

# 6.0 Groundwater and Vadose Zone



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The U.S. Department of Energy (DOE) has monitored groundwater on the Hanford Site since the 1940s to help determine what chemical and radiological contaminants have made their way into the groundwater. When regulatory requirements for groundwater monitoring increased in the 1980s, some overlap of efforts between various monitoring activities occurred. The DOE established the Groundwater Performance Assessment Project (groundwater project) in 1996 to improve the efficiency of monitoring activities and to assure protection of the public and the environment while improving the efficiency of monitoring activities. The groundwater project was designed to support all groundwater monitoring needs at the site, eliminate redundant sampling and analysis, and establish a cost-effective hierarchy for groundwater monitoring activities. An evaluation of groundwater quality beneath the Hanford Site is documented in an annual groundwater monitoring report (e.g., PNNL-14548).

Plutonium production activities on the Hanford Site produced contaminants that reached the Columbia River by moving down through the vadose zone, into the groundwater, and then into the river. The analysis of groundwater samples helps determine the potential effects that contaminants could have on human health and the environment. The DOE works with regulators, such as the U.S. Environmental Protection Agency (EPA) and Washington State Department of Ecology, to make groundwater cleanup decisions based on sound technical information and the technical capabilities available.

## 6.0.1 Highlights and Emerging Issues

The DOE's major accomplishments related to groundwater monitoring in 2003, and emerging issues of potential concern, are outlined in the following paragraphs.

### 6.0.1.1 Groundwater Monitoring Capabilities

**Groundwater Sampling** – Workers sampled 652 monitoring wells and 48 shoreline aquifer tubes in 2003 to determine the distribution and movement of contaminants in Hanford Site groundwater. Many of the wells were sampled multiple times during the year.

**Sample Analyses** – One thousand six hundred and twelve samples of Hanford groundwater were analyzed for chromium, 1,170 for nitrate, and 917 for tritium. Other constituents frequently analyzed for included carbon tetrachloride, technetium-99, and uranium, which were analyzed in approximately 580 samples. Summaries that account for the number of all groundwater wells monitored during 2003 according to groundwater interest area and monitoring purpose are provided in Tables 6.0.1 and 6.0.2, respectively.

**Adequacy of Monitoring Networks** – Groundwater levels in the 200 Areas continued to drop, causing eleven monitoring wells at the Hanford Site to go dry during 2003. Changes in groundwater flow or chemistry also impacted the effectiveness of monitoring networks.

**New Wells** – The DOE, Washington State Department of Ecology, and EPA agreed to revise a Tri-Party Agreement (Ecology et al. 1989) milestone to allow prioritization of drilling for *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) and *Atomic Energy Act of 1954* wells along with *Resource Conservation and Recovery Act* (RCRA) wells. During 2003, drillers completed seven new RCRA monitoring wells, nine CERCLA wells, and two wells for research on chromate bioremediation.



**Table 6.0.1. Summary of Hanford Site Groundwater Performance Assessment Project by Groundwater Interest Area, 2003**

	<u>Hanford Site</u>	<u>100-BC-5</u>	<u>100-FR-3</u>	<u>100-HR-3-D</u>	<u>100-HR-3-H</u>	<u>100-KR-4</u>	<u>100-NR-2</u>
Number of wells	700	24	40	67	52	43	37
Number of sampling events	1,749	24	47	277	130	154	58
Number of analyses	20,719	160	354	2,455	801	1,072	988
Number of results	60,510	577	1,407	4,609	1,731	2,776	2,164
Percent of non-detected results	48	42	45	22	27	35	38
	<u>1100-EM-1</u>	<u>200-BP-5</u>	<u>200-PO-1</u>	<u>200-UP-1</u>	<u>200-ZP-1</u>	<u>300-FF-5</u>	
Number of wells	46	101	82	66	91	51	
Number of sampling events	62	225	171	155	291	155	
Number of analyses	537	5,063	2,952	1,730	3,189	1,418	
Number of results	1,611	12,003	9,004	6,509	11,391	6,728	
Percent of non-detected results	55	46	50	49	50	73	

**Table 6.0.2. Summary of Hanford Site Groundwater Performance Assessment Project by Monitoring Purpose,<sup>(a)</sup> 2003**

	<u>Restoration<sup>(b)</sup></u>	<u>Waste Management<sup>(c)</sup></u>	<u>Environmental Surveillance<sup>(d)</sup></u>
Number of wells	433	230	274
Number of sampling events	1,132	681	685
Number of analyses	10,787	11,950	6,831
Number of results	32,509	34,635	19,638
Percent of non-detected results	48	48	47

(a) Because of the co-sampling between groundwater monitoring programs, the wells monitored, sampling events, analyses, results, and non-detectable results overlap between monitoring purposes.

(b) Wells associated with remediation activities.

(c) Wells sampled to determine impacts, if any, to a waste management unit (e.g., RCRA) on groundwater.

(d) Wells sampled to detect impacts, if any, of site operations on groundwater over the entire Hanford Site and adjacent offsite areas.

**River Shoreline Monitoring** – The DOE monitors aquifer sampling tubes near the Columbia River to track contaminants entering the river. Aquifer sampling tubes are driven into the Columbia River shoreline and used to collect shallow groundwater samples. In late 2003 and early 2004, the DOE installed additional tubes along the river shoreline in the 100-B/C, 100-K, 100-D, 100-H, 100-F, and 300 Areas.

## 6.0.1.2 Tracking Groundwater Contamination

**Site-Wide Tritium Plume** – Monitoring in 2003 indicated that the Hanford Site’s largest contaminant (tritium) plume is gradually decreasing in size and is not affecting Richland’s water-supply wells. The plume is expected to continue to shrink because of dispersion and radioactive decay (half-life of tritium is 12.35 years).

**Tritium in the 100-K Area** – Tritium concentrations increased in two wells near the KE Basin and in one well near the KW Basin in 2003. However, supporting data indicate that the increases were not due to new leakage from the basins. Investigations of tritium in the vicinity of a burial ground in the 100-K Area indicated the presence of a tritium source in the vadose zone along with an underlying tritium plume in the groundwater.

**Chromium in the 100-D Area** – Chromium levels continued to increase sharply in the central part of the 100-D Area, between the influences of two interim remedial action systems that operated during 2003. The DOE and the regulators will expand remedial measures to address this change.

**Carbon Tetrachloride Plume** – A carbon tetrachloride plume beneath the 200-West Area is gradually spreading at the 5-mg/L contour, but the high-concentration portion of the plume appears to be contained. In some monitoring wells, carbon tetrachloride concentrations were higher deep in the aquifer than near the water table. The data indicate that carbon tetrachloride contamination has moved considerable distances downgradient of the source area in deeper parts of the aquifer.

### 6.0.1.3 Groundwater Operable Units

**CERCLA Activities** – The groundwater project continued to monitor 11 operable units during 2003 (Figure 6.0.1). Pump-and-treat systems continued to operate at six of the operable units, an in situ remediation system continued to operate at one operable unit, and a soil-gas vapor extraction system continued to operate at one operable unit during 2003 (Figure 6.0.2).

**Interim Remedial Actions** – Pump-and-treat remediation systems continued to limit the spread of groundwater contamination in the 100 and 200 Areas. Since their inception, remedial measures have treated more than 7 billion liters (1.85 billion gallons) of groundwater to remove carbon tetrachloride, chromium, strontium-90, technetium-99, and uranium. The DOE is evaluating alternative technologies for strontium-90 remediation because no discernable changes in the distribution and concentration of strontium-90 in the aquifer have been observed since the pump-and-treat system began operating in 1995.

**Monitored Natural Attenuation** – Average trichloroethene concentrations in compliance wells in the 1100-EM-1 Operable Unit (Figure 6.0.1) remained below the 5- $\mu$ g/L drinking water standard for the third year in a row. This contaminant has been attenuating naturally. Average trichloroethene concentrations also remained below the drinking water standard in the 300-FF-5 Operable Unit, but uranium is slow to attenuate.

**CERCLA Sampling and Analysis Plans** – The DOE released new plans (DOE/RL-2003-38; DOE/RL-2003-49; DOE/RL-2001-49) for long-term groundwater monitoring in the 100-BC-5, 100-FR-3, and 200-BP-5 Operable Units (Figure 6.0.1) in 2003.

**Working Toward Final Remediation Decisions** – Final decisions for groundwater remediation have been made

only for the 1100-EM-1 Operable Unit. During 2003, the DOE and the regulators began the process to determine what information is needed to make final decisions for the 100-BC-5, 100-FR-3, 200-BP-5, 200-UP-1, 200-ZP-1, 200-PO-1, and 300-FF-5 Operable Units (Figure 6.0.1).

### 6.0.1.4 Waste Facility Monitoring

**RCRA Activities** – The groundwater project continued to monitor 24 RCRA sites in 2003 (Figure 6.0.3). Monitoring provided no evidence of new contamination from existing RCRA sites. Seven sites continued to be monitored under assessment programs (i.e., assessment of contaminants that have been detected in groundwater), and two under corrective action (i.e., monitoring during groundwater cleanup activities).

**Evaluation of Alternative RCRA Statistical Methods** – The groundwater project completed data collection for alternative statistical methods at the 216-B-3 pond and 316-5 process trenches. The alternative statistical methods, which are sensitive to sudden shifts in mean concentrations for each individual well, are used to determine long-term trends.

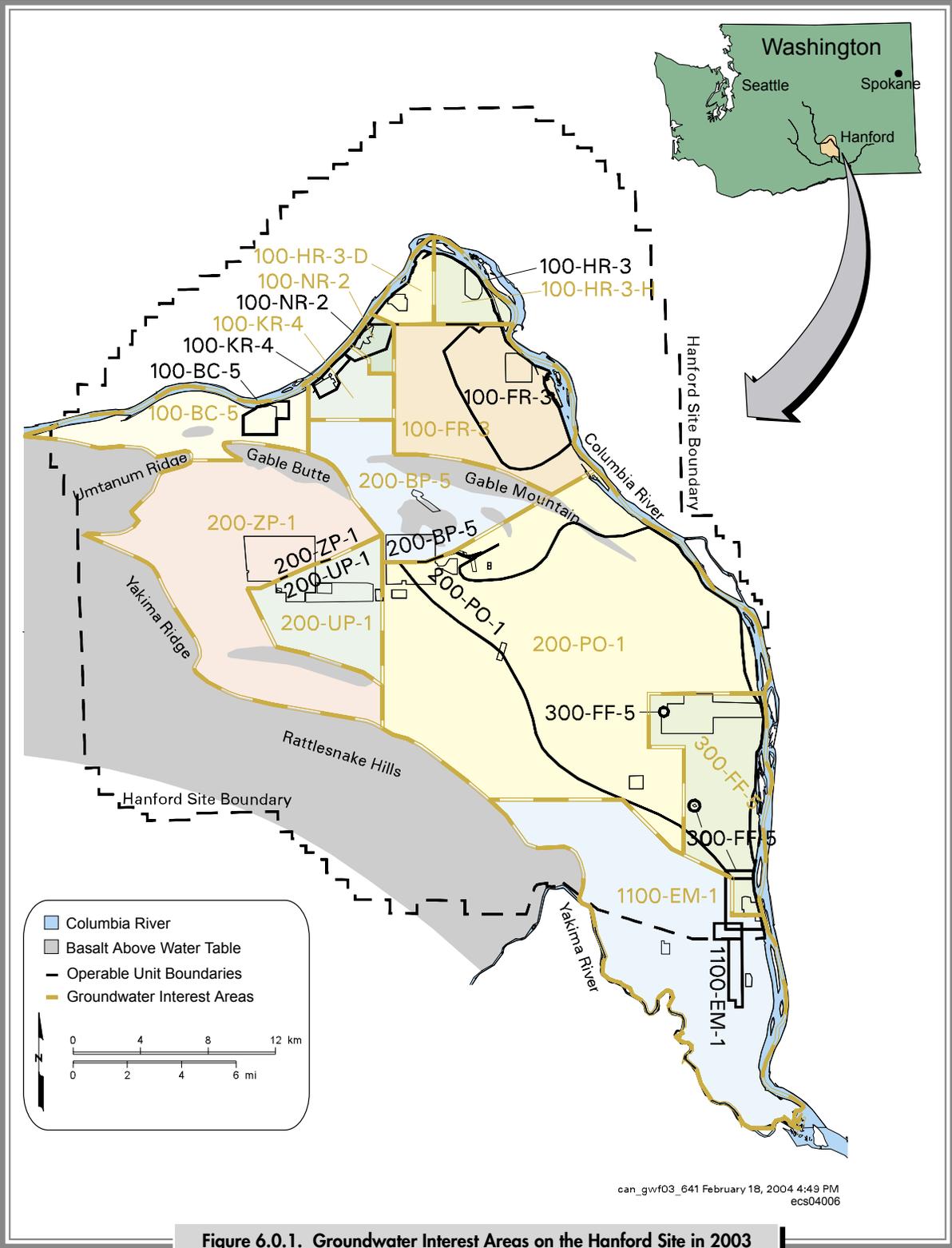
**Other Regulated Units** – Four waste disposal sites regulated under state requirements other than the RCRA were monitored in 2003. Monitoring results at the following sites remained within permit limits: 400 Area process ponds, State-Approved Land Disposal Site (located north of 200-West Area), and 200 Area Treated Effluent Disposal Facility (located east of 200-East Area). At the Solid Waste Landfill, specific conductance, pH, chloride, and sulfate exceeded their background threshold levels in one or more samples.

**Environmental Restoration Disposal Facility** – Concentrations of some constituents of concern were elevated in groundwater beneath this facility in 2003, but reflect migration of contaminant plumes from sources in the 200-West Area. The Environmental Restoration Disposal Facility is located southeast of the 200-West Area.

