provided when only one sample analyzed.
(b) Values are ± total propagated analytical uncertainty (2 sigma).
(c) Sediment was not available at the 1998 spring location.
(d) Sample was collected but not analyzed.

Table A.6. Median Metal Concentrations (mg/kg dry wt.) in Columbia and Snake River Sediments, 1998

Metal	Priest Rapids Dam	Hanford Reach[a]	McNary Dam	Ice Harbor Dam (Snake River)	Riverbank Springs[b]
Antimony	0.63	0.50	0.70	0.67	0.77
Arsenic	3.8	3.6	6.9	7.4	6.8
Beryllium	0.84	1.2	1.2	1.4	2.9
Cadmium	5.8	0.86	1.8	0.19	1.6
Chromium	55	46	53	46	82
Copper	38	25	33	30	22
Lead	31	32	22	15	31
Mercury	0.12	0.057	0.10	0.043	0.014
Nickel	33	20	28	22	23
Selenium	0.52	0.47	0.42	0.45	<1.6
Silver	0.10	0.074	0.13	0.072	0.077
Thalium	1.4	0.79	0.80	0.41	0.88
Zinc	460	260	210	120	260

(a) 100-F Slough, Hanford Slough, Richland, and White Bluffs Slough.
(b) 100-B and 100-F Area.

Table A.7. Radionuclide Activities Measured in Riverbank Springs Water, 1998 Compared to Previous 5 Years

Location/Radionuclide	1998 No. of Samples	1998 Activity,[a] pCi/L Maximum	1993-1997 No. of Samples	1993-1997 Activity,[a] pCi/L Maximum	1993-1997 Activity,[a] pCi/L Median	Washington State Ambient Surface Water Quality Standard,[b] pCi/L
100-B Spring						
Alpha (gross)	1	1.6 ± 1.7	7	3.5 ± 1.8	1.4	15
Beta (gross)	1	7.6 ± 2.7	7	38 ± 4.6	10	50
Strontium-90	1	-0.022 ± 0.067	7	0.072 ± 0.11	0.023	8
Technetium-99	1	10 ± 1.4	7	25 ± 3.2	10	900[c]
Tritium	1	14,000 ± 1,100	7	24,000 ± 1,800	14,000	20,000
100-D Spring						
Alpha (gross)	1	0.98 ± 1.4	8	2.9 ± 1.9	1.1	15
Beta (gross)	1	14 ± 3.6	8	21 ± 3.3	9.1	50
Strontium-90	1	5.3 ± 1.2	8	9.4 ± 1.8	4.1	8
Tritium	1	4,800 ± 450	8	12,000 ± 1,000	6,200	20,000
100-F Spring						
Alpha (gross)	1	4.0 ± 2.0	4	41 ± 18	3.4	15
Beta (gross)	1	5.7 ± 2.5	4	65 ± 11	2.9	50
Strontium-90	1	0.012 ± 0.024	4	0.099 ± 0.091	0.064	8
Tritium	1	740 ± 170	4	1,800 ± 240	1,400	20,000
Uranium (total)	1	3.1 ± 0.40	4	9.2 ± 1.2	4.6	--[d]
100-H Spring						
Alpha (gross)	1	10 ± 3.7	6	4.6 ± 1.9	4.1	15
Beta (gross)	1	72 ± 8.6	6	69 ± 7.0	55	50
Strontium-90	1	[e]	6	25 ± 4.5	17	8
Technetium-99	1	77 ± 8.7	6	140 ± 15	87	900
Tritium	1	2,300 ± 270	6	1,200 ± 240	1,100	20,000
Uranium (total)	1	9.3 ± 1.0	6	8.4 ± 1.2	6.1	--
100-K Spring						
Alpha (gross)	1	3.2 ± 1.8	4	1.6 ± 1.2	0.98	15
Beta (gross)	1	5.0 ± 2.4	4	3.6 ± 2.5	2.3	50
Strontium-90	1	0.035 ± 0.016	4	0.59 ± 0.13	0.041	8
Tritium	1	12,000 ± 970	4	20,000 ± 1,500	18,000	20,000

Table A.7. (contd)

Location/Radionuclide	1998 No. of Samples	1998 Activity,[a] pCi/L Maximum	1993-1997 No. of Samples	1993-1997 Activity,[a] pCi/L Maximum	1993-1997 Activity,[a] pCi/L Median	Washington State Ambient Surface Water Quality Standard,[b] pCi/L
100-N Spring (8-13)[f]						
Alpha (gross)	1	1.3 ± 1.3	6	8.1 ± 3.3	1.1	15
Beta (gross)	1	2.3 ± 2.1	6	8.8 ± 2.3	4.0	50
Strontium-90	1	[e]	6	0.59 ± 0.3	0.066	8
Tritium	1	24,000 ± 1,900	6	31,000 ± 2,400	24,000	20,000
300 Area Spring						
Alpha (gross)	1	56 ± 10	7	110 ± 21	45	15
Beta (gross)	1	21 ± 4.1	7	21 ± 3.3	9.6	50
Iodine-129	1	0.0055 ± 0.00058	4	0.0049 ± 0.00063	0.0033	1
Technetium-99	1	13 ± 1.7	7	14 ± 1.9	8.8	900[c]
Tritium	1	9,600 ± 800	7	12,000 ± 940	9,800	20,000
Uranium (total)	1	58 ± 6.1	7	110 ± 13	61	--
Old Hanford Townsite Spring						
Alpha (gross)	1	3.2 ± 2.2	7	4.9 ± 2.2	1.2	15
Beta (gross)	1	23 ± 4.3	7	95 ± 140	18	50
Iodine-129	1	0.14 ± 0.0081	5	0.22 ± 0.014	0.086	1
Technetium-99	1	100 ± 12	7	130 ± 16	43	900[c]
Tritium	1	120,000 ± 8,800	7	170,000 ± 13,000	56,000	20,000
Uranium (total)	1	3.4 ± 0.43	7	4.3 ± 0.52	2.5	--

(a) Maximum values are ± total propagated analytical uncertainty (2 sigma).
(b) WAC 246-290, 40 CFR 141, and Appendix C, Table C.2.
(c) WAC 173-201A-050 and EPA-570/9-76-003.
(d) Dashes indicate no concentration guides available.
(e) Sample was destroyed during processing at the analytical laboratory.
(f) Refer to Table 4.2.4 for additional details on 100-N Spring samples.

Table A.8. Activities of Selected Radionuclides (pCi/g dry wt.) in Soil, 1998 Compared to Previous 6 Years

		1998				1992-1997			
Location	Radionuclide	No. of Samples	Mean[a]	Minimum[b]	Maximum[c]	No. of Samples	Mean[a]	Minimum[b]	Maximum[c]
Onsite	^{241}Am	4	0.079 ± 0.057	0.002 ± 0.001	0.24 ± 0.14	6	0.01 ± 0.006	0.0008 ± 0.002	0.037 ± 0.006
	$^{239,240}Pu$	13	0.074 ± 0.047	0.0004 ± 0.0002	0.53 ± 0.057	38	0.027 ± 0.012	0.00038 ± 0.0076	0.39 ± 0.38
	^{238}Pu	13	0.0008 ± 0.0006	0.0000 ± 0.0001	0.0081 ± 0.0013	38	0.0005 ± 0.0001	-0.00046 ± 0.0008	0.0039 ± 0.0007
	^{137}Cs	13	0.33 ± 0.14	0.01 ± 0.01	1.8 ± 0.18	38	1.1 ± 0.41	0.0031 ± 0.029	12.3 ± 1.25
	^{90}Sr	13	0.1 ± 0.031	0.014 ± 0.005	0.38 ± 0.069	41	0.16 ± 0.023	0.028 ± 0.0079	0.7 ± 0.13
	$^{238}U_{lepr}$ [d]					38	0.71 ± 0.043	0.32 ± 0.2	1.5 ± 0.29
	$^{239}U_{iso}$ [e]	13	0.15 ± 0.01	0.11 ± 0.02	0.25 ± 0.04	3	0.26 ± 0.053	0.17 ± 0.02	0.36 ± 0.04
Perimeter	^{241}Am	1			0.003 ± 0.0015	5	0.011 ± 0.0097	0.00029 ± 0.0015	0.05 ± 0.018
	$^{239,240}Pu$	6	0.0086 ± 0.0011	0.0057 ± 0.001	0.012 ± 0.002	23	0.0079 ± 0.001	0.0006 ± 0.0004	0.021 ± 0.0029
	^{238}Pu	6	0.0003 ± 0.0001	0.00015 ± 0.0001	0.0004 ± 0.0002	23	0.0003 ± 0.0001	-0.0007 ± 0.001	0.0011 ± 0.0013
	^{137}Cs	6	0.24 ± 0.032	0.16 ± 0.024	0.34 ± 0.04	28	0.35 ± 0.047	0.014 ± 0.026	0.95 ± 0.12
	^{90}Sr	6	0.052 ± 0.005	0.033 ± 0.008	0.067 ± 0.015	28	0.078 ± 0.008	0.013 ± 0.006	0.15 ± 0.032
	$^{238}U_{lepr}$ [d]					23	0.71 ± 0.05	0.15 ± 0.46	1.1 ± 0.51
	$^{239}U_{iso}$ [e]	6	0.17 ± 0.03	0.12 ± 0.02	0.3 ± 0.05	13	0.54 ± 0.07	0.18 ± 0.021	0.84 ± 0.10
Distant	^{241}Am	1			0.004 ± 0.002	3	0.024 ± 0.019	0.0041 ± 0.0056	0.063 ± 0.019
	$^{239,240}Pu$	1			0.006 ± 0.001	5	0.009 ± 0.0024	0.002 ± 0.0005	0.017 ± 0.0021
	^{238}Pu	1			0.0001 ± 0.0002	5	0.0004 ± 0.0001	0.0002 ± 0.0002	0.0007 ± 0.0003
	^{137}Cs	1			0.18 ± 0.03	5	0.51 ± 0.059	0.42 ± 0.053	0.74 ± 0.083
	^{90}Sr	1			0.081 ± 0.017	5	0.1 ± 0.036	0.038 ± 0.0087	0.24 ± 0.055
	$^{238}U_{lepr}$ [d]					5	0.74 ± 0.035	0.66 ± 0.32	0.84 ± 0.3
	$^{239}U_{iso}$ [e]	1			0.1 ± 0.02				
ALE[f]	^{241}Am					2	0.001 ± 0.0003	0.0007 ± 0.0011	0.0013 ± 0.0013
	$^{239,240}Pu$	2	0.0042 ± 0.034	0.0009 ± 0.0005	0.0076 ± 0.0012	2	0.0049 ± 0.0006	0.0043 ± 0.001	0.0055 ± 0.0011
	^{238}Pu	2	0.0002 ± 0.0002	-0.0000 ± 0.0001	0.0004 ± 0.0002	2	0.00014 ± 0.0001	0.000053 ± 0.00013	0.00022 ± 0.00018
	^{137}Cs	2	0.11 ± 0.09	0.02 ± 0.01	0.21 ± 0.03	2	0.21 ± 0.12	0.20 ± 0.05	0.22 ± 0.05
	^{90}Sr	2	0.046 ± 0.034	0.012 ± 0.004	0.08 ± 0.018	2	0.089 ± 0.007	0.082 ± 0.017	0.097 ± 0.021
	$^{238}U_{lepr}$ [d]					2	0.56 ± 0.14	0.419 ± 0.33	0.71 ± 0.30
	$^{239}U_{iso}$ [e]	2	0.16 ± 0.048	0.11 ± 0.024	0.21 ± 0.036				

