6.0 100-NR-2 Operable Unit

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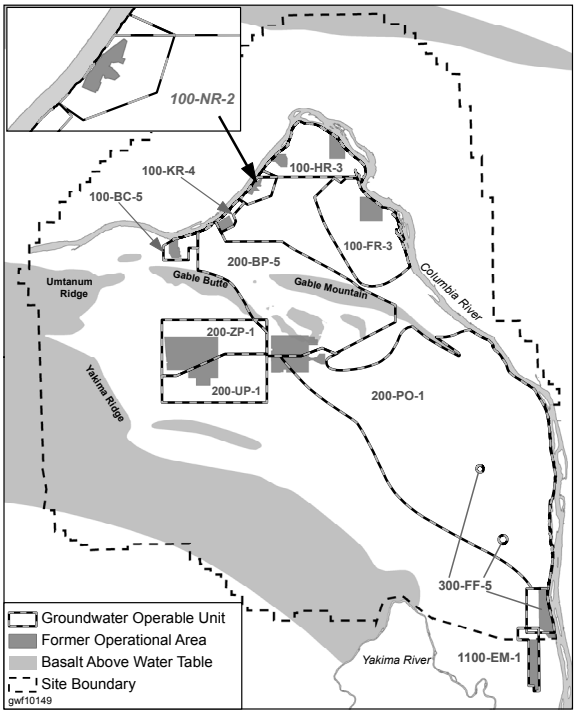

This chapter describes the groundwater conditions and contaminant distributions for the 100-NR-2 groundwater interest area and focuses on the 100-N Area and its associated facilities and operations. The 100-NR-2 Operable Unit (OU) is part of this groundwater interest area and encompasses the groundwater affected by contaminant releases from facilities and waste sites in the 100-N Area. Figure 6-1 shows the facilities and wells in the OU, and Figure 6-2 shows the shoreline monitoring locations and sites related to the apatite barrier tests performed to date at the 100-N Area.

A brief discussion on the conceptual model for the 100-NR-2 OU is provided below. Section 6.1 discusses the contaminant plumes and concentration trends in the vicinity of the 100-N Area. Strontium-90 is the contaminant of concern (COC) for a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) interim action (EPA/541/R-99/112, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*). Several ongoing remedial investigation (RI) activities are working toward development of a final Record of Decision (ROD). The CERCLA activities completed during this reporting period are discussed in Section 6.2. Section 6.3 identifies the groundwater monitoring activities at the four facilities covered by the *Resource Conservation and Recovery Act of 1976* (RCRA) and the *Atomic Energy Act of 1954* (AEA) for calendar year (CY) 2010. Section 6.4 provides conclusions and recommendations for the 100-NR-2 OU. This chapter covers the period from January 1, 2010, through December 31, 2010, which is referred to in the following discussion as CY 2010.

The U.S. Department of Energy (DOE) has identified 185 waste sites in the 100-N Area; one site is closed out, 17 sites are interim closed out, one site requires no action, 10 sites are not accepted, and 27 sites were rejected, totaling 56 sites of the 185 sites (~30% of the sites) that will not need to be considered further as part of the *Integrated 100 Area Remedial Investigation Study/Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units* (DOE/RL-2008-46-ADD5). The high-volume waste sites include the 116-N-1 and 116-N-3 Liquid Waste Disposal Facilities (LWDFs) and the 120-N-1 percolation pond.

The main COC in the 100-N Area is strontium-90. The areal extent of the strontium-90 plume has remained relatively unchanged from 1996 to the present. Strontium-90 contamination is found in portions of the vadose zone that were saturated during discharge operations and in the underlying aquifer extending to the Columbia River. Other contaminants in 100-N Area groundwater include tritium, nitrate, petroleum hydrocarbons, sulfate, and chromium.

The 100-N Area is underlain by the Hanford formation, the Ringold Formation unit 5, and the Ringold Formation upper mud unit. The uppermost unit, the Hanford formation, is 6 to 23 meters thick and underlies most of the area. In a few places along the shoreline lower roadway, the Hanford formation is absent due to excavation and

fill that was placed to build the road. Unit 5 of the Ringold Formation (also known as Ringold unit E) underlies the entire area and is 5 to 20 meters thick. The Ringold Formation upper mud unit also underlies the entire area and is 17 to 29 meters thick. Most of the monitoring wells in the 100-N Area are completed in the upper portion of the unconfined aquifer, which is predominately in the Ringold Formation unit 5. At high Columbia River levels, the aquifer can rise into the Hanford formation in wells along the shoreline and nearby inland wells. Three wells monitor the base of the unconfined aquifer (199-N-69, 199-N-70, and 199-N-121). Another well, 199-N-80, is completed in a fine-grained sandy unit in the Ringold Formation upper mud unit, ~12 meters below the water table. The aquifer monitored by these deeper wells is essentially free of strontium-90 contamination (i.e., nondetected or at levels barely above detection). Nitrate concentrations are higher in the upper aquifer wells than in deep wells. Tritium concentrations are about the same or lower in the deep wells. The Ringold Formation upper mud unit is the confining unit forming the base of the unconfined aquifer. Further information on the geology and hydrology of the 100-N Area is provided in Chapters 2.0 and 4.0 of the RI study/work plan (DOE/RL-2008-46-ADD5).

Groundwater flow is primarily to the north and northwest,toward the Columbia River, with flow influenced by fluctuations in the river level and the river's seasonal variations. The river stage can change daily (±1.5 meters) and seasonally (±2.4 meters) for sustained periods, which changes the saturated zone thickness and causes flow reversals (PNNL-16891, *Hanford 100-N Area Apatite Emplacement: Laboratory Results of Ca-Citrate-PO4 Solution Injection and Sr-90 Immobilization in 100-N Sediments*). Figure 6-3 provides the March 2010 water table map for the 100-N Area. In the spring, the river level is higher than during the remainder of the year and water moves into the aquifer from the river, affecting water levels in shoreline and nearby inland wells. The water level within the soil column is elevated, and portions of the vadose zone (above average water table) are rewetted.

Vertical gradients are difficult to measure in the unconfined aquifer at the 100-N Area. The difference in water levels in well pairs 199-N-81/199-N-70 and 199-N-119/199-N-121 was only a few hundredths of a meter during CY 2010, within measurement error. The screen depths differ by ~5 to 6 meters.

Some wells for the adjacent 100-KR-4 OU pump-and-treat operation are installed in the western and southern portion of the 100-N Area. Injection wells are located between the 100-N Area (proper) and the extraction wells for the 100-KR-4 pump-and-treat systems. Placement of the injection wells was planned to put a "clean" water area between 100-N Area groundwater and the 100-K Area chromium plume further south. The wells and the pump-and-treat systems that are supported are discussed in detail in Chapter 5.0.

6.1 Groundwater Contaminants

Plume areas (square kilometers) in the 100-NR-2 Operable Unit:

Nitrate, 45 mg/L — 0.569

Strontium-90, 8 pCi/L — 0.579

Tritium, 20,000 pCi/L — 0.034

Petroleum Hydrocarbons, 1,000 µg/L — 0.009

Wells and aquifer tubes within the 100-NR-2 OU (Figures 6-1 and 6-2) are sampled for constituents of concern identified in the interim action ROD (EPA/541/R-99/112), which include strontium-90, tritium, nitrate, sulfate, petroleum hydrocarbons, manganese, iron, and chromium. Figure 6-2 shows the locations of current performance monitoring sites at the apatite permeable reactive barrier (PRB) and other planned remediation activities (see discussion in Section 6.2).

Field parameters are obtained whenever a well or an aquifer tube is sampled. Field parameters include pH, temperature, specific conductance, and turbidity on all wells/aquifer tubes. Two other parameters collected for wells/aquifer tubes under the influence of the diesel plume and the apatite barrier include dissolved oxygen and oxidation-reduction potential.

Strontium-90 is the principal COC in the 100-NR-1 OU. The plume has not changed much since 1996.

6.1.1 Strontium-90

The majority of the strontium-90 remaining in the unsaturated and saturated zones in the 100-N Area is present in the vadose zone above the aquifer. Far more strontium-90 is contained within the unsaturated zone than in the groundwater. Strontium-90 has a much greater affinity for sediment than for water (i.e., a high distribution coefficient), so its rate of transport in groundwater to the Columbia River is considerably slower than the actual groundwater flow rate. The relative velocity of strontium-90 to groundwater is ~1 to 100.

Soil data have been collected from wells and borings within and around the 116-N-1 (1301-N) and 116-N-3 (1325-N) LWDFs, as well as along the Columbia River shoreline. Strontium-90 is generally distributed in a layer around the current water table, mostly in the upper portion of the Ringold Formation unit 5. This layer is thickest around the LWDFs (up to 12.2 meters) and thins toward the Columbia River (1.5 to 6.1 meters). Strontium-90 concentrations in soil from wells/borings near the LWDFs show a decreasing trend with distance and depth from the LWDFs. The majority of strontium-90 contamination within the LWDFs was retained within the facilities (nearer the head end and immediately below the base). The LWDFs were interim remediated in 2005 and 2006, and contaminated concrete and soil were removed to a depth of 4.6 meters. The sites were backfilled in 2006 (DOE/RL-2006-76, *Calendar Year 2006 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operations*).

Strontium-90 concentrations in soil samples collected from the wells/borings further from the LWDFs along the 100-N Area shoreline indicate that the majority of strontium-90 is located in the top of the Ringold Formation unit 5 and the bottom of the Hanford formation. The water table near the Columbia River is located in the top of the Ringold Formation unit 5 during low river-level conditions (July through March), but the water table can rise up into the Hanford formation when river levels are elevated (late March/April to June). This causes the strontium-90 contamination to smear vertically within the areal extent of the plume (PNNL-16891). The majority of the contamination in soil along the Columbia River is in the immediate vicinity of the current apatite PRB, between wells 199-N-123 to 199-N-121 (PNNL-16894, *Investigation of the Strontium-90 Contaminant Plume Along the Shoreline of the Columbia River at the 100-N Area of the Hanford Site*).

The size and shape of the strontium-90 plume in groundwater has varied little over the years due to the way strontium and strontium-90 act in the environment. The plume currently has nearly the same areal extent and shape as in 1996, prior to startup of 100-N Area pump-and-treat operations. Effluent discharge totals of strontium-90 to 116-N-1 and 116-N-3 LWDFs from 1964 through 1993 were slightly more than 2,997 curies. As of 2010, this amount was ~1,325 curies, corrected for radioactive decay (DOE/RL-2008-46-ADD5). The 2010 value does not reflect any contamination that was removed during the 2005/2006 excavation of the 116-N-1 and 116-N-3 LWDFs; therefore, some of the remaining 1,325 curies have been removed to the Environmental Restoration Disposal Facility. In a previous calculation for the 116-N-1 Crib and Trench sediments (BHI-00368, *Data Quality Objectives Workshop*

Results for 1301-N and 1325-N Characterization), the strontium-90 inventory was estimated at 500 curies, assuming an average strontium-90 concentration from soil analyses, distributed through a 1-meter-thick crib/trench/vadose zone interface (DOE/RL-2008-46-ADD5). Of the inventory remaining, ~99% is absorbed on the soil in the vadose zone and upper aquifer and 1% is actually in groundwater (PNNL-16891). The plume extends from beneath the 116-N-1 and 116-N-3 LWDFs to the Columbia River at levels exceeding the drinking water standard (DWS) of 8 pCi/L (Figure 6-4). Concentrations exceeding 100 pCi/L are limited to the upper ~3 meters of the aquifer (PNNL-16436, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*). Concentrations in several wells and aquifer tubes exceeded the DOE's derived concentration guideline of 1,000 pCi/L (which is the reference value given for conducting radiological environmental protection programs at DOE facilities per DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, Chapter 3).

The highest strontium-90 concentrations along the Columbia River in soil and groundwater are found near the current apatite PRB and immediately downriver to the northeast. This area is the focus of increased monitoring and remediation activities. Figure 6-5 depicts the strontium-90 concentrations at the 100-N Area shoreline in the area affected by the current apatite PRB. Figures 6-6 and 6-7 show the effects of the apatite PRB on strontium-90 concentrations. The barrier helped to reduce strontium-90 concentration in its immediate vicinity, including wells within the barrier itself, on both sides of the injection wells on each end of the barrier, and monitoring wells downgradient of the barrier. It also includes one well upgradient of the barrier; 199-N-46 has shown a decrease in strontium-90 concentration from a high in September 2006 of 6,040 pCi/L to 530 pCi/L in April 2010. Prior to apatite PRB installation, strontium-90 concentrations in this well were consistently above 1,000 pCi/L; however, since December 2008, the concentration has been below 650 pCi/L. Strontium-90 concentrations in all of the wells and aquifer tubes are less than those reported in last year's annual report (DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2*). Several of the wells were nondetect for strontium-90 in 2010. All but one monitoring point are below 1,000 pCi/L; tube NVP2-116.0m remained at 1,200 pCi/L as of December 2010. Some variability in concentration is based on the depth of well completion but, overall, the values are well below pre-treatment levels. The effects of the apatite PRB are discussed in greater detail in Section 6.2.4.

Strontium-90 in monitoring wells near the former 116-N-1 LWDF and the former 116-N-3 LWDF show no obvious long-term decline in concentrations, but concentrations do vary significantly in relation to water levels within the wells (Figures 6-8 and 6-9, respectively). Water levels were significantly higher below the LWDFs in the 1980s and early 1990s, when discharges were still occurring. As the water level decreased, strontium-90 remained in the vadose zone above the water table. Therefore, when the water table rises beneath the former LWDFs, strontium-90 from the vadose zone is remobilized and the concentrations in groundwater increase. Levels have been consistent for the last few years, with the increase and decrease of strontium-90 concentrations mirroring changes in the water table elevation. Seven wells are showing increasing strontium-90 concentration trends: three wells are former 100-N Area pump-and-treat extraction wells (199-N-75, 199-N-103A, and 199-N-105A); three wells (199-N-2, 199-N-67, and 119-N-14) are downgradient of the 116-N-1 LWDF; and the fourth well, 199-N-122, is a monitoring well in the apatite PRB. Well 199-N-122 is located in one of the most contaminated portions

of the shoreline. The concentrations in all seven of these wells have increased since the pump-and-treat system shutdown in 2006. Six of the seven wells have higher concentrations now than in 1996, before the pump-and-treat system was started. It appears that the increase may be due to a rebound effect that has been occurring since pump-and-treat operations ceased. Another possible explanation is that higher river levels in the last few years have caused the lower vadose zone to be rewetted and allowed remobilization of strontium-90 from these contaminated sediments. As the river level and aquifer levels decrease, this contamination is smeared back down into the aquifer and could cause higher concentrations in the monitoring wells over time. This effect will be studied further in next year's report to determine if it is contributing to the uptrend observed in these six wells. Well 199-N-122 is the only exception, because it was not drilled and installed until October 2005, and the concentration of this well is under the influence of the apatite PRB. As the development of apatite continues along the barrier, changes occur in strontium-90 concentrations due to interaction with nearby treated wells and changes in river stage, remobilizing strontium-90 from rewetted contaminated sediment above the water table. All other wells in the 100-N Area that were monitored in 2010 are showing slight downward strontium-90 trends.

Figure 6-6 shows the screened intervals of aquifer tubes and near-shore wells in a cross section parallel to the Columbia River and illustrates strontium-90 concentrations with depth. Strontium-90 concentrations greater than the DWS are present only above ~115 meters in elevation (i.e., the top 2 to 3 meters of the aquifer). Although few aquifer tubes are completed at elevations less than 115 meters, the majority of the aquifer tubes completed below this elevation are in the area where strontium-90 concentrations along the river are known to be highest. Therefore, if the lower elevation tubes in this area are free of strontium-90 contamination, it is likely the adjacent areas along the river shore will also be free of strontium-90. Appendix C provides additional information on 100-N Area aquifer tube sampling. Figure 6-7 depicts the same information for the apatite PRB area. Some of the strontium-90 values shown in these graphs were calculated as half of a gross beta value where strontium-90 data were not available. This is an accurate representation of potential strontium-90 values, as there are no other competing beta emitters to consider, and previous studies performed at the 100-N Area have confirmed that this is a reliable calculation (PNNL-16894).

Figure 6-10 shows the strontium-90 depth profiles through the "NVP" cluster of aquifer tubes for the three sampling periods in CY 2010. The highest concentrations were at the elevation of 116.0 to 116.3 meters. Along the river shore in the 100-N Area, the 116.0 meter elevation (±1 meter) is the elevation where the aquifer intersects the river. During the porewater sampling conducted by Washington Closure Hanford (WCH) (from 2008 through 2009) and CHPRC (in 2010) along the 100-N Area shoreline, the majority of the groundwater detections were in this elevation range. The elevated strontium-90 values also correlate with higher conductivity readings in most cases for the sample collected. However, not every higher strontium-90 value has a corresponding higher conductivity value; in several samples from both elevations, conductivity increased and strontium-90 concentrations decreased.

Figure 6-11 shows the historical ranges and the March/April 2010 strontium-90 concentrations in 100-N Area aquifer tubes. The aquifer tubes located from Array-3A to Array-6A have historically had the highest and the widest ranges of concentrations. All of these tubes are completed at the 116.0 meter elevation, which is the elevation where most of the highest strontium-90 concentrations are found and the elevation

where groundwater most often intersects the Columbia River (see discussion in previous paragraph). The variability in concentrations in these four tubes is due to the effects of ongoing apatite PRB remediation (Section 6.2.4).

Figure 6-12 shows strontium-90 and gross beta concentrations over time in tube NVP2-116.0, where concentrations are typically the highest of any of the aquifer tubes. The top panel in the figure shows peaks in concentrations caused by mobilization of strontium-90 following chemical injections in 2007 and 2008 (DOE/RL-2008-66, *Hanford Site Groundwater Monitoring for Fiscal Year 2008*). The lower panel in the figure shows the trend without the larger peaks, so smaller trends are more discernable. Strontium-90 concentrations increased in early 2009 and subsequently dropped to ~1,000 pCi/L by December 2009. Fluctuations in concentrations also occurred in CY 2010, but the overall trend from 2006 through 2010 was downward. Gross beta values were greater than 5,000 pCi/L in early 2006 before apatite injections began. As of December 2010, the gross beta concentration had decreased to 2,600 pCi/L and the strontium-90 concentration had decreased to 1,200 pCi/L.

Samples were collected in five sets of aquifer tubes as part of the RI/feasibility study (FS) work in the 100-N Area (TPA-CN-353), which are discussed in Section 6.2.8.

6.1.2 Tritium

The source of the tritium in groundwater at the 100-N Area is from past-practice disposal operations associated with the N Reactor. Liquid effluent disposed to the 116-N-1 and 116-N-3 LWDFs contained tritium. Tritium is nonreactive with subsurface sediments, so tritium in effluent wastewater migrated quickly through the vadose zone without leaving residuals. Unlike strontium-90, tritium is present throughout the entire thickness of the unconfined aquifer. Concentrations in wells 199-N-69 and 199-N-70, which are completed at the base of the unconfined aquifer, are similar to nearby wells completed in the upper unconfined aquifer (DOE/RL-2010-11). The tritium concentration in well 199-N-80, completed in a confined aquifer in the Ringold Formation, was 13,000 pCi/L in 2010, which is less than the CY 2009 reported value of 16,000 pCi/L.

The tritium plume has diminished since 1991, when effluent discharge to the 116-N-3 LWDF ceased. The plume currently covers the area beneath both the 116-N-1 and 116-N-3 LWDFs and stretches north and northeast to the Columbia River shoreline. Figure 6-13 shows the data averages for CY 2010, and Figure 6-14 shows the tritium concentration between the wells near 116-N-1 (199-N-14) and 116-N-3 (199-N-32) LWDFs. The overall trend for tritium concentration near these former disposal facilities is slowly decreasing. In CY 2010, tritium concentrations were below the 20,000 pCi/L DWS in all wells. The highest tritium concentration in a 100-N Area well was 17,500 pCi/L in well 199-N-32 (Figure 6-14).

Nitrate concentrations continued to exceed the DWS in several wells and in some wells downgradient of the 116-N-1 LWDF in 2010.

6.1.3 Nitrate

The source of the nitrate plume at the 100-N Area is not well known. Based on information gathered to date, it is not believed that the source of nitrate contamination is from any past-practice effluent disposal at the 100-N Area. However, efforts continue to identify the source(s) of the plume, which include evaluating facility effluent streams, septic systems, and disposal sites (DOE/RL-2008-46-ADD5). Data collected from the 100-N Area RI/FS effort will be used to further identify the possible sources of the nitrate plume, including any sources located within the 100-N Area.

Nitrate concentrations exceed the 45 mg/L DWS in eighteen wells in the 100-N Area (Table 6-1). The majority of these wells are found near the 116-N-1 and 116-N-3 LWDFs. The nitrate plume lies under the former 116-N-1 and 116-N-3 LWDFs, under portions of the southwest 100-N Area (the reactor and associated buildings), and extending to the Columbia River below well 199-N-21. Figure 6-15 shows the average nitrate concentrations in the upper unconfined aquifer of the 100-N Area.

Figure 6-16 provides nitrate trend plots for two wells near the former 116-N-1 LWDF and includes the entire recorded history for these two wells. Figure 6-17 provides the nitrate trend plot for a well near the 116-N-3 LWDF. At both sites, nitrate concentrations were high in the mid- to late 1980s, declined sharply in the early1990s, and have been generally increasing since that time. As shown in Figure 6-16, both wells 199-N-2 and 199-N-67 showed increased concentrations in CY 2010. As shown in Figure 6-17, well 199-N-32 showed an overall decrease in CY 2010.

Figure 6-18 shows the nitrate concentrations for three wells near the 120-N-1 percolation pond and includes the entire recorded history for these wells. (Note that well 199-N-59 went dry and was replaced by well 199-N-165 in 2008.) Nitrate concentrations at this location have also increased since the early 1990s. During the 120-N-1 percolation pond's period of use from 1977 to 1990, only low levels of nitrate (~1 mg/L) were detected in the pond's effluent stream (DOE/RL-96-39, *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measures Study/Closure Plan*). When monitoring began in 1987, the nitrate concentrations in groundwater were low at 1 to 4 mg/L. Nitrate levels have exceeded the 45 mg/L DWS in well 99-N-59 (1998 to 2008) and also in replacement well 199-N-165 (but only for the first sample in 2009). Nitrate levels in well 199-N-72 exceeded the DWS from 2005 through 2008 (DOE/RL-2008-66). The source of the nitrate plume and the reason for the increasing concentrations are unknown.

Wells 199-N-18 and 199-N-16 have variable nitrate trends that are believed to be related to chemical reduction and biodegradation of hydrocarbons (DOE/RL-2010-11). The lower concentrations are believed to be caused by chemical reduction of nitrate due to biodegradation of petroleum hydrocarbons near the well (Section 6.1.4). Other chemical constituents and parameters that support the interpretation of chemical reduction in and around well 199-N-18 include low dissolved oxygen, low pH, detectable nitrite, and elevated concentrations of iron and manganese.

Aquifer tubes C6132 and C6322 had nitrate concentrations greater than the DWS in 2009, at 46 and 64.6 mg/L, respectively. Aquifer tube C6132 was not sampled in CY 2010. Aquifer tube C6320 had a value of 48.3 mg/L in September but decreased to 11.6 mg/L in December. Aquifer tubes C6317, C6318, and C6319 had respective values of 17, 41.7, and 753 mg/L (data flagged as suspect) in August and values of 31.7, 44.7, and 40.7 mg/L in September.

6.1.4 Petroleum Hydrocarbons

Petroleum hydrocarbon from a 1960s diesel fuel tank spill (UPR-100-N-17) continues to be detected in 100-N Area groundwater. The full nature and extent of subsurface hydrocarbon impacts in the UPR-100-N-17 waste site has not been determined (WCH-490, *UPR-100-N-17: Bioventing Pilot Plant Performance Report*). The petroleum hydrocarbon plume in groundwater (shown in Figure 6-19; data from spring through fall of CY 2010) is confined to a relatively small region in the 100-N Area and is centered on well 199-N-18 with a concentration of 420,000 µg/L.

The diesel plume in the 100-N Area has been further defined due to increased groundwater and vadose zone work. The groundwater plume has a limited extent and stems directly from spills in and around the former 166-N Tank Farm facility.