### 6.0.1.5 Groundwater Modeling

**Site-Wide Groundwater Model** – During 2003, development of the site-wide groundwater model focused on calibration based on an alternative conceptual model. The alternative conceptual model defines zones within the





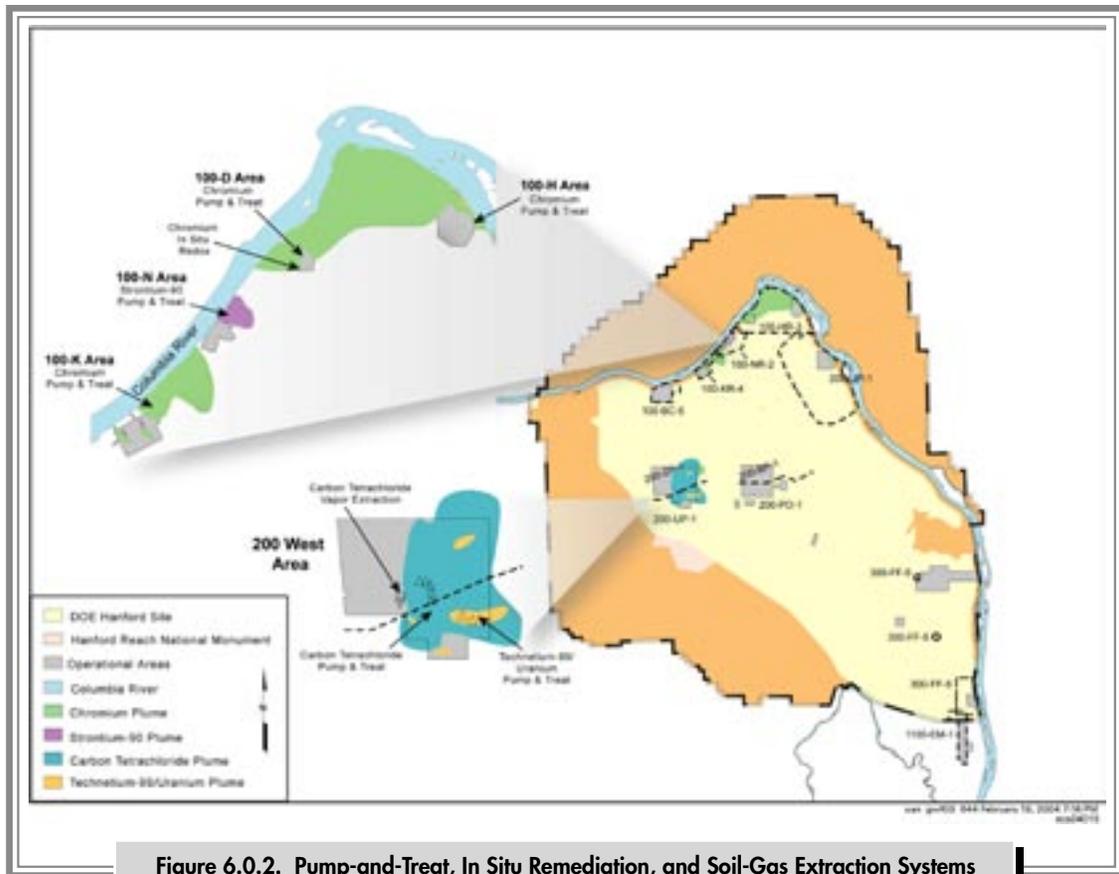


Figure 6.0.2. Pump-and-Treat, In Situ Remediation, and Soil-Gas Extraction Systems Operating on the Hanford Site in 2003

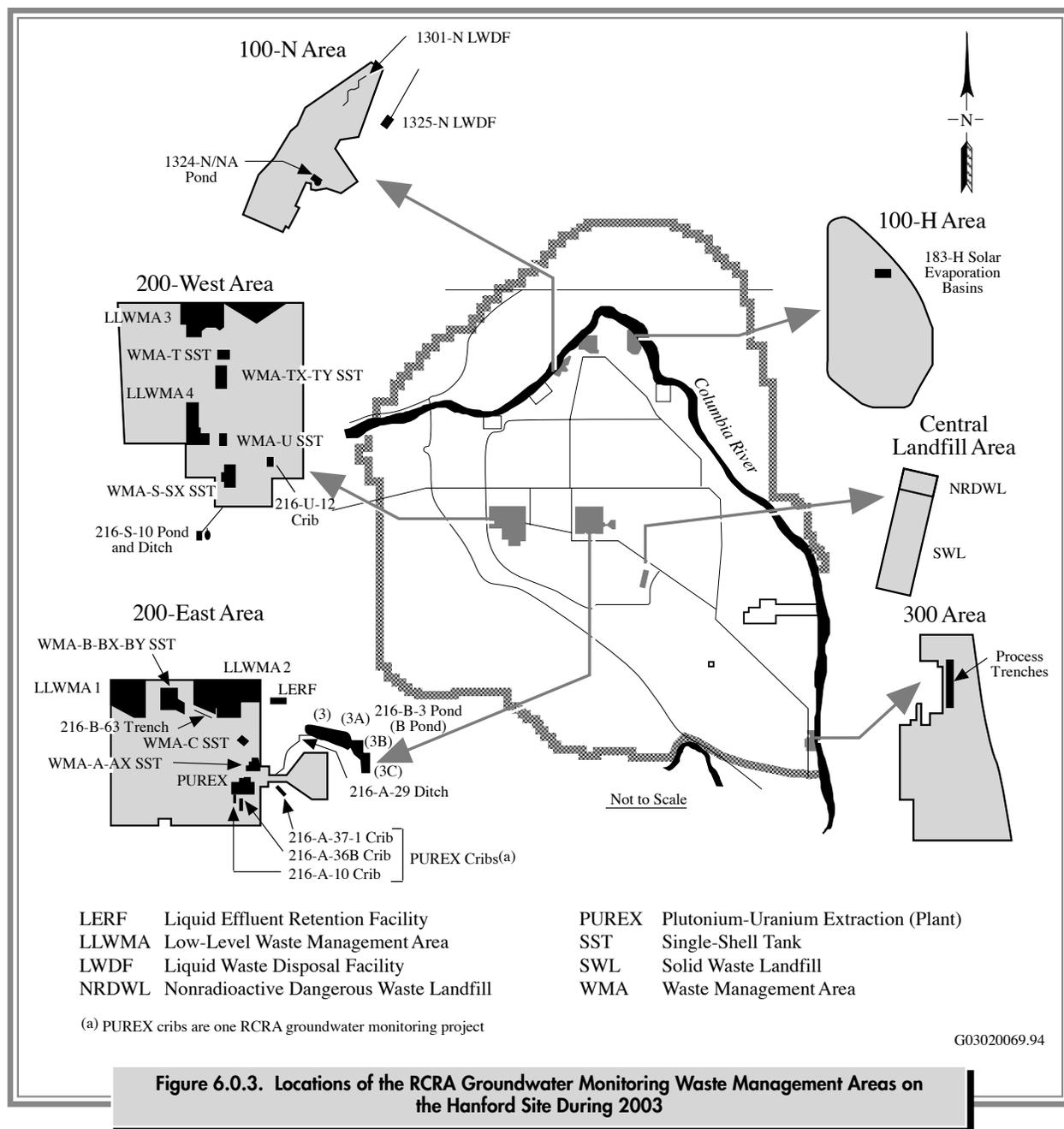
most important transmissive hydrogeologic units based on geologic information, knowledge of depositional environments, aquifer testing information, and hydraulic head responses in wells. The site-wide model was developed to improve predictions of contaminant transport and to evaluate uncertainty in model results.

**System Assessment Capability** – The System Assessment Capability is an integrated system that links computer models and databases designed to simulate the movement of contaminants from waste sites through the vadose zone and groundwater. The computer models include an atmospheric transport module, a vadose zone module, and groundwater flow and transport module. In 2003, the model was updated; an atmospheric transport module was added and newer versions of groundwater flow and transport modules were incorporated into the system.

## 6.0.2 Groundwater Flow and Movement

Groundwater in the unconfined aquifer generally flows from west to east across the Hanford Site to discharge areas along the Columbia River. The direction of groundwater flow is inferred from water-table elevations, barriers to flow (e.g., basalt or mud units at the water table), and the distribution of contaminants.

General directions of groundwater flow are illustrated on the map for March 2003 (Figure 6.0.4). Beneath the reactor areas, groundwater flows generally toward the Columbia River. Farther inland, north of Gable Mountain, flow is toward the northeast and east. Groundwater flows eastward beneath the 200 Areas and then flows to the southeast or north through the gap between Gable Butte and Gable Mountain. Groundwater converges on the 300 Area from the northwest, west, and southwest and

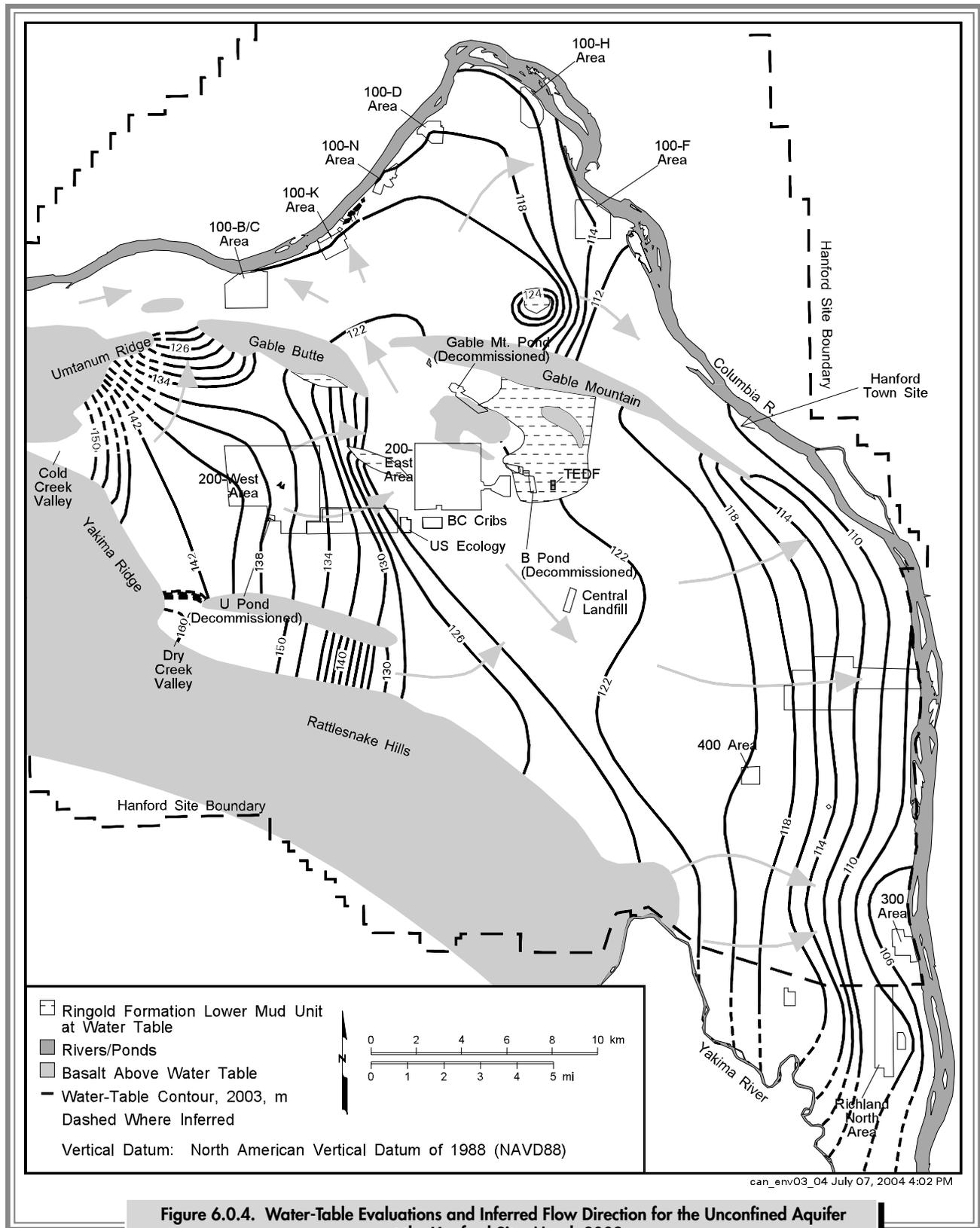


discharges into the Columbia River to the east. Groundwater in the Richland North Area flows generally eastward to the Columbia River.

The natural pattern of groundwater flow was altered during the Hanford Site's operating years by the formation of mounds in the water table. The mounds were created by the discharge of large volumes of wastewater to the ground and were present in each reactor area and beneath the 200 Areas. Since effluent disposal decreased significantly in the 1990s, these mounds are disappearing.

East of the 200-East Area, a fine-grained confining unit creates a barrier to movement in the surrounding unconfined aquifer. Beneath this confining unit, the uppermost aquifer is a permeable unit in the Ringold Formation. Groundwater flow in this confined aquifer still is influenced by a recharge mound.

Groundwater in the upper basalt-confined aquifer generally flows from west to east across the Hanford Site, up through the unconfined aquifer, and into the Columbia River. Vertical gradients between the basalt-confined



**Figure 6.0.4. Water-Table Evaluations and Inferred Flow Direction for the Unconfined Aquifer at the Hanford Site, March 2003**

aquifer and the unconfined aquifer are upward on most of the Hanford Site. Therefore, there is little potential for contaminants to migrate from the unconfined aquifer into the basalt-confined aquifer, where it could move offsite. Downward gradients are measured beneath the west portion of the Hanford Site and north and east of the Columbia River.

## 6.0.3 Groundwater Monitoring and Remediation

This section summarizes results of Hanford Site groundwater monitoring for various requirements, including RCRA and CERCLA monitoring. Progress on groundwater remediation also is summarized.

### 6.0.3.1 Overview

The DOE has developed a plan (DOE/RL-2002-68) to accelerate cleanup of Hanford's groundwater, which will return it to its beneficial use where practicable or will at least prevent further degradation. Specific results that can be expected using the accelerated plan include (a) remediating waste sites that pose the highest risk to groundwater, (b) shrinking contaminated areas, (c) reducing groundwater recharge, (d) remediating (cleaning up) groundwater, and (e) monitoring groundwater contaminant levels. Figures 6.0.5 and 6.0.6 show the distribution of nine principal groundwater contaminant plumes.

The total area of contaminant plumes with contaminant concentrations exceeding drinking water standards was estimated to be approximately 190 square kilometers (73 square miles) during 2003 (Table 6.0.3). This area occupies 12.5% of the total area of the Hanford Site. The tritium and iodine-129 plumes have the largest areas with concentrations exceeding drinking water standards. The dominant plumes had sources in the 200-East Area and extend toward the east and southeast. Technetium-99 exceeds standards in smaller plumes, one of which has moved northward from the 200-East Area. Uranium is less mobile than tritium, iodine-129, or technetium-99; small plumes are found in the 100-H, 200-East, 200-West, and 300 Areas. Strontium-90 is not very mobile in groundwater, but it exceeds standards in each of the 100 Areas except the 100-D Area. Other radionuclides including cesium-137, cobalt-60, and plutonium are even less mobile

in the subsurface and rarely exceed drinking water standards in Hanford Site groundwater.

Nitrate is a widespread contaminant in Hanford Site groundwater, with plumes originating from the 100 and 200 Areas and from offsite industry and agriculture. Carbon tetrachloride forms a large plume beneath the 200-West Area, the most widespread organic contaminant on the Hanford Site. Other organic contaminants include chloroform and trichloroethene. Chromium contamination underlies the 100-K, 100-D, and 100-H Areas. Local plumes of chromium contamination also are present in the 200 Areas.

Contaminant plumes with concentrations exceeding the DOE derived concentration guides occur in isolated areas. The contaminants at levels above the DOE derived concentration guides during 2003 were strontium-90, technetium-99, tritium, and uranium.

Summaries of maximum concentrations for the most widespread contaminants are presented in Table 6.0.4 and by monitoring purpose in Table 6.0.5. As expected, most of the maximum concentrations were detected in the 100 and 200 Areas because these areas contain the largest number of waste sites that have affected groundwater quality. For each monitoring purpose, the maximum concentrations detected were greater than the drinking water standards for all of the most widespread contaminants listed in Table 6.0.5. A list of drinking water standards for these contaminants is provided in Table 6.0.3.