(a) Reported mean error values ± standard error of the mean.
(b) Reported minimum error values ± total propagated analytical error.
(c) Reported maximum error values ± total propagated analytical error.
(d) Samples analyzed by low-energy photon system.
(e) Isotopic uranium.
(f) Fitzner/Eberhardt Arid Lands Ecology Reserve.

Table A.9. Radionuclide Activities (pCi/g dry wt.) in Soil Collected from the Fitzner-Eberhardt Arid Lands Ecology Reserve

Location[a]	Radionuclide	1993[b]	1998[b]
Rattlesnake Springs	Strontium-90	0.07 ± 0.02	0.08 ± 0.02
	Cesium-137	0.29 ± 0.04	0.21 ± 0.03
	Uranium-238[c]	0.51 ± 0.39	0.11 ± 0.02
	Plutonium-238	0.0002 ± 0.0001	0.0004 ± 0.0002
	Plutonium-239,240	0.007 ± 0.001	0.008 ± 0.001
Arid Lands Ecology Field Laboratory	Strontium-90	0.11 ± 0.02	0.012 ± 0.004
	Cesium-137	0.22 ± 0.04	0.02 ± 0.01
	Uranium-238[c]	1.01 ± 0.50	0.21 ± 0.04
	Plutonium-238	0.0002 ± 0.0002	ND[d]
	Plutonium-239,240	0.006 ± 0.001	0.0009 ± 0.0005

(a) See Figure 4.6.1.
(b) ± total propagated uncertainty (2 sigma).
(c) 1993 uranium-238 was determined by low-energy photon analysis; 1998 sample was determined by alpha spectrometry.
(d) ND = Not detected.

Table A.10. Activities of Selected Radionuclides (pCi/g dry wt.) in Vegetation, 1998 Compared to Previous 6 Years

	1998				1992-1997			
Radionuclide	No. Less Than Dectection	Mean[a]	Minimum[b]	Maximum[c]	No. Less Than Detection	Mean[a]	Minimum[b]	Maximum[c]
Onsite								
$^{239,240}Pu$	5 of 6	0.00007 ± 0.0006	0.00003 ± 0.0001	0.0039 ± 0.0008	7 of 14	0.0027 ± 0.0013	-0.00002 ± 0.0002	0.015 ± 0.0024
^{238}Pu	6 of 6	0.00003 ± 0.00002	-0.00003 ± 0.0001	0.0001 ± 0.0002	11 of 14	0.0072 ± 0.0045	-0.0006 ± 0.0007	0.051 ± 0.0062
^{137}Cs	6 of 6	0.001 ± 0.01	-0.02 ± 0.01	0.02 ± 0.01	6 of 14	0.29 ± 0.15	-0.003 ± 0.01	1.54 ± 0.17
^{90}Sr	2 of 7	0.02 ± 0.01	0.001 ± 0.005	0.037 ± 0.01	0 of 14	3.07 ± 2.65	0.01 ± 0.004	37.4 ± 9.19
$^{238}U_{NAT}$[d]					2 of 4	0.003 ± 0.01	-0.02 ± 0.02	0.02 ± 0.01
$^{239}U_{iso}$[e]	7 of 7	-0.002 ± 0.002	-0.007 ± 0.004	0.003 ± 0.001	7 of 10	0.002 ± 0.001	-0.0005 ± 0.005	0.01 ± 0.003
Perimeter								
$^{239,240}Pu$	2 of 4	0.0001 ± 0.0001	0.00004 ± 0.00008	0.0003 ± 0.0003	7 of 13	0.0002 ± 0.00003	-0.00001 ± 0.0003	0.0004 ± 0.0003
^{238}Pu	4 of 4	0.0001 ± 0.0001	0.00002 ± 0.0001	0.0001 ± 0.0001	13 of 13	0.00003 ± 0.0001	-0.0003 ± 0.0009	0.0006 ± 0.001
^{137}Cs	4 of 4	0.01 ± 0.006	0.004 ± 0.01	0.03 ± 0.02	12 of 13	0.003 ± 0.003	-0.03 ± 0.03	0.02 ± 0.02
^{90}Sr	0 of 4	0.02 ± 0.005	0.01 ± 0.01	0.04 ± 0.01	1 of 13	0.02 ± 0.006	0.002 ± 0.003	0.07 ± 0.02
$^{238}U_{NAT}$[d]					4 of 4	-0.003 ± 0.003	-0.01 ± 0.01	0.005 ± 0.01
$^{239}U_{iso}$[e]	4 of 4	0.006 ± 0.002	0.001 ± 0.006	0.016 ± 0.019	2 of 9	0.01 ± 0.003	0.0002 ± 0.002	0.03 ± 0.008
Distant								
$^{239,240}Pu$	2 of 2	0.00001 ± 0.00001	-0.00001 ± 0.00006	0.00002 ± 0.0001	4 of 5	0.0001 ± 0.00002	0.00004 ± 0.0001	0.0002 ± 0.0001
^{238}Pu	2 of 2	0.00002 ± 0.00003	-0.00001 ± 0.0001	0.00004 ± 0.0001	5 of 5	0.00001 ± 0.00001	-0.00001 ± 0.0001	0.0001 ± 0.0001
^{137}Cs	2 of 2	0.02 ± 0.01	0.01 ± 0.01	0.03 ± 0.01	4 of 5	0.01 ± 0.01	-0.02 ± 0.02	0.03 ± 0.03
^{90}Sr	0 of 2	0.03 ± 0.02	0.01 ± 0.01	0.04 ± 0.01	1 of 5	0.01 ± 0.003	0.003 ± 0.003	0.02 ± 0.005
$^{238}U_{NAT}$[d]					1 of 1			-0.002 ± 0.01
$^{239}U_{iso}$[e]	2 of 2	-0.004 ± 0.004	-0.01 ± 0.007	-0.0002 ± 0.006	1 of 4	0.004 ± 0.001	0.001 ± 0.002	0.005 ± 0.003

(a) Reported mean error values ± standard error of the mean.
(b) Reported minimum error values ± total propagated analytical error.
(c) Reported maximum error values ± total propagated analytical error.
(d) U_{NAT} is a chemical analysis not used in 1998.
(e) Isotopic uranium.

Table A.11. Metal Concentrations in Hanford Site Fruit Tree Samples, 1997 and 1998

Location	Medium	Antimony ICP-MS[a]	Arsenic ICP-MS	Beryllium ICP-MS	Cadmium ICP-MS	Chromium ICP-MS	Copper ICP-MS	Lead ICP-MS
		Concentration, µg/kg dry wt.						
1997								
100-D Area	Apricot leaves	0.015 U[b]	0.250	0.150 U	0.151	0.285	8.73	0.114
100-D Area	Apricot leaves	0.015 U	0.170	0.150 U	0.206	0.314	8.75	0.194
100-F Area	Apricot leaves	0.015 U	0.394	0.150 U	0.0971	0.200 U	4.25	0.145
Old Hanford Townsite	Quince fruit	0.015 U	0.154	0.150 U	0.0528	0.200 U	4.78	0.111
Old Hanford Townsite	Quince leaves	0.015 U	0.0327	0.150 U	0.0794	0.200 U	3.38	0.036 U
1997 Detection Limits		**0.015**	**0.030**	**0.150**	**0.020**	**0.200**	**0.020**	**0.036**
1998								
Old Hanford Townsite	Apple fruit	0.020 U	0.15 U	0.010 U	0.055	1.0 U	2.59	0.0298
Old Hanford Townsite	Apple leaves	0.020 U	0.248	0.010 U	0.04 U	1.0 U	6.70	0.251
100-F Area	Apricot fruit	0.020 U	0.214	0.010 U	0.04 U	1.0 U	14.1	0.0343
100-F Area	Apricot leaves	0.020 U	0.333	0.010 U	0.04 U	1.0 U	5.50	0.119
1998 Detection Limits		**0.020**	**0.15**	**0.010**	**0.04**	**1.0**	**0.8**	**0.01**

Location	Medium	Mercury CVAA[c]	Nickel ICP-MS	Selenium ICP-MS	Silver ICP-MS	Thallium ICP-MS	Zinc ICP-MS
		Concentration, µg/kg dry wt.					
1997							
100-D Area	Apricot leaves	0.0203	0.842	1.00 U	0.045 U	0.005 U	12.9
100-D Area	Apricot leaves	0.0210	1.08	1.00 U	0.045 U	0.0188	16.7
100-F Area	Apricot leaves	0.0174	0.790	1.00 U	0.045 U	0.005 U	9.81
Old Hanford Townsite	Quince fruit	0.0221	0.946	1.00 U	0.045 U	0.005 U	5.86
Old Hanford Townsite	Quince leaves	0.00180	0.125	1.00 U	0.045 U	0.00640	3.08
1997 Detection Limits		**0.001**	**0.020**	**1.00**	**0.045**	**0.005**	**0.150**
1998							
Old Hanford Townsite	Apple fruit	0.0016 U	0.15 U	2.0 U	0.01 U	0.01 U	2.00
Old Hanford Townsite	Apple leaves	0.0210	0.931	2.0 U	0.0243	0.01 U	12.2
100-F Area	Apricot fruit	0.0016 U	0.634	2.0 U	0.0164	0.01 U	16.7
100-F Area	Apricot leaves	0.0016 U	0.469	2.0 U	0.01 U	0.01 U	16.7
1998 Detection Limits		**0.0016**	**0.15**	**2.00**	**0.010**	**0.01**	**1.00**

(a) ICP-MS = Inductively coupled plasma-mass spectrometry.
(b) U = Undetected.
(c) CVAA = Cold vapor atomic absorption.