This represents a substantial increase from the CY 2009 value of 16,000 µg/L and may be due in part to two activities: (1) this well did not have as much active removal of free product in CY 2010 as in previous years, and (2) WCH began testing bioventing on the vadose zone in the area immediately east and southeast of this well. These activities are discussed later in this section. In a sample taken at well 199-N-18 on December 5, 2010, the concentration had decreased to 41,000 µg/L. Total petroleum hydrocarbon-diesel detections occurred in seven other nearby wells at the following concentrations:

- Well 199-N-167 at 4,600 µg/L
- Well 199-N-169 at 1,100 µg/L
- Well 199-N-170 at 360 µg/L
- Well 199-N-171 at 2,800 µg/L
- Well 199-N-172 at 25,000 µg/L
- Well 199-N-173 at 2,100 µg/L
- Well 199-N-96A at 200 µg/L.

Wells 199-N-167, 199-N-169, 199-N-170, 199-N-171, and 199-N-172 are part of the system installed to test bioventing techniques on the vadose zone in the area near the main diesels spills that occurred in the 100-N Area. Wells 199-N-96A and 199-N-173 are located immediately downgradient of the spill area and these other wells.

The DOE continued passive remedial actions to remove free product from well 199-N-18. Passive remediation involves the use of a polymer "smart sponge" that selectively absorbs petroleum products from the surface of the water within the well. Every 2 months, two of the sponges are lowered into the surface of the aquifer in well 199-N-18 and left in place to soak up the diesel fuel. The sponges are weighed prior to placement in the well and again after removal. The weight difference between the two measurements is the amount of "product," or diesel fuel contamination, removed from the well. Table 6-2 shows the results of this remediation activity since it began in 2003. Removal of product from well 199-N-18 continued in CY 2010 in accordance with the interim action ROD (EPA/541/R-99/112); however, this did not occur during the entire CY. In mid-June 2010, one of the smart sponges came apart inside the well (the package containing the polymer was breached), which created a slime coating everything in the well, and made sampling or product removal very difficult. Well maintenance staff was able to remove a great deal of the sponge material, but the removal process smeared the material inside the well casing as it was removed. In July, the well was sampled before the well maintenance crew could finish cleaning the well. The diesel contamination value from this sampling event (July 9, 2010) is reflected on the plume map as the highest value measured in the well in CY 2010. The well was cleaned further with some success, but it was decided to replace well 199-N-18 based on the *Remedial Design Report/Remedial Action Work Plan for the 100-NR-2 Operable Unit* (DOE/RL-2001-27). This decision was made for two main reasons: (1) low water level in the well makes sampling difficult and requires the use of a bailer, and (2) the inability to completely remove the smart sponge material from the well will cause long-term potential for interference with sampling and the quality of samples that can be collected. Well 199-N-18 will be kept for continued product removal because that particular process is not affected by the residual smart sponge material on the well casing. Smart sponges were reinstalled in well 199-N-18 in January 2011 and product removal from the well continues.

Low levels of hydrocarbon contamination have previously been observed in wells 199-N-3, 199-N-16, 199-N-19, and 199-N-96A (PNNL-14187, *Hanford Site Groundwater Monitoring for Fiscal Year 2002*). Previous detections in the 1990s were also found in wells 199-N-17 and 199-N-20 (both have been decommissioned). Wells that did not have detectable levels of diesel-range total petroleum hydrocarbons in CY 2010 were 199-N-3, 199-N-19, 199-N-21, 199-N-56, and 199-N-57. These wells bound the area of the diesel spill contamination and are indicators that the extent of contamination in groundwater is most likely limited to the area northwest and southeast of well 199-N-18.

When the apatite PRB expansion wells were drilled in 2009 and 2010, three of the wells in the vicinity of 199-N-173 and 199-N-96A had detections of petroleum hydrocarbon odors and staining of soils immediately above and into the water table.

- Well 199-N-346 (C7442), a monitoring well located between wells 199-N-173/199-N-96A and the two barrier wells on the uppermost end of the PRB expansion
- Well 199-N-201 (C7326)
- Well 199-N-200 (C7327).

These three wells have not been included in the plume map for this report, as they have only been sampled once and were not sampled at the same time. Shallow well 199-N-200 (completed in the Hanford formation) only contains water during high river stage. With the expansion of the apatite PRB scheduled within the next couple of years, these wells and others in the vicinity of wells 199-N-173 and 199-N-96A will have more samples taken and provide additional information on the extent of the petroleum hydrocarbon plume along the 100-N Area shoreline below well 199-N-18. The borehole logs for these wells are provided in the borehole summary report for the 171 wells installed for the apatite PRB expansion (SGW-47791, *Borehole Summary for the Installation of One Hundred and Seventy One Wells at 100-NR-2 Operable Unit, FY 2009-2010*).

Aquifer tubes near wells 199-N-173 and 199-N-96A along the 100-N Area shoreline are also sampled for petroleum hydrocarbons. In CY 2010, three of four aquifer tubes sampled near the intersect of the plume and the Columbia River showed detections of total petroleum hydrocarbon-diesel. Upstream aquifer tube C6320 was nondetect for total petroleum hydrocarbon-diesel. Aquifer tubes adjacent to the shoreline next to the above-mentioned wells had the following detections: C6135 at 910 µg/L and 116mArray-0A at 570 µg/L. The downstream aquifer tube 116mArray-1A had a detection at 220 µg/L; this aquifer tube was nondetect during the CY 2009 sampling events. It should be noted that these samples were collected in mid-September when the river level was low. It is possible that diesel contamination is more likely to be upwelling into the river under these conditions, as groundwater flow is into the river.

6.1.5 Sulfate

Wastewater from the former 120-N-1 percolation pond introduced sulfate and sodium into 100-N Area groundwater. The sulfate plume in the 100-N Area is depicted in Figure 6-20. The highest sulfate concentrations in CY 2010 were in well 199-N-18 at 504 mg/L and well 199-N-165 at 161 mg/L. Well 199-N-165 is used to monitor the 120-N-1 and 120-N-2 RCRA facilities. Wells located downgradient of the percolation pond (199-N-41, 199-N-56, 199-N-57, 199-N-64, and 199-N-105A) also had elevated sulfate levels. One other well near the 120-N-1 and 120-N-2 facilities also had elevated sulfate (well 199-N-72 at 123 mg/L). The contamination beneath

these facilities is residual from previous flow conditions that carried sulfate from the 120-N-1 percolation pond inland. Current groundwater flow conditions are carrying this plume to the north and northwest toward the Columbia River (DOE/RL-2010-11).

Only well 199-N-18 had sulfate values exceeding the 250 mg/L secondary DWS. In CY 2009, this well had a very low sulfate concentration (0.265 mg/L). The sulfate concentrations may be elevated in the well because of the excess diesel that is present in the well. Very little product removal was performed in well 199-N-18 during CY 2010 (see discussion in Section 6.1.4). Elevated sulfate concentrations were also detected at other wells near 199-N-18, namely 199-N-19 and 199-N-21.

Manganese and iron continue to be detected in areas where diesel biodegradation is believed to be occurring.

6.1.6 Manganese and Iron

Manganese concentrations in groundwater continued to be elevated in wells affected by the diesel plume. Figure 6-21 shows filtered manganese and iron concentrations in the 100-N Area from the fall of CY 2010. Several wells exceeded the secondary DWS of 50 µg/L for manganese:

- Well 199-N-16 at 748 µg/L
- Well 199-N-18 at 10,400 µg/L
- Well 199-N-32 at 70.5 µg/L
- Well 199-N-57 at 61 µg/L
- Well 199-N-167 at 1,270 µg/L
- Well 199-N-169 at 219 µg/L
- Well 199-N-170 at 142 µg/L
- Well 199-N-171 at 1,170 µg/L
- Well 199-N-172 at 3,240 µg/L
- Well 199-N-173 at 4,460 µg/L.

All of these wells, with the exception of 199-N-32 and 199-N-57, are under the influence of the current diesel plume. Well 199-N-16 is showing the effects of diesel degradation from three separate diesel spills that occurred in the area of the well (all from the 184-N day tank): UPR-100-N-19 in 1984, UPR-100-N-21 in 1986, and UPR-N-42 in 1987. In 2007, this well had detectable levels of total petroleum hydrocarbon-diesel; it did not have detectable levels in 2008 or 2009, but once again had detectable levels in CY 2010.

Several wells also exceeded the 300 µg/L secondary DWS for iron: 199-N-18 at 50,100 µg/L; 199-N-32 at 341 µg/L; 199-N-57 at 465 µg/L; 199-N-172 at 2,950 µg/L; and 199-N-173 at 834 µg/L. Well 199-N-26 did not exceed the secondary DWS of manganese but did exceed the iron 300 µg/L secondary DWS at a concentration of 366 µg/L. With the exception of wells 199-N-26, 199-N-32, and 199-N-57, all of these wells are under the influence of the diesel plume and/or the effects of diesel biodegradation. Natural biodegradation of hydrocarbons creates reducing conditions, which increases the solubility of metals (e.g., manganese and iron). The sources of the two metals may be the actual well casing or the aquifer sediments.

Aquifer tube 116mArray-0A had elevated levels of manganese (4,860 µg/L) and iron (1,130 µg/L). Aquifer tube C6135 also had elevated levels of manganese (2,250 µg/L) and iron (1,070 µg/L). These aquifer tubes also had detections of total petroleum hydrocarbon-diesel.

6.1.7 Chromium

Chromium above the 100 µg/L DWS is present in only one well at the 100-N Area. The majority of the remaining chromium detections were at or just above the 13 µg/L detection limit for chromium.

Chromium was reported as present in the effluent discharged to the 116-N-1 LWDF but was found at low concentrations in the waste stream. Sodium dichromate was only used in the 100-N Area from 1964 to 1973 and in lesser amounts than at the other 100 Area reactors because of the design of the N Reactor cooling system and the use of corrosion-resistant metals (e.g., zircaloy) in the fuel and facility (DOE/RL-2008-46-ADD5). The chromium fraction of the sodium dichromate used in the 100-N Area was ~24,704 kilograms. Given the mobility and nonsorbing nature of chromium in solution, the high continuous discharge rates while chromium was delivered to the 116-N-1 LWDF, and the fact that discharges continued for another 10 years after sodium dichromate use ceased, the mobile portion of discharged chromium was thoroughly flushed from the subsurface and into the Columbia River by the end of the reactor's operational period (DOE/RL-2008-46-ADD5). Together, all of the dangerous waste discharged to the LWDFs collectively made up only 0.002% of the total volume of wastes, according to the RCRA Part A Permit (WA7890008967, *Hanford Facility Resource Conservation and Recovery Act Permit, Dangerous Waste Portion, Revision 8C, for the Treatment, Storage, and Disposal of Dangerous Waste*). Chromium was never detected in samples of the effluent waste stream from the 116-N-1 LWDF. Levels in wells monitoring the unconfined aquifer were low when the facility was in use.

Continued monitoring of wells in the 100-N Area shows sporadic, low-level detections of chromium throughout the area. Even in wells where chromium is detectable, nearby wells often do not show any detection. There is no reason to believe that a continuing source for chromium groundwater contamination exists in the 100-N Area based on available data from all wells being monitored. Any possible source of the contamination has dissipated, being flushed from the aquifer through years of high-volume effluent disposal and the high mobility of chromium when in solution (see Chapter 4 in DOE/RL-2008-46-ADD5 for further description of the use of sodium dichromate at the 100-N Area). Work on the 100-N Area RI/FS includes samples taken from the vadose zone, Hanford formation, Ringold Formation, and into the Ringold Formation upper mud unit at several locations. If a source of deep chromium contamination is found, it will be addressed and discussed in the 100-N Area RI report.

Two wells in the 100-N Area had dissolved (filtered) chromium concentrations above the DWS of 100 µg/L (199-N-80 and 199-N-18). Well 199-N-80, which is completed in a thin, confined aquifer in the Ringold Formation, had filtered chromium concentrations during the reporting period of 172, 192, and 176 µg/L in samples taken on September 20, 2010. These values are similar to the values reported in 2007, 2008, and 2009 for this well of 172, 172, and 169 µg/L, respectively. This well has shown very little change in chromium concentration over time. A down-hole camera survey performed in 2001 showed visible corrosion along the length of the well screen (33.7 to 42.7 meters depth) in this well. Corrosion of the stainless-steel well screen is likely the contributor of chromium to the groundwater sampled from this well. Stainless-steel corrosion is caused by sulfur impurities present in the metal. These small sulfur inclusions cause depletion of the chromium from the surrounding metal and a "pit" is created in the metal where this process is occurring ("Why Stainless Steel Corrodes" [Ryan et al., 2002]). In a stainless-steel well where this corrosion is occurring, chromium and sulfate are released into solution; when a groundwater sample is taken, similar trends are noted in chromium and sulfate concentrations. Figure 6-22 shows the trend plot for chromium and sulfate in well 199-N-80. The two

trends mirror each other and are a strong indicator that the elevated chromium is from the stainless-steel corrosion occurring in the well. Hexavalent chromium samples collected in CY 2010 show that the concentration of filtered chromium and hexavalent chromium are essentially the same, which is another indicator that the chromium source is from corrosion in the well. The chromium released by corrosion is in hexavalent form, as it is the soluble and mobile species of chromium. Soil and groundwater samples taken from wells drilled near 199-N-80 as part of the RI/FS process will be sampled in the lower Ringold Formation and the Ringold Formation upper mud unit. Analyses of both hexavalent chromium and total chromium are planned as part of this process. Results from the RI/FS work will be discussed in the RI report.

Well 199-N-18 had filtered total chromium results of 159 and 127 µg/L for samples taken in December 2010 when the diesel concentration was 41,000 µg/L in the well. Hexavalent chromium results for that date were much lower (36.4 µg/L and less than 2 µg/L in unfiltered and filtered samples, respectively). The data are being reviewed because of the inconsistencies. Samples taken in July 2010 (when the diesel concentration was an order of magnitude higher at 420,000 µg/L) had chromium concentrations considerably lower (at or near the detection limit). Well 199-N-18 has had very few chromium detections in the past (from 1989 through 2006). As of 2007, chromium has been detected in the well, with levels increasing as diesel levels increased. It is possible that the effects of diesel degradation may be interacting with the carbon-steel casing of the well and causing elevated levels of chromium, in addition to iron and manganese. Monitoring for chromium and hexavalent chromium will continue at this well.

Figure 6-23 shows unfiltered and filtered detectable total chromium results from the fall 2010 for the 100-N Area. Well 199-N-74 had detections of total and hexavalent chromium at 25 to 30 µg/L. The source of the chromium in this well is unknown; it is possible that the chromium may be migrating in from somewhere to the south of the 100-N Area or from the 100-K Area to the west. As part of the 100-N Area RI/FS work plan, a new well is being drilled between wells 199-N-74 and 199-K-182 (to the west) to determine if detectable chromium exists between the two wells.

The remaining detectable levels of total chromium in the 100-N Area are all low, at just above the 13 to 14 µg/L detection limit for chromium in most samples. Detection levels for chromium vary in the data set for the 100-N Area depending on which method was used and which laboratory performed the analysis. The majority of the samples are analyzed at the Waste Sampling and Characterization Facility using U.S. Environmental Protection Agency (EPA) Method 6010, which has a detection limit of 13 to 14 µg/L. The other samples are analyzed at the Test America St. Louis Laboratory using EPA Method 6010 with a detection limit of 3.10 to 3.3 µg/L. Hexavalent chromium results were less than 10 µg/L in 2010, except in the wells discussed above.

Two wells in the 600 Area that were sampled for the 100-N Area RI/FS had elevated levels of hexavalent chromium. Well 699-77-54, located ~3 kilometers southeast of the 100-N Area, had concentrations between ~20 and 25 µg/L. Well 699-87-55, located between the 100-N and 100-D Areas, had concentrations between 10 and 20 µg/L.

Total chromium concentrations were below the current 13 to 14 µg/L detection limit (for Waste Sampling and Characterization Facility samples) in 100-N Area aquifer tube samples in CY 2010.

6.2 CERCLA Activities

This section summarizes the CERCLA activities during the reporting period related to 100-NR-2 OU groundwater. For purposes of the RI/FS, the groundwater and source OUs were combined into the 100-N River Corridor unit, which has a slightly different configuration than the groundwater OU. The principal COC in the 100-N Area is strontium-90, which is currently the focus of most remediation efforts at the OU. The CERCLA activities in 2010 included performing interim action groundwater monitoring, performing continued monitoring of the existing apatite PRB, reporting conclusions for the initial phytoextraction study, planning infiltration testing, and continuing work to characterize the diesel plume.

6.2.1 CERCLA Decision Documents

In 1996, the overall pace of Hanford Site cleanup along the Columbia River was accelerated. An expedited response action to address strontium-90 contamination in groundwater was implemented at N-Springs. In 1999, the interim action ROD was issued (EPA/ROD/R10-99/112), which was specific to the 100-N Area OUs.

The RI/FS (DOE/RL-2008-46-ADD5) and the sampling and analysis plan (DOE/RL-2009-42, *Sampling and Analysis Plan for the 100N Decision Unit Remedial Investigation Feasibility Study*) for the 100-N Area were issued in March 2011 and December 2010, respectively.

The *Proposed Plan for Amendment of 100-NR-1/NR-2 Interim Action Record of Decision* (DOE/RL-2009-54) was issued in June 2010.

The *Remedial Design/Remedial Action Work Plan for the 100-NR-2 Operable Unit* (DOE/RL-2001-27, Rev. 1 Draft A) was submitted to the Washington State Department of Ecology (Ecology) on March 25, 2011.

6.2.2 Status of the Five-Year Review Action Items

The Second CERCLA Five-Year Review Report for the Hanford Site was published in 2006 (DOE/RL-2006-20). The review identified two actions pertaining to the 100-N Area, and DOE made progress on both actions in 2010.

- **Action 6-1.** *Implement the treatability test for the PRB using apatite sequestration (DOE/RL-2005-96, Strontium-90 Treatability Test Plan for 100-NR-2 Groundwater Operable Unit) and issue the treatability test report.* ***Complete.***
  - This action was satisfied by installing the apatite PRB in 2006 and implementing the initial pilot test injections in 2006, 2007, and 2008. The *Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injections for In Situ Strontium-90 Immobilization* (PNNL-17429) discusses progress at the PRB through the low-concentration injections completed in 2007. In the *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization* (PNNL-19572), progress is discussed through the completion of the high-concentration injections in 2008, the coring activities in 2009, and performance monitoring results. Section 6.2.4 provides additional information on the apatite PRB.
- **Action 7-1.** *Perform additional data collection to support risk assessment, provide previously collected data, and collect additional porewater data from new and existing aquifer tubes.* ***Complete.***

– Water samples continued to be collected from aquifer tubes in 2010. Section 6.1 discusses significant results, and data are included in the electronic files accompanying this report.

– River upwelling samples were collected in December 2010 as part of the RI/FS work plan and the results are discussed in Section 6.2.7. These results will also be included in the 100-N Area RI report.

The remedial action objectives in the 100-NR-2 OU (EPA/541/R-99/112) are as follows.

- ***Protect the Columbia River from the adverse impact of groundwater contamination by limiting exposure pathways, reducing or removing sources, controlling groundwater movement, or reducing the concentration of contaminants.***
- ***Protect the unconfined aquifer by implementing remedial actions that reduce the concentration of contaminants.***
- ***Obtain information to evaluate technologies to remove strontium-90 and evaluate the impact to ecological receptors.***
- ***Prevent destruction of sensitive wildlife habitat and minimize the disruption of cultural resources. In 2006, Ecology added a requirement for the pump-and-treat system to be put on standby and an alternative in situ treatment technology to be tested.***

6.2.3 Interim Action Monitoring

A pump-and-treat system operated from 1995 until March 2006 in the 100-N Area as part of the CERCLA interim action (EPA/541/R-99/112). The system removed ~1.8 curies of strontium-90 from the aquifer. Because strontium-90 binds strongly to the sediment, the pump-and-treat system was not effective in cleanup of the aquifer. One of the requirements of the interim action ROD was to evaluate alternative technologies for groundwater cleanup. Therefore, Ecology, EPA, and DOE approved Tri-Party Agreement Change Control Form M-16-06-01 in 2006, which required placing the pump-and-treat system in cold-standby status and constructing a PRB. Based on the treatability test results, the apatite technology is showing promise as a remediation option. As a result, the DOE proposed in June 2009 to amend the existing interim remedial action ROD for the 100-NR-1 and 100-NR-2 OUs (EPA/541/R-99/112) to include as an interim remedial action for expanding the existing apatite PRB to a total length of ~762 meters in the aquifer and the vadose zone. Regulatory approval of the amendment to the interim action ROD was issued in September 2010 and allows for proposed expansion to the apatite PRB and permanent decommissioning of the 100-NR-2 pump-and-treat facility.

Implementation of the interim remedy apatite barrier expansion will be conducted under a revision to the 100-NR-2 OU interim action remedial action/remedial design work plan (DOE/RL-2001-27) that was submitted as Rev. 1 Draft A to Ecology in March 2011.

Plans to optimize this apatite barrier technology prior to full-scale expansion will initially move forward under two approved design optimization studies: the barrier expansion design optimization study (DOE/RL-2010-29, *Design Optimization Study for Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit*), and the jet injection design optimization study (DOE/RL-2010-68, *Jet Injection Design Optimization Study for the 100-NR-2 Groundwater Operable Unit*).

Wells and constituents monitored for the 100-NR-2 OU are defined in (1) the remedial design report/remedial action work plan (DOE/RL-2001-27) and modifications thereto (TPA-CN-256), (2) *100-N Area Integrated Groundwater Sampling and Analysis Plan* (DOE/RL-2009-58), and (3) the strontium-90 treatability teat plan for the 100-NR-2 OU (DOE/RL-2005-96) and modifications thereto (TPA-CN-271). The CERCLA sampling is conducted mainly in September, with selected wells also monitored in March. Sampling under RCRA is conducted quarterly or semiannually, as required. Analytical results from these other monitoring programs are presented in this report where the data are useful for assessing rebound or defining plumes. The wells, constituents, and sampling frequencies for interim action monitoring are shown in Appendix A. During 2010, two wells were unable to be sampled as scheduled in September due to (1) a breaker that tripped twice on a pump (unable to sample for well 199-N-106A), and (2) not enough water remained in well 199-N-46 for sampling because the well was pumped dry before a sample could be taken.

The monitoring results for each of the constituents of interest are discussed in further detail in Section 6.1.

6.2.4 Permeable Reactive Barrier

The DOE agreed to construct and evaluate the effectiveness of a PRB for strontium-90 using apatite sequestration technology as part of the of the CERCLA RI/FS process, which is consistent with the interim remedial action ROD for the 100-NR-1 and 100-NR-2 OUs (EPA/541/R-99/112) and the *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al., 1989) Change Control Form M-16-06-01. Strontium-90 sequestration using this technology occurs by injecting a calcium-citrate-phosphate solution into the aquifer. After the solution is injected, biodegradation of the citrate results in apatite (a calcium phosphate mineral [$Ca_5(PO_4)^3(F, Cl, OH)$]) precipitation. Strontium-90 ions in groundwater substitute for calcium ions via cation exchange and eventually become "trapped" as part of the mineral matrix during apatite crystallization (PNNL-16891).

Apatite (a naturally occurring calcium phosphate mineral) is being used to form a PRB along the 100-N Area shoreline. This barrier allows free movement of groundwater through the treated zone, but strontium-90 is substituted for calcium and is bound up within the mineral matrix. The strontium-90 that is part of the mineral matrix does not reach the river and will naturally decay in place.

The apatite treatability test site covers ~90 meters along the Columbia River shoreline (Figure 6-2). Forty-five monitoring points are associated with this site, including injection/barrier wells, monitoring wells, and aquifer tubes. Sixteen wells comprise the actual PRB. Four monitoring wells are parallel to the PRB, between the river and the injection/barrier wells. Two pilot test sites (PT#1 and PT#2) are located at each end of the PRB (around the two end injection/barrier wells) and contain smaller diameter monitoring wells surrounding the individual end injection/barrier wells (Figure 6-2).

Strontium-90 contamination in the 100-N Area is primarily absorbed to sediments by ion exchange (99% absorbed and 1% in solution in the groundwater) in the lower vadose zone and upper portion of the unconfined aquifer. Although primarily absorbed, strontium-90 is still considered a high-mobility risk because it is mobilized by seasonal river stage increases; water level increases remobilize strontium-90 absorbed to sediments not previously in contact with groundwater (PNNL-16891). Apatite-forming solution injections were made to the Hanford formation and Ringold Formation over a period of 3 years (from 2006 through 2008). Table 6-3 summarizes the timeline and injection history for the apatite PRB.