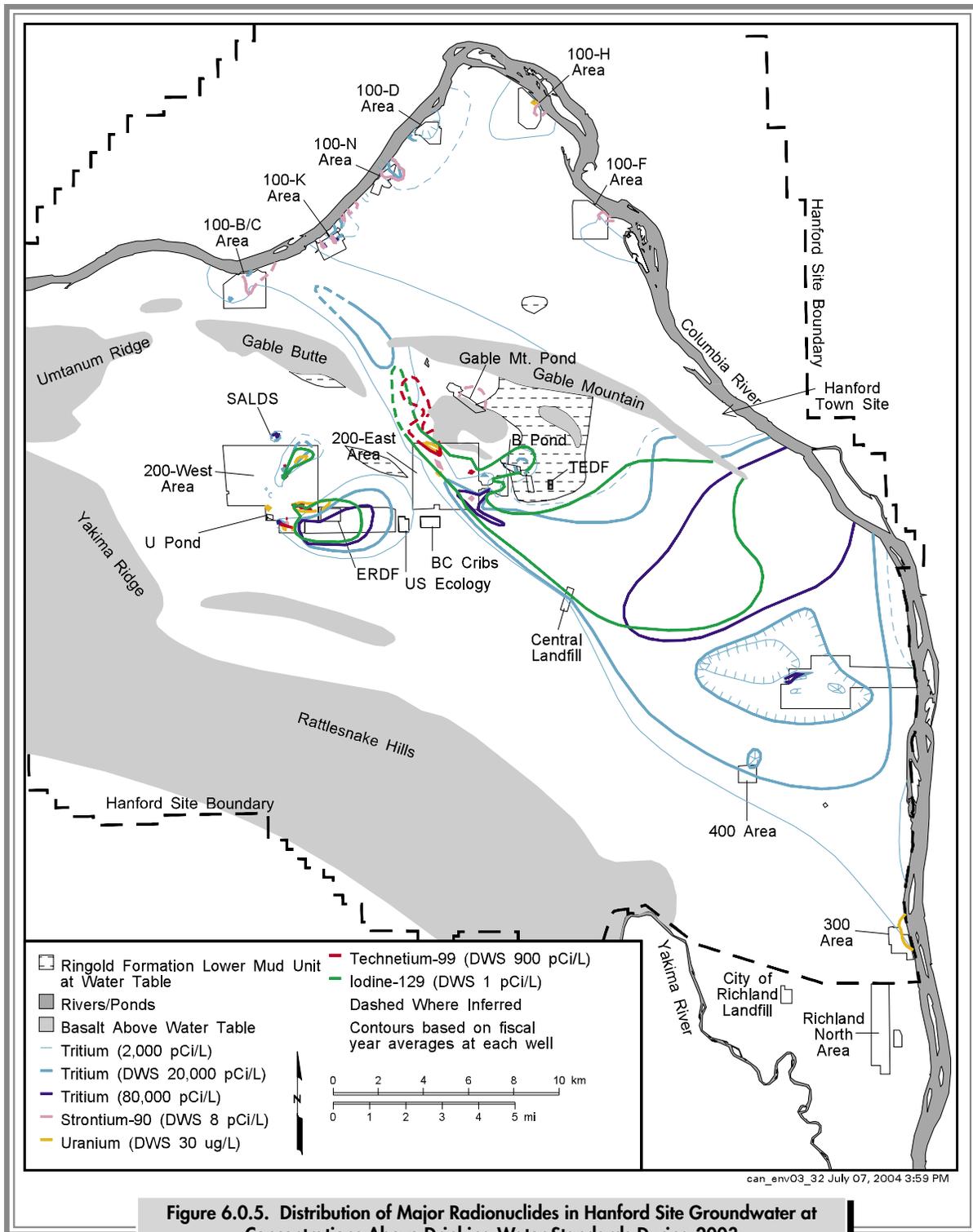
The following text discusses groundwater contamination, monitoring, and remediation in each of the 11 groundwater operable units and in the confined aquifers.

### 6.0.3.2 100-BC-5 Operable Unit

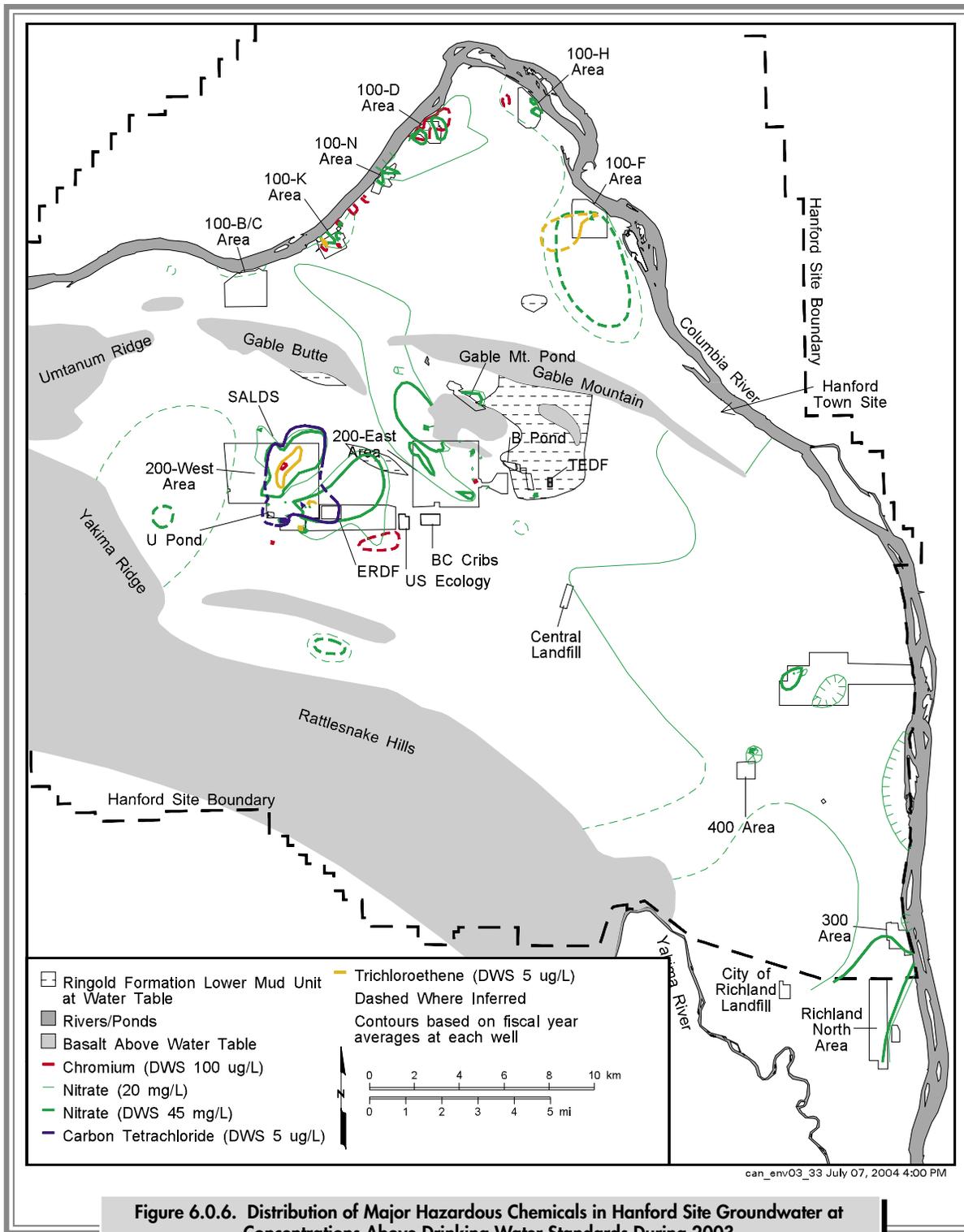
The 100-BC-5 Operable Unit includes the groundwater beneath the 100-B/C Area (Figure 6.0.1). Most of the groundwater contamination in this unit is found in the north portion of the area beneath former waste trenches and retention basins. During 2003, tritium and strontium-90 exceeded drinking water standards in several wells. Nitrate and chromium were somewhat elevated, but have been below drinking water standards in recent years.

The EPA approved a new sampling and analysis plan (DOE/RL-2003-38) for this unit at the end of September





**Figure 6.0.5. Distribution of Major Radionuclides in Hanford Site Groundwater at Concentrations Above Drinking Water Standards During 2003**



**Table 6.0.3. Areas of Contaminant Plumes on the Hanford Site at Levels Above Drinking Water Standards, 2003**

<u>Constituent</u>	<u>Drinking Water Standard</u>	<u>Area (km<sup>2</sup>)</u>	<u>Constituent</u>	<u>Drinking Water Standard</u>	<u>Area (km<sup>2</sup>)</u>
Tritium	20,000 pCi/L	136	Filtered chromium	100 µg/L	2.6
Iodine-129	1 pCi/L	75.5	Strontium-90	8 pCi/L	2.6
Nitrate	45 mg/L	36.2	Technetium-99	900 pCi/L	2.3
Carbon tetrachloride	5 µg/L	10.6	Total uranium	30 µg/L	1.4
Trichloroethene	5 µg/L	3.4	Combined plumes		190 <sup>(a)</sup>

(a) Total reflects some overlap of contaminant plumes.

1 pCi/L = 0.037 Bq/L.

1 µg/L = 0.001 ppm.

1 mg/L = 1 ppm.

**Table 6.0.4. Summary of Maximum Contaminant Concentrations in Hanford Site Groundwater by Groundwater Interest Area, 2003**

	<u>Hanford Site</u>	<u>100-BC-5</u>	<u>100-FR-3</u>	<u>100-HR-3-D</u>	<u>100-HR-3-H</u>	<u>100-KR-4</u>	<u>100-NR-2</u>
Tritium (pCi/L)	3,620,000	21,900	4,360	25,200	5,750	1,270,000	31,400
Iodine-129 (pCi/L)	36.7	NA <sup>(a)</sup>	NA	NA	NA	NA	NA
Nitrate (mg/L)	2,160	27.9	104	74.4 N	192	195	228
Carbon tetrachloride (µg/L)	5,500	ND <sup>(b)</sup>	ND	NA	NA	ND	ND
Trichloroethene (µg/L)	26	NA	19	NA	NA	10	ND
Filtered chromium (µg/L)	5,440	46	97.8	5,440	123	542	168
Strontium-90 (pCi/L)	8,000	98.9	11.3	8.2	29.6	2,270	8,000
Technetium-99 (pCi/L)	188,000	109	NA	ND	485	117	ND
Total uranium (µg/L)	1,190	NA	NA	7.6	54.3	NA	NA
	<u>1100-EM-1</u>	<u>200-BP-5</u>	<u>200-PO-1</u>	<u>200-UP-1</u>	<u>200-ZP-1</u>	<u>300-FF-5</u>	
Tritium (pCi/L)	251	27,600	676,000	634,000	2,170,000	3,620,000	
Iodine-129 (pCi/L)	ND	5.3	11.9	35.3	36.7	ND	
Nitrate (mg/L)	224 C	660 N	125	1,930 N	2,160	134 C	
Carbon tetrachloride (µg/L)	ND	ND	0.29	690	5,500	0.35	
Trichloroethene (µg/L)	3.1	ND	0.88 J	11	26	4	
Filtered chromium (µg/L)	ND	54.9	2,510	209	592	7.3	
Strontium-90 (pCi/L)	ND	5,680 B	20.8	35	1.3 B	4	
Technetium-99 (pCi/L)	27	9,740	13,100	188,000	14,300 N	319	
Total uranium (µg/L)	18 B	554	3.2	1,190	367	178	

(a) Not analyzed.

(b) Not detected.

B = Detected at a value less than contract required detection limit.

C = Analyte detected in both the sample and the associated quality control blank.

J = Reported value is an estimate.

N = Spike sample recovery is outside control limits.

**Table 6.0.5. Summary of Maximum Contaminant Concentrations in Hanford Site Groundwater by Monitoring Purpose, 2003**

	<u>Restoration</u>	<u>Waste Management</u>	<u>Environmental Surveillance</u>
Tritium (pCi/L)	3,620,000	2,170,000	3,620,000
Iodine-129 (pCi/L)	35.3	36.7	6.4
Nitrate (mg/L)	2,160	2,160	660 N
Carbon tetrachloride (µg/L)	5,500	3,400 N	2,200
Trichloroethene (µg/L)	26	15	10
Filtered chromium (µg/L)	5,440	2,510	5,440
Strontium-90 (pCi/L)	8,000	1,200	8,000
Technetium-99 (pCi/L)	18,200	188,000	9,740
Total uranium (µg/L)	1,190	554	276

N = Spike sample recovery is outside control limits.

2003. The new plan, which was implemented at the end of calendar year 2003, revises the monitoring program slightly and calls for the addition of more aquifer sampling tubes to monitor contaminants near the Columbia River. There is no active groundwater remediation in the 100-B/C Area.

### 6.0.3.3 100-KR-4 Operable Unit

The principal groundwater issues in the 100-KR-4 Operable Unit include (a) chromium contamination associated with past liquid waste disposal to a former infiltration trench near the Columbia River, (b) monitoring near the active fuel storage basins, which have contaminated groundwater in the past with tritium, and (c) tritium associated with a waste burial ground. In addition to chromium and tritium, constituents of concern in this unit include carbon-14, strontium-90, technetium-99, nitrate, and trichloroethene.

**CERCLA Interim Action.** A pump-and-treat system operates as a CERCLA interim action to reduce the amount of chromium entering the Columbia River at the 100-K Area (Figure 6.0.7). An interim action is a temporary remedy for groundwater cleanup before the final decision is made for cleanup. One new extraction well and one new monitoring well were installed in 2003. Also, an existing monitoring well (well 199-K-126) was converted to an extraction well.

Chromium concentrations appear to be decreasing with time as a result of pump-and-treat operations and the attenuation of the plume by natural processes, such as dispersion.

Concentrations remained above the remediation goal (22 µg/L) in most of the compliance wells, however.

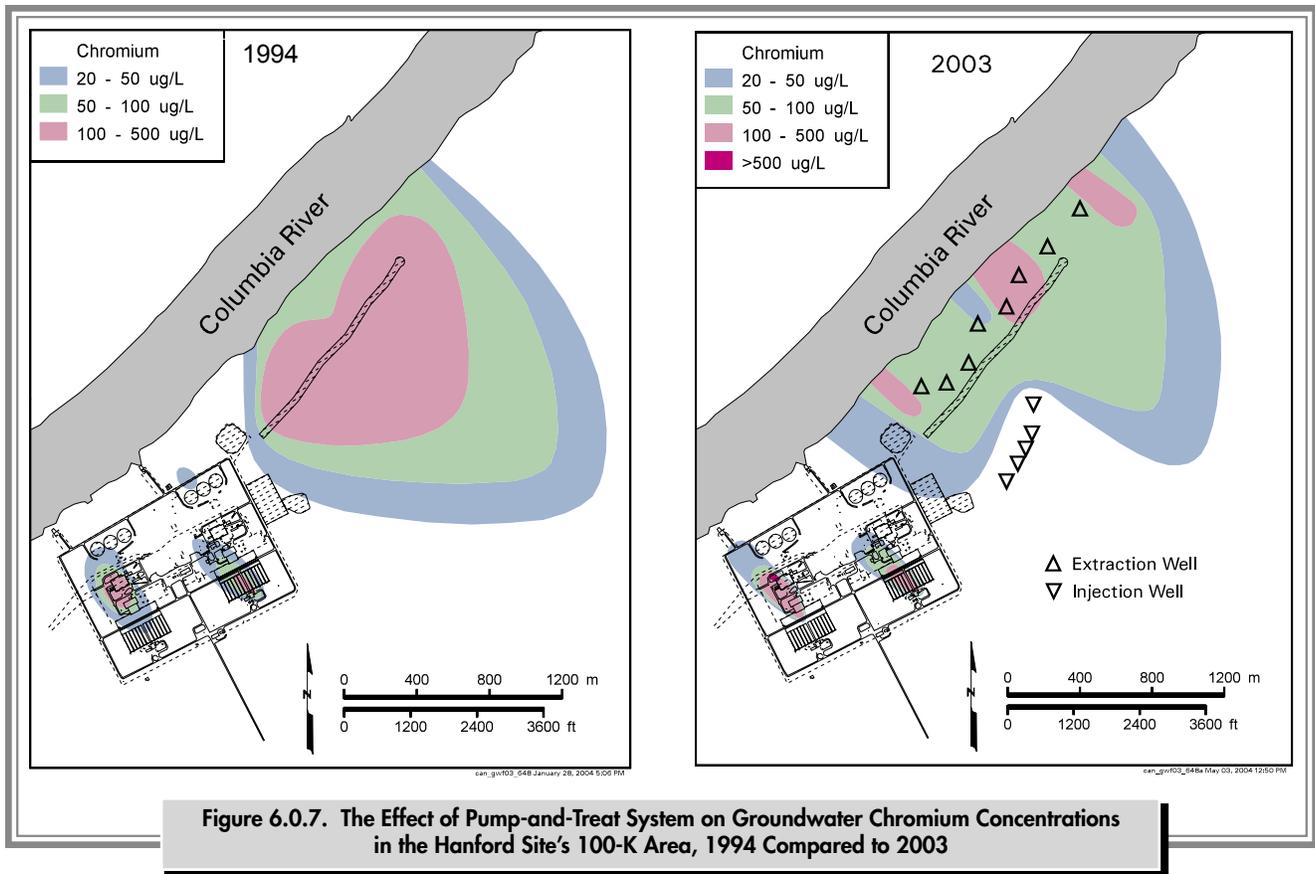
**K Basins.** Tritium concentrations increased sharply during 2003 in several monitoring wells near the 100-K Area basins. The locations of the wells, groundwater flow direction, and concentrations of co-contaminants indicate the increases in tritium were caused by infiltration of water through former waste disposal cribs and do not represent new leakage from the fuel storage basins.