References

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Appendix B
Glossary

absorbed dose - Energy absorbed per unit mass from any kind of ionizing radiation in any kind of matter.

activation product - Material made radioactive by exposure to radiation from a source such as a nuclear reactor's neutrons.

anion - A negatively charged ion.

aquifer - Permeable geologic unit that can hold and/or transmit significant quantities of water.

background radiation - Radiation in the natural environment, including cosmic rays from space and radiation from naturally occurring radioactive elements in the air, in the earth, and in our bodies. In the United States, the average person receives approximately 300 millirems (mrem) of background radiation per year.

bank storage - Hydrologic term that describes river water that flows into and is retained in permeable stream banks during periods of high river stage. Flow is reversed during periods of low river stage.

becquerel (Bq) - Unit of radioactivity equal to one nuclear transformation per second (1 Bq = 1/s). Another unit of radioactivity, the curie, is related to the becquerel in which 1 Ci = 3.7×10^{10} Bq.

boundary dose rate - Dose rate measured or calculated at publicly accessible locations on or near the Hanford Site boundary.

collective effective dose equivalent - Sum of the effective dose equivalents for individuals composing a defined population. The units for this are "person-rem" or "person-sievert."

composite sample - Sample formed by mixing discrete samples taken at different times or from different locations.

confined aquifer - An aquifer bounded above and below by less-permeable layers. Groundwater in the confined aquifer is under a pressure greater than atmospheric pressure.

continuous sample - Sample formed by the continuous collection of the medium or contaminants within the medium during the entire sample period.

controlled area - An area to which access is controlled to protect individuals from exposure to radiation or radioactive and/or hazardous materials.

cosmic radiation - High-energy subatomic particles and electromagnetic radiation from outer space that bombard the earth. Cosmic radiation is part of natural background radiation.

curie (Ci) - A unit of radioactivity equal to 37 billion (3.7×10^{10}) nuclear transformations per second.

decay - The decrease in the amount of any radioactive material with the passage of time, as a result of the spontaneous emission from the atomic nuclei of nucleons or either alpha or beta particles, often accompanied by gamma radiation. When a radioactive material decays, the material may be converted to another radioactive species (decay product) or to a nonradioactive material.

derived concentration guide (DCG) - Concentrations of radionuclides in air and water that an individual could continuously consume, inhale, or be immersed in at average annual rates, and not receive an effective dose equivalent of greater than 100 mrem/yr.

detection level - Minimum amount of a substance that can be measured with a 99% confidence that the analytical result is greater than zero.

dispersion - Process whereby effluents are spread or mixed as they are transported by groundwater or air.

dose equivalent - Product of the absorbed dose, the quality factor, and any other modifying factors. The dose equivalent is a quantity for comparing the biological effectiveness of different kinds of radiation on a common scale. The unit of dose equivalent is the rem. A millirem is one one-thousandth of a rem.

dosimeter - Portable device for measuring the total accumulated exposure or absorbed dose from ionizing radiation fields.

effective dose - See "effective dose equivalent."

effective dose equivalent - A value used for estimating the total risk of potential health effects from radiation exposure. This estimate is the sum of the committed effective dose equivalent (see above) from internal deposition of radionuclides in the body and the effective dose equivalent from external radiation received during a year.

effluent - Liquid or gaseous waste streams released from a facility.

effluent monitoring - Sampling or measuring specific liquid or gaseous effluent streams for the presence of pollutants.

exposure - The interaction of an organism with a physical agent (e.g., radiation) or a chemical agent (e.g., arsenic) of interest. Also used as a term for quantifying x and gamma radiation fields (see "roentgen").

external radiation - Radiation originating from a source outside the body.

fallout - Radioactive materials that are released into the earth's atmosphere following a nuclear explosion or atmospheric release and that eventually fall to earth.

fission - The splitting or breaking apart of a nucleus into at least two other nuclei, accompanied with a release of a relatively large amount of energy. For example, when a heavy atom such as uranium is split, large amounts of energy, including radiation and neutrons, are released along with the new nuclei (which are fission products; see below).

fission products - Elements formed from fissioning. Many fission products are radioactive.

gamma radiation - Form of electromagnetic, high-energy radiation emitted from a nucleus. They require heavy shielding (e.g., concrete, steel) to be stopped and may cause biological damage when originating internally or externally to the body in sufficient amounts.

grab sample - A sample that is randomly collected or "grabbed" from the collection site.

grand mean - A "means of means" or an "overall mean" where there is some subdivision of the data where means were already provided for each subdivision.

groundwater - Subsurface water that is in the pore spaces of soil and geologic units.

gray (Gy) - Unit of absorbed dose in the International System of Units (SI) equal to 1 joule per kilogram. 1 Gy = 100 rad.

half-life - Length of time in which a radioactive substance will lose one half of its radioactivity by decay. Half-lives range from a fraction of a second to billions of years, and each radionuclide has a unique half-life.

ion exchange - The reversible exchange of one species of ion for a different species of ion within a medium.

irradiation - Exposure to radiation.

isotopes - Radionuclides (or nuclides) with the same number of protons (same atomic number) but a different number of neutrons (different mass). Isotopes of the same element (e.g., ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu) have almost identical chemical properties.

maximally exposed individual - A hypothetical member of the public residing near the Hanford Site who, by virtue of location and living habits, could receive the highest possible radiation dose from nuclides/radiation originating from Hanford.

mean - Average value of a series of measurements. The mean, X, was computed as:

$$X = \frac{1}{n}\sum_{i=1}^{n} X_i$$

where n is the number of measurements and X_i is the ith measurement.

median - Middle value in a set of results when the data are ranked in increasing or decreasing order.

millirem (mrem) - A unit of radiation dose equivalent that is equal to one one-thousandth (1/1000) of a rem. According to U.S. Department of Energy standards, an individual member of the public may receive no more than 100 mrem per year from a site's operation. This limit does not include radiation received for medical treatment or the approximately 300 mrem that people receive annually from natural background radiation.

minimum detectable concentration - Smallest amount or concentration of a radioactive or nonradioactive element that can be reliably detected in a sample.

noble gas - Any of a group of chemically and biologically inert gases that includes argon, krypton, and xenon. These gases are not retained in the body following inhalation. The principal exposure pathways for radioactive noble gases are direct external dose from the surrounding air.

nuclide -A general term referring to all known isotopes, both stable and unstable, of the chemical elements (Shleien 1992).

offsite locations - Sampling and measurement locations outside the Hanford Site boundary.

onsite locations - Sampling and measurement locations within the Hanford Site boundary.

operable unit - A discrete area for which an incremental step can be taken toward comprehensively addressing site problems. The cleanup of a site can be divided into a number of operable units, depending on the complexity of the problems associated with the site.

outfall - End of a drain or pipe that carries wastewater or other effluents into a ditch, pond, or river.

plume - The cloud of a pollutant in air, surface water, or groundwater formed after the pollutant is released from a source.

plutonium - A heavy, radioactive, man-made metallic element consisting of several isotopes. One important isotope is ^{239}Pu, which is produced by the irradiation of ^{238}U. Routine analysis cannot distinguish between the ^{239}Pu and ^{240}Pu isotopes; hence, the term $^{239,240}Pu$ as used in this report is symbolic of the presence of one or both of these isotopes in the analytical results.

quality assurance - Actions that provide confidence that an item or process meets or exceeds that user's requirements and expectations.

quality control - Comprises all those actions necessary to control and verify the features and characteristics of a material, process, product, or service to specified requirements. Quality control is an element of quality assurance.

rad - A special unit of absorbed dose equal to 100 ergs/g or 0.01 J/kg.

radiation - The energy emitted in the form of photons or particles such as those thrown off by transforming (decaying) atoms. For this report, radiation refers to ionizing types of radiation; not radiowaves, microwaves, radiant light, or other types of non-ionizing radiation.

radioactivity - Property possessed by some isotopes of elements of emitting radiation (such as alpha, beta, or gamma photons) spontaneously in their decay process to stable element isotopes.

radioisotope - An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation (Shleien 1992).

radionuclide - A species of atoms having a particular number of protons (Z), a particular number of neutrons (A), and a particular atomic weight (N = Z + A) that happens to emit radiation. Carbon-14 is a radionuclide. Carbon-12 is not and is called just a "nuclide."

recruitment - Survival from one life form or stage to the next or from one age class to the next.

rem - A unit of dose equivalent and effective dose equivalent.

risk - The probability that a detrimental health effect will occur.

roentgen (R) - Unit of x ray or gamma photon exposure measured in air, historically used to describe external radiation levels. An exposure of 1 roentgen typically causes an effective dose of 1 rem.

sievert (Sv) - Unit of dose equivalent and effective dose equivalent in the International System of Units (SI) equal to 100 rem.

spectrometer - A spectroscope with a calibrated scale for measuring the positions of spectral lines.