A report on the treatability test (PNNL-19572) was issued in September 2010 to document the work completed to date on development of a high-concentration amendment formulation and field-scale testing of the solution. The high-concentration

amendment solution was formulated to maximize apatite formation within the targeted treatment zone while minimizing the short-term increases in strontium-90 concentration associated with injecting high ionic strength solutions. (An interim report, *100-NR-2 Apatite Treatability Test FY09 Status: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization: Interim Report* [PNNL-SA-70033] was issued in 2009, which was discussed in the CY 2009 annual report [DOE/RL-2010-11]). PNNL-19572 provides details regarding the high-concentration apatite amendment formulation, PRB emplacement operations, and barrier performance assessment, including aqueous monitoring results and sediment core analysis.

6.2.4.1 Performance Monitoring at the Existing Permeable Reactive Barrier

Performance monitoring at the existing apatite barrier was performed quarterly (usually in February, May, August, and November) through August 2010. This phase of monitoring was required by the original test plan and continued for 2 years following the final injections in July 2008. In August 2010, quarterly sampling was completed with a sampling event that covered all 45 of the original monitoring points (including the 16 injection wells, 21 monitoring wells, and 7 of the 8 original aquifer tubes). Until August 2010, sampling included four sets of wells that were monitored along the length of the PRB, including all four of the main monitoring wells, paired injection/barrier wells (with one well screened in the Ringold Formation only and one well screened across both the Hanford and Ringold Formations), and smaller diameter monitoring wells (completed in both the Hanford and Ringold Formations on the two ends of the PRB). Table 6-4 lists the wells that were sampled, formations monitored, screen depth, and their locations. These wells were chosen to cover portions of the whole barrier and to allow for both areal and vertical distribution of sampling points. Figure 6-2 depicts the four main monitoring locations along the PRB (PT#1 end, mid-upper, mid-lower; and PT#2 end).

Wells were sampled for a minimum of gross beta and/or strontium-90 during each of the four quarterly sampling events. Duplicate samples were collected during each sampling event. Split samples were collected at a minimum frequency of twice per year. Once each year (2008 through 2009) during low river conditions in October/November, samples were collected from each well for a full suite of analyses, including strontium-90, gross beta, metals/cations, and anions. The last scheduled monitoring event under the original test plan (DOE/RL-2005-96) occurred in August 2010 and included a full suite of analyses on all PRB sampling points, including the injection and monitoring wells and the aquifer tubes. Table 6-5 includes a full list of all constituents sampled during performance monitoring for this reporting period. Future performance monitoring at the existing barrier will be twice a year and is scheduled to coincide with the highest and lowest river levels, likely occurring in May/June and October/November, respectively. The full suite of analytes will be collected for each event for all monitoring points, including duplicate and split samples, as required. Appendix A provides lists of the well and constituents, as well as a status of monitoring during the reporting period.

Since injections ceased at the PRB in July 2008, a general, steady decline has been observed for strontium-90 and gross beta in the sampled wells, with very few exceptions. As of August 2010, the strontium-90/gross beta values were considerably less in all wells and aquifer tubes monitored along the PRB. All of the wells have shown ~90% decline in gross beta from the measured pre-injection values.

PNNL has prepared a follow-up document to the final high-concentration report (PNNL-19572) issued for the apatite PRB. The *100-NR-2 Apatite Treatability Test: An Update on Barrier Performance* (PNNL-20252) discusses an additional year of performance monitoring data than the previous report, as well as noting changes in trends for strontium-90 concentrations along the treated barrier. While in some areas the strontium-90 concentrations have slightly increased, the aqueous concentrations over the entire length of the barrier are generally being maintained at levels well below the pre-treatment levels (PNNL-20252).

Nearly all of the wells are showing a 90% decline in the amount of detectable gross beta 2 years after injections of apatite-forming chemicals ceased.

Figure 6-24 provides the trend plot for gross beta concentration in the mid-upper portion (Figure 6-2) of the existing apatite PRB. This set of three wells consists of a monitoring well (199-N-146) and two injection wells (well 199-N-164 screened only in the Ringold Formation, and well 199-N-142 screened across the Hanford formation and Ringold Formation). The high-concentration apatite injection solution had a higher ionic strength than groundwater (3.6 mM calcium, 9.0 mM citrate, and 40 mM phosphate, respectively). Therefore, all three wells showed high strontium-90 concentrations following the injections in 2008. When the fluid is initially injected, it temporarily mobilizes cations and anions, causing their concentrations in groundwater to increase. Over time, the concentration of gross beta begins to steadily decline, which is the most evident in monitoring well 199-N-146. The injection wells show more fluctuation in gross beta values, but all three wells show much lower concentrations of gross beta than prior to injections in CY 2008.

Figure 6-25 provides the trend plot for gross beta concentration in the mid-lower portion (Figure 6-2) of the existing apatite PRB. The set of three wells consists of a monitoring well (199-N-122) and two injection wells (199-N-160 screened only in the Ringold Formation, and 199-N-145 screened across the Hanford formation and Ringold Formation). All three wells showed high concentrations following the injections in CY 2008. Over time, the concentration of gross beta begins to steadily decline, which again is most evident in monitoring well 199-N-122. Again, the injection wells show more fluctuation in gross beta values, but all three wells show much lower concentrations of gross beta than prior to injections in CY 2008.

Figure 6-26 shows the trend plot for gross beta concentration across the highest concentration portion of the strontium-90 plume along the existing apatite PRB. Wells 199-N-122 and 199-N-147 are monitoring wells located upriver and downriver of aquifer tube NVP2-116.0 (Figure 6-2), respectively. After the 2008 high-concentration injections, tube NVP2-116.0 had the highest gross beta concentrations of all monitoring points along the PRB, as evidenced by the spike in July/August 2008. Even with the higher values in this portion of the PRB, the reduction in gross beta concentration is prominent for all three locations.

As of the end of CY 2010, the entire PRB has shown indications of a slight upward trend in some wells. At some point, additional injections will need to occur in the existing PRB, based on data presented in the two reports on the initial low-concentration and high-concentration injections (PNNL-17429; PNNL-19572). Injections for the existing barrier will occur as budget and schedule allow within the next few years. Twice yearly, performance monitoring (high and low river stage) will continue for the existing PRB until those injections occur, at which time a revised performance monitoring schedule will be initiated.

6.2.4.2 Core Samples

During the fall of 2009, three monitoring wells were drilled in the PT#2 site of the existing PRB for the purpose of collecting core sample data. These monitoring wells

Core sample data has shown the formation of apatite in the treated sediments.

were drilled and cored from ground surface to a depth of ~7.6 meters. Figure 6-27 shows the location of these core wells in relation to the other wells in the PT#2 site. Core samples were collected to determine the radial and vertical extent of injection fluid penetration from well 199-N-137 and whether the calcium-citrate-phosphate injection fluid is forming apatite in the soil matrix as predicted. The well locations were chosen to examine the vertical and areal distribution of injection chemicals in the sediment around injection well 199-N-137 at 1.5 meters, 3.1 meters, and 4.6 meters distance from the injection well. Results of these core samples were reported in September 2010 (PNNL-19572). The objectives of the core analysis were to characterize the following:

- Phosphate mass with depth and different radial distance from the injection well(s)
- Strontium-90 distribution absorbed on sediment and incorporated into apatite.

Considering the 10 mM (low concentration) and 40 mM (high concentration) phosphate injections conducted in the area where these cores were taken, an average apatite loading of 1.9 milligrams of apatite per gram of sediment (0.608 milligrams of phosphate per gram) was expected. The Hanford formation received an average of 0.559 (±0.253) milligrams of phosphate/g (92% of the mass that would be expected for full concentration arrival), and the Ringold Formation received an average of 0.268 (±0.113) milligrams of phosphate per gram (44% of the mass that would be expected for full concentration arrival). The average phosphate for the three boreholes (both Hanford and Ringold formations) was 0.415 (±0.232) milligrams of phosphate per gram of sediment. Although the boreholes were located at different distances from injection well 199-N-137, the average phosphate concentration was relatively constant at 0.376 milligrams per gram at 1.5 meters (well 199-N-368), 0.420 milligrams per gram at 3.1 meters (well 199-N-369), and 0.406 milligrams per gram at 4.5 meters (well 199-N-370). The relatively uniform distribution of average phosphate concentration with radial distance from the wells demonstrates one benefit of the calcium-citrate-phosphate injection formulation. The amount of phosphate present at different depths is related to the amount of total strontium-90 located at a given depth. Phosphate concentrations are high where total strontium-90 is high, and the concentrations low where total strontium-90 is low. One reason for this relationship may be the grain size of the sediments involved, as zones of finer grained material with higher surface area and more cation-exchange sites will have more strontium-90 absorbed on the sediments. Overlap in treatment zones between the injection wells (199-N-137 and 199-N-159) also contributed to higher phosphate concentrations.

Analysis of ion-exchangeable Ca^{2+} and Sr^{2+} from field cores shows significant depletion of both cations (95% lower for strontium and 47% lower for calcium); ion exchange during the initial calcium-citrate-phosphate solution injection has altered the cations on the sediment ion-exchange sites from their natural condition. The much greater depletion of ion-exchangeable Sr^{2+} compared to Ca^{2+} is likely due to the incorporation of strontium into the apatite mineral matrix. In the next few years, ion-exchangeable Ca^{2+} and Sr^{2+} will be replenished as upgradient groundwater (with Ca^{2+}, Sr^{2+}, and strontium-90) invades the apatite laden zone. However, because the sediments are being amended with a relatively small amount of apatite, the total ion-exchangeable strontium-90 on both sediment and apatite will only be slightly larger than for natural sediments. The real value of the apatite amendment is the permanent incorporation of strontium and strontium-90 into the apatite structure, which allows the strontium-90 to decay in place (PNNL-19572).

6.2.4.3 Proposed Extension of Existing Apatite Permeable Reactive Barrier

Apatite PRB extensions will increase the amount of 100-N Area shoreline treated to sequester strontium-90 up to 762 meters.

During the fall of 2009 and spring of CY 2010, 171 wells were installed to extend the existing apatite PRB (DOE/RL-2009-32, *100-NR-2 Groundwater Operable Unit Sr-90 Plume Rivershore Sampling and Analysis Plan*). The wells were installed on both the upriver and downriver ends of the existing barrier. The extensions cover the entire length of ~762 meters of where the strontium-90 plume intersects the Columbia River along the 100-N Area shoreline (Figure 6-4). Beginning at the upper (PT#1) end of the existing apatite PRB, the new injection/barrier wells alternate at depth completions of 4.6 meters (vadose) and 7.6 meters (top of unconfined aquifer) and continue to near monitoring well 199-N-173. Starting on the downriver (PT#2) end of the existing apatite PRB, the new injection/barrier wells also alternate depth completions of 4.6 meters (vadose) and 7.6 meters (top of unconfined aquifer) and continue to just southwest of monitoring well 199-N-92A. These wells are in line with the existing injection/barrier wells, to the extent that topography, position of the lower road bed, and other existing wells will allow. Approximately every 26 to 27 meters, a new 7.6-meter-deep monitoring well was installed in the top of the unconfined aquifer between the injection/barrier wells and the Columbia River. The injection/barrier wells will allow further injections of apatite-forming chemicals or other chemicals, as determined by ongoing apatite PRB testing. Future plans include injecting wells along an additional 182.8 meters of PRB, 91.4 meters upriver and downriver on both ends of the existing PRB, under a design optimization study (DOE/RL-2010-29, *Design Optimization Study for Apatite Permeable Reactive Barrier Extension for the 100-NR-2 Operable Unit*) and the 100-NR-2 OU remedial design/remedial action work plan (DOE/RL-2001-27, Rev. 1, when issued).

The injections will be performed using a two-step process, where the deeper Ringold Formation wells are injected first and then the overlying Hanford formation wells are injected. This allows the injections to overlay each other and maximizes the coverage in both the upper unconfined aquifer and lower vadose zones. The planned formulation for these injections is the high-concentration calcium-citrate-phosphate solution amendment tested in 2008. The goals of the study are as follows (DOE/RL-2010-29):

- Refine the application of high-concentration calcium-citrate-phosphate solution over a large scale
- Test the effectiveness of high-concentration calcium-citrate-phosphate injection in previously untested sediment to compare with areas that received sequential injections of low- and then high-concentration injections
- Test the new well design installed under DOE/RL-2009-32 to evaluate the adequacy of injection solution delivery to the target zone
- Test and optimize operation of the new injection system to verify that the system can deliver the designed injection solution flow volume at multiple well locations
- Determine if the new well design and injection system can complete chemical injections at various river stages, thereby eliminating the need for injections during specific river levels
- Evaluate that the PRB can achieve up to a 90% reduction in strontium-90 flux to the Columbia River

- Further evaluate the impact the high-concentration calcium-citrate-phosphate solution has on the release of strontium-90 and other metals from previously untreated sediments to groundwater.

6.2.5 Other Strontium-90 Treatment Technologies

Several different types of strontium-90 treatment technologies are also being evaluated at the 100-N Area in addition to the existing PRB. It is necessary to look at several types of treatment to effectively treat the entire zone of contamination. The existing PRB has treated groundwater and the lower vadose zone, but it has not treated the upper vadose zone and near-shore riparian zone. The technologies discussed below are an effort to address these previously untreated areas.

6.2.5.1 Jet Injection Tests

Jet injection tests performed in December 2009 showed promise as a potential remediation technology for strontium-90.

Jet injection technology has been used extensively in many environmental remediation locations to place grout and other materials into the subsurface. This technology was used to test the injection of apatite-forming chemicals and pre-formed apatite into the subsurface at the 100-N Area. Apatite-forming chemical injections to date at the 100-N Area have treated predominantly the lower vadose zone and upper portion of the aquifer along the 100-N Area shoreline. Advantages to using jet injection technology at the 100-N Area included the following: (1) injections could be performed regardless of river level, (2) injections could treat the upper vadose zone that previous injections have left untouched, and (3) injections could be performed with apatite-forming chemicals and/or pre-formed apatite (DOE/RL-2005-96, Addendum 3). The objectives of the jet injection test were as follows:

- Evaluate the ability of jet injection technology to deliver different apatite material/apatite-forming chemical solutions into the vadose zone and upper unconfined aquifer within three distinct treatment zones along the 100-N Area shoreline
- Evaluate the ability of the jet injection technology to deliver apatite-forming solutions to install a PRB in the vadose zone containing 3.4 milligrams of apatite per gram of sediment (1.1 milligram of phosphate per gram of sediment).

In December 2009, jet injection tests were performed in three plots located along the 100-N Area shoreline, just upriver from the existing apatite PRB (Figure 6-28) (SGW-47062, *Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit*). Each test plot was ~3.1 meters (width) by 6.1 meters (length) by 7.6 meters (depth) in size, and injections were made in six locations within each plot to determine if phosphate and apatite could be placed into the vadose zone and upper aquifer using the jet injection technology. The first plot was injected with a phosphate-only solution, the second plot was injected with a phosphate-only solution followed by a suspension of fishbone apatite, and the third plot was injected with a suspension of fishbone apatite only. The three plot sites were laid out along the planned route for extension of the apatite PRB, with the site of one to two of the planned injection/barrier wells located within a given plot. One well each was eventually located in the phosphate-only and apatite-only plots, and two wells were located within the phosphate and apatite plot. These wells were continuously cored from ground surface to a depth of 7.6 meters. The cores were sent to PNNL for analysis (similar to the core collected previously from the PT#2 site). In addition, water samples were obtained from two nearby aquifer tubes (116.0mArray-1A and 116.0mArray-2A) before, during, and after the jet injections.

The treatability test report (SGW-47062) was issued in CY 2010 and reported that both objectives of the test were met. Jet injection technology was successfully used

to emplace three different media in the vadose zone and upper unconfined aquifer. Collection and analysis of post-injection sediment cores enabled the evaluation of apatite emplacement within a vertical sediment column. Apatite emplacement at concentrations equal to or greater than 4 milligrams of apatite per gram of sediment was observed in the sediment cores in all three test plots (SGW-47062; PNNL-19524). Until future groundwater samples are taken at the wells installed in the test area, the results of the groundwater tests will not be available.

Future plans to optimize this apatite-barrier technology prior to full-scale expansion will initially move forward under two approved design optimization studies: (1) barrier expansion (DOE/RL-2010-29), and (2) jet injection (DOE/RL-2010-68).

6.2.5.2 Infiltration Gallery Tests

Apatite injections treat the strontium-90 contamination in the aquifer and lower portions of the vadose zone, but strontium-90 is also absorbed in the upper portion of the vadose zone. PNNL conducted a study of apatite infiltration to treat vadose zone contamination under the DOE Environmental Management Technology (EM-22) program. The study took place in the fall of 2010 at the infiltration gallery test site located ~5 meters past the downriver end of the existing apatite PRB (Figure 6-2). Two tracer tests were conducted using sodium bromide tracer, and the results were as follows:

- Application rate of tracer at 0.7 centimeters per hour
- Tracer arrivals at water table (10 to 12 feet below the base of the infiltration gallery) after ~5 days
- Advancement rate was 2 feet per day.

The test that was performed was with sodium bromide tracer solution only; it is not indicative of the amount of time actual reactive apatite-forming solutions would take to infiltrate, or if they would infiltrate at all. Additional information on the infiltration test and the data from test implementation are provided in *100-NR-2 Apatite Treatability Test: Fall 2010 Tracer Infiltration Test* (PNNL-20322).

6.2.5.3 Phytoextraction

Phytoextraction is a potential remediation technology along the riparian zone of the Columbia River.

Phytoextraction of strontium-90 is being considered as a potential remediation technology (polishing step) along the riparian zone of the Columbia River as part of an apatite PRB to reduce transport of strontium-90 to the river. The process uses coyote willows (*Salix exigua*) to extract strontium-90 from the vadose zone soil and aquifer sediments (phytoextraction) and to filter strontium-90 (rhizofiltration) from the shallow groundwater along the riparian zone of the Columbia River (PNNL-19120, *100-N Area Strontium-90 Treatability Demonstration Project: Phytoextraction Along the Riparian Zone – Field Treatability Study*). The initial test plot was installed in the 100-K Area to allow testing under uncontaminated conditions (i.e., no strontium-90) and to test the methodology along an area of shoreline where the slope was gentle and no large areas of rock (rip-rap) were present (e.g., in the 100-N Area).

The results of the test performed at the 100-K Area from 2007 through 2009 are summarized below:

- During the 3 years of testing, the trees survived multiple flooding events (including total immersion), no trees were uprooted or displaced, and most survived the entire 3-year period.

- Biomass (leaves, twigs, and smaller branches) production followed a typical growth curve for the first 2 years and went to a logarithmic/exponential rate in the third year.
- No intrusion of large or small herbivores occurred at the test plot over the 3-year period. The site had chain-link fencing (with smaller mesh screening around the bottom 0.61 meters of fencing, which also extended underground) surrounding the plot.
- Observed calcium and strontium concentrations found in harvested biomass suggest that the trees could prove effective in removing strontium-90 in the riparian zone.
- Harvested biomass is controlled and disposed of per approved radiological and waste management procedures.

Further information on this study and the results are provided in PNNL-19120. Plans to test this technology along the 100-N Area shoreline were initiated in CY 2010 but will not continue until a decision is made regarding whether the technology will be tested further.

6.2.6 Characterization of Petroleum Contamination

Data collection continues in areas affected by the diesel spill. By 2010, the plume was well defined and potential remediation technologies identified and/or being tested.

PNNL performed work for CH2M HILL Plateau Remediation Company (CHPRC) Soil and Groundwater Remediation Project (S&GRP) to evaluate the nature and extent of the diesel plume at the 100-N Area and to investigate potential remediation technologies. The study included soil, riverbed, and groundwater samples from select locations to collect as much data as possible to make initial remediation decisions (PNNL-18645, Rev. 1, *Summary of TPH Monitoring Conducted at 100-NR-2 2008 Through 2010*). The results of the monitoring investigation are summarized below:

- Samples collected from the top of the aquifer indicate the presence of total petroleum hydrocarbon-diesel range.
- Total petroleum hydrocarbon-diesel range decrease and then disappears with depth.
- High levels of manganese and iron are found in wells with total petroleum hydrocarbon-diesel range detections, which indicates microbial activity.
- Dissolved oxygen levels were low in wells with total petroleum hydrocarbon-diesel range detections, an indicator of reducing conditions and microbial activity.
- Naturally occurring bacteria present in the soil along the shoreline and inland at the 100-N Area are capable of using diesel-range hydrocarbons as their sole carbon source (i.e., the bacteria can break down and degrade diesel contamination into more natural byproducts).
- The large decrease in concentration between well 199-N-18 (the plume hot spot) and shoreline well 199-N-173 indicates that microbial degradation of diesel is occurring between these two wells.
- The extent of vadose zone contamination is not as well known as the extent of groundwater contamination. Ongoing work performed by WCH on the bioremediation site and bioventing study will be included in the 100-N Area RI report.

The S&GRP has also been collecting additional groundwater data in the area affected by the diesel contamination. Five wells (199-N-173, 199-N-96A, 199-N-18, 199-N-172, and 199-N-167) were sampled in August and September 2009 for multiple analyses, including metals, cations, anions, volatile organic analytes,

semivolatile organic analytes, and field parameters (pH, temperature, conductivity, dissolved oxygen, oxidation-reduction potential, and turbidity) (Figure 6-19). In April 2010, additional samples were taken from the five wells used for the WCH 100-N Area bioremediation project, which were the UPR-100-N-17 wells completed in groundwater (199-N-167, 199-N-169, 199-N-170, 199-N-171, and 199-N-172) (WCH-370, *Bioremediation Well Borehole Soil Sampling and Data Analysis Summary Report for the 100-N Area Bioremediation Project [UPR-100-N-17]*). In addition, the CERCLA monitoring program for the 100-N Area added total petroleum hydrocarbon-diesel range, polyaromatic hydrocarbons, and volatile and semivolatile organic analyte compound analyses to all wells and aquifer tubes in the known diesel plume area.

Well 199-N-18 has historically had floating diesel product, which still remains at this time. None of the other wells exhibited floating product, but an oily sheen and diesel-like smell were noted when wells 199-N-167, 199-N-169, 199-N-170, 199-N-171, and 199-N-172 were sampled. Samples from well 199-N-173 provided additional data on where the diesel plume intersects the Columbia River. Well 199-N-96A is located immediately downriver from well 199-N-173. Samples collected from the five wells listed above allowed the diesel plume to be plotted with a greater degree of accuracy. Prior to 2008, several other wells had detectable levels of total petroleum hydrocarbon-diesel, including 199-N-3 (in 1994), 199-N-19 (in 2005), 199-N-20 (in 1994), and 199-N-21 (in 1994), but none of these wells had detectable levels in recent years (year in parentheses notes the last year detected).

WCH is conducting bioventing pilot tests to evaluate contaminant removal rates and the distribution of air flow within the contaminated zone. The tests will consist of soil vapor measurements, respirometry tests, and air injection tests. Soil vapor monitoring is performed to determine the baseline concentrations of oxygen, carbon dioxide, and volatile hydrocarbons. Air injection tests will be performed to evaluate soil permeability and a consistent supply of adequate oxygen to the contaminated soil. The respirometry tests are performed to provide estimates of in situ biodegradation rates (WCH-323, *Sampling and Analysis Instruction for Installation of UPR-100-N-17 Bioremediation Wells and Performance of Bioventing Pilot Tests*). This work began at the UPR-N-17 site (as listed in the Waste Information Data System database) in the fall of 2010 and continues into 2011. A draft report on the tests progress was issued in early 2011 but was not yet available for use in this report.