Results of a soil-gas survey conducted near a 100-K Area burial ground during 2003 indicated the presence of tritium in the vadose zone as well as in the underlying groundwater. The data suggest the burial ground is a likely tritium source.

### 6.0.3.4 100-NR-2 Operable Unit

The primary groundwater contaminant in the 100-N Area is strontium-90, which originated at two former liquid waste disposal cribs. The extent of the strontium-90 plume has changed little in over 12 years; however, concentrations increased during the 1990s because of changing water levels and the end of effluent discharge to the cribs. Tritium also was present in waste discharged to the 100-N Area cribs. Tritium concentrations in groundwater beneath the 100-N Area are declining, and the plume is shrinking. Nitrate, sulfate, and petroleum hydrocarbons also are present in 100-N Area groundwater.





**CERCLA Interim Action.** A pump-and-treat system in the 100-N Area operated to reduce the movement of strontium-90 toward the Columbia River (Figure 6.0.8). Since strontium-90 binds to sediment grains, the pump-and-treat system is not an effective way to remove strontium-90 from the aquifer. Concentrations remained far above the 8 pCi/L (0.3 Bq/L) drinking water standard in most 100-N Area monitoring wells in 2003. The DOE is investigating alternative methods for remediation of the strontium-90 plume in this area.

**116-N-1, 116-N-3, 120-N-1, and 120-N-2 (1301-N, 1325-N, 1324-N/NA) Facilities.** Four RCRA units are located in the 100-N Area. During 2003, RCRA monitoring indicated that these sites were not contaminating groundwater with non-radioactive, hazardous constituents. However, the former 120-N-1 percolation pond added sulfate, a non-hazardous constituent, to the groundwater.

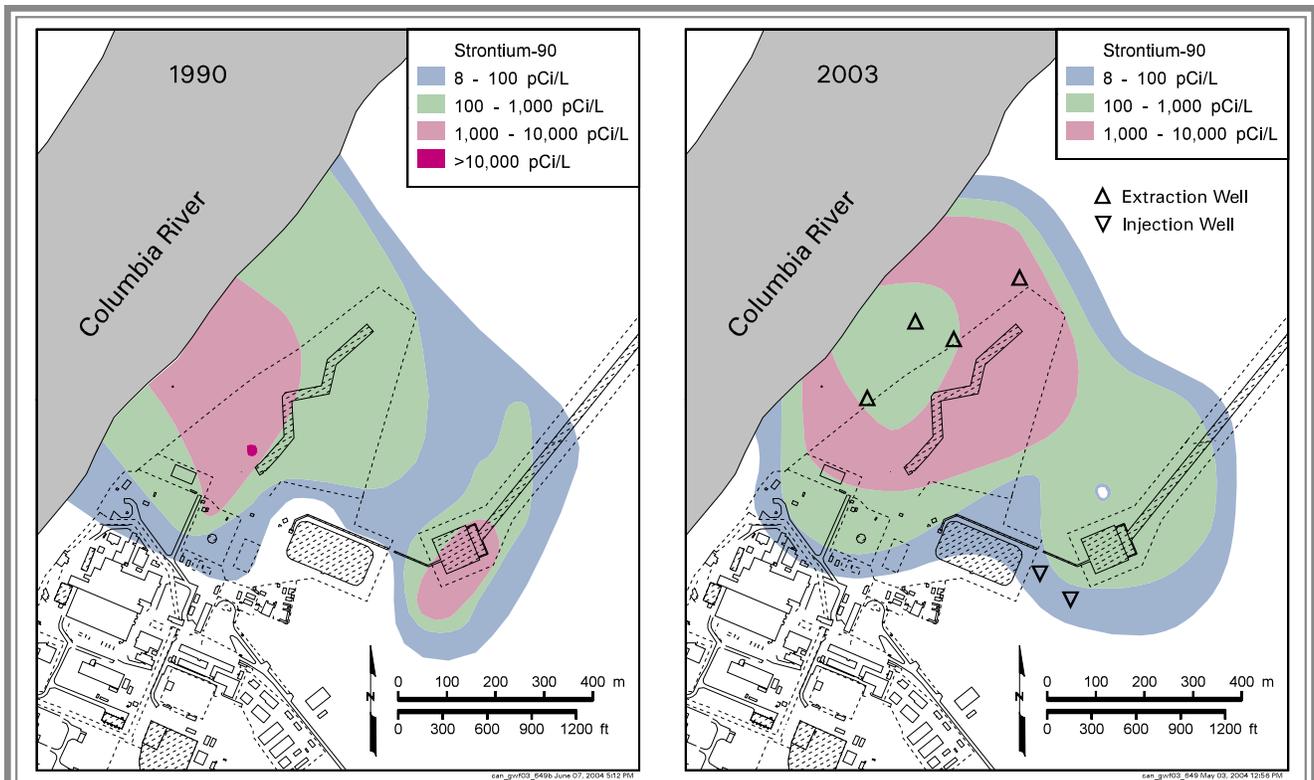
### 6.0.3.5 100-HR-3-D Operable Unit

The 100-HR-3 Operable Unit underlies the 100-D and 100-H Areas and the region between. Hexavalent

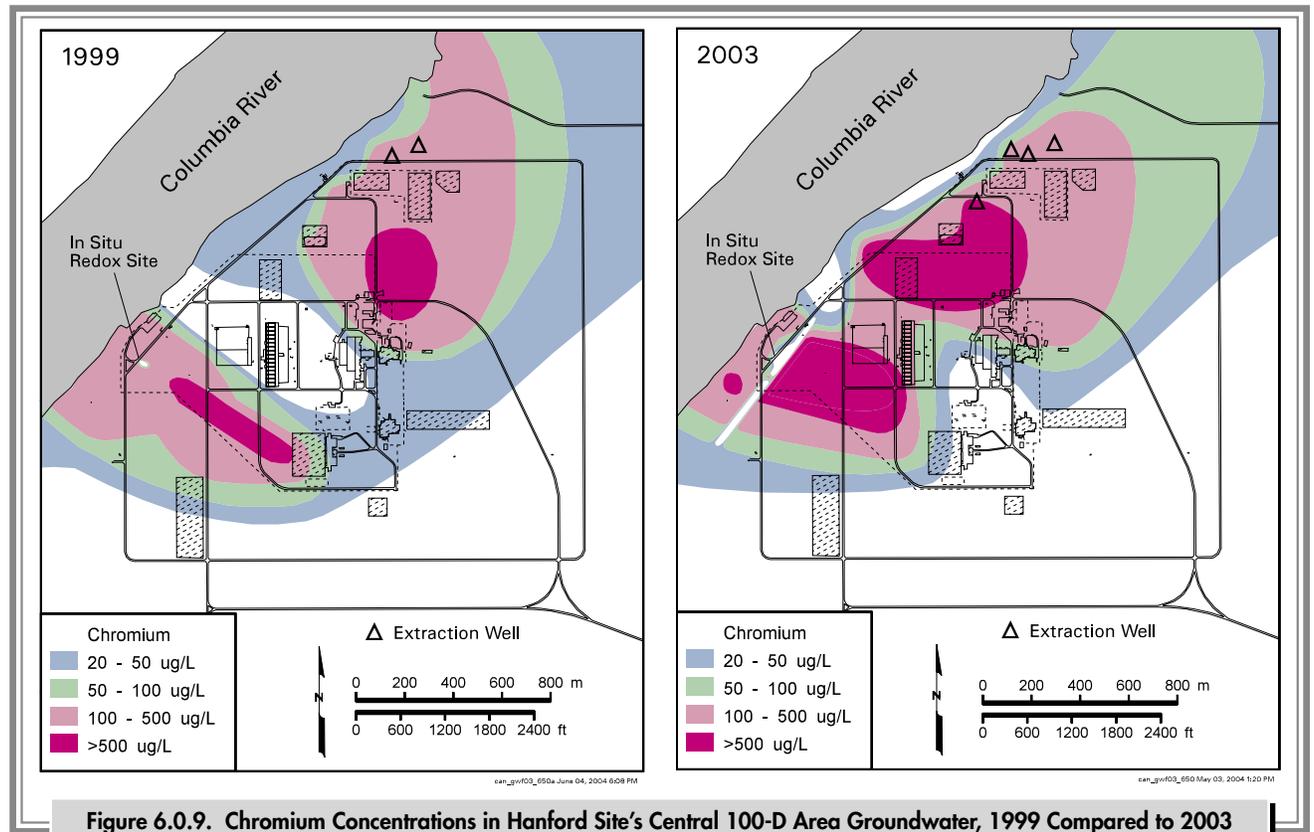
chromium is the primary contaminant of concern in the 100-D Area. The source of this contaminant was sodium dichromate added to reactor cooling water to inhibit corrosion, which was discharged to cribs and ditches. Chromium is distributed in two plumes (north and southwest) that have merged in recent years. Other contaminant plumes in this unit include tritium, nitrate, and sulfate.

**CERCLA Interim Actions.** The north chromium plume is the target of a pump-and-treat system, which is designed to reduce the amount of chromium entering the Columbia River (Figure 6.0.9). During 2003, concentrations remained above the remediation goal (22 µg/L) in compliance wells. The southwest chromium plume is being remediated with an in situ system that immobilizes chromium in the aquifer. Chromium concentrations down-gradient of the remediation system have declined in some wells and Columbia River shoreline aquifer tubes; however, levels remained above the remediation goal (20 µg/L).

During 2003, chromium concentrations increased in the central 100-D Area, bypassing both remediation systems.



**Figure 6.0.8. Strontium-90 Concentrations in the Hanford Site's 100-N Area Groundwater, 1990 Compared to 2003**



**Figure 6.0.9. Chromium Concentrations in Hanford Site's Central 100-D Area Groundwater, 1999 Compared to 2003**

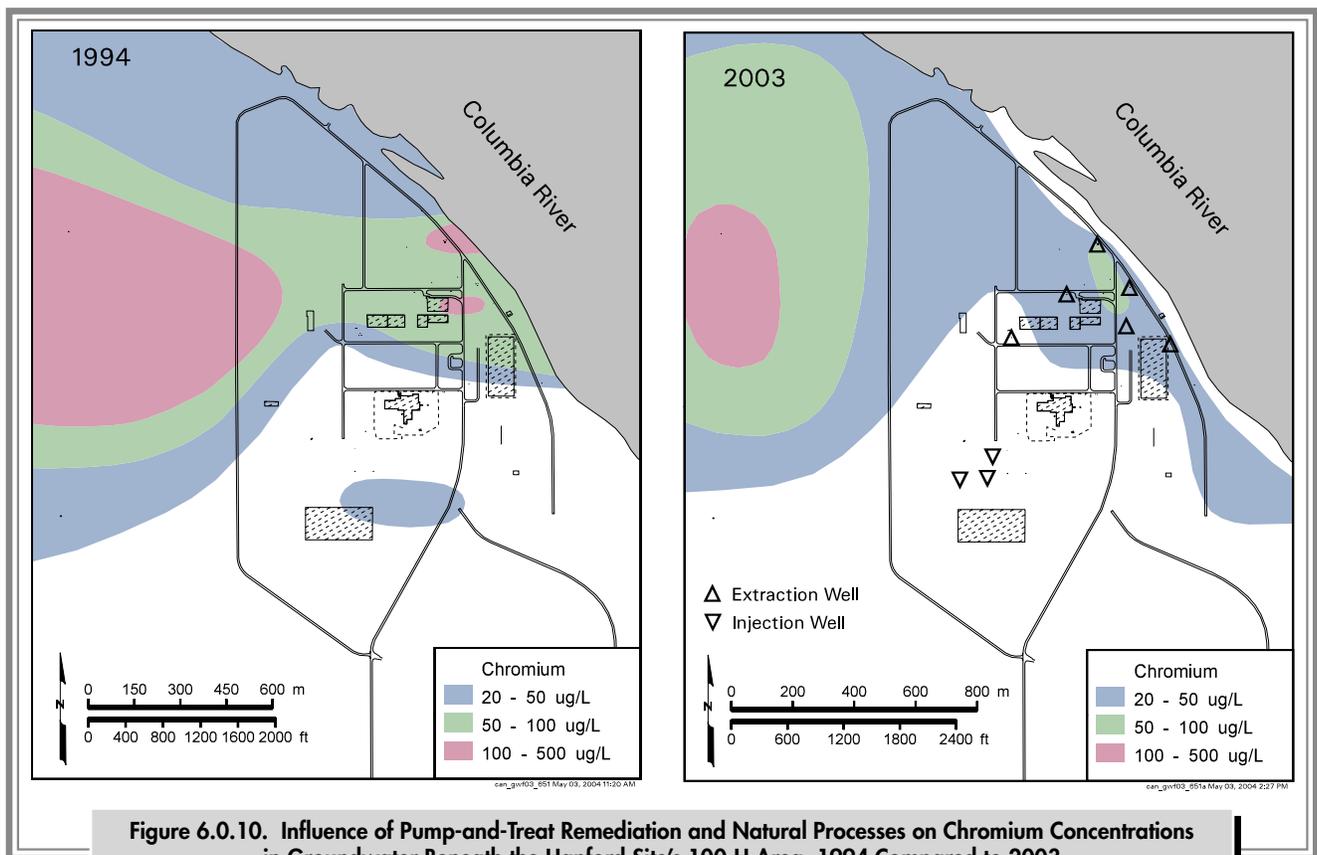
The DOE and regulators are working together to expand the remediation systems so they intercept the changing plume.

### 6.0.3.6 100-HR-3-H Operable Unit

The east part of the 100-HR-3 Operable Unit underlies the 100-H Area. Hexavalent chromium is the primary groundwater constituent of concern, but its plume is smaller and concentrations are lower than in the 100-D Area. Nitrate also is elevated, but concentrations have declined from their peak levels. Strontium-90 exceeds the drinking water standard beneath former waste water retention basins. Technetium-99 and uranium are elevated in a small area.

**CERCLA Interim Action.** The chromium plume is the target of a pump-and-treat system. Chromium concentrations have decreased in recent years due to remediation and natural processes (Figure 6.0.10). However, concentrations in some compliance wells in 2003 remained above the remediation goal (22 µg/L).

**116-H-6 (183-H) Evaporation Basins.** These former basins are the only RCRA site in the 100-H Area. Leakage from the basins contaminated groundwater with chromium, nitrate, technetium-99,<sup>(a)</sup> and uranium. The 183-H evaporation basins were closed in 1995. The site is being monitored during the post-closure period to track contaminant trends during the operation of the CERCLA interim action (pump-and-treat system) for chromium.



**Figure 6.0.10. Influence of Pump-and-Treat Remediation and Natural Processes on Chromium Concentrations in Groundwater Beneath the Hanford Site's 100-H Area, 1994 Compared to 2003**

- (a) Source, special nuclear, and by-product materials, as defined in the *Atomic Energy Act of 1954*, are regulated at DOE facilities exclusively by the DOE acting pursuant to its *Atomic Energy Act of 1954* authority. These materials are not subject to regulation by the state of Washington. All information contained herein and related to, or describing materials regulated by the *Atomic Energy Act of 1954* and processes in any manner, may not be used to create conditions or other restrictions set forth in any permit, license, order, or any other enforceable instrument. The DOE asserts that pursuant to the *Atomic Energy Act of 1954*, it has sole and exclusive responsibility and authority to regulate source, special nuclear, and by-product materials at DOE-owned nuclear facilities. Information contained herein on radionuclides is provided for process description purposes only.

### 6.0.3.7 100-FR-3 Operable Unit

Nitrate exceeds the drinking water standard in groundwater beneath much of the 100-F Area and the downgradient region. Other groundwater contaminants in this unit include strontium-90 and trichloroethene.