spectroscopy - The branch of physics concerned with the production, measurement, and interpretation of electromagnetic spectra arising from either emission or absorption of radiant energy by various substances.

spent fuel - Uranium metal or oxide and its metal container that have been used to power a nuclear reactor. It is highly radioactive and typically contains fission products, plutonium, and residual uranium.

standard error of the mean - A measure of the precision of a mean of observed values; that is, an estimate of how close a mean of observed values is expected to be to the true mean. The standard error (SE) of the mean is computed as

$$SE = \sqrt{\frac{S^2}{n}}$$

where S^2 is the variance of the measurements, n, computed as

$$S_M^2 = \frac{1}{n-1} \sum_{i=1}^{n} (X_i - X)^2$$

This estimator, S^2, includes the variance among the samples and the counting variance. The estimated S^2 may occasionally be less than the average counting variance.

thiourea - An organic chemical soluble in cold water used in photography, photocopying, and thyroid medication.

transuranic - An element with an atomic number greater than 92 (92 is the atomic number of uranium).

thermoluminescent dosimeter - A device containing a material that, after being exposed to beta and/or gamma radiation, emits light when processed and heated. The amount of light emitted is proportional to the absorbed dose to the thermoluminescent dosimeter.

unconfined aquifer - An aquifer containing groundwater that is not confined above by relatively impermeable rocks. The pressure at the top of the unconfined aquifer is equal to that of the atmosphere. At Hanford, the unconfined aquifer is the uppermost aquifer and is most susceptible to contamination from site operations.

vadose zone - Underground area from the surface to the top of the water table or aquifer.

volatile organic compounds - Lightweight organic compounds that vaporize easily. Used in solvents and degreasing compounds as raw materials, volatile compounds are generally considered to be below the molecular weight of C_{10} hydrocarbons.

water table - Theoretical surface represented by the elevation of water surfaces in wells penetrating only a short distance into the unconfined aquifer.

wind rose - Star-shaped diagram that shows how often winds of various speeds blow from different directions, usually based on yearly averages.

Reference

Shleien, B. (ed.). 1992. *The Health Physics and Radiological Health Handbook, Revised Edition*. Scinta, Inc., Silver Spring, Maryland.

Appendix C
Standards and Permits

Operations at the Hanford Site must conform to a variety of governmental standards and permits designed to ensure the biological and physical quality of the environment for public health, ecological, or aesthetic considerations. The primary environmental quality standards and permits applicable to Hanford Site operations in 1998 are listed in the following tables. The State of Washington has promulgated water quality standards for the Columbia River, Washington Administrative Code (WAC) 173-201A. The Hanford Reach of the Columbia River has been designated as Class A (Excellent). This designation requires that the water be usable for substantially all needs, including drinking water, recreation, and wildlife. Class A water standards are summarized in Table C.1. Drinking water standards promulgated by the U.S. Environmental Protection Agency (EPA) in Title 40, Code of Federal Regulations, Part 141 (40 CFR 141) and WAC 246-290 are summarized in Table C.2. Select surface freshwater quality criteria for toxic pollutants are included in Table C.3.

Environmental radiation protection standards are published in U.S. Department of Energy (DOE) Order 5400.5. That Order establishes limits for public radiation dose and gives guidance for keeping radiation exposures to members of the public as low as reasonably achievable. These standards are based on guidelines recommended by authoritative organizations such as the International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements. DOE has initiated a policy for creating and implementing public radiation protection standards that are generally consistent with the standards used by the U.S. Nuclear Regulatory Commission in regulating and licensing non-DOE nuclear facilities (i.e., nuclear power plants). Table C.4 shows the radiation standards from DOE Order 5400.5 and 40 CFR 61. These standards govern allowable public exposures to ionizing radiation from DOE operations.

In DOE Order 5400.5, the derived concentration guides are established that reflect the activities of radionuclides in water and air that an individual could continuously consume, inhale, or be immersed in at average annual activities without exceeding an effective dose equivalent of 100 mrem/yr. Derived concentration guides are not exposure limits but are simply reference values that are provided to allow for comparisons of radionuclide activities in environmental media. Table C.5 lists selected DOE derived concentration guides for radionuclides of particular interest at the Hanford Site. The guides are useful reference values but do not generally represent concentrations in the environment that ensure compliance with either the DOE, the Clean Air Act of 1986, or drinking water dose standards.

Permits required for regulated releases to water and air have been issued by the EPA under the National Pollutant Discharge Elimination System of the Clean Water Act of 1977 and the Prevention of Significant Deterioration requirements of the Clean Air Act. Also, under authority granted by the Clean Air Act, the Washington State Department of Health has issued a permit for Hanford Site radioactive air emissions. Permits for collecting wildlife for environmental sampling are issued by the Washington State Department of Fish and Wildlife and the U.S. Fish and Wildlife Service. Current permits are discussed in Table C.6.

Table C.1. Washington State Water Quality Standards for the Hanford Reach of the Columbia River

Parameter	Permissible Levels
Fecal coliform	1) Geometric mean value ≤100 colonies/100 mL 2) ≤10% of samples may exceed 200 colonies/100 mL
Dissolved oxygen	>8 mg/L
Temperature	1) ≤20°C (68°F) as a result of human activities 2) When natural conditions exceed 20°C (68°F), no temperature increases will be allowed that will raise the temperature of the receiving water by more than 0.3°C (32.5°F) 3) Incremental temperature increases resulting from point sources shall not at any time exceed 34/(T + 9), where T = background temperature. Incremental temperature increases resulting from nonpoint sources shall not exceed 2.8°C (37°F)
pH	1) 6.5 to 8.5 range 2) <0.5 unit induced variation
Turbidity	≤5 nephelometric turbidity units over background turbidity
Toxic, radioactive, or deleterious materials	Concentrations shall be below those of public health significance, or which cause acute or chronic toxic conditions to the most sensitive aquatic biota, or which may adversely affect characteristic water uses
Aesthetic value	Shall not be impaired by the presence of materials or their effects, excluding those of natural origin, which offend the senses of sight, smell, touch, or taste
Radioactive substances	Deleterious activities of radioactive materials for all classes shall be as determined by the lowest practicable activity attainable and in no case shall exceed EPA drinking water regulations for radionuclides, as published in EPA-570/9-76-003 or subsequent revisions thereto (see Table C.2)
Toxic substances	Shall not be introduced above natural background levels into waters of the state that have the potential either singularly or cumulatively to adversely affect characteristic water uses, cause acute or chronic toxicity to the most sensitive biota dependent on those waters, or adversely affect public health, as determined by the department (see Table C.3)

Table C.2. Selected Drinking Water Standards

Radiological Constituent	Primary Maximum Contaminant Level	Interim Drinking Water Standard	Agency[a]	Status
Gross alpha[b]	15 pCi/L		DOH,[c] EPA[d]	Final
Radium-226		3 pCi/L	DOH[c]	Final
Beta particle and photon activity	4 mrem/yr[e]		DOH,[c] EPA[d]	Final
Tritium		20,000[f] pCi/L	DOH,[c] EPA[d]	Interim
Beryllium-7		6,000[f] pCi/L	EPA[g]	Interim
Cobalt-60		100[f] pCi/L	EPA[g]	Interim
Strontium-90		8[f] pCi/L	DOH,[c] EPA[d]	Interim
Technetium-99		900[f] pCi/L	EPA[g]	Interim
Ruthenium-106		30[f] pCi/L	EPA[g]	Interim
Antimony-125		300[f] pCi/L	EPA[g]	Interim
Iodine-129		1[f] pCi/L	EPA[g]	Interim
Iodine-131		3[f] pCi/L	EPA[g]	Interim
Cesium-134		20,000[f] pCi/L	EPA[g]	Interim
Cesium-137		200[f] pCi/L	EPA[g]	Interim
Europium-154		200[f] pCi/L	EPA[g]	Interim
Europium-155		600[f] pCi/L	EPA[g]	Interim
Uranium	20 µg/L[h]		EPA[i]	Proposed
Fluoride	4 mg/L		DOH,[c] EPA[d,i]	Final/under review
Nitrate, as NO_3^-	45 mg/L		DOH,[c] EPA[d,i]	Final
Chromium	100 µg/L		DOH,[c] EPA[d,i]	Final
Cyanide	200 µg/L		EPA[c,d,i]	Final
Trichlorethylene	5 µg/L		DOH,[c] EPA[d,i]	Final
Tetrachloroethylene	5 µg/L		DOH,[c] EPA[d,i]	Final
Carbon tetrachloride	5 µg/L		DOH,[c] EPA[d,i]	Final
Chloroform (THM)[j]	100 µg/L		DOH,[c] EPA[i]	Final
cis-1,2-Dichloroethylene	0.07 mg/L		EPA[i]	Final

(a) DOH = Washington State Department of Health, EPA = U.S. Environmental Protection Agency.
(b) Including radium-226 but excluding radon and uranium.
(c) WAC 246-290.
(d) 40 CFR 141.
(e) Beta and gamma radioactivity from man-made radionuclides. Annual average activity shall not produce an annual dose equivalent from man-made radionuclides to the total body or any internal organ >4 mrem/yr. Compliance may be assumed if annual average activities of gross beta, tritium, and strontium-90 are <50, 20,000, and 8 pCi/L, respectively.
(f) Activity assumed to yield an annual dose of 4 mrem/yr.
(g) EPA-570/9-76-003.
(h) Equivalent to 13.4 pCi/L (assuming typical uranium natural abundance in rock).
(i) EPA 822-R-96-001.
(j) Standard is for total trihalomethanes (THM).