6.2.7 River Sediment Porewater Sampling

WCH Studies. WCH performed porewater sampling in river sediments along the 100-N Area shoreline in 2008 and 2009, and the results from the sampling events were published in November 2010 (WCH-380, *Field Summary Report for Remedial Investigation of Hanford Site Release to the Columbia River, Hanford Site, Washington: Collection of Surface Water, Pore Water, and Sediment Samples for Characterization of Groundwater Upwelling*; WCH-381, *Data Quality Assessment Report for Remedial Investigation of Hanford Site Releases to the Columbia River, Hanford Site, Washington*). The study was performed in three phases:

- **Phase I, Technology Demonstration:** Testing the Trident™ probe technology in Hanford Reach conditions.
- **Phase II, Delineating Eight Areas of Suspected Groundwater Plume Upwelling:** Overall rationale for selecting the eight areas to be studied is provided in the *Remedial Investigation Work Plan for Hanford Site Releases*

to the Columbia River (DOE/RL-2008-11). Constituents of interest for the 100-N Area were strontium-90 and total petroleum hydrocarbons.

– Phase IIa: Collecting in situ porewater measurements of specific conductance (conductivity) and temperature to determine the location of the groundwater/riverwater interface. Conductivity values above 160 µS/cm indicated groundwater upwelling.

– Phase IIb: Included screening analysis for key Hanford Site indicator contaminants (e.g., hexavalent chromium, strontium-90, uranium, and tritium) from areas identified in Phase IIA as having groundwater upwelling.

- **Phase III, Groundwater Plume Upwelling Characterization:** More extensive characterization of upwelling conditions through porewater, sediment, and surface water sampling at locations selected from review of Phase II results.

In the 100-N Area under Phase IIa, a total of 97 locations were sampled. The maximum conductivity measured was 1,058 µS/cm and the maximum temperature measured was 6.9 degrees Celsius. Under Phase IIb, thirty sample locations were selected for strontium-90 analysis based on the Phase IIa results. Ten of those thirty locations were also sampled for total petroleum hydrocarbons. Five of the thirty locations had strontium-90 detections above the minimum detectable limit. All five of these samples also exceeded the DWS for strontium-90 (8 pCi/L), with concentrations ranging from 10.7 to 72.3 pCi/L. Two of these samples were taken from outside the area where the known strontium-90 plume intersects the Columbia River, near the outfall structure for the 100-N Area (located on the river below the N Reactor/109-N heat exchanger and associated buildings). None of the ten samples collected for total petroleum hydrocarbon analysis had detections. Under Phase III, four sample locations (T100N1A, T100N2A, JT100N3A, and T100N5Ring) and one additional sediment only sample location (T100N3A) were selected. Conductivity values ranged from 359 to 895 µS/cm, which are strong indicators of a groundwater sample being taken. Site T100N1A yielded the maximum porewater conductivity (895 µS/cm). Laboratory results for hexavalent chromium, total uranium, and strontium-90 in surface water were all nondetects. All hexavalent chromium porewater samples were nondetects, with the exception of one detection of 26 µg/L at station T100N1A. Strontium-90 concentrations ranged from 8 to 55 pCi/L, with the maximum concentration at the 100-N outfall station. Tritium detections ranged from 1,100 to 12,000 pCi/L, with the maximum at station T100N5Ring.

S&GRP Studies. Based on the results of the WCH sampling activities, S&GRP performed follow-up porewater sampling at selected sites. A sampling and analysis plan was developed for the scope of work (DOE/RL-2010-69, *Sampling and Analysis Plan for the 100-NR-2 Operable Unit River Pore Water Investigation*), which included (1) collecting porewater samples from ten locations along a near-shore transect that is near and somewhat downriver of the 100-N outfall and spillway; (2) collecting porewater samples at three locations in the area of sample station T100N1A, where hexavalent chromium was detected during Phase III WCH sampling; and (3) analyzing porewater samples for strontium-90, hexavalent chromium, contaminants of potential concern, and additional analytes of interest to define the contamination extent and support a contaminant transport evaluation. Figure 6-29 shows the sample locations along the 100-N Area shoreline.

- **Sample point T100N1A:** Location where hexavalent chromium was detected during Phase III WCH sampling. Three samples were collected in the immediate vicinity at sample stations T100N1A-1, T100N1A-2, and T100N1A-3. Hexavalent

chromium was not detected at any of the three locations, so the detection found in Phase III at location T100N1A was not repeatable. Strontium-90 and tritium were detected at all three locations; these points are located offshore of the area where the known strontium-90 and tritium groundwater plumes intersect the river. Table 6-6 provides the sample results for strontium-90, tritium, and hexavalent chromium.

- **Transect sample points:** Locations along shoreline near 100-N outfall and spillway structure; eleven samples were collected along this transect, and one sample was a duplicate sample (Figure 6-29). Strontium-90 was detected only at locations N Transect 10 and N Transect 8, which are both near the 100-N outfall structure. Tritium was detected at all ten locations. All ten transect locations were nondetect for hexavalent chromium. Table 6-6 provides the samples results for strontium-90, tritium, and hexavalent chromium.

The strontium-90 detected near the 100-N outfall appears to be an isolated occurrence, as indicated by the transect sample results. Based on the construction of the outfall and its location relative to the N Reactor building and fuel storage basin, it is believed that past leaks from these or other nearby buildings entered groundwater flowing toward the Columbia River, and then followed the engineered fill around the concrete outfall structure. When this structure was built in the late 1950s/early 1960s, it extended over half way into the river channel. Concrete was poured, gravel or other clean fill was placed on either side of the structure, and it was then backfilled. Figure 6-30 depicts the geologic/hydrologic setting and generalized potential pathways the contamination may have taken to show up where detected in the river near the outfall. The 100-N Area RI/FS work plan (DOE/RL-2008-46-ADD5) includes a data gap evaluation associated with the fuel storage basin located on the river side of the N Reactor building. A characterization borehole (which would be completed as a groundwater monitoring well) may be reinstalled near the 118-N reactor fuel storage basin after remediation activities allow. As part of ongoing cleanup for the 100-NR-1 OU, contamination on the riverside of the reactor and associated buildings (e.g., fuel storage basin) is being excavated and the activities are being documented. Any additional data that become available regarding the source of this contamination will be provided in future annual reports and in the 100-N Area RI report.

6.2.8 Remedial Investigation/Feasibility Study Aquifer Tube Sampling

Strontium-90 detected near the 100-N outfall during WCH sampling activities has also been addressed through the RI/FS work plan with the installation of two new sets of three aquifer tubes (one set adjacent to the downriver side of the outfall structure [C7934/35/36], and one set midway between the outfall structure [C7937/38/39] and existing aquifer tube set C6320/21/22) (CHSGW1007-29) (Figure 6-31). As part of the RI/FS sampling and analysis plan, three rounds of sampling (high, low, and transition river stages) on each of four sets of aquifer tubes were initiated in July 2010 and were completed in December 2010 (TPA-CN-353). In addition to the four sites listed in TPA-CN-353, one other site (C6317/18/19) was also sampled for two of the three rounds. Strontium-90 was not detected at the set furthest upriver of the 100-N outfall (C6263/64/65) or at one of the three sets downriver (C7937/38/39). Strontium-90 was detected in one of the sets upriver of the outfall structure (C6317/18/19) but only in tube C6317 (shallow tube). Strontium-90 was also detected in the set nearest the 100-N outfall (C7934/35/36), which is in the same area as the porewater detections listed in the previous section (N Transect 10 and

N Transect 8). The set of tubes furthest downriver (C6320/21/22) had strontium-90 detections in all three tubes but at low levels (less than 10 pCi/L). Strontium-90, tritium, and chromium results are shown in Table 6-7. These results will also be included in the final RI/FS report.

6.3 RCRA Facility Monitoring

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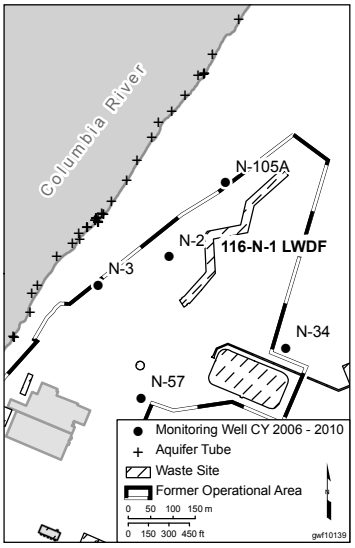


This section describes the monitoring results for the 116-N-1 and 116-N-3 LWDFs, the 120-N-1 percolation pond, and the 120-N-2 surface impoundment. Groundwater is monitored at these facilities to meet the requirements of RCRA and WAC 173-303 ("Dangerous Waste Regulations") for dangerous waste constituents. Groundwater data for these facilities are available in the Hanford Environmental Information System database and in the data files accompanying this report. Appendix B includes well and constituent lists, maps, flow rates, and statistical tables for the 100-N Area RCRA units.

6.3.1 116-N-1 (1301-N) Liquid Waste Disposal Facility

The 1301-N LWDF (waste site 116-N-1) was an unlined crib and trench used for disposal of liquid effluent from the 1960s through 1985. The waste site has been excavated to remove shallow vadose zone sediment (where most of the radionuclide contamination resided) and was backfilled with clean fill.

Groundwater flows to the northwest beneath the 116-N-1 LWDF and discharges to the Columbia River. The hydraulic gradient in March 2010 was 0.0016, with an estimated flow rate between 0.03 and 0.60 meter per day (Appendix B, Table B-1).

6.3.1.1 Network Evaluation and Compliance Status

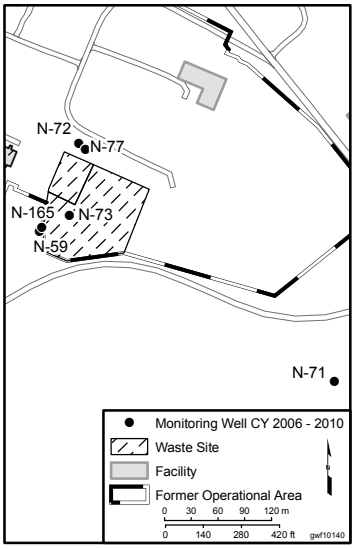
Two upgradient wells (199-N-34 and 199-N-57) and three downgradient wells (199-N-2, 199-N-3, and 199-N-105A) monitor the 116-N-1 LWDF (Appendix B, Table B-3). No changes to the monitoring network are planned until implementation of an integrated groundwater monitoring program (CERCLA, RCRA, and AEA) for the 100-N Area.

This facility is included in the Hanford Facility RCRA Permit (WA7890008967). The Permit states that RCRA monitoring during closure activities will follow the requirements of *100-N Pilot Project: Proposed Consolidated Groundwater Monitoring Program* (BHI-00725). That plan and a supplemental plan (PNNL-13914, *Groundwater Monitoring Plan for the 1301-N, 1324-N/NA, and 1325-N RCRA Facilities*) are similar to an interim status indicator evaluation program (40 CFR 265.93[b], "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities," "Preparation, Evaluation, and Response"), as referenced by WAC 173-303-400 ("Dangerous Waste Regulations," "Interim Status Facility Standards").

6.3.1.2 Groundwater Contaminants

Upgradient and downgradient wells are scheduled for sampling twice each year for RCRA contamination indicator parameters (i.e., pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters. The wells were sampled as scheduled during the reporting period and there were no critical mean exceedances.

6.3.2 120-N-1 (1324-NA) Percolation Pond and 120-N-2 (1324-N) Surface Impoundment



The 1324-NA percolation pond and the 1324-N surface impoundment (waste sites 120-N-1 and 120-N-2) were used to treat and dispose corrosive, nonradioactive waste from 1977 to 1990. Both facilities have been remediated and backfilled.

Groundwater flows to the northwest beneath the 120-N-1 and 120-N-2 facilities, discharging to the Columbia River. The hydraulic gradient in March 2010 was 0.0024, with an estimated flow rate between 0.05 and 0.88 meter per day (Appendix B, Table B-1).

6.3.2.1 Network Evaluation and Compliance Status

Upgradient well 199-N-71 and downgradient wells 199-N-72, 199-N-73, 199-N-77, and 199-N-165 monitor the 120-N-1 percolation pond and 120-N-2 surface impoundment (Appendix B, Table B-3). Well 199-N-77 is screened at the base of the unconfined aquifer and statistical comparisons are not performed on data from this well. No changes to the monitoring network are planned until implementation of an integrated groundwater monitoring program for the 100-N Area.

Both of these units are included in the Hanford Facility RCRA Permit. The Permit states that RCRA monitoring during closure activities will follow the requirements of BHI-00725. BHI-00725 and a supplemental plan (PNNL-13914) are similar to an interim status indicator evaluation program (40 CFR 265.93[b], as referenced by WAC 173-303-400). The two units are monitored as a single site (waste management area) because of their proximity and similar waste types.

6.3.2.2 Groundwater Contaminants

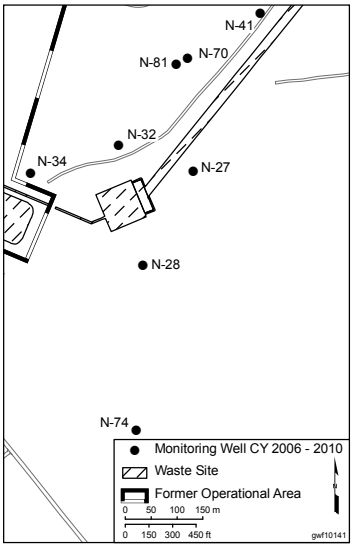
During the reporting period, all of the monitoring wells for this site were sampled as scheduled, twice for RCRA contamination indicator parameters and groundwater quality, and once for site-specific parameters (Appendix B, Table B-3).

Average specific conductance values in downgradient wells 199-N-72, 199-N-73, and 199-N-165 continued to exceed the critical mean value of 752 µS/cm at least once in CY 2010. A previous groundwater quality assessment indicated that the high specific conductance is caused by the nonregulated constituents sulfate and sodium (WHC-SD-EN-EV-003, *Results of Groundwater Quality Assessment Monitoring at the 1301-N and 1324-N/NA Facilities*). Recent data indicate that this conclusion remains valid (DOE/RL-2008-01, Appendix B).

The average total organic carbon concentration exceeded the critical mean value of 865 µg/L in well 199-N-73 in September 2010, but the value was below the limit of quantitation of 990 µg/L. No other critical mean exceedances occurred during the reporting period.

Specific conductance increased sharply in well 199-N-73 in September 2010 (Figure 6-32). The change was caused by increases in calcium, sodium, nitrate, sulfate, and other ions. Nearby wells did not show a similar increase, and the cause of the change is unknown.

6.3.3 116-N-3 (1325-N) Liquid Waste Disposal Facility



The 1325-N LWDF (waste site 116-N-3) was an unlined crib and trench used to dispose liquid effluent from 1983 through 1991. The waste site was excavated to remove shallow vadose zone material (which contained the highest concentrations of radionuclides) and was backfilled.

Groundwater flows to the north beneath the 116-N-3 LWDF, turns to the northwest, and discharges to the Columbia River. The hydraulic gradient in March 2010 was 0.0012, with the groundwater flow rate estimated between 0.03 and 0.46 meter per day (Appendix B, Table B-1).

6.3.3.1 Network Evaluation and Compliance Status

The 116-N-3 LWDF is included in the Hanford Facility RCRA Permit. The Permit states that RCRA monitoring during closure activities will follow the requirements of BHI-00725. BHI-00725 and a supplemental plan (PNNL-13914) are similar to an interim status indicator evaluation program (40 CFR 265.93[b], as referenced by WAC 173-303-400).

Upgradient well 199-N-74 and down-gradient wells 199-N-32, 199-N-41, and 199-N-81 monitor the 116-N-3 LWDF. Well 199-N-28 is monitored for supporting information but its data are not evaluated statistically. No changes to the monitoring network are planned until implementation of an integrated groundwater monitoring program for the 100-N Area.

6.3.3.2 Groundwater Contaminants

All five wells in the RCRA network were sampled as planned during the reporting period, twice for RCRA contamination indicator parameters (i.e., pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters (Appendix B, Table B-3).

Average specific conductance values in downgradient well 199-N-41 continued to exceed the critical mean value of 513 µS/cm during the reporting period, which is a continuation of previous exceedances noted from 1999 through 2009. The DOE notified Ecology of the original exceedance and submitted an assessment report (00-GWVZ-054, *Results of Assessment at the 1325-N Facility*), which concluded that the exceedance was caused by past discharges of nonregulated contaminants to the 120-N-1 percolation pond. Recent data indicate that this conclusion remains valid (DOE/RL-2008-01, Appendix B). No other critical mean exceedances occurred during the reporting period.

6.4 Conclusions and Recommendations

The conclusions and recommendations for the 100-NR-2 OU are presented below:

- Strontium-90 in groundwater within the 100-N Area is well characterized, with the plume varying little since before interim remedial actions (mainly pump-and-treat operations) began in 1996 to the present. Strontium-90 has a much greater affinity for sediment than for water (high distribution coefficient), so its rate of transport in groundwater to the Columbia River is considerably slower than the actual groundwater flow rate. The relative velocity of strontium-90 to groundwater is ~1 to 100 (between 0.0005 and 0.009 meters per day).
- Current work at the existing apatite PRB is promising and should provide an effective barrier between the strontium-90 plume and the Columbia River. Strontium-90 and gross beta concentrations in the existing apatite PRB, in both aquifer tubes and wells, are generally decreasing. Many sites have shown more than 90% reduction in gross beta concentrations.
- The jet injection test successfully demonstrated that the vadose zone and upper unconfined aquifer can be treated using this technology in conjunction with groundwater injections.

- Future activities planned for the 100-N Area shoreline include expansion of both the existing apatite PRB and installation of further jet-injected PRB, as well as further phytoextraction testing.
- Tritium is present beneath much of the 100-N Area and along the Columbia River. The concentrations in the plume are decreasing and no locations were above the DWS of 20,000 pCi/L in CY 2010. This reflects no continuing source of tritium contamination in the 100-N Area and attenuation through radioactive decay of the remaining tritium contamination.
- Nitrate continues to be an issue at the 100-N Area, with concentrations above the DWS of 45 mg/L in several locations. Data from the Waste Information Data System database and historical documents are being examined to determine if any potential sources of the nitrate plume may have been missed. Nitrate is also being investigated as part of the RI/FS process planned at the 100-N Area.
- A plume map has been generated showing the current extent of the diesel contamination in groundwater in the 100-N Area. The plume appears localized, with well 199-N-18 having the highest detections of total petroleum hydrocarbon-diesel. Several other nearby wells and aquifer tubes have detections of total petroleum hydrocarbon-diesel. The plume extends to the northwest to the Columbia River. WCH is continuing bioventing pilot testing, and S&GRP will take additional groundwater samples in support of that work during 2011.
- Sulfate levels are elevated in the 100-N Area, but only one well exceeded the secondary DWS of 250 mg/L. The highest value was found in well 199-N-18, and the cause is uncertain. Monitoring of this well will continue to determine if the sulfate concentration remains elevated in 2011. Well 199-N-165 had the second highest sulfate concentration; this well monitors a known source of the sulfate contamination in the 100-N Area. Most of the sulfate values are well below the regulatory limits.
- Manganese and iron are elevated in wells associated with the diesel plume, which is a side effect of the reducing conditions created by the biodegradation of diesel.
- Chromium is elevated in only two wells at the 100-N Area: well 199-N-80, which has known screen corrosion (exceeds the DWS of 100 µg/L); and well 199-N-74, which is being monitored to determine if the chromium detection trend continues. The RI/FS process is also investigating this well and trying to determine the source of the contamination. No evidence exists of any chromium groundwater contamination source in the remainder of the 100-N Area.
- The RI/FS work plan (DOE/RL-2008-46-ADD5) for the 100-N Area was issued in March 2011. The RI/FS sampling and analysis plan (DOE/RL-2009-42) was issued in December 2010. Drilling of the eight RI/FS wells for the 100-N Area began in March 2011. Spatial/temporal sampling was completed at the 100-N Area in February 2011, with the final well sampled near the end of the month. Data from the sampling is currently being evaluated.
- Eight new aquifer tubes were installed in the 100-N Area; two sets of three each (C7934/C7235/C7936 and C7937/C7938/C7939) near the 100-N outfall structure and two tubes at location N116mArray-7A (C7881/C7882) to replace this array which became unusable.
- Three rounds of RI/FS sampling were performed at four sets of aquifer tubes in the vicinity of the 100-N outfall structure.

Groundwater monitoring in the 100-NR-2 groundwater interest area includes the following activities:

CERCLA and AEA Monitoring (Appendix A) —

- ***Forty-three wells are scheduled for biannual or yearly sampling as part of the integrated monitoring plan for the 100-N Area (CERCLA, RCRA, AEA). Two wells were not sampled as planned.***
- ***Eighteen wells were sampled quarterly for performance monitoring of the apatite PRB. All forty-five wells/aquifer tubes were sampled in August 2010. Sampling will be performed twice each year for the next few years.***
- ***Fifteen wells and twenty-eight aquifer tubes are scheduled for quarterly to annual sampling under a shoreline groundwater monitoring plan.***

Facility Monitoring (Appendix B) —

- ***Five wells are scheduled for semiannual sampling for the 116-N-1 LWDF to meet RCRA and AEA requirements. The wells were sampled as planned.***
- ***Five wells are scheduled for semiannual sampling for the 120-N-1 percolation pond and 120-N-2 surface impoundment to meet RCRA and AEA requirements. The wells were sampled as planned.***
- ***Five wells are scheduled for semiannual sampling for the 116-N-3 LWDF the meet RCRA requirements. The wells were sampled as planned.***

Table 6-1. Nitrate Concentrations in Wells in the 100-N Area Exceeding the Drinking Water Standard (45 mg/L)

Well Name	Concentration (mg/L)	Nearest Facility	Well Name	Concentration (mg/L)	Nearest Facility
199-N-2	224 (D)	116-N-1	199-N-57	60.6 (D)	105-N
199-N-3	94.3 (D)	116-N-1	199-N-67	500 (D)	116-N-1
199-N-14	50 (D)	116-N-1	199-N-69	61.1 (D)	116-N-1
199-N-19	89.4 (D)	105-N	199-N-75	49.6 (D)	116-N-1
199-N-21	64.6 (D)	105-N	199-N-76	66.4 (D)	116-N-1
199-N-26	50.5 (D)	---	199-N-99A	47.8 (D)	116-N-1
199-N-28	52.2 (D)	116-N-3	199-N-103A	73.9 (D)	116-N-1
199-N-32	70.8 (D)	116-N-3	199-N-105A	109 (D)	116-N-1
199-N-56	51.4 (D)	105-N	199-N-121	45.2 (D)	116-N-1

D = analyte reported at a secondary dilution factor

Table 6-2. Hydrocarbon Product Removal from Well 199-N-18 (2003 to Present)

Year	Product Removed (g)	Notes
2003	~1,200 (see notes below)	Estimate provided per information given in note below; data records lost when original work package was lost in the field.
2004	3,475	Changed out twice per month.
2005	780	Changed approximately every 2 months.
2006	1,370	Changed every 2 months.
2007	1,294	Changed every 2 months.
2008	920	Changed every 2 months.
2009	1,380	Changed approximately every 2 months.
2010	225.5	Changed only twice prior to June 2010; smart sponge broke apart in well. No removal for second half of 2010.
	Total	**10,644.5 g (~10.64 kg) removed through end of 2010**

Notes:

1. DOE/RL-2004-21, *Calendar Year 2003 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit (OU) Pump & Treat Operations*, reports that product removal started in October 2003.

2. DOE/RL-2005-18, *Calendar Year 2004 Annual Summary Report for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Unit Pump-and-Treat Operations*, states that the average mass removal for FY 2004 (October 2003 through October 2004) was approximately 0.4 kilograms per month, so an estimate is provided for the 3 months missing in CY 2003.