The EPA approved a new sampling and analysis plan (DOE/RL-2003-49) at the end of September 2003. The new plan, which was implemented in late 2003, revised the monitoring program slightly and called for the addition of more aquifer sampling tubes to monitor contaminants along the shoreline of the Columbia River. There is no active groundwater remediation in the 100-FR-3 Operable Unit (Figure 6.0.1).

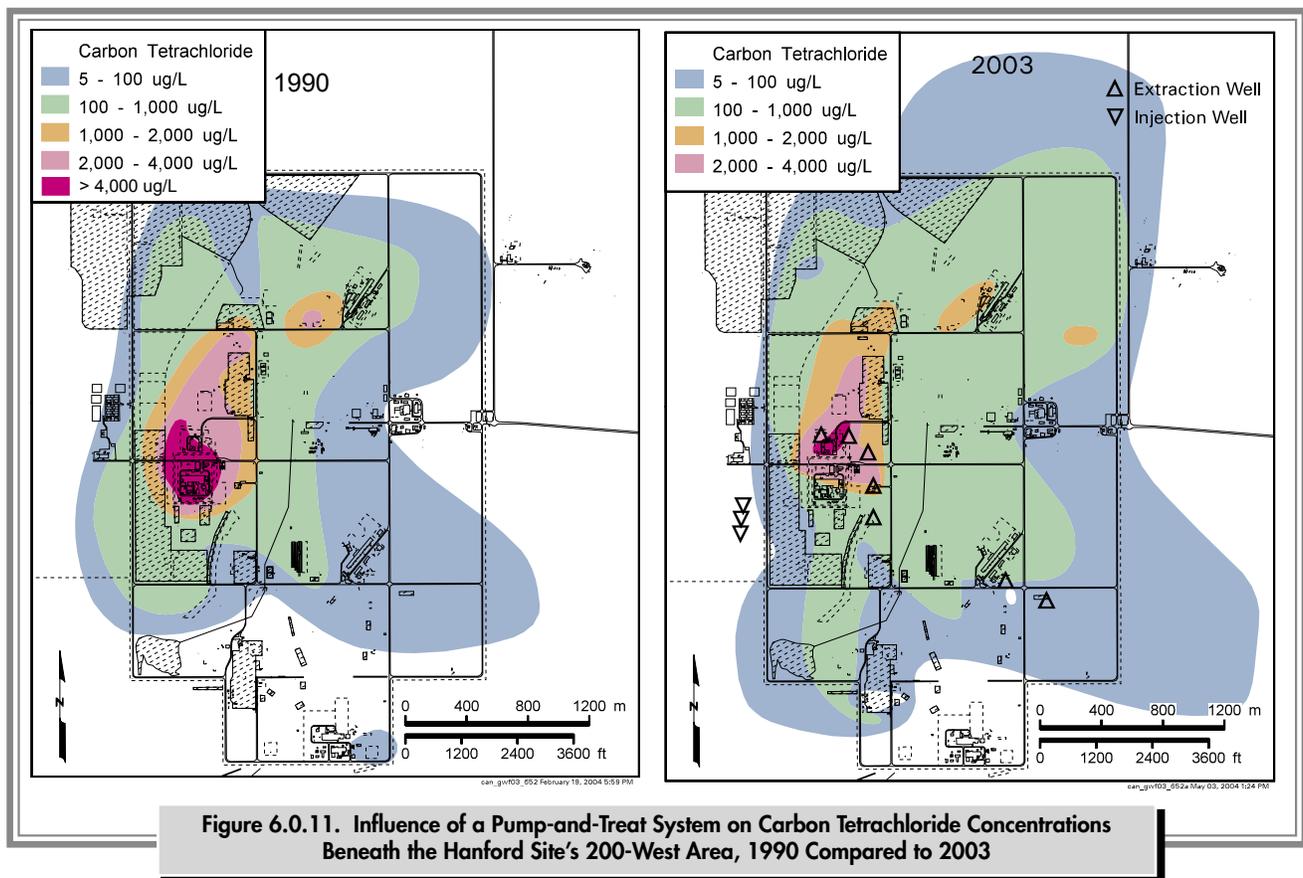
### 6.0.3.8 200-ZP-1 Operable Unit

The 200-ZP-1 Operable Unit encompasses the northern portion of the 200-West Area (Figure 6.0.1). The primary contaminant of concern is carbon tetrachloride, which forms the largest plume of chlorinated hydrocarbons on the Hanford Site. The contamination is principally from

past waste disposal associated with the Plutonium Finishing Plant, where organic chemicals were used to process plutonium. Trichloroethene and chloroform also are associated with this plume. Other contaminants include tritium, nitrate, chromium, fluoride, iodine-129, technetium-99, and uranium. There are four RCRA sites, one other regulated unit, and one CERCLA interim action (pump-and-treat system) for groundwater in the 200-ZP-1 Operable Unit.

**CERCLA Interim Action.** A groundwater pump-and-treat system operated in this operable unit during 2003 to prevent the spread of the central, high-concentration portion of the carbon tetrachloride plume (Figure 6.0.11). The remediation is proving effective, and the plume area at concentrations greater than 4,000 µg/L has shrunk.

**Low-Level Burial Grounds Waste Management Areas 3 and 4.** Groundwater monitoring under interim status RCRA requirements continued at these waste management areas in 2003. Monitoring results indicate no groundwater contamination attributable to these waste management areas.



A downgradient monitoring well for Waste Management Area 4 went dry in 2003. Monitoring networks for Waste Management Areas 3 and 4 contain fewer than the optimal number of wells for monitoring.

The DOE submitted an application in 2002 to incorporate the low-level burial grounds into the Hanford Facility RCRA Permit (Ecology 1994). As part of the application, new groundwater monitoring wells, constituents, and statistical evaluations were proposed in 2003. Workshops with the Washington State Department of Ecology to address this application are in progress.

**Waste Management Area T.** Results of RCRA groundwater quality assessment monitoring at Waste Management Area T continued to suggest that the waste management area has not contributed to dangerous waste contamination of the uppermost aquifer in this area. Carbon tetrachloride, trichloroethene, chromium, and nitrate are present in groundwater, but the contamination is believed to have originated at other facilities.

**Waste Management Area TX-TY.** RCRA assessment monitoring at Waste Management Area TX-TY continued in 2003 (Figure 6.0.3). Chromium concentrations were elevated in groundwater; the most likely source is the waste management area. However, other sources of chromium contamination are located nearby. Some nitrate contamination may be from Waste Management Area TX-TY, but other sources nearby clearly have contributed.

Carbon tetrachloride and trichloroethene contamination from other sources also is present.

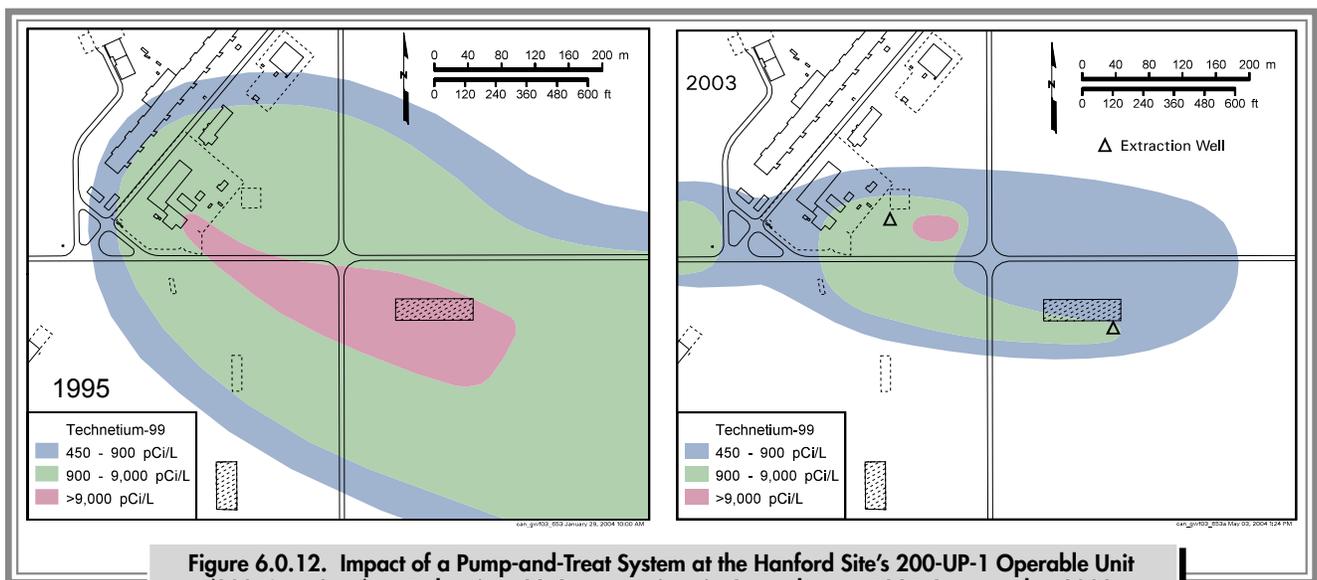
**State-Approved Land Disposal Site.** This active disposal facility is regulated under a state waste discharge permit. The State-Approved Land Disposal Site is located just north of the 200-West Area. Groundwater beneath this facility is monitored for tritium and 15 other constituents. Concentrations in monitoring wells did not exceed permit enforcement limits during 2003.

### 6.0.3.9 200-UP-1 Operable Unit

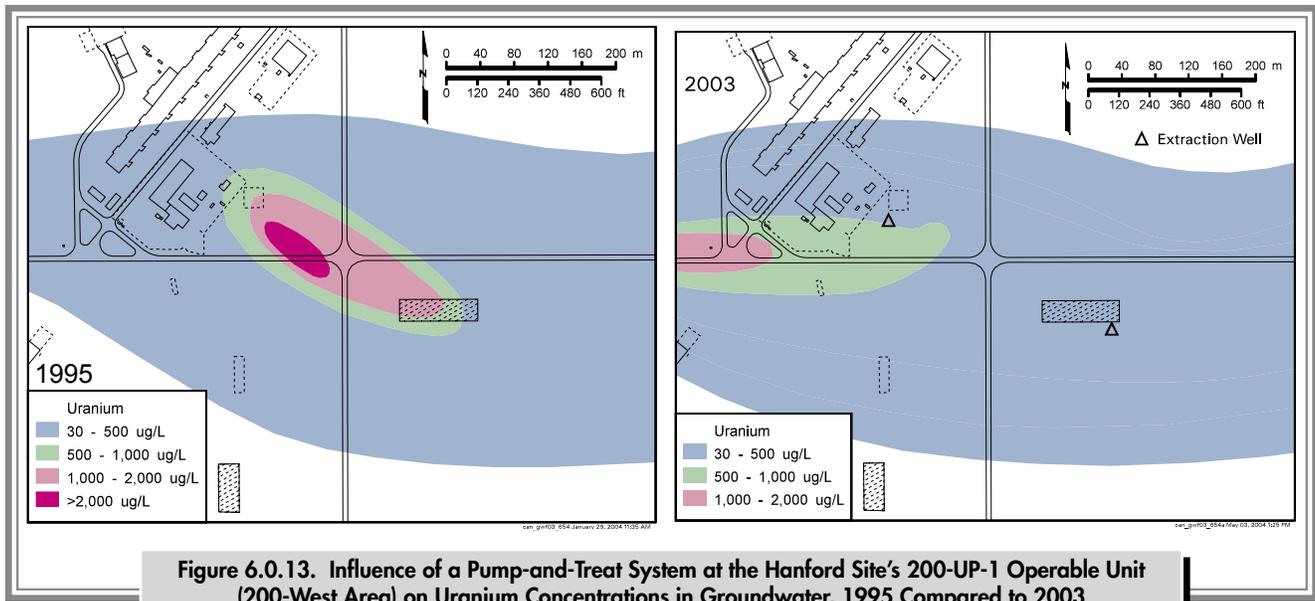
The 200-UP-1 Operable Unit underlies the south 200-West Area (Figure 6.0.1). The primary contaminants of concern in this unit are technetium-99 and uranium. Tritium, iodine-129, and nitrate plumes have origins in this operable unit. Sources of carbon tetrachloride were primarily within the 200-ZP-1 Operable Unit, but the contamination underlies the 200-UP-1 Operable Unit as well.

There are four RCRA sites, one CERCLA interim action (pump and treat), and a CERCLA disposal site in the 200-UP-1 Operable Unit. Monitoring activities are summarized below.

**CERCLA Interim Action.** A groundwater pump-and-treat system operated to contain the technetium-99 (Figure 6.0.12) and uranium (Figure 6.0.13) plumes near



**Figure 6.0.12. Impact of a Pump-and-Treat System at the Hanford Site's 200-UP-1 Operable Unit (200-West Area) on Technetium-99 Concentrations in Groundwater, 1995 Compared to 2003**



**Figure 6.0.13. Influence of a Pump-and-Treat System at the Hanford Site's 200-UP-1 Operable Unit (200-West Area) on Uranium Concentrations in Groundwater, 1995 Compared to 2003**

U Plant. During 2003, the high concentration portions of the technetium-99 and uranium plumes (9,000 pCi/L [333 Bq/L]) and 480 µg/L contours, respectively, were contained within the influence of the pump-and-treat system. Although more sampling is required to confirm the trend, technetium-99 concentrations appear to have been reduced to levels below the 9,000-pCi/L (333-Bq/L) remediation goal at all wells in the baseline plume area. The baseline plume area is the area of the plume before the pump-and-treat system began operating. Uranium concentrations remained above the 480-µg/L remediation goal in one well in 2003.

During 2003, one monitoring well in the baseline area went dry, leaving only one monitoring well to track plume behavior. Two wells went dry in another portion of the operable unit. A new monitoring well was installed south of the baseline plume area to replace another dry well.

**216-U-12 Crib.** RCRA assessment monitoring continued at the 216-U-12 crib in 2003 (Figure 6.0.3). The crib is one of several sources that have contributed to a nitrate plume in the area. Closure of the crib will be coordinated with and

conducted under CERCLA regulations. The monitoring network for this crib contains just two useable downgradient wells and no upgradient wells.

**216-S-10 Pond and Ditch.** Indicator parameter data have not indicated that the 216-S-10 pond and ditch (Figure 6.0.3) have affected groundwater quality in the uppermost aquifer beneath the facility. In 2003, one monitoring well at this facility went dry and a new well was installed. The current RCRA monitoring network consists of only two downgradient wells.

**Waste Management Area S-SX.** RCRA assessment monitoring continued at Waste Management Area S-SX in 2003 (Figure 6.0.3). Results continued to indicate that an apparent source within each of the S and SX Tank Farms have contaminated groundwater with chromium. Concentrations of nitrate, chromium, and the non-RCRA-regulated constituent technetium-99<sup>(a)</sup> increased significantly during 2003 in one monitoring well. At the request of the Washington State Department of Ecology, the practice of pumping and treating at least 3,785 liters (1,000 gallons) of water from the well after each quarterly sampling event

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was started in March 2003. Data from a vertical sampling study in the same well show that pumped water is a blend of water entering the well from all parts of the screened interval. Therefore, the vertical location of the sample pump intake does not have a significant effect on measured constituent concentrations, as long as the well is purged adequately before a sample is collected.

**Waste Management Area U.** RCRA assessment monitoring continued at Waste Management Area U in 2003 (Figure 6.0.3). The waste management area has affected groundwater quality with nitrate and possibly chromium. During 2003, nitrate concentrations continued to increase in downgradient wells in the south half of the waste management area.

**Environmental Restoration Disposal Facility.** Several constituents (tritium, iodine-129, nitrate, and carbon tetrachloride) are present in groundwater at or above drinking water standards, but these results are due to plumes originating from the 200-West Area. Higher concentrations of gross beta and unfiltered chromium were detected in 2003. The causes of these higher concentrations are unknown. Future results will be evaluated to confirm any increasing trends.