Table C.3. Selected Surface Freshwater Quality Criteria for Toxic Pollutants

Compound	Level that Yields Acute Toxicity, µg/L[a]	Level that Yields Chronic Toxicity, µg/L[a]	Level to Protect Human Health for the Consumption of Water and Organisms, µg/L[b]
Total Recoverable Metals			
Antimony	--	--	14
Arsenic	360.0	190.0	0.018
Cadmium	1.7[c]	0.64[d]	--
Chromium(III)[e]	950[f]	110[g]	--
Chromium(VI)	16.0	11.0	--
Copper	8.9[h]	6.3[i]	--
Lead	32[j]	1.2[k]	--
Mercury	2.4	0.012	0.14
Nickel	760[l]	85[m]	610
Selenium	20.0	5.0	--
Silver	1.2[n]	--	--
Thallium	--	--	1.7
Zinc	63[o]	57[p]	--
Anions			
Cyanide[q]	22.0	5.2	700
Chloride[r]	860,000	230,000	--
Organic Compounds			
Benzene	--	--	1.2
Carbon tetrachloride	--	--	0.25
Chloroform	--	--	5.7
1,2-Dichloroethane	--	--	0.38
Methylene chloride	--	--	4.7
Toluene	--	--	6,800
Tetrachloroethylene	--	--	0.8
1,1,2-Trichloroethane	--	--	0.60
Trichloroethylene	--	--	2.7
Vinyl chloride	--	--	2
1,4-Dichlorobenzene	--	--	400

(a) WAC 173-201A-040.
(b) 40 CFR 131.36.
(c) exp(1.128[ln(hardness)]-3.828). Limiting value for 1992-1997 U.S. Geological Survey results is 48 mg $CaCO_3$/L. Hardness expressed as mg $CaCO_3$/L.
(d) exp(0.7852[ln(hardness)]-3.490).
(e) Where methods to measure trivalent chromium are unavailable, these criteria are to be represented by total recoverable chromium.
(f) exp(0.8190[ln(hardness)]+3.688).
(g) exp(0.8190[ln(hardness)]+1.561).
(h) exp(0.9422[ln(hardness)]-1.464).
(i) exp(0.8545[ln(hardness)]-1.465).
(j) exp(1.273[ln(hardness)]-1.460).
(k) exp(1.273[ln(hardness)]-4.705).
(l) exp(0.8460[ln(hardness)]+3.3612).
(m) exp(0.8460[ln(hardness)]+1.1645).
(n) exp(1.72[ln(hardness)]-6.52).
(o) exp(0.8473[ln(hardness)]+0.8604).
(p) exp(0.8473[ln(hardness)]+0.7614).
(q) Criteria based on weak and dissociable method.
(r) Dissolved in association with sodium.

Table C.4. Radiation Standards (dose limits[a]) for Protection of the Public from All Routine DOE Activities

All Pathways (limits from DOE Order 5400.5)

The effective dose equivalent for any member of the public from all routine DOE activities[b] shall not exceed the values given below.

	Effective Dose Equivalent[c]	
	mrem/yr	mSv/yr
Routine public dose	100	1
Potential authorized temporary public dose[d]	500	5

Dose to Native Aquatic Animal Organisms from Liquid Discharges (interim limits from DOE Order 5400.5)

Radioactive material in liquid wastes discharged to natural waterways shall not cause an absorbed dose[e] to native aquatic animal organisms that exceeds 1 rad/d (10 mGy/d).

Drinking Water Pathway Only (limits from 40 CFR 141 and DOE Order 5400.5)

Radionuclide concentrations in DOE-operated public drinking water supplies shall not cause persons consuming the water to receive an effective dose equivalent >4 mrem/yr (0.04 mSv/yr). DOE activities shall not cause private or public drinking water systems downstream of the facility discharge to exceed the radiological drinking water limits in 40 CFR 141 (see Table C.2).

Air Pathways Only (limits from 40 CFR 61)

	Effective Dose Equivalent[c]	
	mrem/yr	mSv/yr
Public dose limit at location of maximum annual air concentration as a consequence of routine DOE activities[b]	10	0.1

(a) Radiation doses received from natural background, residual weapons testing and nuclear accident fallout, medical exposures, and consumer products are excluded from the implementation of these dose limits.
(b) "Routine DOE activities" implies normal, planned activities and does not include actual or potential accidental or unplanned releases.
(c) Effective dose equivalent is expressed in rem (or millirem) and sievert (or millisievert).
(d) Authorized temporary annual dose limits may be >100 mrem/yr (but cannot exceed 500 mrem/yr) if unusual circumstances exist that make avoidance of doses >100 mrem/yr to the public impracticable. DOE Richland Operations Office is required to request and receive specific authorization from DOE Headquarters for an increase from the routine public dose limit to a temporary annual dose limit.
(e) Absorbed dose is expressed in rad (or millirad) with the corresponding value in gray (or milligray) in parentheses.

Table C.5. Selected Derived Concentration Guides[a,b,c]

Radionuclide	Ingested Water, pCi/L	Inhaled Air, pCi/m^3
Tritium	2,000,000	100,000
Carbon-14	70,000	500,000
Chromium-51	1,000,000	60,000
Manganese-54	50,000	2,000
Cobalt-60	5,000	80
Zinc-65	9,000	600
Krypton-85	NS[d]	3,000,000[e]
Strontium-90	1,000	9
Technetium-99	100,000	2,000
Ruthenium-103	50,000	2,000
Ruthenium-106	6,000	30
Antimony-125	60,000	1,000
Iodine-129	500	70
Iodine-131	3,000	400
Cesium-137	3,000	400
Cerium-144	7,000	30
Europium-154	20,000	50
Europium-155	100,000	300
Uranium-234	500	0.09
Uranium-235	600	0.1
Uranium-238	600	0.1
Plutonium-238	40	0.03
Plutonium-239	30	0.02
Plutonium-240	30	0.02
Americium-241	30	0.02

(a) Activity of a specific radionuclide in water or air that could be continuously consumed or inhaled 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) NS = No numerical standard, but the effective dose equivalent cannot exceed 100 mrem/yr.
(e) Air immersion derived concentration guides.

Table C.6. Environmental Permits

Clean Water Act Permit

Additional details are given in Section 2.2, "Compliance Status."

Clean Air Act Permits

Prevention of Significant Deterioration Permit No. PSD-X80-14, issued to DOE Richland Operations Office by EPA Region 10; covers emission of NO_x to the atmosphere from the Plutonium-Uranium Extraction Plant and the Uranium-TriOxide Plant. No expiration date.

Radioactive Air Emission Permit No. FF-01, issued to DOE Richland Operations Office by the Washington State Department of Health under authority granted by the Clean Air Act; covers operations on the Hanford Site having a potential to emit radioactive airborne effluents. Initially issued August 15, 1991, the permit was updated August 1993.

Wildlife Sampling Permits

Scientific Collection Permit 98-218, issued by Washington State Department of Fish and Wildlife to Pacific Northwest National Laboratory for 1998; covered the collection of food fish, shellfish, and wildlife, including game fish, for environmental monitoring purposes. Renewed annually.

Federal Fish and Wildlife Permit No. 671877, issued by the U.S. Fish and Wildlife Service to Pacific Northwest National Laboratory; covers the collection of migratory wildlife. Expires December 31, 1999.

National Pollutant Discharge Elimination System Permits (governing effluent discharges to the Columbia River)

Permit #WA-000374-3 includes two outfalls in the 100-K Area, one in the 300 Area, and two inactive outfalls in the 100-N Area.

Permit #WA-002591-7 includes the outfall for the 300 Area Treated Effluent Disposal Facility.

Permit #'s WAR-00-000F and WAR-10-000F covering two stormwater permits.

Copies of the regulations concerning these permits may be obtained from the following organizations:

State of Washington
Department of Ecology
P.O. Box 47600
Olympia, WA 92504-7600

U.S. Environmental Protection Agency
Region 10
1200 Sixth Avenue
Seattle, WA 98101

U.S. Department of Energy
Richland Operations Office
825 Jadwin Ave.
Richland, WA 99352

References

40 CFR 61. U.S. Environmental Protection Agency. "National Emission Standards for Hazardous Air Pollutants." *Code of Federal Regulations*.

40 CFR 131.36. U.S. Environmental Protection Agency. "Toxics Criteria for Those States not Complying with the Clean Water Act Section 303(c)(2)(B)." *Code of Federal Regulations*.

40 CFR 141. U.S. Environmental Protection Agency. "National Primary Drinking Water Regulations; Radionuclides; Proposed Rule." *Code of Federal Regulations*.

Clean Air Act. 1986. Public Law 88-206, as amended, 42 USC 7401 et seq.

Clean Water Act. 1977. Public Law 95-217, as amended, 91 Stat. 1566 and Public Law 96-148, as amended.

DOE Order 5400.5. "Radiation Protection of the Public and the Environment."

EPA-570/9-76-003. 1976. *National Interim Primary Drinking Water Regulations*. Office of Water Supply, U.S. Environmental Protection Agency, Washington, D.C.

EPA 822-R-96-001. 1996. *Drinking Water Regulations and Health Advisories*. Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

Washington Administrative Code (WAC) 173-201A. "Water Quality Standards for Surface Waters of the State of Washington." Olympia, Washington.

Washington Administrative Code (WAC) 246-290. "Group A Public Water Systems." Olympia, Washington.

Appendix D
Dose Calculations

E. J. Antonio

The radiological dose that the public could have received in 1998 from Hanford Site operations was calculated in terms of the "total effective dose equivalent." The total effective dose equivalent is the sum of the effective dose equivalent from external sources and the committed effective dose equivalent for internal exposure. Effective dose equivalent is a weighted sum of doses to organs and tissues that accounts for the sensitivity of the tissue and the nature of the radiation causing the dose. It is calculated in units of millirem (millisievert)[(a)] for individuals and in units of person-rem for the collective dose received by the total population within an 80-km (50-mi) radius of the site. This appendix describes how the doses in this report were calculated.

Releases of radionuclides from Hanford Site activities are usually too low to be measured in offsite air, drinking water, and food crops. Therefore, the air dose calculations were based on measurements made at the point of release (stacks and vents). The water pathway dose calculations were based on measurements of releases to the Columbia River (from the 100 Areas) or the difference in detectable radionuclide concentrations measured upstream and downstream of the site. Environmental radionuclide activities were estimated from the effluent measurements by environmental transport models.