Table 6-3. 100-NR-2 Operable Unit Apatite Permeable Reactive Barrier Timeline

Dates		Injection Wells[a]	Description of Test/Injection	Injection Chemistry
2006[b]	May 3	N-138	Tracer test at the pilot test #1 location (upriver end of PRB)	NaBr
	May 31 to June 1	N-138	Pilot test #1 location (upriver end of PRB) — Hanford/ Ringold injection at high river level	4 mM Ca, 10 mM citrate, 2.4 mM PO4
	Sept. 27 to Sept. 28	N-137	Pilot test #2 location (downriver end of PRB) — Ringold Formation injection at low river level	2 mM Ca, 5 mM citrate, 2.4 mM PO4
2006 – 2007	9/28/06 to 2/28/07	N/A	Performance monitoring	N/A
2007[d]	Feb. 28 to Mar. 2	N-136, N-142, and N-145[c]	Low concentration injections into Ringold Formation at low river level	1 mM Ca, 2.5 mM citrate, 10 mM PO4
	Mar. 2 to Mar. 5	N-140 and N-144	Low concentration injections into Ringold Formation at low river level	1 mM Ca, 2.5 mM citrate, 10 mM PO4
	Mar. 20 to Mar. 23	N-137 and N-141	Low concentration injections into Hanford formation and Ringold Formation at high river level	1 mM Ca, 2.5 mM citrate, 10 mM PO4
	Mar. 23 to Mar. 25	N-139 and N-143	Low concentration injections into Hanford formation and Ringold Formation at high river level	1 mM Ca, 2.5 mM citrate, 10 mM PO4
	June 5 to June 6	N-142, N-136, and N-144	PT#3, Phases I and II — Hanford formation injections at high river level	1 mM Ca, 2.5 mM citrate, 10 mM PO4
	June 8 to June 10	N-138	PT#3, Phase III — Hanford formation injections at high river level	1 mM Ca, 2.5 mM citrate, 10 mM PO4
2007 – 2008	6/10/07 to 6/4/08	N/A	Performance monitoring	N/A
2008	June 4 to June 6	N-138, N-137, and N-159	High-concentration injection #1 — Hanford formation and Ringold Formation at higher river levels	3.6 mM Ca, 9.0 mM citrate, 40 mM PO4
	June 26 to June 28	N-145, N-161, and N-141	High-concentration injection #2 — Hanford formation and Ringold Formation at higher river levels	3.6 mM Ca, 9.0 mM citrate, 40 mM PO4
	June 30 to July 3	N-143, N-163, and N-139	High-concentration injection #3 — Hanford formation and Ringold Formation at higher river levels	3.6 mM Ca, 9.0 mM citrate, 40 mM PO4
	July 14 to July 17	N-136, N-160, N-142, and N-164	High-concentration injection #4 — Hanford formation and Ringold Formation at lower river levels	3.6 mM Ca, 9.0 mM citrate, 40 mM PO4
	July 22 to July 24	N-144, N-162, and N-140	High-concentration injection #5 — Hanford formation and Ringold Formation at lower river levels	3.6 mM Ca, 9.0 mM citrate, 40 mM PO4
	7/24/08 to 12/31/08	N/A	Performance monitoring	N/A
2009	January to December	N/A	Performance monitoring	N/A
2010	January to August	N/A	Performance monitoring	N/A

a. Well names are prefixed by "199-".

b. Original apatite PRB wells installed in 2005, including 199-N-136, 199-N-137, 199-N-139, 199-N-139, 199-N-140, 199-N-141, 199-N-142, 199-N-143, 199-N-144, and 199-N-145 (screened across lower Hanford formation and upper Ringold Formation), on 9.1-meter spacing between wells. Also installed two additional monitoring wells (199-N-146 and 199-N-147). Monitoring wells 199-N-122 and 199-N-123 were in place before PRB installation. All monitoring wells are screened across the lower Hanford formation and upper Ringold Formation.

c. Well 199-N-145 replaced well 199-N-142 part way through injection due to problems with well 199-N-142.

d. Six additional injection wells were installed in fall 2007 along existing the apatite PRB, including 199-N-159, 199-N-160, 199-N-161, 199-N-162, 199-N-163, 199-N-164, and 199-N-165 (screened in upper Ringold Formation), on 4.6-meter spacing between wells. Wells installed in lower portion of existing PRB, between wells 199-N-141 and 199-N-137.

N/A = not applicable

PT = pilot test

Table 6-4. 100-NR-2 Operable Unit Apatite Permeable Reactive Barrier Monitoring Locations (Includes Barrier Wells, Monitoring Wells, and Aquifer Tubes)

Well Name/ID	Well Type	Geological Unit(s), Screened Interval	Screened Interval (ft bgs)	Location in PRB
N116mArray-2A/C5256	AT	--	--	Upriver end of PRB — pilot test #1 site
APT-1/C5269	AT	--	--	
199-N-138/C5044	IBW	Hanford/Ringold Formations	7.8 to 24.8	
199-N-123/C4955	MW	Hanford/Ringold Formations	9.99 to 29.97	
199-N-126/C5032	MW	Ringold Formation	22.3 to 27.3	
199-N-127/C5033	MW	Hanford formation	12.7 to 17.7	
199-N-128/C5034	MW	Ringold Formation	21.6 to 26.6	
199-N-129/C5035	MW	Hanford formation	12.1 to 17.1	
199-N-130/C5036	MW	Ringold Formation	22.5 to 27.5	
199-N-131/C5037	MW	Hanford formation	12.5 to 17.5	
199-N-132/C5038	MW	Ringold Formation	22.2 to 27.2	
199-N-133/C5039	MW	Hanford formation	12.7 to 17.7	
N116mArray-3A/C5257	AT	--	--	Upper half of PRB
199-N-139/C5045	IBW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-140/C5046	IBW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-146/C5052	MW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-141/C5047	IBW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-164/C6182	IBW	Ringold Formation	17.14 to 24.14	
N116mArray-4A/C5258	AT	--	--	
199-N-142/C5048	IBW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-163/C6181	IBW	Ringold Formation	17.35 to 24.35	
199-N-143/C5049	IBW	Hanford/Ringold Formations	7.0 to 24.0	Upper half of PRB
199-N-162/C6180	IBW	Ringold Formation	17.20 to 24.20	Lower half of PRB
199-N-122/C4954	MW	Hanford/Ringold Formations	7.06 to 26.92	
199-N-144/C5050	IBW	Hanford/Ringold Formations	7.0 to 24.0	
NVP2-116.0m/C5251	AT	--	--	
199-N-161/C6179	IBW	Ringold Formation	17.25 to 24.25	
199-N-145/C5051	IBW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-160/C6178	IBW	Ringold Formation	17.20 to 24.20	
199-N-136/C5042	IBW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-159/C6177	IBW	Ringold Formation	17.11 to 24.11	
N116mArray-6A/C5259	AT	--	--	
199-N-137/C5043	IBW	Hanford/Ringold Formations	7.0 to 24.0	Downriver end of PRB — pilot test #2 site
199-N-147/C5116	MW	Hanford/Ringold Formations	7.0 to 24.0	
199-N-148/C5326	MW	Ringold Formation	19.7 to 24.7	
199-N-149/C5317	MW	Hanford formation	11.0 to 16.0	
199-N-150/C5318	MW	Hanford formation	11.0 to 16.0	
199-N-151/C5319	MW	Ringold Formation	20.0 to 25.0	
199-N-152/C5320	MW	Lower Ringold Formation	28.2 to 33.2	
199-N-153/C5321	MW	Hanford formation	10.9 to 15.9	
199-N-154/C5322	MW	Ringold Formation	19.1 to 24.1	

Table 6-4. (Cont.)

Well Name/ID	Well Type	Geological Unit(s), Screened Interval	Screened Interval (ft bgs)	Location in PRB
199-N-155/C5323	MW	Hanford formation	11.0 to 16.0	Downriver end of PRB — pilot test #2 site
199-N-156/C5324	MW	Ringold Formation	19.0 to 24.0	
APT-5/C5386	AT	--	--	
N116mArray-7A/C5260*	AT	--	--	
C7881 (N116mArray-7A replacement)*	AT	--	--	

* N116mArray-7A was monitored for the apatite PRB from June 2006 through September 2009. It became unusable in 2009 and was replaced at the same location with C7881.

Table 6-5. 100-NR-2 Operable Unit Apatite Permeable Reactive Barrier Performance Monitoring Constituents

Analysis	Constituents
Strontium-90	Strontium-89/90
Gross beta	Gross beta
Inductively coupled plasma (ICP) metals	Aluminum, antimony, arsenic, barium, calcium, cadmium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, potassium, silver, sodium, strontium, vanadium, and zinc
Ion chromatography (IC) anions	Chloride, fluoride, nitrate in nitrogen, nitrite in nitrogen, phosphate in phosphorous, and sulfate

Table 6-6. Porewater Sampling Results for Strontium-90, Tritium, and Hexavalent Chromium

Location	Strontium-90 (pCi/L) (DWS = 8 pCi/L)	Tritium (pCi/L) (DWS = 20,000 pCi/L)	Hexavalent Chromium — Unfiltered (µg/L) (DWS = 100 µg/L)
N Transect 1	-0.13 (U)	410	0.002 (U)
N Transect 2	-2.6 (U)	260	0.002 (U)
N Transect 3	-5 (U)	540	0.002 (U)
N Transect 4	-2.5 (U)	760	0.002 (U)
N Transect 5	-3 (U)	-82 (U)	0.002 (U)
N Transect 6	-4.1 (U)	670	0.002 (U)
N Transect 7	-1.4 (U)	800	0.002 (U)
N Transect 7 — Duplicate	-3.8 (U)	690	0.002 (U)
N Transect 8	3.2	740	0.002 (U)
N Transect 9	-5.5 (U)	4,300	0.002 (U)
N Transect 10	18	4,000	0.002 (U)
T100N1A-1	100	1,700	0.002 (U)
T100N1A-2	77	1,200	0.002 (U)
T100N1A-3	95	2,600	0.002 (U)

Note: Yellow-shaded cells indicate detection; orange-shaded cells indicate concentration above DWS. The DWS for strontium-90 = 8 pCi/L; DSW for tritium = 20,000 pCi/L; DWS for chromium = 100 µg/L.

U = not detected in sample; value shown is the detection limit

Table 6-7. Remedial Investigation/Feasibility Study Aquifer Tube Sampling Results for Strontium-90, Tritium, and Hexavalent Chromium

Location C6263 (Shallow)								
August 17, 2010			September 13, 2010			December 28, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-6 (U)	2,500	2.01 (BD) 14 (U)	-5.6 (U)	2,400	2.93 (BD) 14 (U)	-2.6 (U) -1.1 (U)	2,400 3,000	2.74 (BD) 14 (U)
Location C6264 (Middle)								
August 17, 2010			September 13, 2010			December 28, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-8.1 (U)	2,100	1.23 (BD) 14 (U)	-3.7 (U)	2,700	2.19 (BD) 24 (B)	-0.86 (U)	3,400	2.41 (BD) 14 (U)
Location C6265 (Deep)								
August 17, 2010			September 13, 2010			December 28, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-7.6 (U)	1,000	1.34 (BD) 14 (U)	-8.1 (U) -4 (U)	1,400 1,400	1.81 (BD) 14 (U) 1.92 (BD) 14 (U)	-2.2 (U)	3,100	2.74 (BD) 14 (U)
Location C6317 (Shallow)								
August 12, 2010			September 13, 2010			December 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
0.06 (U) 3.2	2,500 2,600	2.52 (BD) 14 (U) 1.96 (BD) 14 (U)	-2 (U) 0.93 (U)	1,600 1,400	2.15 (BD) 14 (U) 2.47 (BD) 14 (U) 2.88 (BD) 14 (U)	---	---	---
Location C6318 (Middle)								
August 12, 2010			September 13, 2010			December 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-7.8 (U)	750	5.04 (BD) 14 (U)	-3.1 (U)	730	5.03 (BD) 14 (U)	---	---	---

Table 6-7. (Cont.)

Location C6319 (Deep)								
August 12, 2010			September 13, 2010			December 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-3.1 (U)	870	4.06 (BD) 14 (U)	-1.8 (U)	990	4.15 (BD) 14 (U)	---	---	---
Location C7934 (Shallow)								
July 17, 2010			September 12, 2010			December 28, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
220	7,600	9.46 (BD) 13 (U)	300	9,800	8.37 (BD) 14 (U)	320	11,000	6.32 (BD) 14 (U)
Location C7935 (Middle)								
July 17, 2010			September 12, 2010			December 28, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
200	6,000	4.78 (BD) 13 (U)	300	9,400	8.45 (BD) 14 (U)	300	12,000	6.33 (BD) 14 (U)
Location C7936 (Deep)								
July 17, 2010			September 12, 2010			December 28, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
39	6,200	5.12 (BD) 13 (U)	69	4,300	5.32 (BD) 14 (U)	84	5,000	5.8 (BD) 14 (U)
Location C7937 (Shallow)								
July 15, 2010			September 12, 2010			December 27, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-2.2 (U)	-5.4 (U)	2.21 (BD) 13 (U)	-3.7 (U)	950	4.69 (BD) 14 (U)	0.04 (U) -3.7 (U)	84 (U) 140 (U)	1 (UD) 14 (U) 1 (UD) 14 (U)

Table 6-7. (Cont.)

Location C7938 (Middle)								
July 15, 2010			September 12, 2010			December 27, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-4.2 (U)	180	4.63 (BD) 13 (U)	-4.6 (U)	850	6.32 (BD) 14 (U)	-1.4 (U)	16 (U)	4.99 (BD) 15 (B)
Location C7939 (Deep)								
July 15, 2010			September 12, 2010			December 27, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-3.9 (U)	650	2.3 (BD) 13 (U)	-3.1 (U)	730	3.7 (BD) 14 (U)	-0.7 (U)	210	2.76 (BD) 14 (U)
Location C6320 (Shallow)								
August 11, 2010			September 9, 2010			December 27, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
5.4	220	12.6 (BD) 14 (U)	9.5	740	3.45 (BD) 14 (U)	1.2 (U)	380	1.6 (BD) 14 (U)
Location C6321 (Middle)								
August 11, 2010			September 9, 2010			December 27, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
5.8	390	2.27 (BD) 14 (U)	5.5	840	2.96 (BD) 14 (U)	3.6	410	1.65 (BD) 14 (U)
Location C6322 (Deep)								
August 11, 2010			September 9, 2010			December 27, 2010		
Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)	Sr-90 (pCi/L)	Tritium (pCi/L)	Chromium (unfiltered)
-4 (U)	710	3.95 (BD) 14 (U)	-0.23 (U)	1,200	5.71 (BD) 14 (U)	1.6	890	3.67 (BD) 14 (U)

Notes:

1. B = analyte detected at a value less than contract required detection limit but greater than or equal to the instrument or method detection limit, D = analyte reported at a secondary dilution factor, U = detected in sample; value shown is the detection limit.

2. Yellow-shaded cells indicatedetection; orange-shaded cells indicate concentrations above DWS. The DWS for strontium-90 is 8 pCi/L; the DWS for tritium is 20,000 pCi/L; and the DWS for chromium is 100 µg/L.

Figure 6-1. Facilities and Groundwater Monitoring Wells in the 100-N Area

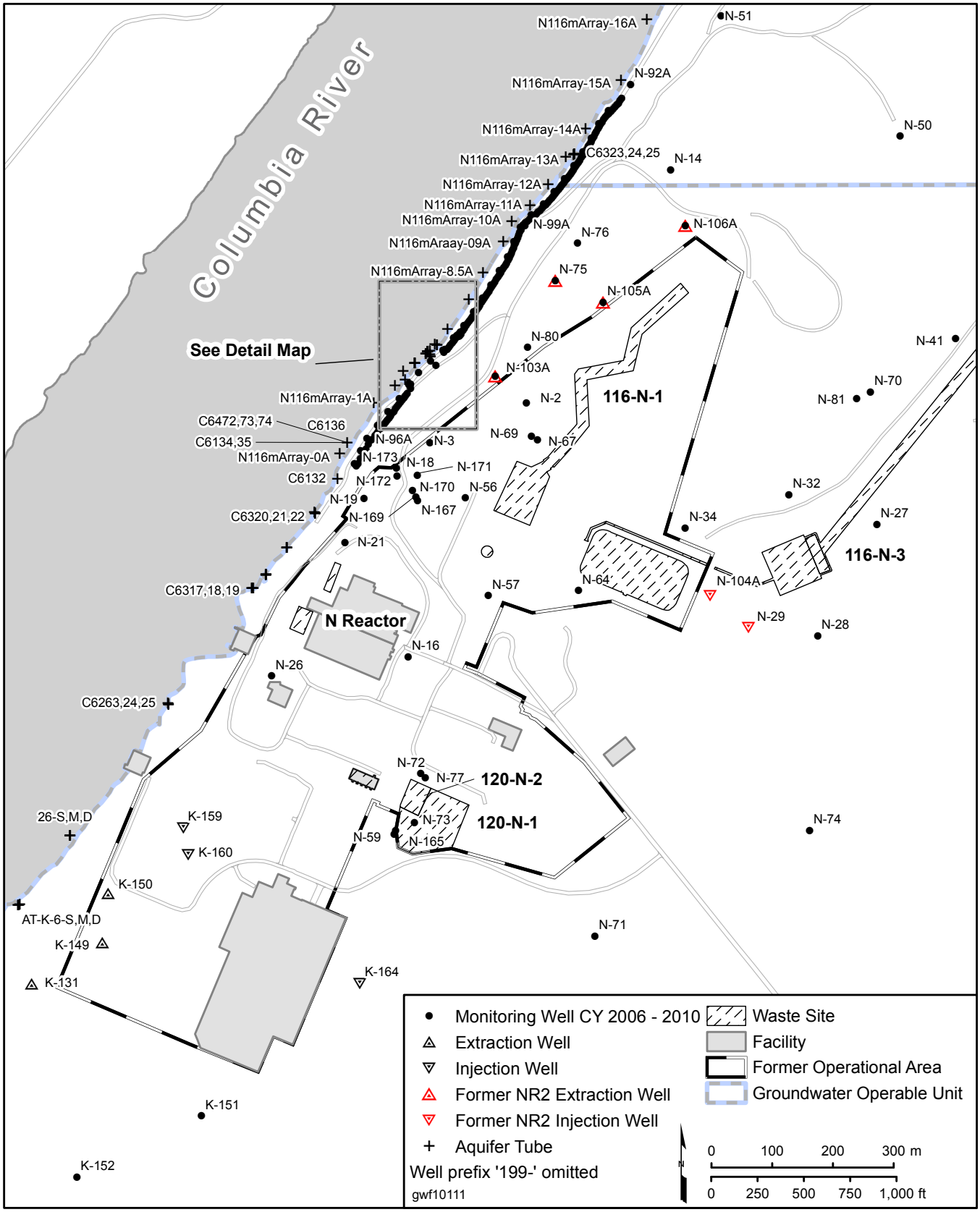


Figure 6-2. Aquifer Tubes, Monitoring Wells, and Apatite Permeable Reactive Barrier Monitoring Locations on the 100-N Area Shoreline

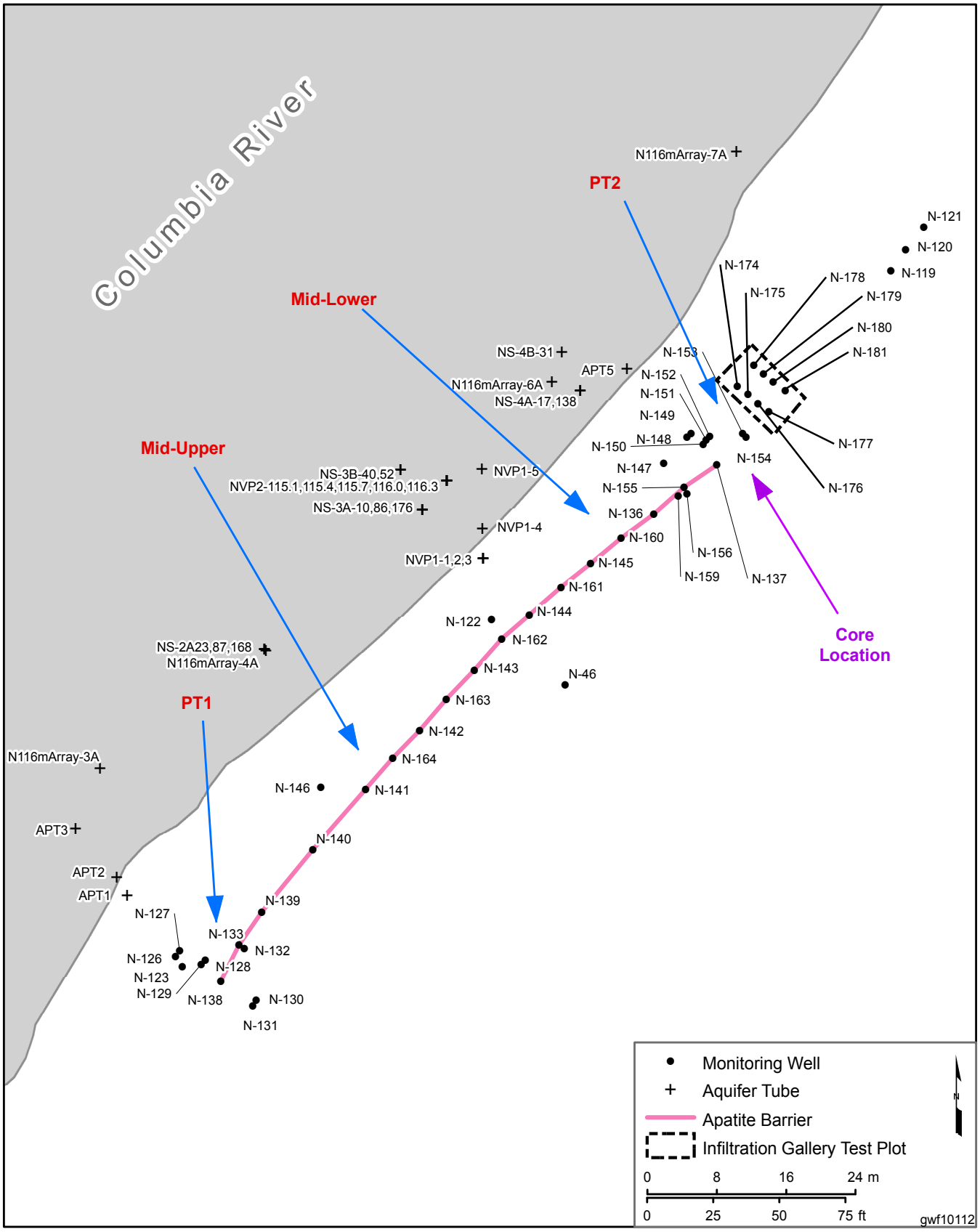


Figure 6-3. 100-N Area Water Table Map, March 2010

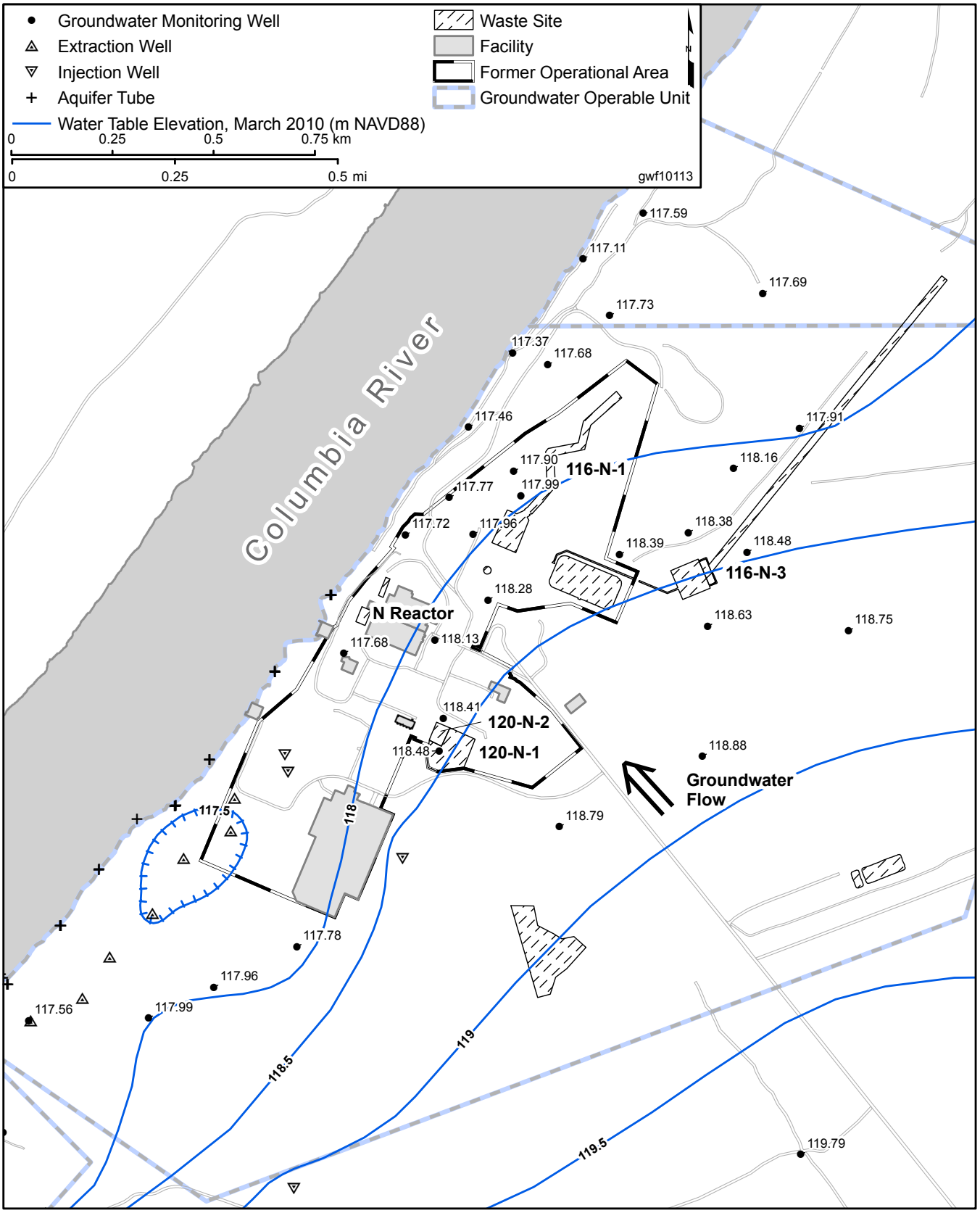


Figure 6-4. Average Strontium-90 Concentrations in the 100-N Area, Upper Portion of Unconfined Aquifer