### 6.0.3.10 200-BP-5 Operable Unit

The 200-BP-5 Operable Unit (Figure 6.0.1) includes groundwater beneath the north 200-East Area. A technetium-99 plume extends northward between Gable Mountain and Gable Butte. Other contaminants include uranium, iodine-129, cobalt-60, cyanide, strontium-90, cesium-137, plutonium, tritium, and nitrate.

CERCLA monitoring activities had been interrupted during the past several years in the 200-BP-5 Operable Unit because waste management documentation in support of sampling needed to be developed. Sampling activities resumed in 2003 following approval of new sampling and analysis (DOE/RL-2001-49) and waste control plans (DOE/RL-2003-30). There is no active groundwater remediation in this operable unit.

There are five RCRA sites in the 200-BP-5 Operable Unit. Monitoring activities are summarized below.

**Waste Management Area B-BX-BY.** Assessment monitoring continued at Waste Management Area B-BX-BY

in 2003. Contamination observed in downgradient wells around this waste management area is primarily due to vertical movement of residual waste in the soil under each of the B, BX, and BY Tank Farms.

**Waste Management Area C.** Waste Management Area C (Figure 6.0.3) continued to be monitored under an interim status indicator evaluation program in 2003. Indicator parameters did not exceed critical mean values. Four new monitoring wells were installed at this waste management area in 2003.

**216-B-63 Trench.** Results of interim status detection monitoring continued to support the interpretation that the 216-B-63 trench (Figure 6.0.3) has not impacted groundwater with hazardous constituents.

**Low-Level Waste Management Areas 1 and 2.** Groundwater monitoring under interim status requirements continued at Low-Level Waste Management Areas 1 and 2 in 2003 (Figure 6.0.3). Monitoring results indicated no contaminants in groundwater attributable to these waste management areas.

The DOE submitted an application in 2002 to incorporate these low-level burial grounds into the Hanford Facility RCRA Permit (Ecology 1994). As part of the application, the installation of new groundwater monitoring wells, monitoring of additional constituents, and statistical evaluations were proposed in 2003. Workshops with the Washington State Department of Ecology to address this application are in progress.

**Liquid Effluent Retention Facility.** A 2001 letter from the Washington State Department of Ecology directed the DOE to discontinue statistical evaluation of groundwater sample results at the Liquid Effluent Retention Facility (Figure 6.0.3) because all but two wells monitoring the facility have gone dry. The DOE has continued to sample the two remaining wells and is exploring alternative approaches to monitoring the facility.

### 6.0.3.11 200-PO-1 Operable Unit

The 200-PO-1 Operable Unit (Figure 6.0.1) encompasses the south portion of the 200-East Area and a large portion of the Hanford Site extending to the east and southeast. The operable unit includes widespread plumes of tritium,



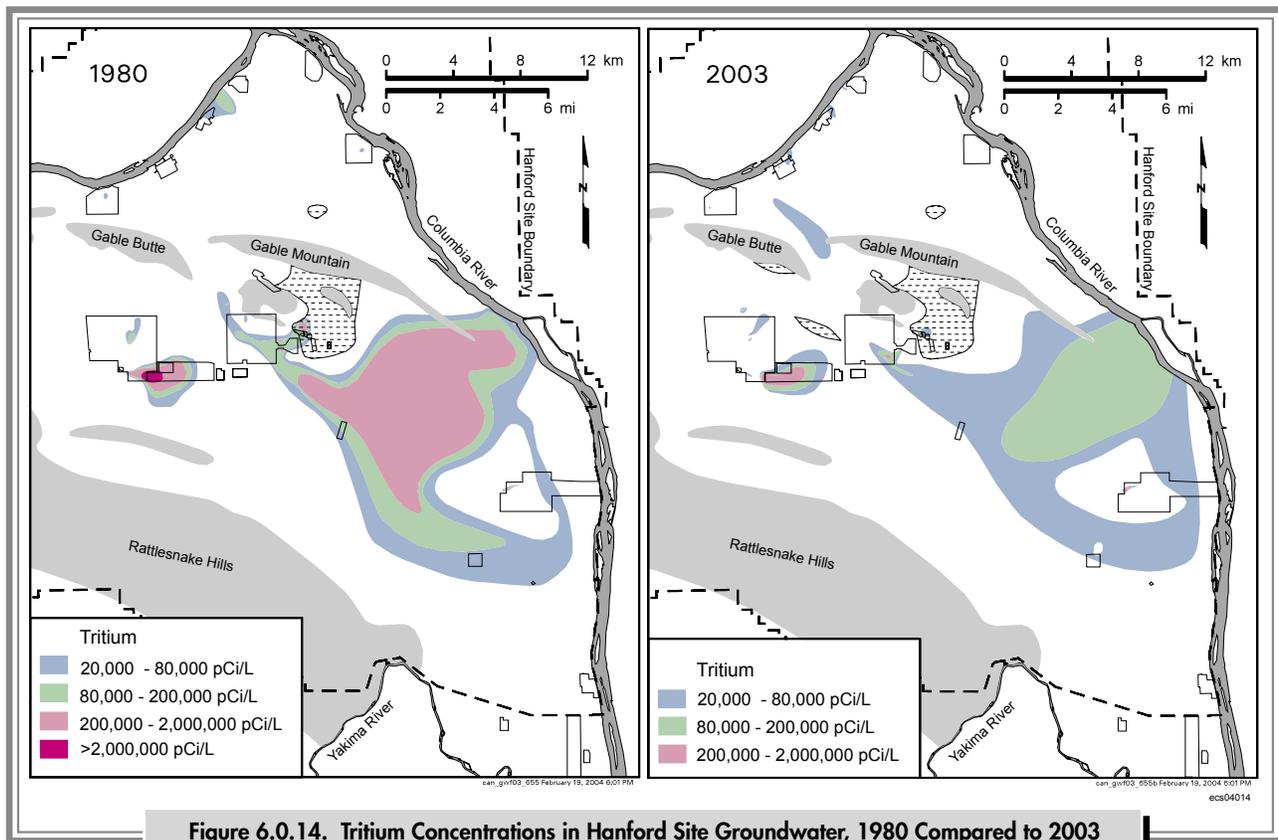
nitrate, and iodine-129. Concentrations of tritium continued to decline as the plume attenuates naturally due to radioactive decay and dispersion (Figure 6.0.14). Other groundwater contaminants in this unit include strontium-90 and technetium-99, but these are limited to very small areas.

There are six RCRA sites and three other regulated units, respectively, in the 200-PO-1 Operable Unit:

**Plutonium-Uranium Extraction Plant Cribs.** Three cribs (216-A-10, 216-A-36B, and 216-A-37-1) are monitored jointly at the Plutonium-Uranium Extraction Plant under a RCRA interim status assessment program. The cribs have contributed to widespread groundwater contaminant plumes in the area, including a nitrate plume and plumes containing non-RCRA constituents of tritium and

iodine-129.<sup>(a)</sup> The nitrate plume is generally attenuating throughout most of its area, except near the three cribs. During 2003, the concentration of nitrate in monitoring wells at the cribs has either held steady or increased. The cause of the increased nitrate concentrations in recent years is not known. However, it may be related to a smaller contribution of groundwater flow from the B Pond area and a greater contribution of groundwater flow from the northwest. During 2003, one monitoring well at the cribs went dry. An existing well was added to replace the dry well.

**Waste Management Area A-AX.** Waste Management Area A-AX continued to be monitored under an interim status indicator evaluation program in 2003. Indicator parameters in monitoring wells did not exceed critical



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mean values during the year. Two new monitoring wells were installed at this waste management area in 2003.

**216-A-29 Ditch.** Groundwater beneath the 216-A-29 ditch (Figure 6.0.3) is monitored as required by interim status detection regulations. To date, the ditch has not contaminated groundwater with regulated constituents, although sulfate attributable to manmade sources from the 200-East Area has been detected in two wells.

**Integrated Disposal Facility.** The Integrated Disposal Facility will be an expandable, lined, RCRA-compliant landfill. This facility is located near the Plutonium-Uranium Extraction Plant (PUREX) in the 200-East Area. Construction is scheduled to begin in 2004. The Part B permit application for this landfill was submitted to the Washington State Department of Ecology and is scheduled to be incorporated into the Hanford Facility RCRA Permit in 2004 (Ecology 1994). Four out of seven monitoring wells scheduled for this facility have already been installed.

**216-B-3 Pond.** The 216-B-3 pond continued to be monitored in 2003 under a temporary, alternative monitoring plan. During 2001, the Washington State Department of Ecology granted a variance to apply a new approach to groundwater monitoring at this site for a 2-year trial period. The trial approach used statistical methods based on comparisons between all wells instead of the standard upgradient/downgradient concentration comparisons. The constituents selected for the comparisons between all wells were gross alpha, gross beta,<sup>(a)</sup> and specific conductance. The final samples for the trial period were collected in July 2003, and an evaluation of the approach is currently underway.

**Nonradioactive Dangerous Waste Landfill.** The Nonradioactive Dangerous Waste Landfill is located in the 600 Area, within the footprint of the 200-PO-1 regional plume (Figure 6.0.1). During 2003, seven volatile organic compounds were detected in Nonradioactive Dangerous

Waste Landfill monitoring wells. The levels of 1,1,1-trichloroethane, 1,1-dichloroethene, acetone, chloroform, tetrachloroethene, toluene, and trichloroethene were reported to be well below drinking water standards. The source of these volatile organic compounds could either be the Nonradioactive Dangerous Waste Landfill or the Solid Waste Landfill.

**Solid Waste Landfill.** The Solid Waste Landfill (Figure 6.0.3) is regulated under state dangerous waste regulations. In 2003, specific conductance, pH, chloride, and sulfate exceeded their background threshold levels in one or more groundwater samples collected near this facility. The lower pH apparently is a result of high concentrations of carbon dioxide in the vadose zone resulting from the degradation of sewage material disposed to the Solid Waste Landfill.

**200 Area Treated Effluent Disposal Facility.** A state waste discharge permit governs groundwater sampling and analysis in the three monitoring wells at the 200 Area Treated Effluent Disposal Facility. The 200 Area Treated Effluent Disposal Facility is located southeast of the B Pond RCRA facility. No permit criteria for constituents in groundwater were exceeded at this facility in 2003. The groundwater monitoring network continues to show that effluent from the facility has not reached the underlying uppermost aquifer, which is confined.

**4608 B/C Process Ponds.** The 4608 B/C ponds (also called the 400 Area process ponds), are regulated under a state waste discharge permit. Groundwater quality near these ponds met permit conditions in 2003. The permit was modified in 2003, and the requirement for groundwater monitoring at this site ended on October 1, 2003.

### 6.0.3.12 300-FF-5 Operable Unit

The 300-FF-5 Operable Unit (Figure 6.0.1) is divided into two general regions: the 300 Area and the 300-FF-5 North region, which includes the 618-11 burial ground, the 618-10 burial ground, and the 316-4 cribs.

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Groundwater constituents from 300 Area sources include uranium and volatile organic compounds. The size of the 300 Area uranium groundwater plume is generally consistent from year to year, but concentrations in the plume are variable throughout the year as a result of changes in river stage. A plume of trichloroethene in the 300 Area is attenuating naturally, and average concentrations remained below the drinking water standard in 2003. Trichloroethene contamination in this area is associated with other hydrocarbons (e.g., cis-1,2-dichloroethene). The interim action chosen for the 300-FF-5 Operable Unit includes natural attenuation of the uranium and organic contamination.

Contaminants from the north part of the operable unit include tritium, uranium, various volatile organic compounds, petroleum hydrocarbons, and tributyl phosphate. Tritium concentrations in groundwater near the 618-11 burial ground have decreased in recent years but remained among the highest (3,620,000 pCi/L [134,000 Bq/L]) on the Hanford Site during 2003. This high-concentration contamination is limited to a narrow plume extending approximately 1 kilometer (0.6 mile) to the east of the burial ground.

**316-5 Process Trenches.** The 316-5 process trenches (a former disposal facility) is the only RCRA site in the 300-FF-5 Operable Unit (Figure 6.0.3). The trenches have contributed to groundwater contamination when they received effluent discharges of dangerous mixed waste in the past. Only two of the contaminants of concern remain above drinking water standards, uranium and cis-1,2-dichloroethene. Groundwater contamination beneath the trenches will be remediated under CERCLA regulations. While the CERCLA interim action (natural attenuation) is in progress, groundwater near the trenches is monitored under a final status, corrective action monitoring program.

### 6.0.3.13 1100-EM-1 Operable Unit

The 1100-EM-1 Operable Unit (Figure 6.0.1) includes a small, narrow plume of trichloroethene, which is attenuating naturally. Annual average concentrations have remained below the drinking water standard since 2001. Contaminants also flow into the unit from offsite sources (e.g., nitrate from agriculture and industry).

The city of Richland maintains a well field in the 1100-EM-1 groundwater interest area, which includes a much broader area than the operable unit. Wells near the well field are monitored frequently to detect any changes in Hanford contaminants near the city's wells. The tritium plume from the 200-East Area has not been detected in these wells. Low levels of tritium, similar to levels in Columbia River water, continued to be detected.

The selected remedy for cleaning up 1100-EM-1 Operable Unit groundwater is to continue to monitor the natural attenuation of volatile organic compounds.

### 6.0.3.14 Confined Aquifers

Although most of Hanford's groundwater contamination is in the unconfined aquifer, the DOE monitors wells in deeper aquifers because of the potential for downward migration of contamination and the potential migration of contamination offsite through the basalt-confined aquifer.

The Ringold Formation confined aquifer occurs within fluvial sand and gravel comprising the lowest sedimentary unit of the Ringold formation. It is confined below by basalt and above by the lower mud unit. Groundwater in this aquifer flows generally west to east in the vicinity of the 200-West Area. In the central portion of the aquifer, flow converges on the 200-East Area from the west, south, and east. Groundwater discharges from the confined aquifer into the overlying unconfined aquifer near the 200-East Area.

While effluent disposal was occurring at the B Pond system, groundwater mounding forced groundwater and any associated contamination a limited distance into the Ringold Formation confined aquifer. Groundwater analyses for 2003 at the 200 Area Treated Effluent Disposal Facility continued to demonstrate that the confined aquifer has not been influenced by disposal activities at this facility.

Within the upper basalt-confined aquifer system, groundwater occurs within basalt fractures and joints, interflow contacts, and sedimentary interbeds. Groundwater in the upper basalt-confined aquifer system generally flows from west to east across the Hanford Site toward the Columbia River.

Results of sampling basalt-confined groundwater show that tritium was detected in some wells at very low levels, while



iodine-129, strontium-90, gamma-emitting isotopes, and uranium isotopes were not detected. Cyanide, nitrate, and technetium-99 were elevated in one well in the north part of the 200-East Area, but contaminant migration during well construction is responsible for this contamination. Contaminants on the Hanford Site have not migrated through the upper basalt-confined aquifer system to offsite sample locations south and southeast of the Hanford Site.

## 6.0.4 Well Installation, Maintenance, and Decommissioning

The Washington State Department of Ecology, EPA, and DOE negotiated an integrated well drilling list that coordinates and prioritizes the requirements of various groundwater monitoring regulations. During 2003, a total of 18 new wells were installed at Hanford. These included seven for RCRA monitoring, nine for CERCLA operable units, and two for research on chromate bioremediation. Two hundred and forty-three wells received maintenance, and 63 wells were decommissioned (filled with grout) because they were no longer needed, were in poor condition, or were in the way of remediation activities.

## 6.0.5 Modeling

Computer simulations of groundwater flow and contaminant movement help predict future conditions and assess the effects of remediation systems. During 2003, the consolidated groundwater flow and transport site-wide model was calibrated based on an alternative conceptual model that defines zones within the most important transmissive hydrogeologic units.

The System Assessment Capability is an integrated assessment tool that includes several linked computer models designed to simulate the movement of contaminants from waste sites through the vadose zone, groundwater, and Columbia River to receptors. It also incorporates modules that calculate the risks to human health and the environment. During 2003, the System Assessment Capability was updated; an atmospheric transport module was added and newer versions of the groundwater flow and transport modules were added. The three-dimensional “base case” site-wide groundwater model was used in the

initial assessment performed during 2002. In 2003, the model grid was refined around the contaminant plume areas.