The transport of radionuclides in the environment to the point of exposure is predicted by empirically derived models of exposure pathways. These models calculate radionuclide activities in air, water, and foods. Radionuclides taken into the body by inhalation or ingestion may be distributed among different organs and retained for various times. In addition, long-lived radionuclides deposited on the ground become possible sources for long-term external exposure and uptake by agricultural products. Dietary and exposure parameters were applied to calculate radionuclide intakes and radiological doses to the public. Standardized computer programs were used to perform the calculations. These programs contain internally consistent mathematical models that use site-specific dispersion and uptake parameters. These programs are incorporated in a master code, GENII (PNL-6584), which employs the dosimetry methodology described in International Commission on Radiological Protection reports (1979a, 1979b, 1980, 1981a, 1981b, 1982a, 1982b, 1988). The assumptions and data used in these calculations are described below.

CRITRII is used for assessment of radiological doses to aquatic organisms and their predators. Both internal and external doses to fish, crustacea, molluscs, and algae, as well as organisms that subsist on them such as muskrats, raccoons, and ducks, may be estimated using CRITRII (PNL-8150).

The computer program, CAP88-PC, was used to calculate dose to a maximally exposed individual as required by Title 40, Code of Federal Regulations, Part 61, Subpart H from airborne radionuclide effluents (other than radon) released at U.S. Department of Energy (DOE) facilities. Technical details of the CAP88-PC calculations are provided in detail in the 1998 air emissions report (DOE/RL-99-41).

(a) 1 rem (0.01 Sv) = 1,000 mrem (10 mSv).

Types of Dose Calculations Performed

Calculations of radiological doses to the public from radionuclides released into the environment are performed to demonstrate compliance with applicable standards and regulations.

DOE requires:

- effective dose equivalent to be used in estimating public doses
- biokinetic models and metabolic parameters given by the International Commission on Radiological Protection to be used when estimating doses
- doses to the public to be calculated using facility effluent data when environmental concentrations are too low to measure accurately.

The calculation of the effective dose equivalent takes into account the long-term (50-yr) internal exposure from radionuclides taken into the body during the current year. The effective dose equivalent is the sum of individual committed (50-yr) organ doses multiplied by weighting factors that represent the proportion of the total health effect risk that each organ would receive from uniform irradiation of the whole body. Internal organs may also be irradiated from external sources of radiation. The external exposure received during the current year is added to the committed internal dose to obtain the total effective dose equivalent. In this report, the effective dose equivalent is expressed in rem (or millirem) with the corresponding value in sievert (or millisievert) in parentheses. The numerous transfer factors used for pathway and dose calculations have been documented in GENII (PNL-6584) and in PNL-3777, Rev. 2.

The following types of radiological doses were estimated.

Boundary Dose Rate (mrem/h and mrem/yr). The external radiological dose rates during the year in areas accessible by the general public were determined from measurements obtained near operating facilities.

Maximally Exposed Individual Dose (mrem). The maximally exposed individual is a hypothetical member of the public who lives at a location and has a lifestyle such that it is unlikely that other members of the public would receive higher doses. All potentially significant exposure pathways to this hypothetical individual were considered, including the following:

- inhalation of airborne radionuclides
- submersion in airborne radionuclides
- ingestion of foodstuffs contaminated by radionuclides deposited on vegetation and the ground by both airborne deposition and irrigation water drawn from the Columbia River downstream of N Reactor
- exposure to ground contaminated by both airborne deposition and irrigation water
- ingestion of fish taken from the Columbia River
- recreation along the Columbia River, including boating, swimming, and shoreline activities.

80-km (50-mi) Population Doses (person-rem). Regulatory limits have not been established for population doses. However, evaluation of the collective population doses to all residents within an 80-km (50-mi) radius of Hanford Site operations is required by DOE Order 5400.5. The radiological dose to the collective population within 80 km (50 mi) of the site was calculated to demonstrate compliance with environmental regulations, confirm adherence to DOE environmental protection policies, and provide information to the public. The 80-km (50-mi) population dose is the sum of the product of the individual doses and the number of individuals exposed for all pathways.

Pathways similar to those used for the maximally exposed individual were used to calculate doses to the offsite population. In calculating the effective dose, an estimate was made of the fraction of the

offsite population expected to be affected by each pathway. The exposure pathways for the population are as follows.

Drinking Water. The cities of Richland and Pasco obtain their municipal water directly and Kennewick indirectly from the Columbia River downstream from the Hanford Site. A total population of approximately 70,000 in the three cities drinks water derived from the Columbia River.

Irrigated Food. Columbia River water is withdrawn for irrigation of small vegetable gardens and farms in the Riverview district of Pasco in Franklin County. Enough food is grown in this district to feed an estimated 2,000 people. Commercial crops are also irrigated by Columbia River water in the Horn Rapids area of Benton County. These crops are widely distributed.

River Recreation. These activities include swimming, boating, and shoreline recreation. Specific pathways include external exposure from radionuclides in the water or on the shoreline and ingestion of river water while swimming. An estimated 125,000 people who reside within 80 km (50 mi) of the Hanford Site are assumed to be affected by these pathways.

Fish Consumption. Population doses from the consumption of fish obtained locally from the Columbia River were calculated from an estimated total annual catch of 15,000 kg/yr (33,075 lb/yr) (without reference to a specified human group of consumers).

Data

The data that are needed to perform dose calculations are based on either measured upstream/downstream differences or measured effluent releases and include information on initial transport through the atmosphere or river, transfer or accumulation in terrestrial and aquatic pathways, and public exposure. By comparison, radiological dose calculations based on measured activities of radionuclides in food require data describing only dietary and recreational activities and exposure times. These data are discussed below.

Population Distribution and Atmospheric Dispersion

Geographic distributions of the population residing within an 80-km (50-mi) radius of the Hanford Site operating areas are shown in PNNL-12088, APP. 1. These distributions are based on 1990 Bureau of the Census data (PNL-7803). These data influence the population dose by providing estimates of the number of people exposed to radioactive effluents and their proximity to the points of release.

Atmospheric dispersion data are also shown in PNNL-12088, APP. 1. These data describe the transport and dilution of airborne radioactive material, which influences the amounts of radionuclides being transported through the air to specific locations.

Terrestrial and Aquatic Pathways

Important parameters affecting the movement of radionuclides within exposure pathways such as irrigation rates, growing periods, and holdup periods are listed in Table D.1. Certain parameters are specific to the lifestyles of either "maximally exposed" or "average" individuals.

Public Exposure

The offsite radiological dose is related to the extent of external exposure to or intake of

Table D.1. Food Pathway Parameters Used in Dose Calculations, 1998

Medium	Holdup, d[a] Maximally Exposed Individual	Holdup, d[a] Average Individual	Growing Period, d	Yield, kg/m²	Irrigation Rate, L/m²/mo
Leafy vegetables	1	14	90	1.5	150
Other vegetables	5	14	90	4	170
Fruit	5	14	90	2	150
Cereal	180	180	90	0.8	0
Eggs	1	18	90	0.8	0
Milk	1	4	--	--	--
Hay	(100)[b]	(100)	45	2	200
Pasture	(0)	(0)	30	1.5	200
Red meat	15	34	--	--	--
Hay	(100)	(100)	45	2	200
Grain	(180)	(180)	90	0.8	0
Poultry	1	34	90	0.8	0
Fish	1	1	--	--	--
Drinking water	1	1	--	--	--

(a) Holdup is the time between harvest and consumption.
(b) Values in ( ) are the holdup in days between harvest and consumption by farm animals.

radionuclides released from Hanford Site operations. Tables D.2 through D.4 give the parameters describing the diet, residency, and river recreation assumed for "maximally exposed" and "average" individuals.

Dose Calculation Documentation

DOE established the Hanford Dose Overview Panel to promote consistency and defensibility of environmental dose calculations at Hanford. The panel has the responsibility for defining standard, documented computer codes and input parameters to be used for radiological dose calculations for the public in the vicinity of the Hanford Site. Only those procedures, models, and parameters previously defined by the panel were used to calculate the radiological doses (PNL-3777, Rev. 2). The calculations were then reviewed by the panel. Summaries of dose calculation technical details for this report are shown in Tables D.5 through D.9 and in PNNL-12088, APP. 1.

400 Area Drinking Water

Drinking water at the Fast Flux Test Facility contained slightly elevated levels of tritium. The potential doses to 400 Area workers consuming this water in 1998 are given in Table D.10.

300 Area Drinking Water

In 1998, water to the 300 Area was primarily obtained from the Columbia River and supplied by the 312 Pumphouse. The potential doses to people consuming this water in 1998 are given in Table D.11.

Table D.2. Dietary Parameters Used in Dose Calculations, 1998

Medium	Consumption: Maximally Exposed Individual	Consumption: Average Individual
Leafy vegetables	30 kg/yr	15 kg/yr
Other vegetables	220 kg/yr	140 kg/yr
Fruit	330 kg/yr	64 kg/yr
Grain	80 kg/yr	72 kg/yr
Eggs	30 kg/yr	20 kg/yr
Milk	270 L/yr	230 L/yr
Red meat	80 kg/yr	70 kg/yr
Poultry	18 kg/yr	8.5 kg/yr
Fish	40 kg/yr	--[a]
Drinking water	730 L/yr	440 L/yr

(a) Average individual consumption not identified; radiation doses were calculated based on estimated total annual catch of 15,000 kg (33,075 lb).

Table D.3. Residency Parameters Used in Dose Calculations, 1998

Parameter	Exposure, h/yr: Maximally Exposed Individual	Exposure, h/yr: Average Individual
Ground contamination	4,383	2,920
Air submersion	8,766	8,766
Inhalation[a]	8,766	8,766

(a) Inhalation rates: adult 270 cm^3/s.

Table D.4. Recreational Parameters Used in Dose Calculations, 1998

Parameter	Exposure, h/yr[a] Maximally Exposed Individual	Exposure, h/yr[a] Average Individual
Shoreline	500	17
Boating	100	5
Swimming	100	10

(a) Assumed river-water travel times from 100-N Area to the point of aquatic recreation were 8 h for the maximally exposed individual and 13 h for the average individual. Correspondingly lesser times were used for other locations.