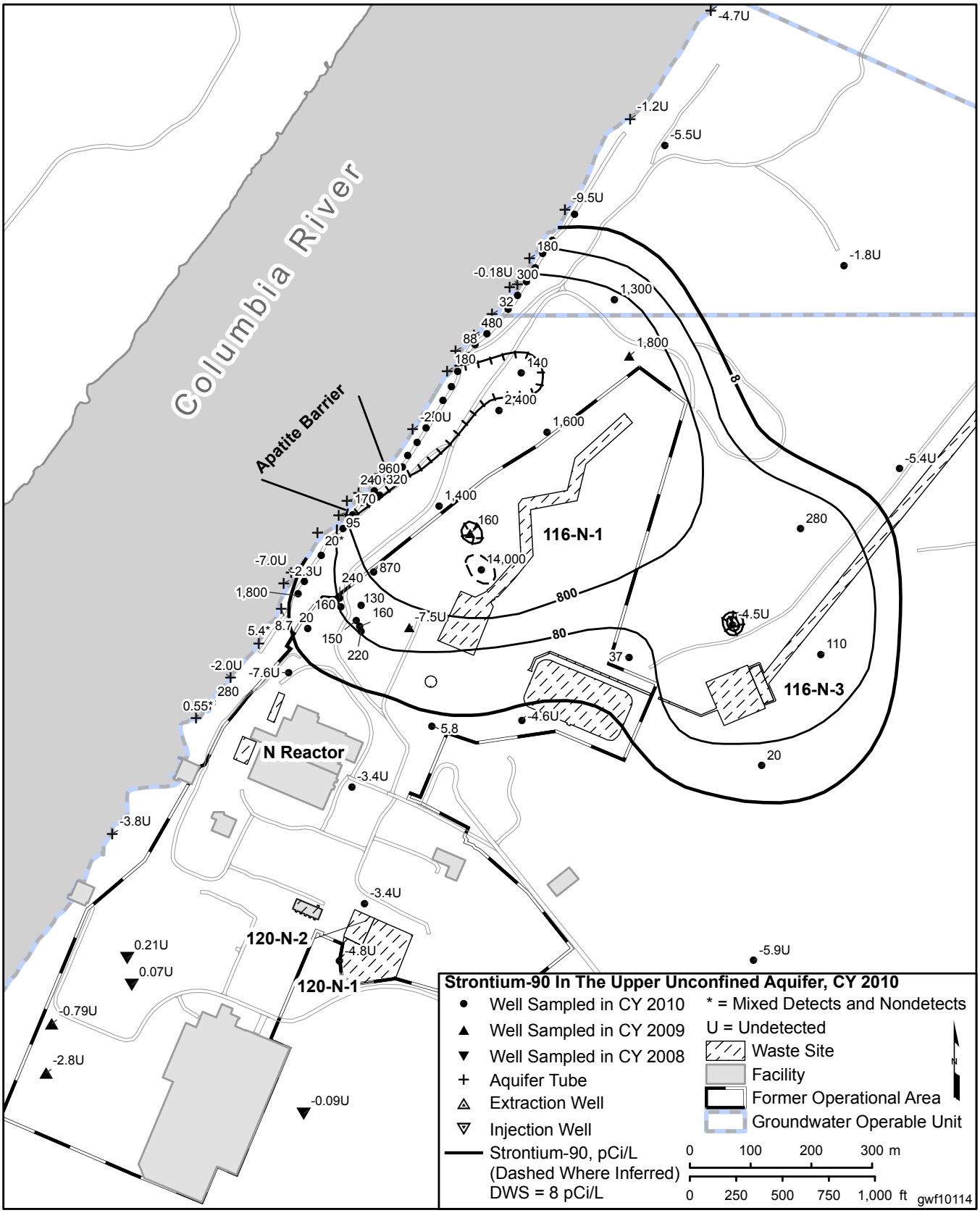


Figure 6-5. Strontium-90 in Groundwater at the Apatite Permeable Reactive Barrier Study Area, Fall 2010, Upper Portion of Unconfined Aquifer

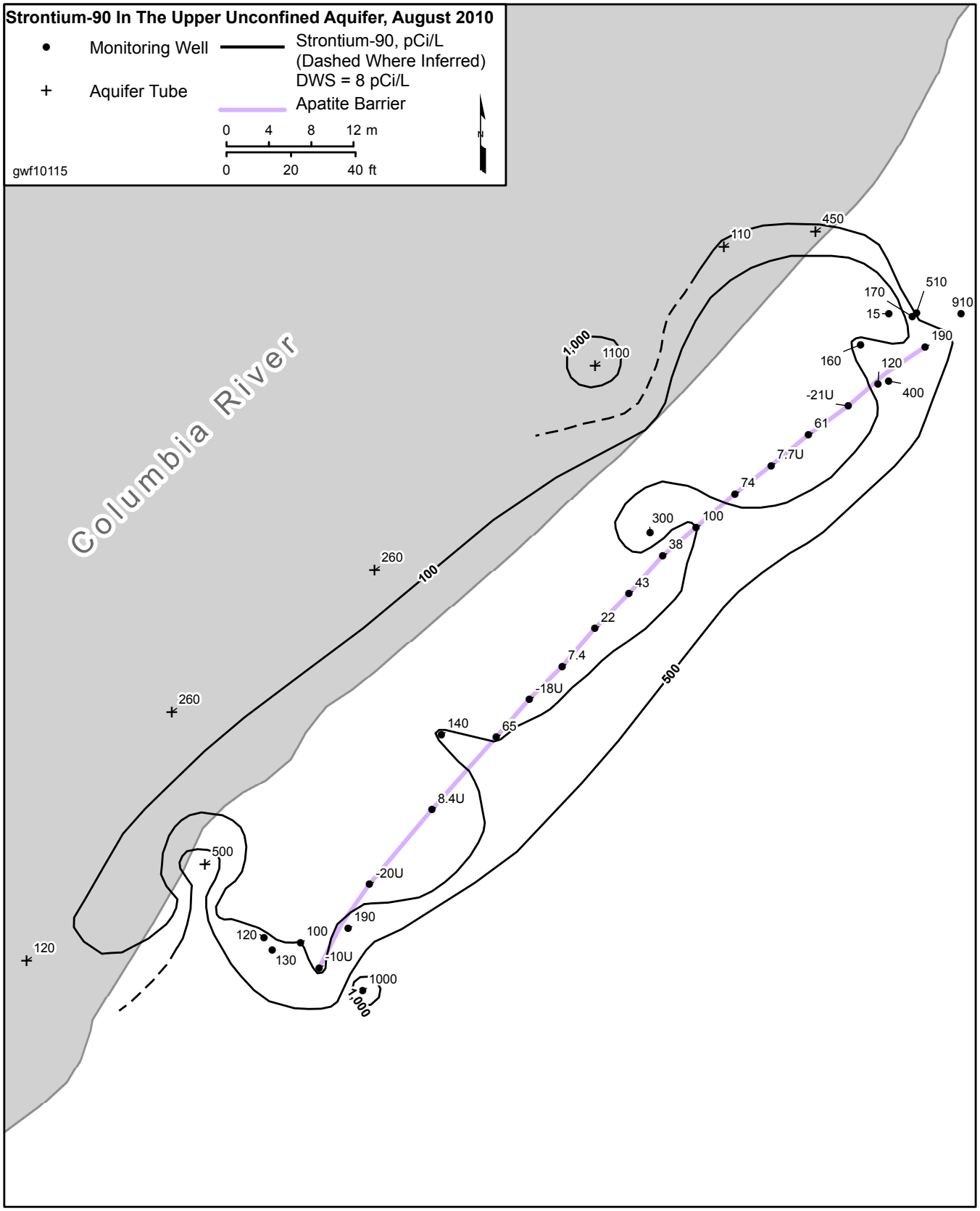


Figure 6-6. Strontium-90 Concentrations and Water Levels near 116-N-1 Liquid Waste Disposal Facility

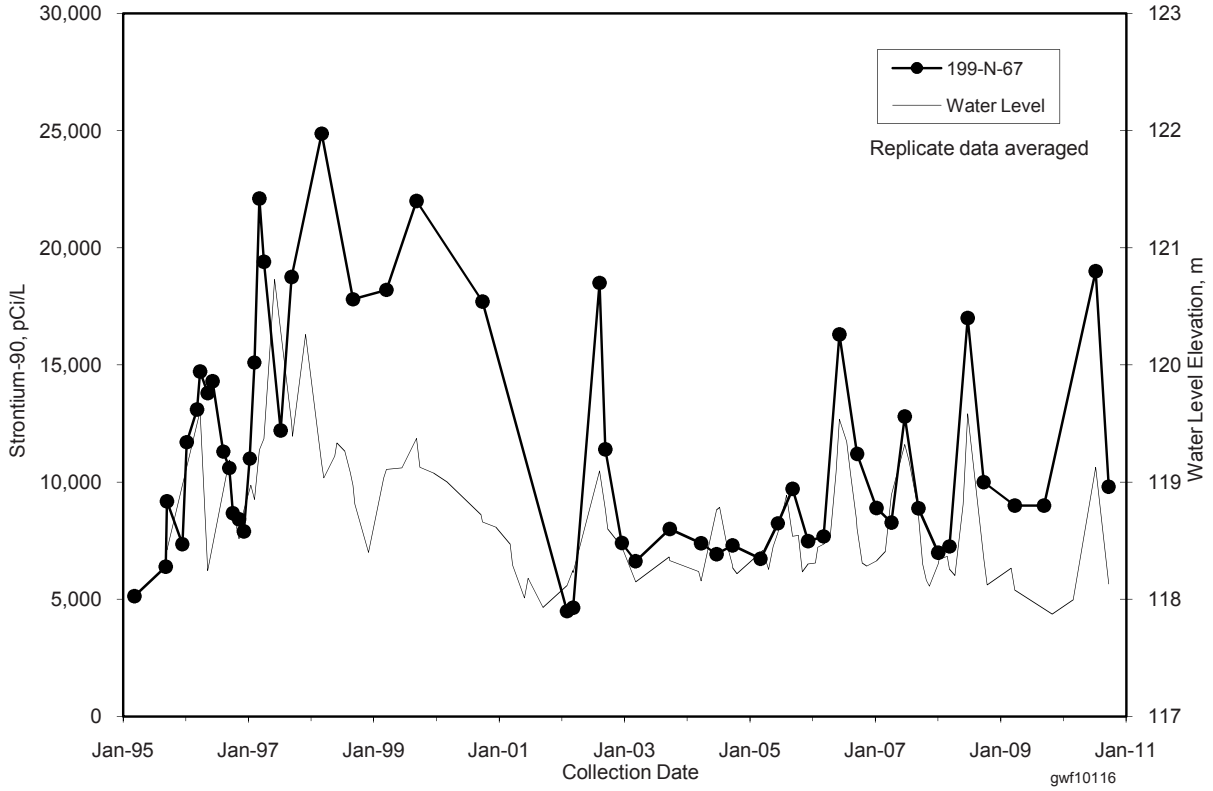


Figure 6-7. Strontium-90 Concentrations and Water Levels near 116-N-3 Liquid Waste Disposal Facility

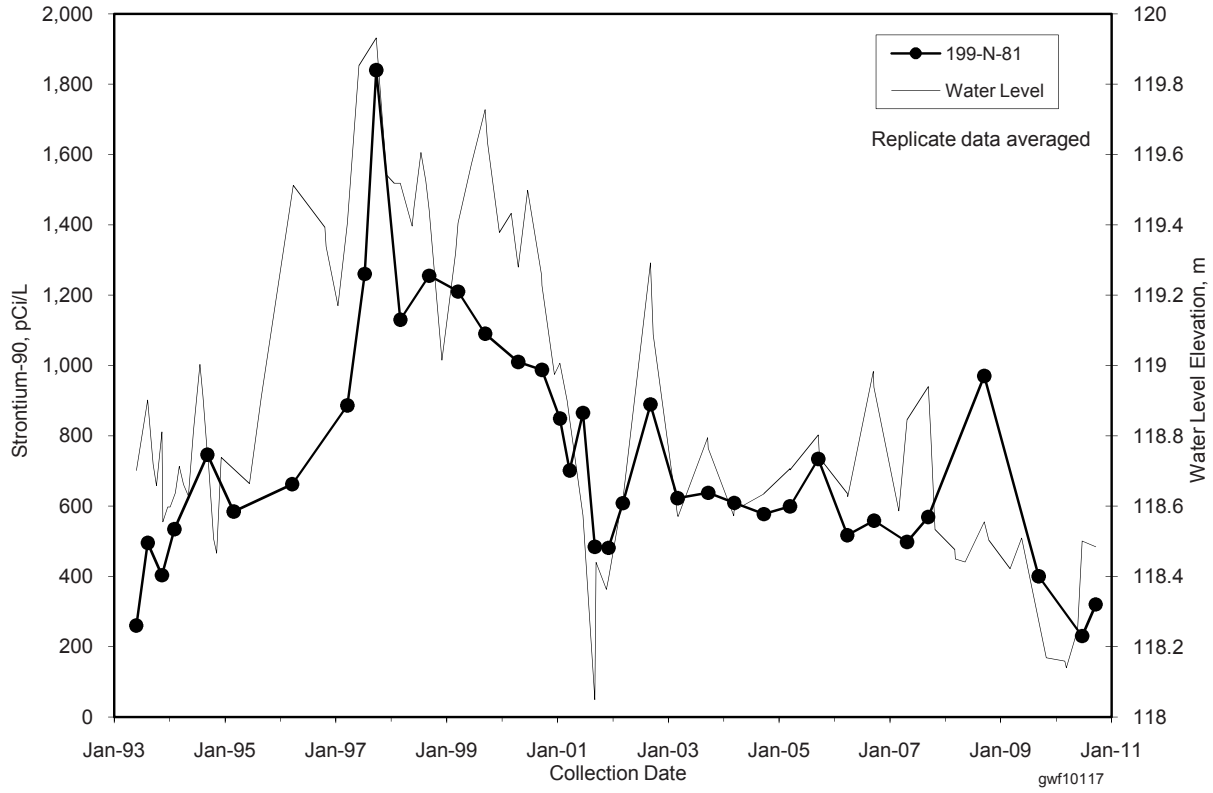


Figure 6-8. Cross Section of Wells and Aquifer Tubes and Strontium-90 Concentrations with Depth Along the 100-N Area Shoreline

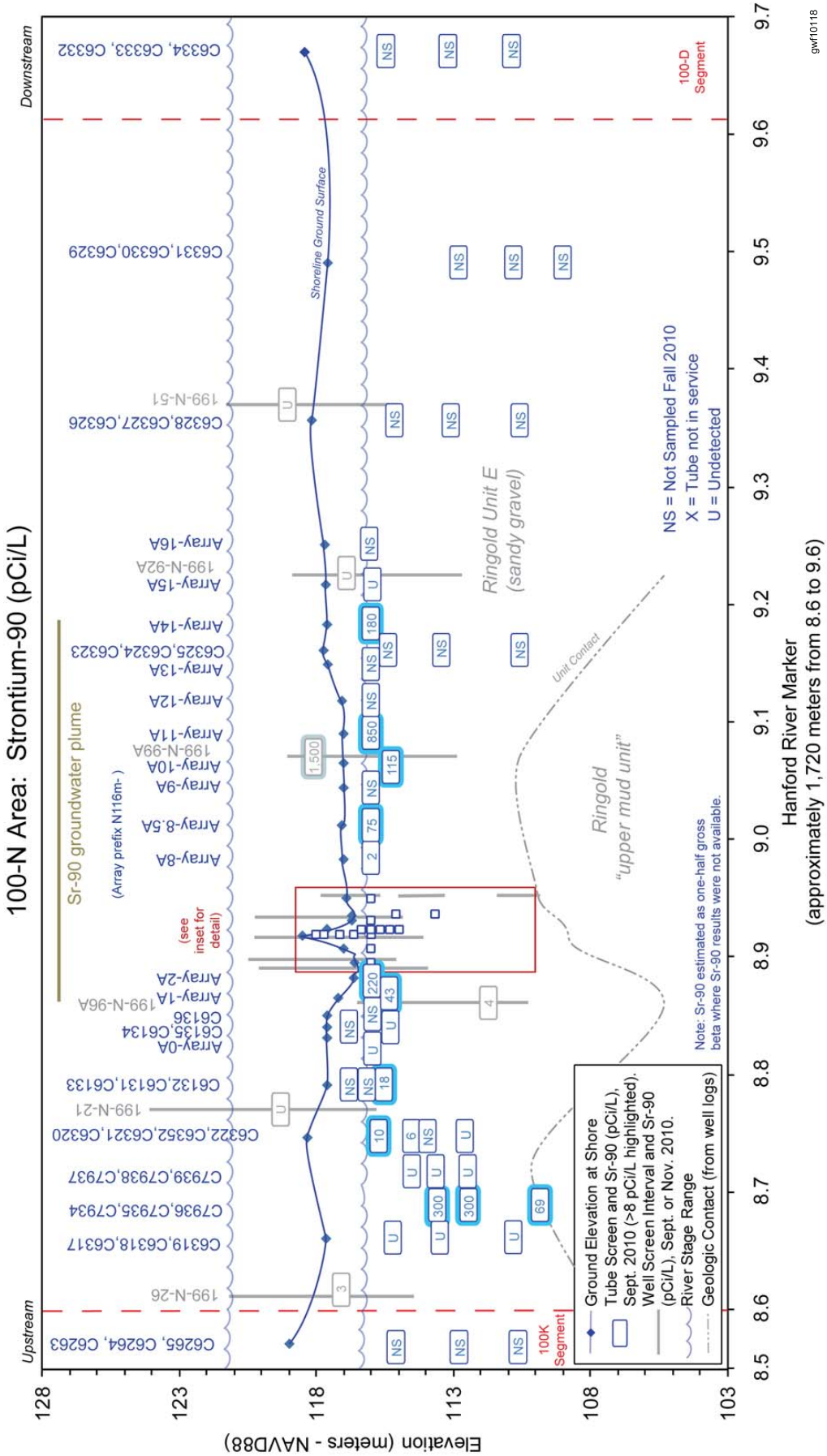


Figure 6-9. Cross Section of Wells and Aquifer Tubes and Strontium-90 Concentrations with Depth Along the Apatite Permeable Reactive Barrier, 100-N Area Shoreline