## 6.0.6 Vadose Zone

S.M. Stoller Corporation performs geophysical logging at the Hanford Site for both DOE Richland Operations Office and DOE Office of River Protection. The primary goal of logging activities performed for the DOE Richland Operations Office is characterization of waste sites on the Central Plateau. For the DOE Office of River Protection, the logging effort involves vadose zone monitoring around the single-shell tanks.

### 6.0.6.1 Geophysical Logging in Cased Boreholes at Hanford

Geophysical logging in existing boreholes represents a cost-effective means to obtain subsurface information to support planning for more detailed remedial investigation and/or cleanup activities. All Hanford boreholes contain steel casing, which precludes the use of conventional electromagnetic and seismic (acoustic) logging methods. Radioactivity and nuclear logs can be run in cased holes. The gross gamma log and spectral gamma log are particularly effective in detecting gamma-emitting radionuclides through steel casing, and neutron logging methods can be used to measure moisture content in the vadose zone, or to detect the presence of alpha-emitting radionuclides from neutrons emitted from alpha interactions with elements in the sediment.

“Gross gamma logging” refers to logs in which gamma activity is measured without regard to energy level. Gross gamma logs may use spectral detectors such as the high-purity germanium detector (HPGe), or sodium iodide scintillator, or they may use a simpler detector such as a Geiger-Mueller meter (Geiger counter) tube, which does not differentiate between energy levels. The gross gamma log simply reports the total gamma activity as a function of depth.

“Spectral gamma logging” refers to logs in which gamma energy spectra are collected in the borehole. These systems can use either a semiconductor detector, such as the high-purity germanium detector, or a sodium iodide



scintillator. In a spectral gamma log, individual gamma photons are counted as a function of energy level. This allows radionuclides to be identified and quantified on the basis of gamma activity at specific energy levels. In some cases, generally with a sodium iodide detector, gamma activity may be reported for “windows,” which represent specific energy ranges. Most conventional spectral gamma logs are calibrated for naturally occurring radionuclides, primarily potassium-40, thorium-232, and uranium-238. Variations in naturally occurring radionuclides have proven useful in stratigraphic correlation, but many of the assumptions made in conventional spectral gamma logging are not applicable to detection and evaluation of manmade radionuclides. For example, uranium processed for reactor fuel has been chemically separated from its daughter products, and a period on the order of a million years will be required for secular equilibrium to be re-established throughout the decay chain. Processed or manmade uranium, therefore, exhibits few of the gamma rays typically associated with natural uranium. However, manmade uranium-238 can be detected and quantified by measurement of relatively low yield gamma activity associated with protactinium-234, an “early” daughter in the uranium-238 decay series for which secular equilibrium is established relatively quickly. Other manmade radionuclides emit characteristic gamma rays which are detectable with conventional spectral gamma logging equipment, but they may not be recognized by a conventional log evaluation approach. High resolution gamma spectroscopy is necessary to determine net count rates associated with specific gamma lines, from which identification and quantification can be performed.

The spectral gamma logging system, utilizes a cryogenically cooled high-purity germanium detector to detect, identify, and quantify gamma-emitting radionuclides in the subsurface. Identification of naturally occurring and manmade radionuclides is based on detection of gamma rays at characteristic energy levels. Conventional gamma spectroscopy software is used for peak recognition and to determine net counts. A

calibration function defines detector response as a function of energy level, and radionuclide concentrations (activity per unit mass of soil) are calculated from net count rates. Correction functions are available for dead time, casing thickness, and water. Tables 6.0.6 and 6.0.7 list commonly encountered natural and manmade radionuclides at the

**Table 6.0.6. Naturally Occurring Radionuclides**

<b>Radionuclide</b>	<b>Primary Gamma Rays Daughter</b>	<b>Secondary Gamma Rays Daughter</b>
Potassium-40		
Thorium-232	Thallium-208	Lead-212 Thallium-208 Actinium-228
Uranium-238 <sup>(a)</sup>	Bismuth-214	Lead-214 Bismuth-214

(a) Attainment of secular equilibrium between uranium-238 and bismuth-214/lead-214 requires time periods on the order of several million years. Activities of both bismuth-214 and lead-214 are commonly assumed to be equal to the amount of naturally occurring uranium-238. However, these radionuclides are short-term daughter products of radon-222, and accumulations of radon gas inside the casing may temporarily perturb the secular equilibrium between uranium-238 and bismuth-214/lead-214.

**Table 6.0.7. Manmade Gamma-Emitting Radionuclides**

<b>Radionuclide</b>	<b>Half-Life Years</b>	<b>Typical MDL, pCi/g<sup>(a)</sup></b>
Cobalt-60	5.2714	0.15
Ruthenium-106	1.0238	
Antimony-125	2.7582	
Tin-126	1.E+05	
Cesium-134	2.062	
Cesium-137	30.07	0.2
Europium-152	13.542	
Europium-154	8.593	0.2
Europium-155	4.7611	
Uranium-235	7.04E+08	0.6
Protactinium-234 (uranium-238) <sup>(b)</sup>	4.47E+09	12
Neptunium-237	2.14E+06	
Plutonium-239	24,110	1,300
Americium-241	432.2	5,000

(a) The MDL is affected by variables such as count time, casing thickness, water, shielding, and the presence of other radionuclides. Values shown are for typical logging conditions in a minimally contaminated zone.

(b) Protactinium-234 is a short-term daughter of uranium-238. Secular equilibrium is achieved relatively quickly. Because of the relatively low gamma yield, this peak is not seen when only background levels of naturally occurring uranium-238 are present. Hence, the presence of gamma peaks associated with protactinium-234 without corresponding peaks associated with lead-214 and bismuth-214, is taken as an indication of manmade or chemically processed uranium.

Hanford Site. A variation of the spectral gamma logging system known as the high rate logging system uses a much smaller detector to collect log data in zone of intense gamma radiation. The high rate logging system is used in borehole intervals where the dead time for the spectral gamma logging system exceeds 40%. When used in combination, the spectral gamma logging system and high rate logging system provide a measurement capability from approximately 0.1 to 109 pCi/g (0.0037 to 4 Bq/g) cesium-137.

The neutron moisture logging system utilizes a 50-mCi (1.85-GBq) americium-beryllium source and helium-3 detector. Neutrons generated from the interaction of alpha particles emitted from americium-241 with beryllium bombard the surrounding formation and are scattered back to the detector. In geologic media, the dominant mechanism for neutron scattering is interaction with hydrogen atoms, and the count rate at the detector is a function of the proportion of hydrogen in the formation, which is generally an indication of the moisture content. In the neutron moisture logging system, the detector is located relatively close to the source, so that neutron counts at the detector increase with increasing moisture content. This arrangement provides very good vertical resolution. Calibration functions are available to relate neutron counts to moisture content for 15.24- and 20.32-centimeter (6- and 8-inch) diameter boreholes and a correction function is available for casing thickness. Neutron moisture logging system logs are useful as an indication of in situ moisture content, and for stratigraphic correlation.

The passive neutron logging system has seen limited use at Hanford. This log uses a helium-3 detector to count neutrons originating from the surrounding formation. The most likely sources of neutrons are interactions between alpha particles and elements in the sediment, particularly the interaction between alpha particles and oxygen. This log has been used to qualitatively detect transuranics in the subsurface (BHI-01436).

Another log that shows promise is the neutron capture log. This device bombards the formation with neutrons from a californium-252 source. As the neutrons are scattered by collisions with atoms in the formation, they are slowed and eventually captured. The probability of capture depends on the velocity (energy) of the neutron and the capture cross section of the target atom. When capture occurs, the atom

may emit a gamma ray at a characteristic energy level, or it may become unstable and decay, emitting gamma rays as part of the decay process. Gamma rays emitted as a result of the capture process are “prompt” in that they occur immediately after the capture event, whereas gamma rays emitted as a result of decay may occur somewhat later, depending on the decay constant of the new isotope formed by the capture event. The sensitivity of the neutron capture log depends on the capture cross section of the target element and the characteristics of the resulting gamma ray.

### 6.0.6.2 Vadose Zone Characterization Results

The baseline characterization project for past-practice disposal sites in the Hanford areas is an extension of the Hanford Tank Farms Vadose Zone Project. From 1995 to 2000, spectral gamma logging system logs from 769 existing monitoring boreholes in the single-shell tanks farms were used to develop an understanding of subsurface contamination conditions in the vicinity of the single-shell tanks.

Beginning in 2001, spectral gamma logging system logs are being collected in more than 800 existing boreholes associated with past-practice disposal sites in the Hanford 200 Areas. All available boreholes are logged and log plots and log data reports are prepared for individual boreholes. Log data from a specific area or group of contiguous waste sites are incorporated into a waste site summary report, which also summarizes geologic conditions, waste site construction details, and operational history and provides an evaluation of subsurface contamination conditions. Characterization began in the 200-East Area with a report (GJO-2002-322-TAR) on the 216-B-35 to 216-B-42 trenches (west of the BX Tank Farm). This was followed by reports on the 216-B-8 crib and adjacent sites (GJO-2002-343-TAR); the 216-B-5 injection well and 216-B-9 crib and tile field (GJO-2002-358-TAC); and the 216-B-43 to 216-B-50, 216-B-57, and 216-B-61 cribs (GJO-2003-458-TAC). Logging activities in and around the B-BX-BY Waste Management Area were completed in fiscal year 2003. Currently, a report is being prepared on the B-BX-BY Waste Management Area and adjacent waste sites. This report integrates results from the above reports with previous baseline reports for the B, BX, and BY Tank



Farms. It incorporates log data from 284 boreholes. Cesium-137, cobalt-60, uranium-235 and -238, antimony-125, strontium-90, and europium-152 and -154 were detected. The predominant contaminant was cesium-137, which was measured at a maximum concentration of more than 20 million pCi/g (0.74 MBq/g). This high activity level was observed in boreholes 299-E33-27 (21-02-04) near tank BX-102 and in 299-E33-223 near tank BX-110. Concentrations of cesium-137 greater than 1 million pCi/g (0.37 MBq/g) were found above elevation 525 in the vicinity of the single-shell tank farms and in the vicinity of the BY cribs.

Manmade uranium-238 concentrations as high as 1,000 pCi/g (37 Bq/g) were found in the area east of tank BX-102. Of the 284 boreholes logged in the B-BX-BY Waste Management Area, only 17 encountered detectable amounts of manmade uranium-238. The most extensive area of uranium contamination was found to extend downward and to the northeast from the vicinity of BX-102, intercepting the groundwater in the vicinity of 299-E33-18. Evaluation of historical log data suggests that the uranium plume reached the groundwater in this area between 1991 and 1997. This is consistent with groundwater monitoring results, which show elevated uranium levels beginning in about 1994. Little evidence of subsurface uranium contamination was found in the vicinity of other waste sites for which uranium disposal is assumed.

The maximum concentration of antimony-125 did not exceed 10 pCi/g (0.37 Bq/g). The highest europium-154 concentration encountered was 127 pCi/g (4.7 Bq/g) near tank BX-101.

In general, contamination that appears to be directly associated with a specific waste site or tank was observed at log depths less than 45.7 meters (150 feet) in the immediate vicinity of the waste site. However, most tank farm boreholes and many boreholes associated with the liquid waste sites are less than 45.7 meters (150 feet) in depth, and groundwater occurs at approximately 76.2 meters (250 feet) depth. Hence, the deeper part of the vadose zone is relatively poorly investigated, and the full extent of contamination may not be known. However, borehole evidence of vadose zone contamination extending to groundwater does exist for processed uranium originating from the vicinity of tank BX-102, and for cobalt-60 and cesium-137 originating from the BY cribs. Figures 6.0.15

and 6.0.16 show vadose zone contamination in the B-BX-BY Waste Management Area and vicinity.

S.M. Stoller Corporation also logged selected boreholes in the 200-West Area that were scheduled for decommissioning during fiscal year 2003. These boreholes had been identified in the original database for baseline characterization included in the project management plan. Log data were collected in 23 of the 57 boreholes before they were decommissioned.

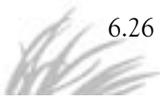
In addition to baseline vadose zone characterization activities described above, S.M. Stoller Corporation also provided geophysical logging of new and existing boreholes in support of ongoing remedial investigation activities by other Hanford contractors. These holes are logged as requested and log plots and log data reports are provided to the cognizant engineers. In some cases, shallow boreholes were installed specifically for spectral gamma logging, and the results from these holes were used to identify locations for more detailed investigation.

Spectral gamma logs are also provided for new groundwater monitoring wells before the wells are completed. In addition, the S.M. Stoller Corporation maintains files for boreholes in the Hanford 200 Areas and provides copies of historical logs and log evaluation as requested.

Log data and reports are accessible via the internet at <http://www.gjo.doe.gov/programs/hanf/HTFVZ.html>.

### 6.0.6.3 Monitoring Activities in the Single-Shell Tank Farms

The Hanford Tank Farms Vadose Zone Monitoring Project was established in fiscal year 2001 for comprehensive routine monitoring of existing boreholes in Hanford single-shell tank farms. Monitoring is fundamentally different from characterization. Once the nature of contamination is known, the measurements required to detect changes are much simpler to implement. In general, monitoring uses simpler equipment and data analysis methods: the value of monitoring is in detecting changes or trends in successive measurements over time. In most cases, recording total gamma activity at regular intervals is sufficient to demonstrate stability or to detect movement in a particular plume.