Table D.5. Technical Details of 100 Areas Airborne Release Dose Calculations, 1998

Facility name	100-N Area
Releases (Ci)	^{90}Sr (1.7×10^{-5}), ^{137}Cs (3.0×10^{-5}), ^{238}Pu (5.2×10^{-7}), $^{239,240}Pu$ (3.4×10^{-6})[a], ^{241}Pu (3.8×10^{-5}), ^{241}Am (2.0×10^{-6})
Meteorological conditions	1998 annual average, calculated from data collected at the 100-N Area and the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual, 1.1×10^{-8} s/m^3 at 41 km (26 mi) SE; 80-km (50-mi) population, 1.0×10^{-2} s/m^3 person-s/m^3
Release height	10-m (33-ft) effective stack height
Population distribution	375,000 (PNNL-11796, Table D-1)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.6. Technical Details of 100-N Area Liquid Release Dose Calculations, 1998

Facility name	100-N Area
Releases (Ci)	^{3}H (2.9×10^{-1}), ^{90}Sr (2.9×10^{-1}), ^{239}Pu (1.3×10^{-6}), ^{241}Am (1.7×10^{-5})
Mean river flow	3,255 m^3/s (115,000 ft^3/s)
Shore-width factor	0.2
Population distribution	70,000 for drinking water pathway 125,000 for aquatic recreation 2,000 for consumption of irrigated foodstuffs 15,000 kg/yr (33,075 lb/yr) total harvest of Columbia River fish
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to irrigated soil, to river water, and to shoreline sediments Ingestion of aquatic foods and irrigated farm products
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90 Bioaccumulation Factor Library, Rev. 10-26-92

Table D.7. Technical Details of 200 Areas Airborne Release Dose Calculations, 1998

Facility name	200 Areas
Releases (Ci)	200-East Area ^{90}Sr (1.2×10^{-4})[a], ^{125}Sb (4.8×10^{-7}), ^{129}I (3.1×10^{-4}), ^{137}Cs (1.9×10^{-4}), ^{238}Pu (7.9×10^{-10}), $^{239,240}Pu$ (1.1×10^{-6})[b], ^{241}Pu (2.9×10^{-8}), ^{241}Am (5.0×10^{-7}) 200-West Area ^{90}Sr (2.3×10^{-4})[a], ^{137}Cs (3.2×10^{-9}), ^{238}Pu (3.4×10^{-6}), $^{239,240}Pu$ (2.0×10^{-4})[b], ^{241}Pu (4.4×10^{-5}), ^{241}Am (3.0×10^{-5})
Meteorological conditions	1998 annual average, calculated from data collected at the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual, 7.6×10^{-9} s/m^3 at 28 km (17 mi) SE; 80-km (50-mi) population, 7.3×10^{-3} person-s/m^3
Release height	89-m (292-ft) effective stack height
Population distribution	376,000 (PNNL-11796, Table D-2)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev. 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be ^{90}Sr for dose calculations.
(b) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.8. Technical Details of 300 Area Airborne Release Dose Calculations, 1998

Facility name	300 Area
Releases (Ci)[a]	^{3}H (as HTO)[b] (6.5×10^{1}), ^{3}H (as HT)[b] (9.3×10^{1}), ^{90}Sr (9.6×10^{-6})[c], ^{129}I (4.6×10^{-8}), ^{137}Cs (5.8×10^{-7}), ^{238}Pu (1.7×10^{-9}), $^{239,240}Pu$ (1.1×10^{-6})[d], ^{241}Am (2.3×10^{-8})
Meteorological conditions	1998 annual average, calculated from data collected at the 300 Area and the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual at residence, 8.2×10^{-7} s/m^3 at 1.5 km (1 mi) E; 80-km (50-mi) population, 1.4×10^{-1} person-s/m^3
Release height	10 m (33 ft)
Population distribution	282,000 (PNNL-11796, Table D-3)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) These release quantities do not include 17 Ci (HT) and 106 Ci (HTO), which were released acutely on August 26, 1998 and which are addressed separately in Section 2.4.2.
(b) HT = elemental tritium; HTO = tritiated water vapor.
(c) This value includes gross beta release data. Gross beta and unspecified beta results assumed to be ^{90}Sr for dose calculations.
(d) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.9. Technical Details of 400 Area Airborne Release Dose Calculations, 1998

Facility name	400 Area
Releases (Ci)	^{3}H (as HTO)[a] (4.2×10^{0}), ^{137}Cs (5.5×10^{-6})[b], $^{239,240}Pu$ (5.0×10^{-7})[c]
Meteorological conditions	1998 annual average, calculated from data collected at the 400 Area and the Hanford Meteorology Station from January through December 1998, using the computer code HANCHI
$\overline{X}/Q'$	Maximally exposed individual at residence, 9.6×10^{-8} s/m^3 at 11 km (7 mi) SE; 80-km (50-mi) population, 1.3×10^{-1} person-s/m^3
Release height	10 m (33 ft)
Population distribution	283,000 (PNNL-11796, Table D-4)
Computer code	GENII, Version 1.485, December 3, 1990 (e.g., PNL-6584)
Doses calculated	Chronic, 1-yr exposure, 50-yr committed internal dose equivalent, and annual effective dose equivalent to individual and population
Pathways considered	External exposure to plume and ground deposits Inhalation Ingestion of locally produced foods
Files addressed	Radionuclide Library, Rev 7-1-92 Food Transfer Library, Rev. 8-29-88 External Dose Factor Library, Rev. 5-9-88 Internal Dose Factor Library, Rev. 12-3-90

(a) HTO = tritiated water vapor.
(b) ^{137}Cs value for the 400 Area is derived fully from gross beta measurements.
(c) This value includes gross alpha release data. Gross alpha and unspecified alpha results assumed to be $^{239,240}Pu$ for dose calculations.

Table D.10. Annual Dose to Workers in the 400 Area from Ingestion of Drinking Water Obtained from Groundwater Wells

Radionuclide	Drinking Water Activity, pCi/L[a]	Intake, pCi/yr[b]	Ingestion Dose Factor, rem/pCi[c]	Ingestion Dose, rem/yr (Sv/yr)
Gross alpha[d]	0.97 ± 2.4	233	2.83×10^{-7}	6.6×10^{-5} (6.6×10^{-7})
Gross beta[e]	6.36 ± 1.6	1,526	5.00×10^{-8}	7.6×10^{-5} (7.6×10^{-7})
Tritium	4,913 ± 658	1.18×10^{6}	6.40×10^{-11}	7.5×10^{-5} (7.5×10^{-7})
^{90}Sr	0.014 ± 0.048	3.36	1.42×10^{-7}	4.8×10^{-7} (4.8×10^{-9})
Total				2.2×10^{-4} (2.2×10^{-6})

(a) Drinking water activities are annual averages obtained from monthly samples taken during 1998.
(b) Intake is based on the assumption that a worker ingests 1 L/d of groundwater during the entire working year (taken to be 240 d for the analysis).
(c) Ingestion intake-to-dose conversion factors are taken from EPA/520/1-88-020 and converted from International System of Units (SI). Where the document lists dose factors for more than one chemical form of a radionuclide, the most soluble chemical form was assumed.
(d) Gross alpha activities were assumed to be ^{234}U for the purposes of this analysis.
(e) Gross beta activities were assumed to be ^{137}Cs for the purposes of this analysis.

Table D.11. Annual Dose to Workers in the 300 Area from Ingestion of Drinking Water Obtained from the Columbia River

Radionuclide	Drinking Water Activity, pCi/L[a]	Intake, pCi/yr[b]	Ingestion Dose Factor, rem/pCi[c]	Ingestion Dose, rem/yr (Sv/yr)
Gross alpha[d]	1.65 ± 1.52	396	2.83×10^{-7}	1.1×10^{-4} (1.1×10^{-6})
Gross beta[e]	1.68 ± 1.80	403	5.0×10^{-8}	2.0×10^{-5} (2.0×10^{-7})
Tritium	277 ± 347	66,480	6.4×10^{-11}	4.3×10^{-6} (4.3×10^{-8})
^{90}Sr	0.07 ± 0.08	16.8	1.42×10^{-7}	2.4×10^{-6} (2.4×10^{-8})
^{234}U	0.91 ± 0.88	218	2.83×10^{-7}	6.2×10^{-5} (6.2×10^{-7})
^{235}U	0.033 ± 0.038	7.9	2.66×10^{-7}	2.1×10^{-6} (2.1×10^{-8})
^{238}U	0.80 ± 0.86	192	2.55×10^{-7}	4.9×10^{-5} (4.9×10^{-7})
Total				2.5×10^{-4} (2.5×10^{-6})

(a) Drinking water activities are annual averages obtained from monthly samples taken during 1998.
(b) Intake is based on the assumption that a worker ingests 1 L/d of groundwater during the entire working year (taken to be 240 d for the analysis).
(c) Ingestion intake-to-dose conversion factors are taken from EPA/520/1-88-020 and converted from International System of Units (SI). Where the document lists dose factors for more than one chemical form of a radionuclide, the most soluble chemical form was assumed.
(d) Gross alpha activities were assumed to be ^{234}U for the purposes of this analysis.
(e) Gross beta activities were assumed to be ^{137}Cs for the purposes of this analysis.

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Appendix E

Radionuclides Detected by Gamma Spectroscopy (Gamma Scan)

One of the several forms of radiation is gamma radiation. Gamma radiation is emitted by many radionuclides. Gamma spectroscopy, sometimes called a gamma scan, is used to detect the presence of the radionuclides shown in Table E.1. These radionuclides may be natural or result from Hanford Site activities. They include activation products formed by the absorption of a neutron by a stable element and fission products that occur following fission (splitting) of nuclear fuel radionuclides such as uranium-235 or plutonium-239. Some of these radionuclides may not be discussed in the main body of this report if they are below detection levels.