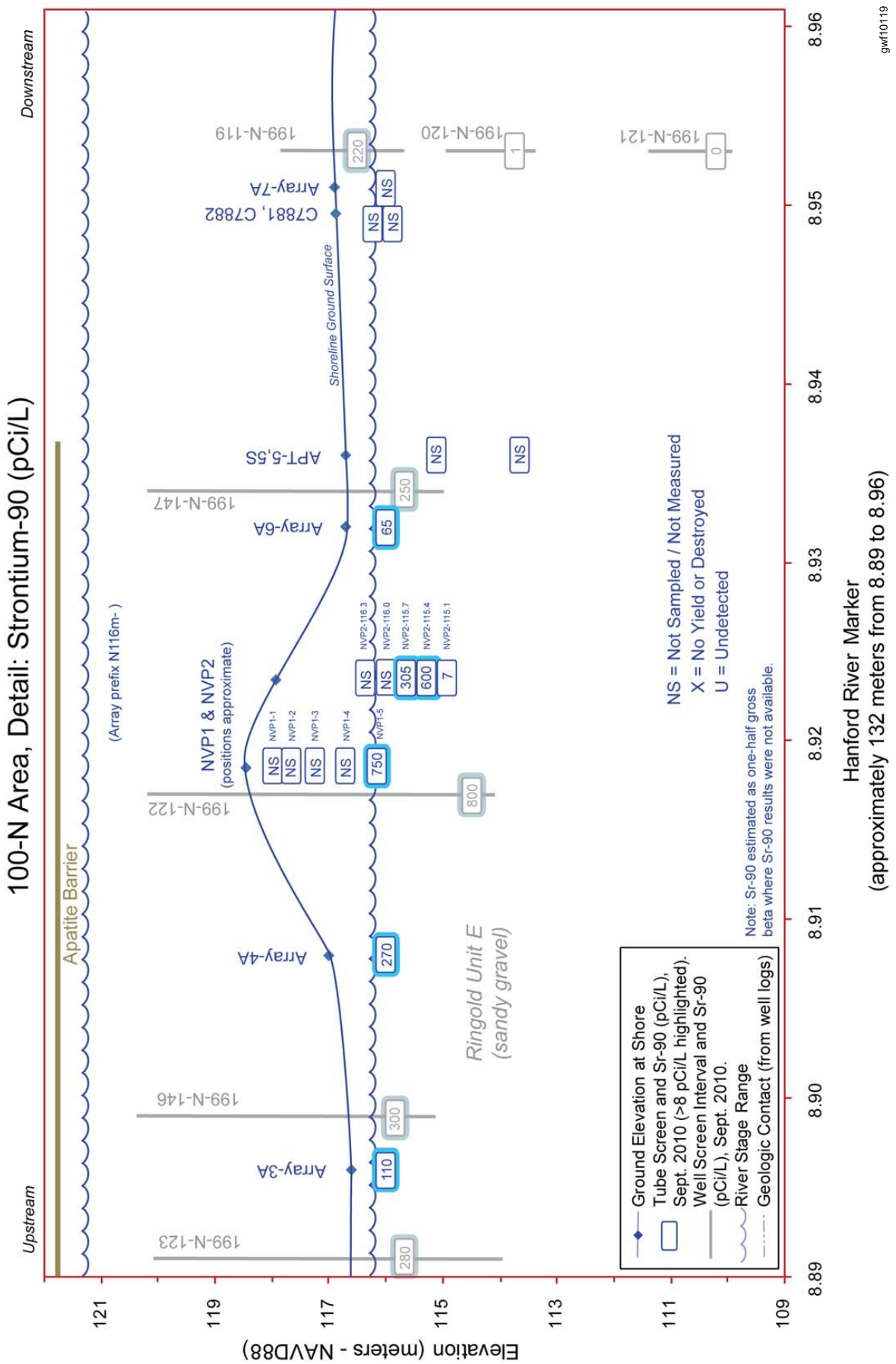


Figure 6-10. Strontium-90 Vertical Profile in the NVP2-Series Aquifer Tubes

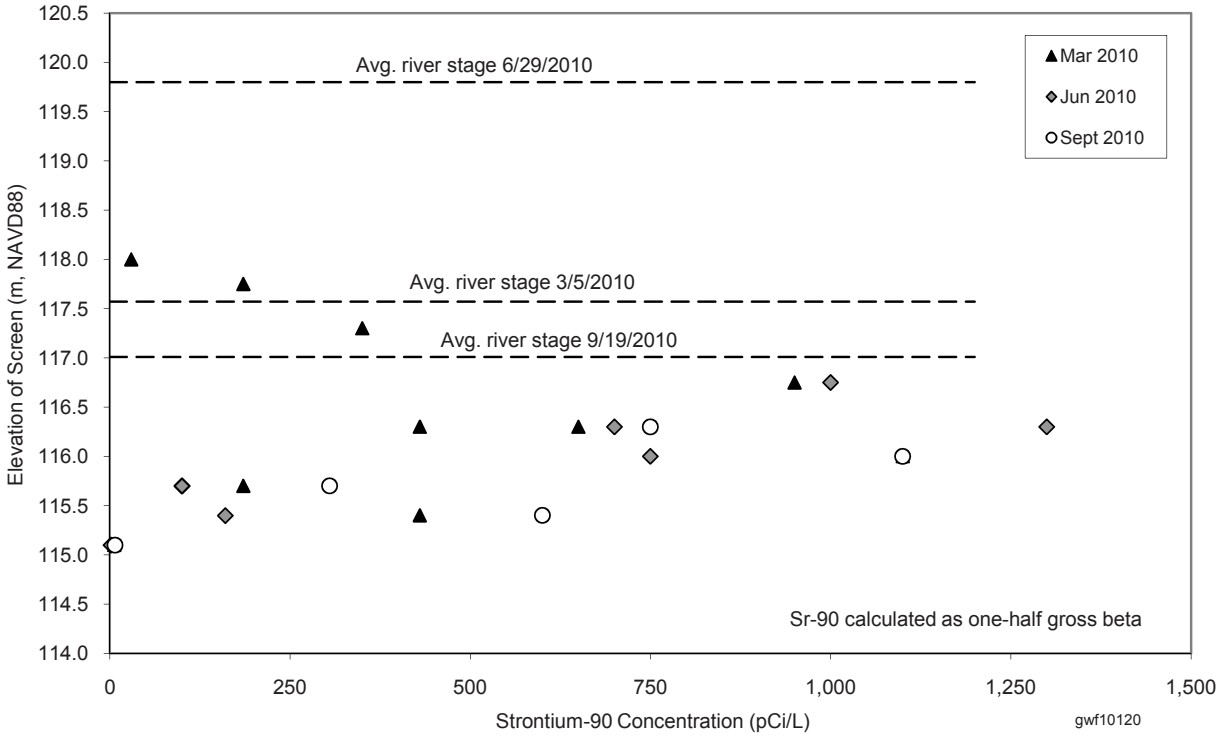


Figure 6-11. Strontium-90 Concentration in Aquifer Tubes in 100-N Area

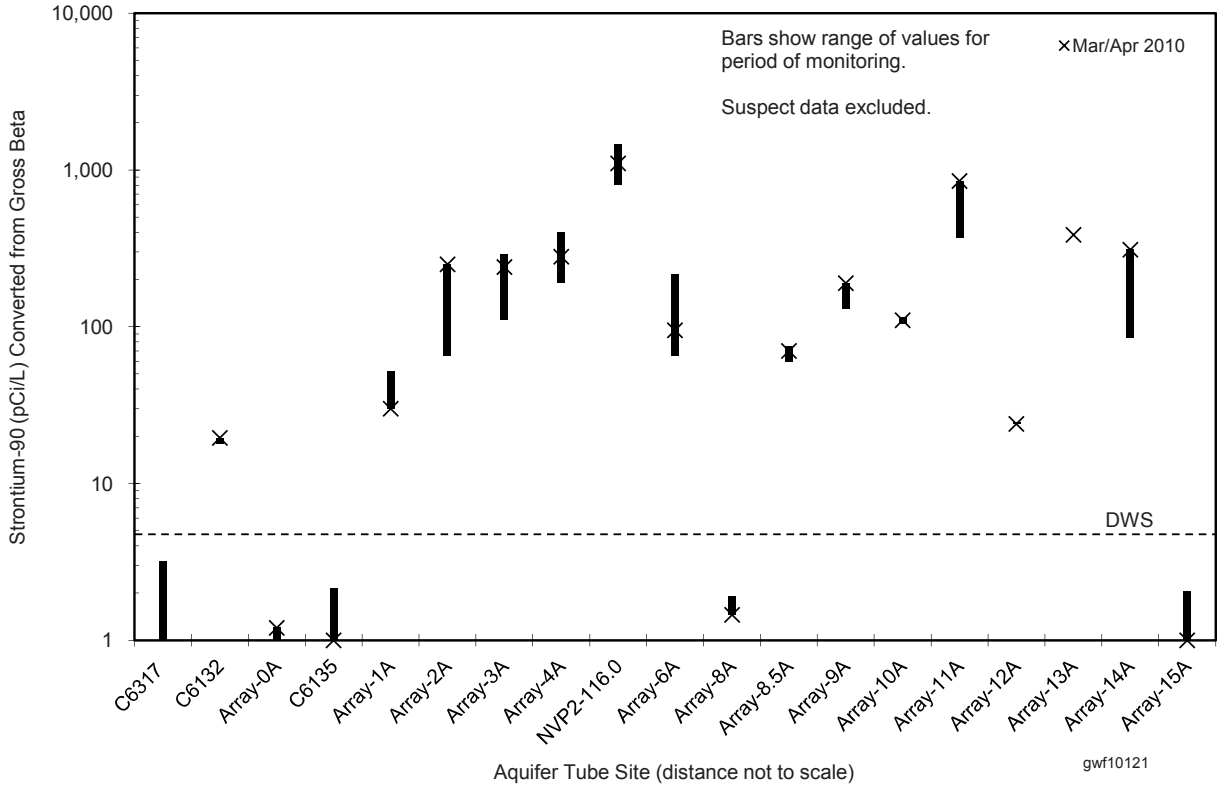
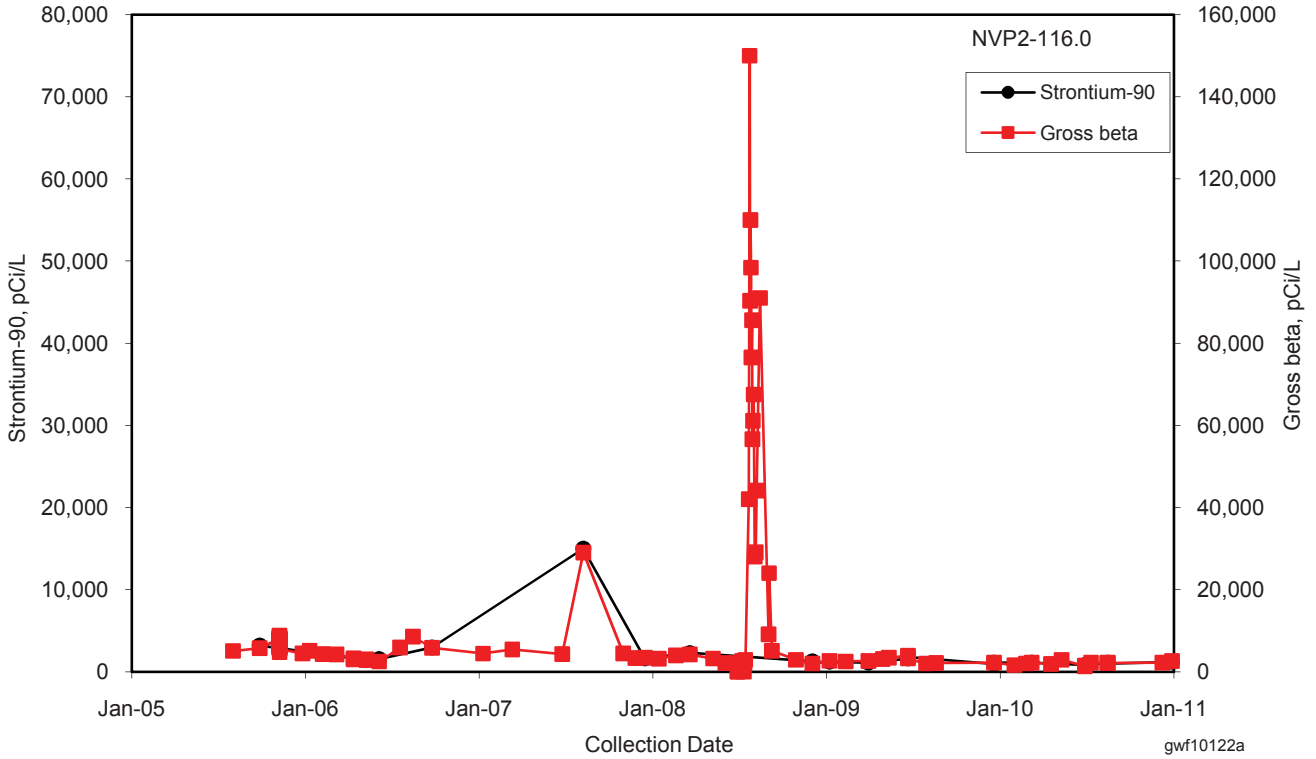


Figure 6-12. Strontium-90 and Gross Beta Concentrations in Aquifer Tube NVP2-116.0m



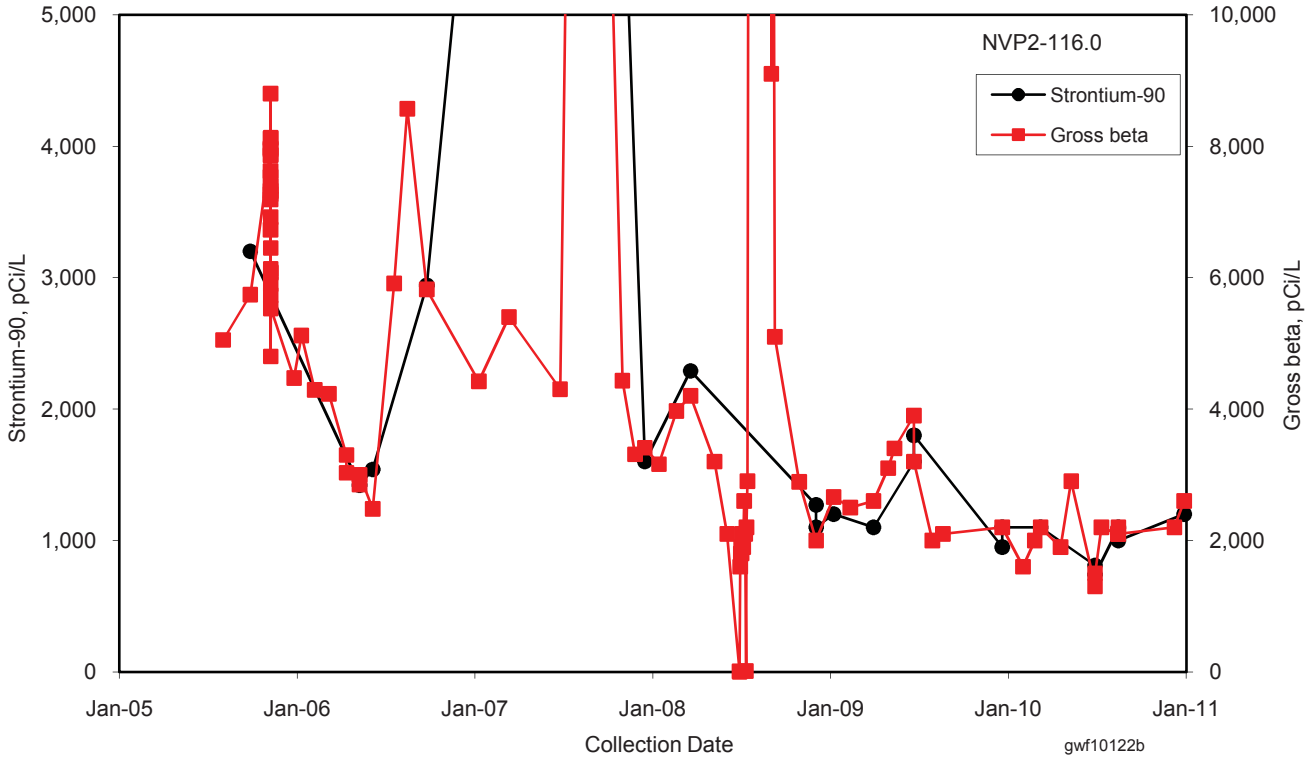


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Figure 6-13. Average Tritium Concentrations in the 100-N Area, Upper Unconfined Aquifer

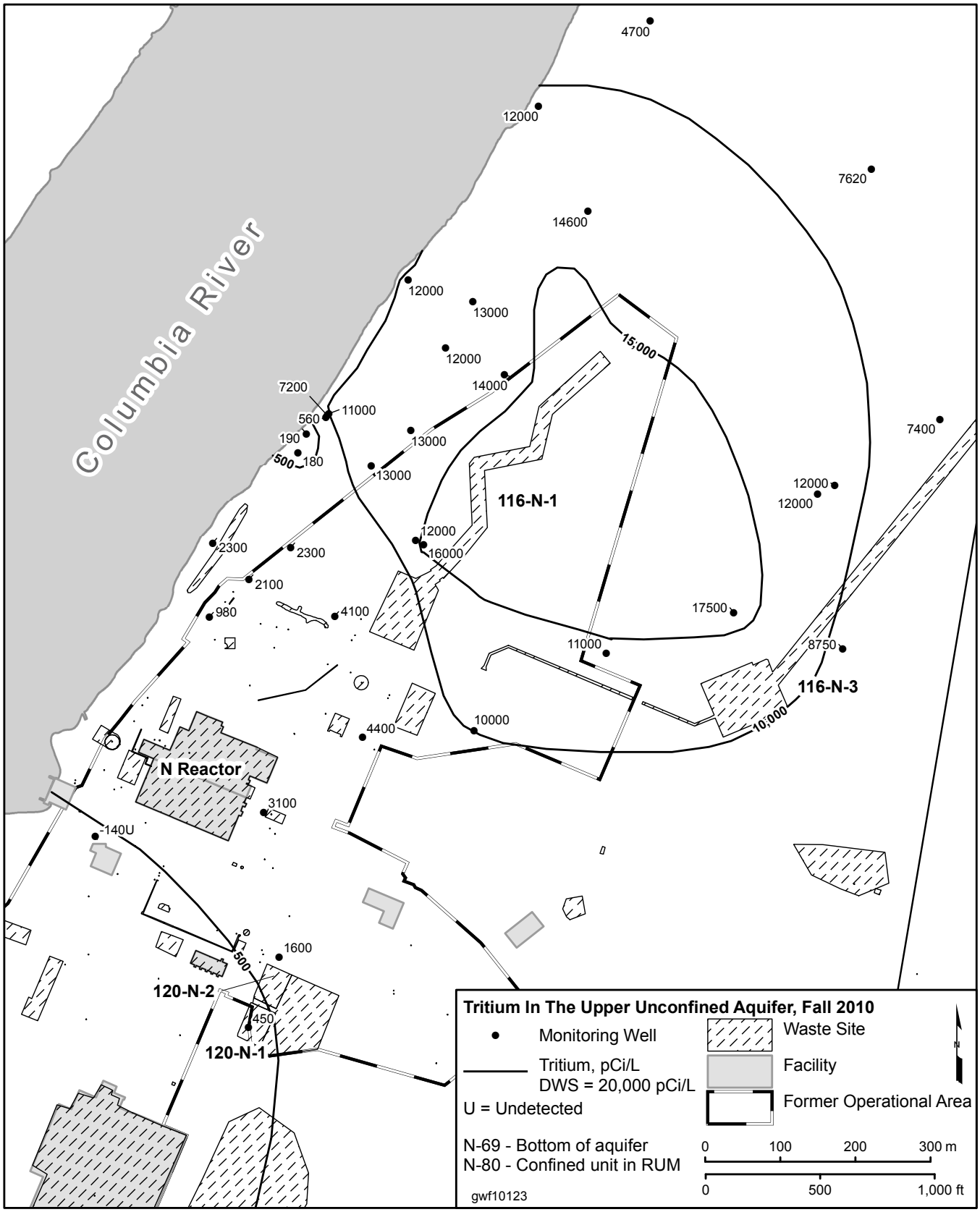

Figure 6-14. Tritium Concentrations near 116-N-1 and 116-N-3 Liquid Waste Disposal Facilities

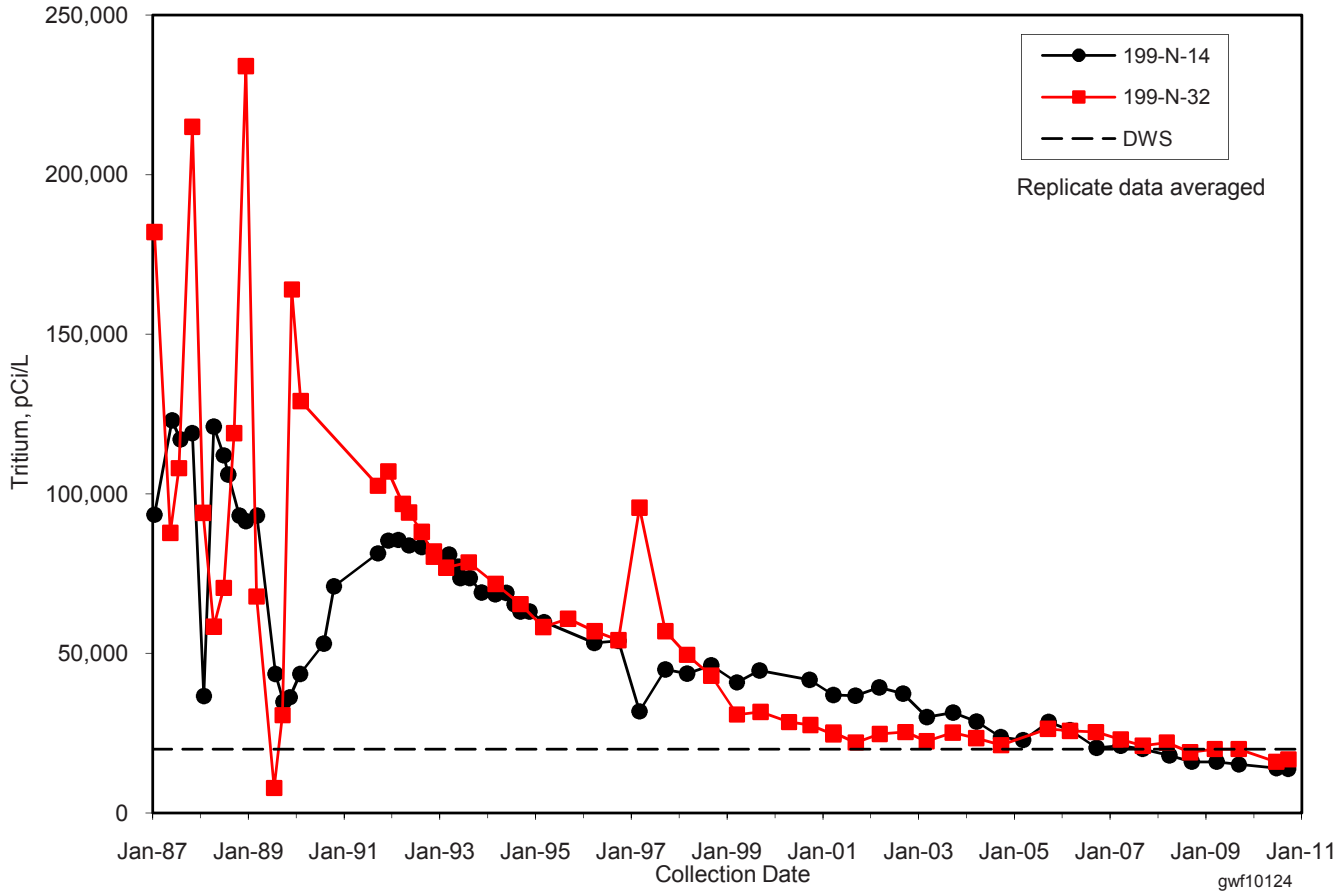

Figure 6-15. Average Nitrate Concentrations in the 100-N Area, Upper Unconfined Aquifer

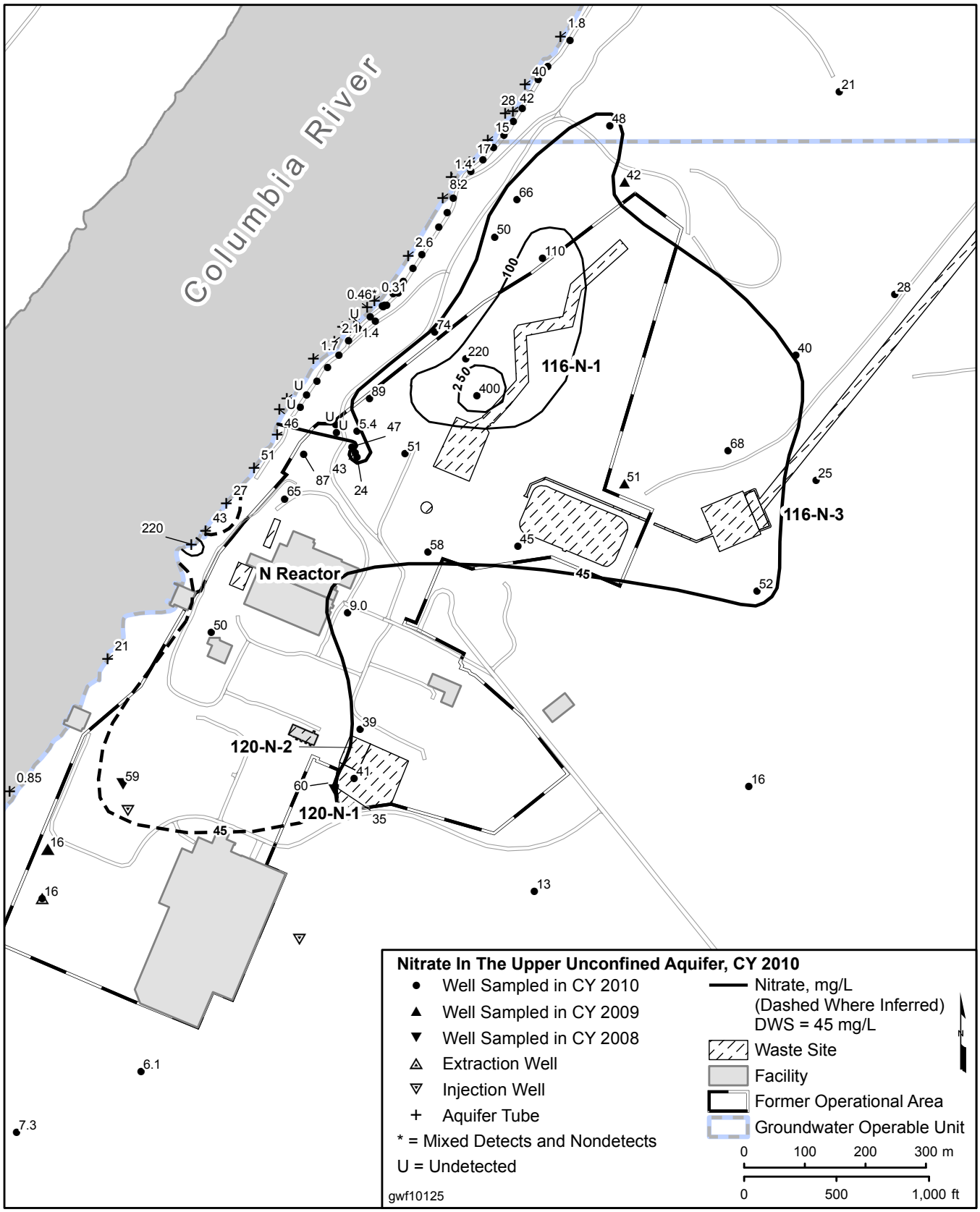

Figure 6-16. Nitrate Concentrations for the 116-N-1 Liquid Waste Disposal Facility