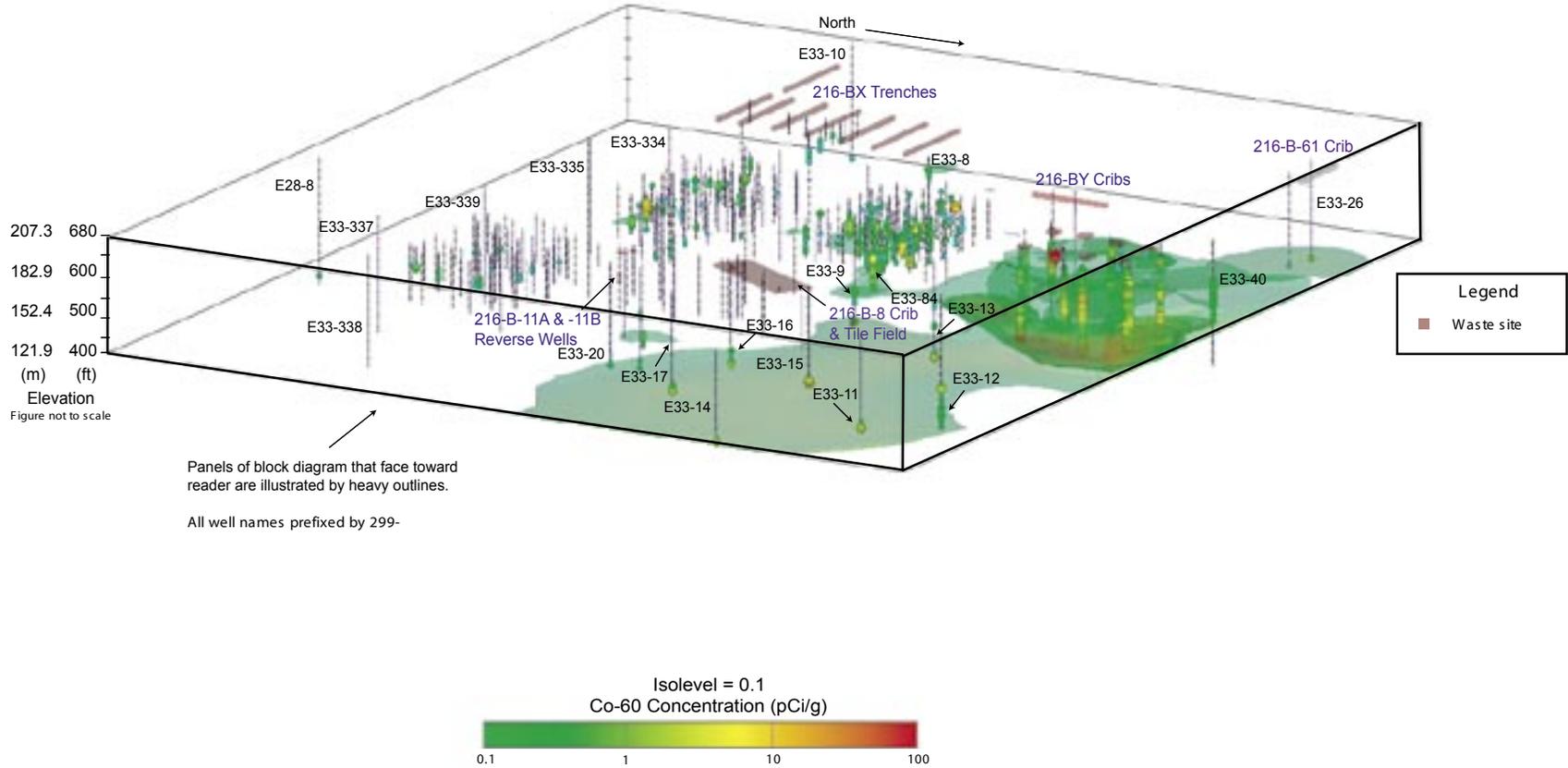
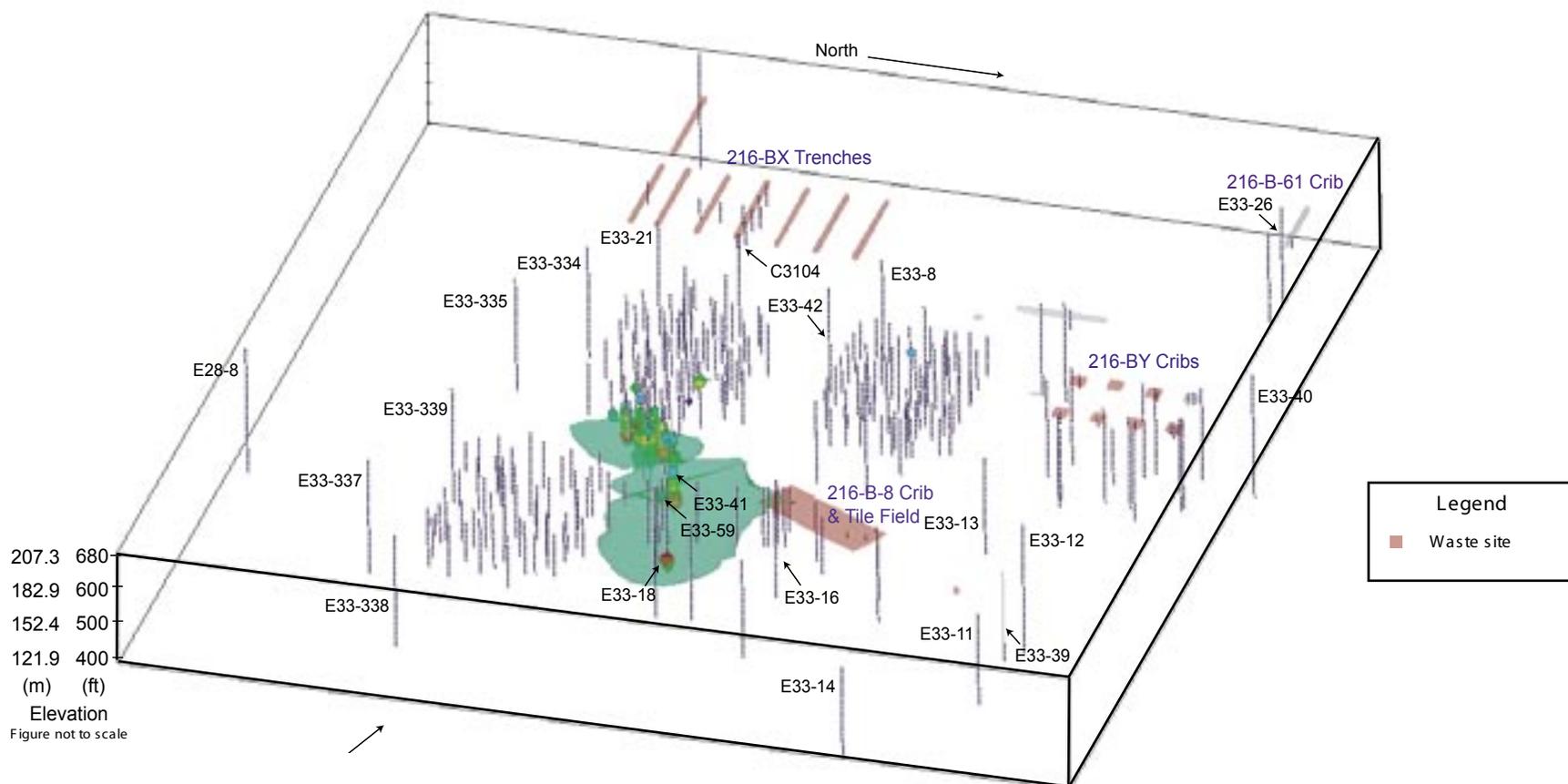


Figure 6.0.15. Cobalt-60 Vadose Zone Contamination in the B-BX-BY Waste Management Area and Vicinity

gwf03487



Panels of block diagram that face toward reader are illustrated by heavy outlines.

All well names prefixed by 299-

**Figure 6.0.16. Uranium-238 Vadose Zone Contamination in the B-BX-BY Waste Management Area and Vicinity**

A baseline record of existing contamination associated with gamma-emitting radionuclides in the vadose zone was established between 1995 and 2000. The tank farm baseline characterization effort identified subsurface contaminant plumes in the vicinity of the single-shell tank farms. Cobalt-60, cesium-137, europium-152, europium-154, uranium-235, and uranium-238 were the predominant gamma-emitting contaminants. Minor amounts of tin-126 and antimony-125 were also detected.

The logging system used for monitoring is the Radionuclide Assessment System. The Radionuclide Assessment System uses a series of sodium iodide (NaI) scintillation detectors to monitor gamma activity in tank farm boreholes. Three different detector sizes are available to provide a wide range of measurement capability. Although less precise, the Radionuclide Assessment System is a simpler and faster logging system than the high resolution spectral gamma logging system. Measurements collected with the Radionuclide Assessment System can be compared to the baseline data to assess the long-term stability of the radionuclide contaminant profile. When routine monitoring identifies anomalies relative to the baseline, these anomalies may be investigated using the spectral gamma logging system, the High Rate Logging System, and/or the Neutron Moisture Logging System. The High Rate Logging System is also used to collect data in boreholes where the contaminant activity exceeds the working range of the Radionuclide Assessment System instrumentation (greater than about 100,000 pCi/g [3.7 MB/g] cesium-137).

Specific borehole and depth intervals for monitoring are selected on the basis of intersection with known contaminant plumes, proximity to tanks known to have leaked or to subsurface contaminant plumes, or proximity to tanks containing relatively large volumes of drainable liquid. The logging frequency is determined by the overall priority. Most boreholes of interest will be logged on at least a yearly basis. The goal of the monitoring program is to collect data from all boreholes at least once in a 5-year period.

During fiscal year 2003, monitoring in boreholes associated with individual tanks undergoing retrieval operations was initiated. Retrieval monitoring requirements for specific tanks are under development but include a pre-retrieval baseline measurement, monthly measurements during the retrieval operations, and monthly measurements for six

months after retrieval operations cease. Both the Radionuclide Assessment System and Neutron Moisture Logging System measurements are made on a monthly basis, and monthly monitoring is supplemented by manual moisture measurements acquired by CH2M HILL Hanford Group, Inc. personnel over limited depth intervals once or twice per week. During fiscal year 2003, two retrieval projects (tanks C-106 and S-112) were initiated. This required that the Radionuclide Assessment System be diverted from the routine monitoring to retrieval monitoring and resulted in a negative impact on the routine monitoring program as originally set forth in 2001. Deployment of the Neutron Moisture Logging System to support retrieval operations requires an additional logging engineer and reassignment of the system from support for the remedial investigation/feasibility study work conducted by the DOE Richland Operations Office.

A total of 377 (336 routine and 51 retrieval) monitoring events were performed with the Radionuclide Assessment System during fiscal year 2003. In addition, 27 moisture monitoring events were conducted in support of retrieval operations. Results are summarized by tank farm in Table 6.0.8. In the interest of brevity, plots for boreholes will not be included in this report. These logs are available on request, or from the internet at <http://www.gjo.doe.gov/programs/hanf/HTFVZ.html>.

The Radionuclide Assessment System has proven useful since its inception in fiscal year 2001 in providing a credible monitoring program for the tank farms vadose zone. Evidence of possible contaminant movement has been detected in 29 boreholes in 9 tank farms; 7 were identified this fiscal year. Of these 29 boreholes, data collected from 2 boreholes indicate movement to a degree that can be confirmed over a short time interval. Of the remaining 27 boreholes, it is likely that the elapsed time between monitoring events is not sufficient to detect subtle changes in contaminant profile, suggesting relatively slow movement of contaminants in the vadose zone. In general, intervals where discernable movement of contaminants through the vadose zone is occurring within short periods of time (e.g., less than 1.5 years) appear to be very limited.

Currently only one logging system (the Radionuclide Assessment System) is available to support both routine monitoring and leak detection monitoring for waste



**Table 6.0.8. Summary of Tank Farm Monitoring Results**

<b>Tank Farm</b>	<b>Boreholes Monitored</b>	<b>Summary of Results</b>
A	28	No significant changes in subsurface contaminant profile
AX	7	No significant changes in subsurface contaminant profile
B	8	No significant changes in subsurface contaminant profile
BX	33	Borehole 21-12-02 showed an abnormal decrease in total and <sup>60</sup> Co counts between 12 and 13.7 m (40 and 45 ft) during the most recent monitoring event on September 23, 2003. <sup>238</sup> U counts between 41.9 and 45 m (137 and 147 ft) have not confirmed this change.
BY	33	Boreholes 22-07-02, 22-07-05, and 22-08-05 have all shown evidence of possible <sup>60</sup> Co movement during previous monitoring events. Monitoring data in these boreholes during fiscal year 2003 failed to provide further evidence of movement.
C	48	<p>Boreholes associated with tank C-106 were monitored several times during fiscal year 2003 in support of the C-106 Waste Retrieval Project.</p> <p>A possible increase of <sup>60</sup>Co was identified in borehole 30-06-10 between 37.8 and 38.4 m (124 and 126 ft) on April 23, 2002. Monitoring events conducted in this borehole during fiscal year 2003 showed no further evidence of movement. A definite change in <sup>60</sup>Co concentrations was observed in borehole 30-08-02 on September 11, 2002 between 18 and 18.5 m (59 and 61 ft). This appears to be related to a <sup>60</sup>Co plume originating between C-108 and C-109, and migrating downward and to the east. Contaminant movement was detected as early as 1999. Subsequent monitoring events during fiscal year 2003 have shown downward movement of <sup>60</sup>Co through this interval. This <sup>60</sup>Co is not related to recent waste retrieval operations in tank C-106. A possible increase in <sup>137</sup>Cs was observed in borehole 30-08-03 from 12.8 and 14.3 m (42 to 47 ft) on January 21, 2003. Subsequent monitoring events did not confirm this change.</p> <p>Five boreholes were logged with neutron moisture logging during fiscal year 2003.</p> <p>Beginning in April 2003, three neutron moisture logging system logs were acquired in boreholes around C-106 during the fiscal year. Preliminary results of the moisture measurements suggest no increases in moisture will continue to be monitored during fiscal year 2004 to determine if the increases are due to seasonal fluctuations in moisture or a potential tank leak. Radionuclide Assessment System measurements suggest no increases in moisture. As of October 2003, it is believed that the observed moisture changes are related to seasonal fluctuations and that no tank leaks associated with the retrieval operations are occurring.</p>
S	28	<p>Boreholes associated with tank S-112 were monitored several times during fiscal year 2003 in support of the S-112 Waste Retrieval Project. These boreholes were also logged several times with the neutron moisture logging system.</p> <p>Eight boreholes located around tank S-102 were monitored in preparation for the S-102 Waste Retrieval Project. An apparent increase in <sup>137</sup>Cs concentration was observed in borehole 30-08-03 during fiscal year 2004.</p> <p>The baseline moisture measurements were acquired during August 2003. Two Radionuclide Assessment System measurements (March and August) have been acquired to support retrieval operations during fiscal year 2003. No changes in activity were observed between the two Radionuclide Assessment System measurements or since the baseline spectral gamma data acquired in 1996.</p> <p>A second pre-retrieval monitoring event is scheduled for January 2004. Currently, baseline moisture logging is planned to be performed in tank S-102 boreholes approximately one month prior to the start of retrieval operations to assess any potential changes in a zone of high gamma flux.</p>

**Table 6.0.8. (contd)**

<b>Tank Farm</b>	<b>Boreholes Monitored</b>	<b>Summary of Results</b>
SX	49	Borehole 41-02-02 showed evidence of possible <sup>137</sup> Cs and/or <sup>90</sup> Sr concentration increases between 13 and 16.7 m (43 and 55 ft) during the initial Radionuclide Assessment System monitoring event. Borehole 41-15-07 showed a possible <sup>137</sup> Cs concentration increase at 20 m (66 ft). This increase was first identified by the spectral gamma logging system repeat logging in 1999. Borehole 41-15-07 showed a possible <sup>137</sup> Cs increase between 17.3 and 18.2 m (57 and 60 ft). This increase was identified during the second monitoring event conducted on February 12, 2003.
T	24	Eight of these boreholes (50 increases and/or contaminant movement in the past. No increases were confirmed in these boreholes during fiscal year 2003. Borehole 50-02-05 indicated an increase during fiscal year 2003. Neutron m drilled in fiscal year 2003. Neut
TX	15	Borehole 51-03-11 showed possible increases in <sup>60</sup> Co concentrations at depths of 18.6 and 18.9 m (61 to 62 ft) and from 27.4 and 28.9 m (90 to 95 ft) during the initial monito
TY	9	Borehole 52-03-06 showed an increase in <sup>137</sup> Cs concentration between 16.7 and 17.7 m (55 and 58 ft) during the initial monitoring event on May 2, 2002. Subsequent monitoring events have not shown additional increases in <sup>137</sup> Cs concentrations. Borehole 52-06-05 continues to show evidence of increasing <sup>60</sup> Co concentrations between 39.6 and 44.8 m (130 and 147 ft). Borehole 52-06-07 showed evidence of possible increases between 60.9 and 68.6 m (200 to 225 ft).
U	21	Seven of these boreholes were monitored to support the U-107 Waste Retrieval Project. A special investigation of the boreholes around tank U-107 (U Farm) has been completed. A final report, <i>Evaluation of Log Data in the Vicinity of Tank U-107</i> (GJO-2003-427-TAC), summarizing all measurements, was prepared and issued in June. A final monitoring event was completed in boreholes around this tank in August 2003. The data from this final event supported the conclusion that there was no apparent change in the gamma-emitting radionuclide distribution in the vicinity of

6.31

retrieval operations. This logging system was originally configured for routine monitoring of gamma activity only. The requirement for neutron moisture logging to support retrieval operations has required that an additional logging system be detached from characterization logging and used to run the moisture log. As waste retrieval operations begin in C and S Tank Farms, increasing demands for retrieval support will interfere with the ability to conduct routine monitoring operations in the other tank farms. Efforts are underway to obtain a second monitoring system, configured for concurrent gamma activity and neutron moisture logging. This type of system will streamline logging operations for retrieval support, achieving significant cost savings, as well as freeing the Radionuclide Assessment System for the routine monitoring program.

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