Table E.1. Radionuclides Analyzed by Gamma Spectroscopy

Radionuclide	Symbol	Source
Beryllium-7	^{7}Be	Natural
Sodium-22	^{22}Na	Activation product
Sodium-24	^{24}Na	Activation product
Potassium-40	^{40}K	Natural
Manganese-54	^{54}Mn	Activation product
Cobalt-58	^{58}Co	Activation product
Cobalt-60	^{60}Co	Activation product
Iron-59	^{59}Fe	Activation product
Zinc-65	^{65}Zn	Activation product
Zirconium/niobium-95	$^{95}Zr/Nb$	Activation product and fission product
Molybdenum-99	^{99}Mo	Activation product and fission product
Ruthenium-103	^{103}Ru	Activation product and fission product
Ruthenium-106	^{106}Ru	Fission product
Antimony-125	^{125}Sb	Activation product
Iodine-131	^{131}I	Fission product
Cesium-134	^{134}Cs	Activation product
Cesium-137	^{137}Cs	Fission product
Barium/lanthanum-140	$^{140}Ba/La$	Fission product
Cerium-141	^{141}Ce	Activation product and fission product
Cerium/praseodymium-144	$^{144}Ce/Pr$	Fission product
Europium-152	^{152}Eu	Activation product
Europium-154	^{154}Eu	Activation product
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Appendix F
Threatened and Endangered Species

B. L. Tiller

This appendix discusses the federal and state threatened and endangered species, candidate species, and plant species of concern potentially found on the Hanford Site. Threatened and endangered species are listed by the federal government in Title 50, Code of Federal Regulations, Part 17 (50 CFR 17); Washington Natural Heritage Program (1997); and Washington State Department of Fish and Wildlife (1996).

The purposes of the Endangered Species Act of 1973, as amended, are to 1) provide a means to conserve critical ecosystems, 2) provide a program for the conservation of threatened and endangered species, and 3) ensure that appropriate steps are taken to achieve the purposes of the treaties and conventions established in the Act. Threatened and endangered species of plants and animals occurring or potentially occurring on the Hanford Site are listed in Table F.1.

Identification of candidate species can assist environmental planning efforts by providing advance notice of potential listing as a threatened or endangered species, allowing resource managers to alleviate threats and thereby possibly remove the need to list species as endangered or threatened. Even if a candidate species is subsequently listed, the early notice could result in fewer restrictions on human activities in the environment by prompting candidate conservation measures to alleviate threats to the species. Washington State candidate animal species potentially found on the Hanford Site are listed in Table F.2. Plant species not listed as threatened or endangered but considered "candidates" for listing are identified by Washington State as "species of concern;" those potentially found on the Hanford Site are listed in Table F.3.

Hanford Status

No plants or mammals on the federal list of endangered and threatened species (50 CFR 17) are known to occur on the Hanford Site. There are, however, three species of birds and two fish on the federal list of threatened and endangered species (see Table F.1). In addition, nine species of plants, seven species of birds, and one mammalian species have been listed as either threatened or endangered by Washington State. The National Marine Fisheries Service has the responsibility for the federal listing of anadromous fish (i.e., those which require both saltwater and freshwater to complete a life cycle). Upper-Columbia River steelhead and upper-Columbia River spring-run chinook salmon were listed as endangered in August 1998 and March 1999, respectively.

Several species of both plants and animals are under consideration for formal listing as candidate species by Washington State. There are 19 state-level candidate species of plants and animals (see Table F.2) and 42 plant species of concern (see Table F.3).

Table F.1. Federal- or Washington State-Listed Threatened (T) and Endangered (E) Species Occurring or Potentially Occurring on the Hanford Site

Common Name	Scientific Name	Federal	State
Plants			
Columbia milkvetch	*Astragalus columbianus*		T
Columbia yellowcress	*Rorippa columbiae*		T
Dwarf evening primrose	*Camissonia (= Oenothera) pygmaea*		T
Hoover's desert parsley	*Lomatium tuberosum*		T
Loeflingia	*Loeflingia squarrosa var. squarrosa*		T
Northern wormwood[a]	*Artemisia campestris borealis* var. *wormskioldii*		E
Umtanum desert buckwheat	*Eriogonum codium*		E
White Bluffs bladderpod	*Lesquerella tuplashensis*		E
White eatonella	*Eatonella nivea*		T
Fish			
Spring-run chinook	*Oncorhynchus tshawytscha*	E	
Steelhead	*Oncorhynchus mykiss*	E	
Birds			
Aleutian Canada goose[b]	*Branta canadensis leucopareia*	T	T
American white pelican	*Pelecanus erythrorhychos*		E
Bald eagle	*Haliaeetus leucocephalus*	T	T
Ferruginous hawk	*Buteo regalis*		T
Peregrine falcon[b]	*Falco peregrinus*	E	E
Sandhill crane	*Grus canadensis*		E
Western sage grouse[a]	*Centrocercus urophasianus phaios*		T
Mammals			
Pygmy rabbit[a]	*Brachylagus idahoensis*		E

(a) Potentially occurring.
(b) Incidental occurrence.

Table F.2. Washington State Candidate Animal Species Potentially Found on the Hanford Site

Common Name	Scientific Name
Molluscs	
Columbia pebble snail	*Fluminicola (= Lithoglyphus) columbiana*
Shortfaced lanx	*Fisherola (= Lanx) nuttalli*
Insects	
Columbia River tiger beetle[a]	*Cicindela columbica*
Juniper hairstreak	*Mitoura siva*
Silver-bordered bog fritillary	*Boloria selene atrocastalis*
Birds	
Burrowing owl	*Athene cunicularia*
Common loon	*Gavia immer*
Flammulated owl[b]	*Otus flammeolus*
Golden eagle	*Aquila chrysaetos*
Lewis' woodpecker[b]	*Melanerpes lewis*
Loggerhead shrike	*Lanius ludovicianus*
Merlin	*Falco columbarius*
Northern goshawk[b]	*Accipter gentilis*
Sage sparrow	*Amphispiza belli*
Sage thrasher	*Oreoscoptes montanus*
Reptiles	
Striped whipsnake[b]	*Masticophis taeniatus*
Mammals	
Merriam's shrew	*Sorex merriami*
Townsend's big-eared bat[a]	*Coryhorhinus townsendii*[c]
Washington ground squirrel[b]	*Spermophilus washingtoni*

(a) Probable, but not observed, on the Hanford Site.
(b) Reported, but seldom observed, on the Hanford Site.
(c) Formally known as *Plecotus townsendii*.

Table F.3. Washington State Plant Species of Concern Occurring on the Hanford Site

Common Name	Scientific Name	State Listing[a]
Annual paintbrush	*Castilleja exilis*	R1
Awned half chaff sedge	*Lipocarpha (= Hemicarpha) aristulata*	R1
Basalt milk-vetch	*Astragalus conjunctus var. rickardii*	R1
Bristly combseed	*Pectocarya setosa*	W
Brittle prickly-pear	*Opuntia fragilis*	R1
Canadian St. John's wort	*Hypericum majus*	S
Chaffweed	*Centunculus minimus*	R1
Columbia River mugwort	*Artemesia lindleyana*	W
Crouching milkvetch	*Astragalus succumbens*	W
Desert dodder	*Cuscuta denticulata*	S
Desert evening-primrose	*Oenothera cespitosa*	S
False pimpernel	*Lindernia dubia anagallidea*	R2
Fuzzytongue penstemon	*Penstemon eriantherus whitedii*	R1
Geyer's milkvetch	*Astragalus geyeri*	S
Grand redstem	*Ammannia robusta*	R1
Gray cryptantha	*Cryptantha leucophaea*	S
Great Basin gilia	*Gilia leptomeria*	R1
Hedge hog cactus	*Pediocactus simpsonii var. robustio nigrispinus*	R1
Kittitas larkspur	*Delphinium multiplex*	W
Miner's candle	*Cryptantha scoparia*	R1
Palouse thistle	*Cirsium brevifolium*	W
Piper's daisy	*Erigeron piperianus*	S
Robinson's onion	*Allium robinsonii*	W
Rosy balsamroot	*Balsamorhiza rosea*	W
Rosy pussypaws	*Calyptridium roseum*	S
Scilla onion	*Allium scilloides*	W
Shining flatsedge	*Cyperus bipartitus (rivularis)*	S
Small-flowered evening-primrose	*Camissonia (= Oenothera) minor*	R1
Small-flowered nama	*Nama densum var. parviflorum*	R1
Smooth cliffbrake	*Pellaea glabella simplex*	W
Snake River cryptantha	*Cryptantha spiculifera (= C. interrupta)*	S
Southern mudwort	*Limosella acaulis*	W
Stalked-pod milkvetch	*Astragalus sclerocarpus*	W
Suksdorf's monkey flower	*Mimulus suksdorfii*	S
Toothcup	*Rotala ramosior*	R1
Winged combseed	*Pectocarya linearis*	R1

The following species have been reported as occurring on the Hanford Site, but the known collections are questionable in terms of location or identification, and have not been recently collected on the Hanford Site.

Coyote tobacco	*Nicotiana attenuata*	S
Dense sedge	*Carex densa*	S
Few-flowered collinsia	*Collinsia sparsiflora var. bruciae*	S
Medic milkvetch	*Astragalus speirocarpus*	W
Palouse milkvetch	*Astragalus arrectus*	S
Thompson's sandwort	*Arenaria franklinii thompsonii*	R2

(a) S = Sensitive (i.e., taxa vulnerable or declining) and could become endangered or threatened without active management or removal of threats.
R1 = Taxa for which there are insufficient data to support listing as threatened, endangered, or sensitive (formerly monitor group 1).
R2 = Taxa with unresolved taxanomic questions (formerly monitor group 2).
W = Taxa that are more abundant and/or less threatened than previously assumed (formerly monitor group 3).

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Hanford Site Environmental Surveillance Data Report for Calendar Year 1998

L. E. Bisping - September 1999

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This disk contains data compiled by the Surface Environmental Surveillance Project during CY 1998. Refer to README file for further information.

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