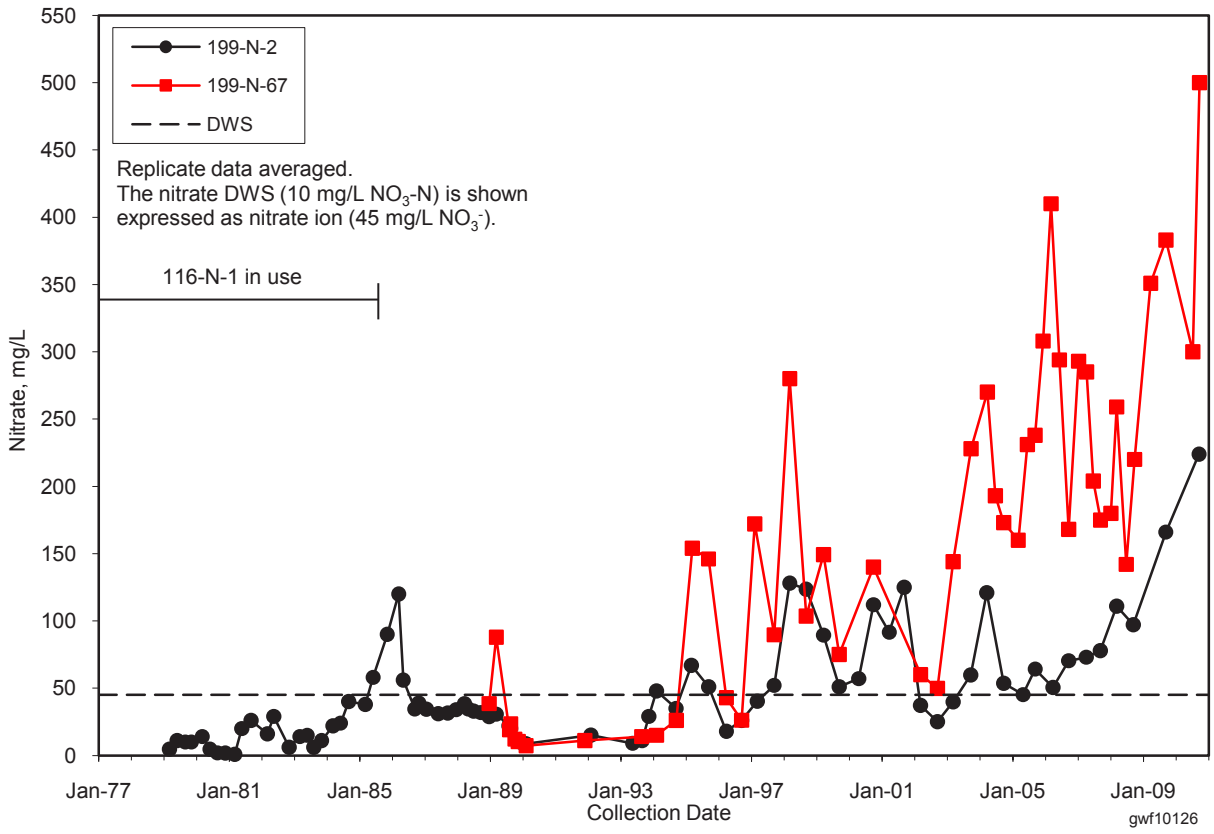

Figure 6-17. Nitrate Concentrations for the 116-N-3 Liquid Waste Disposal Facility

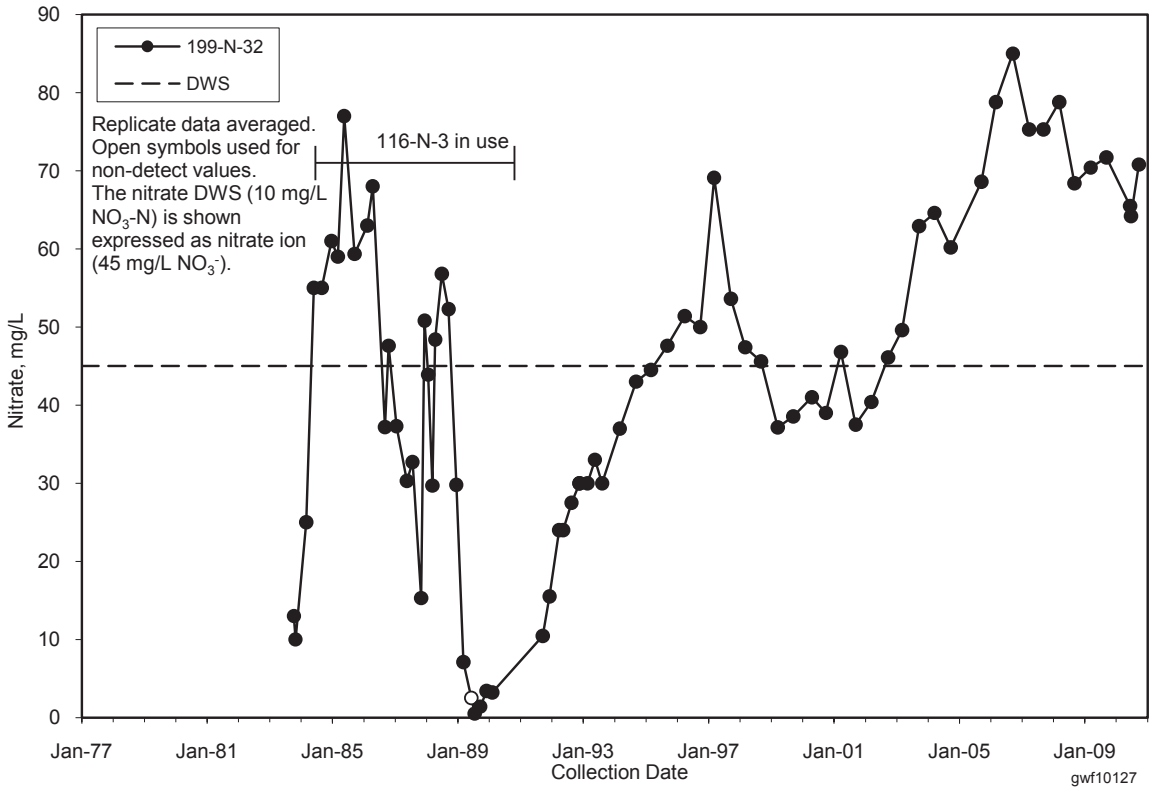

Figure 6-18. Nitrate Concentrations for the 120-N-1 Percolation Pond

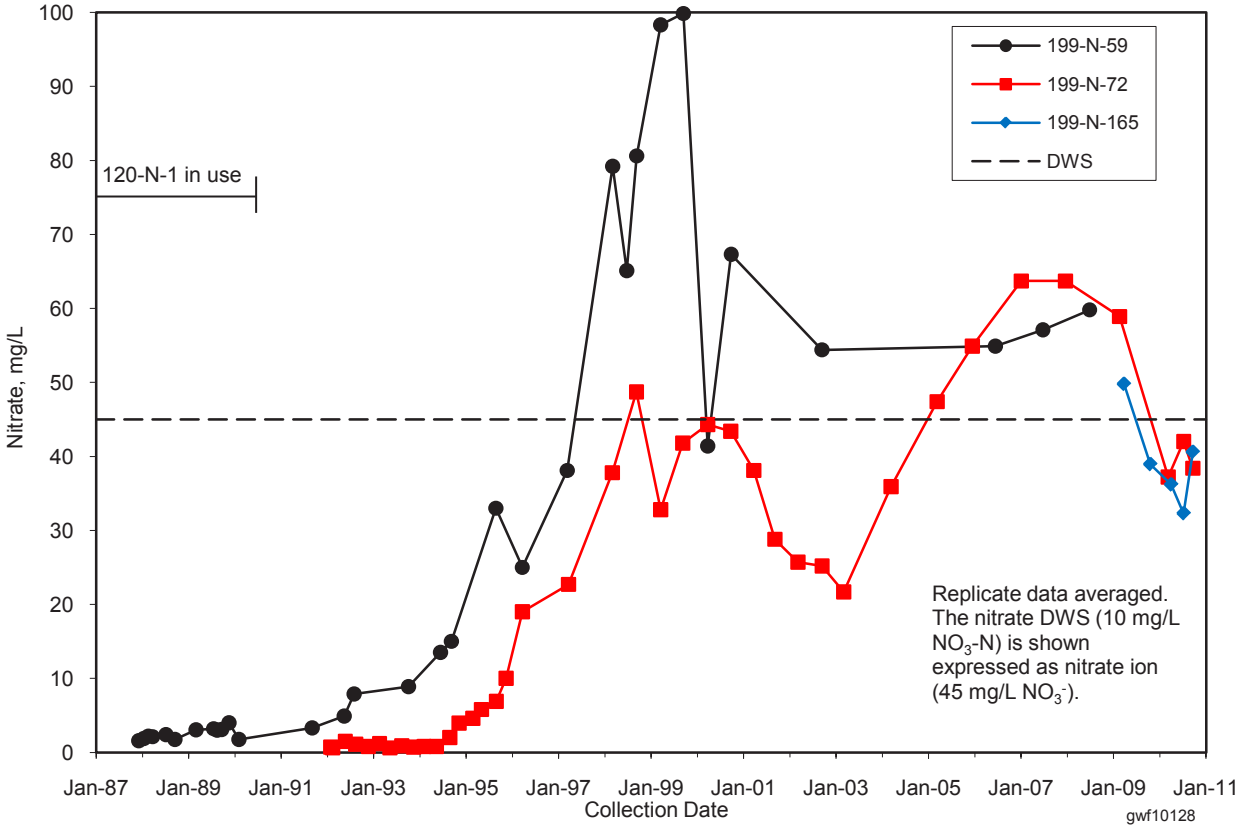

Figure 6-19. Total Petroleum Hydrocarbon-Diesel Range Concentrations in 100-N Area, April Through December 2010, Upper Unconfined Aquifer

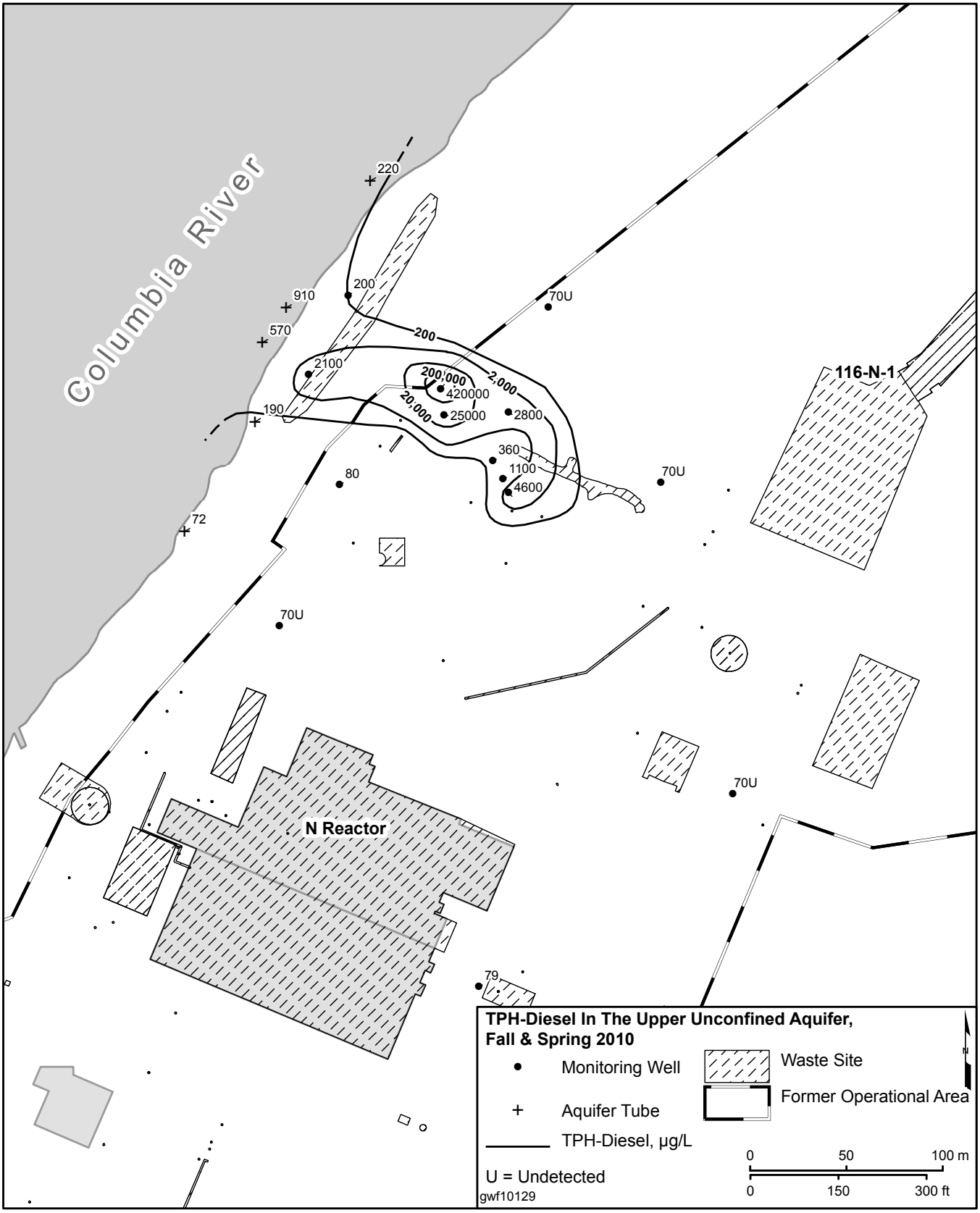

Figure 6-20. Sulfate Concentrations in 100-N Area, Upper Unconfined Aquifer

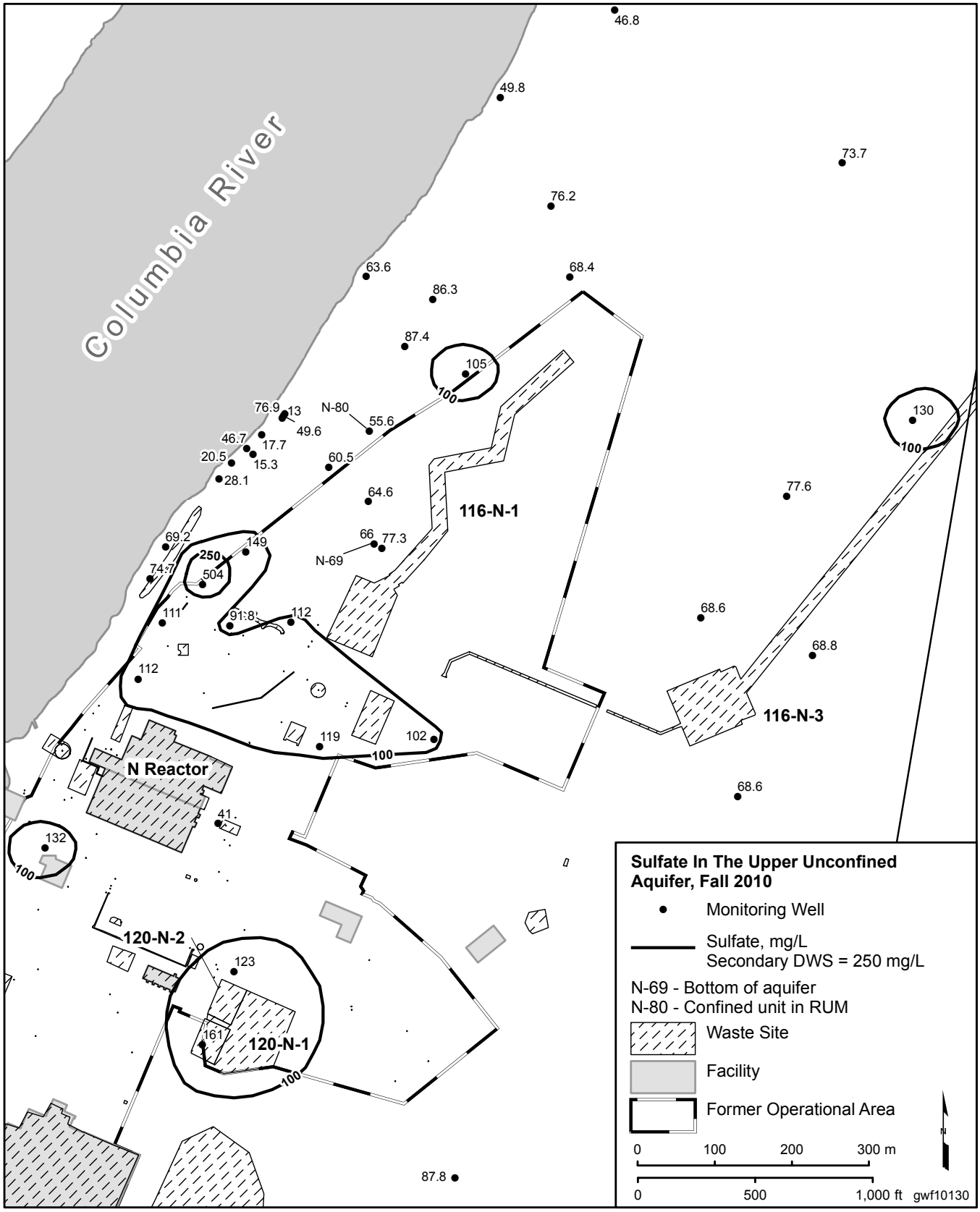

Figure 6-21. Manganese and Iron Detections in 100-N Area, Upper Portion of Unconfined Aquifer

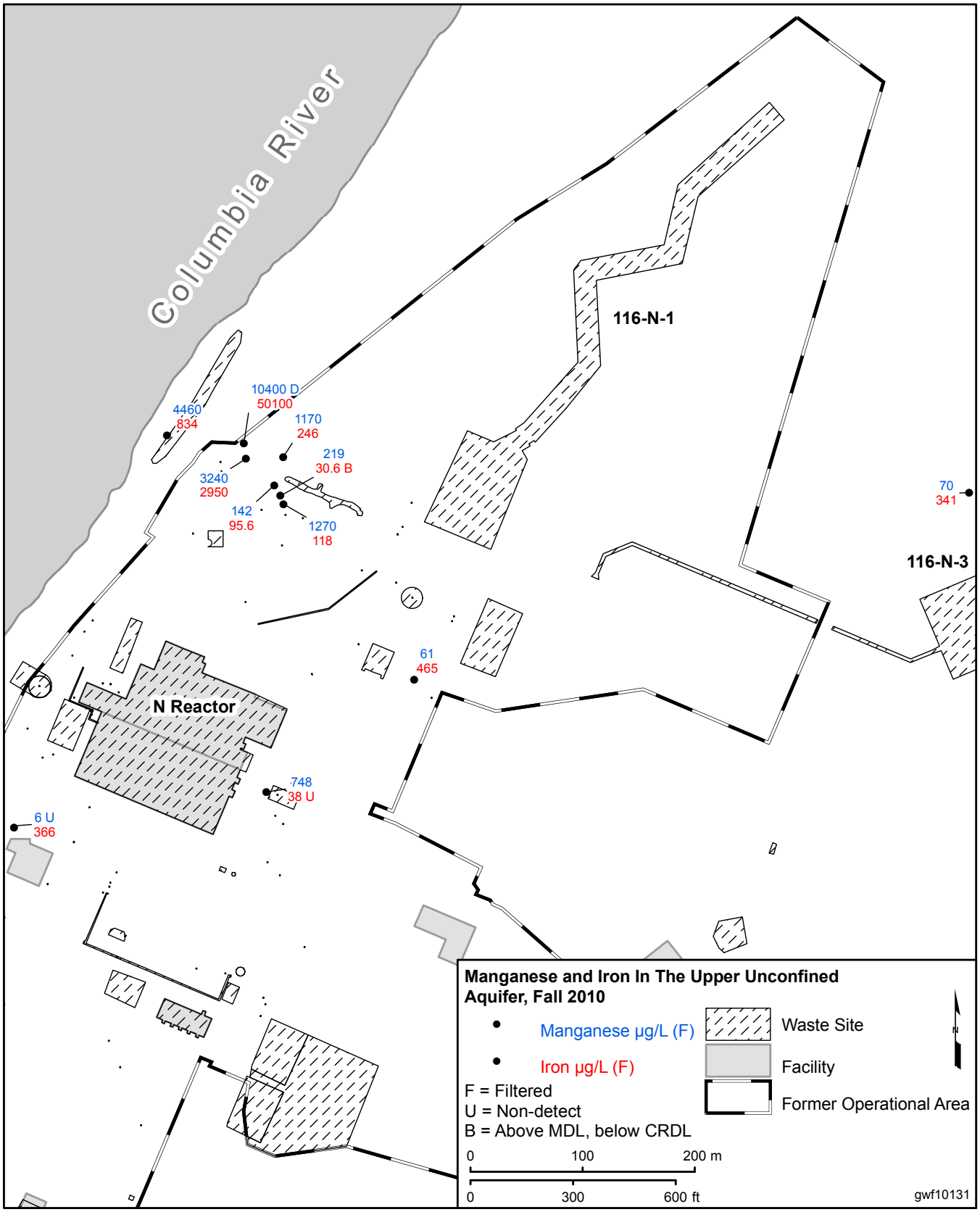

Figure 6-22. Filtered Total Chromium and Sulfate Trend Plot for Well 199-N-80

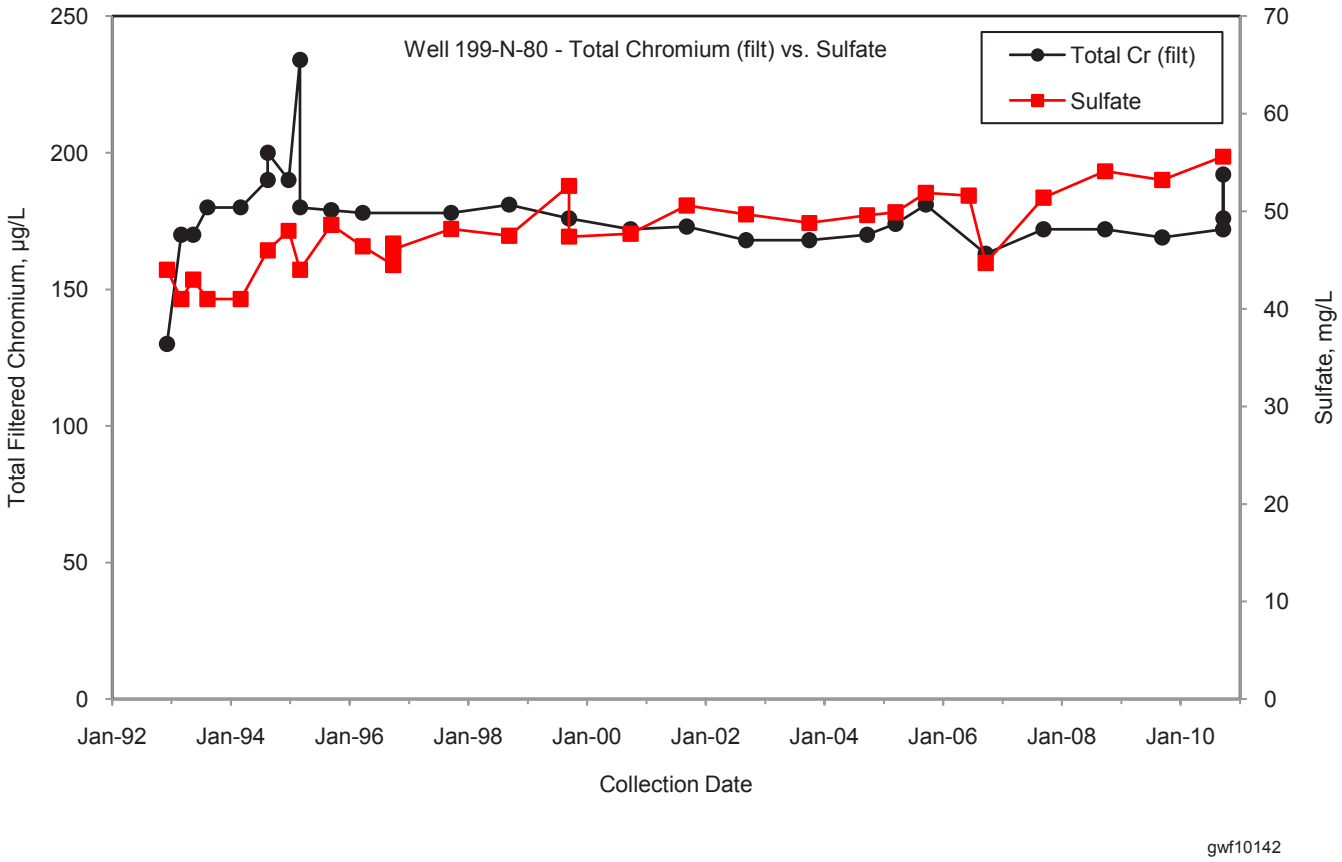

Figure 6-23. Chromium Detections in 100-N Area, Upper Portion of Unconfined Aquifer

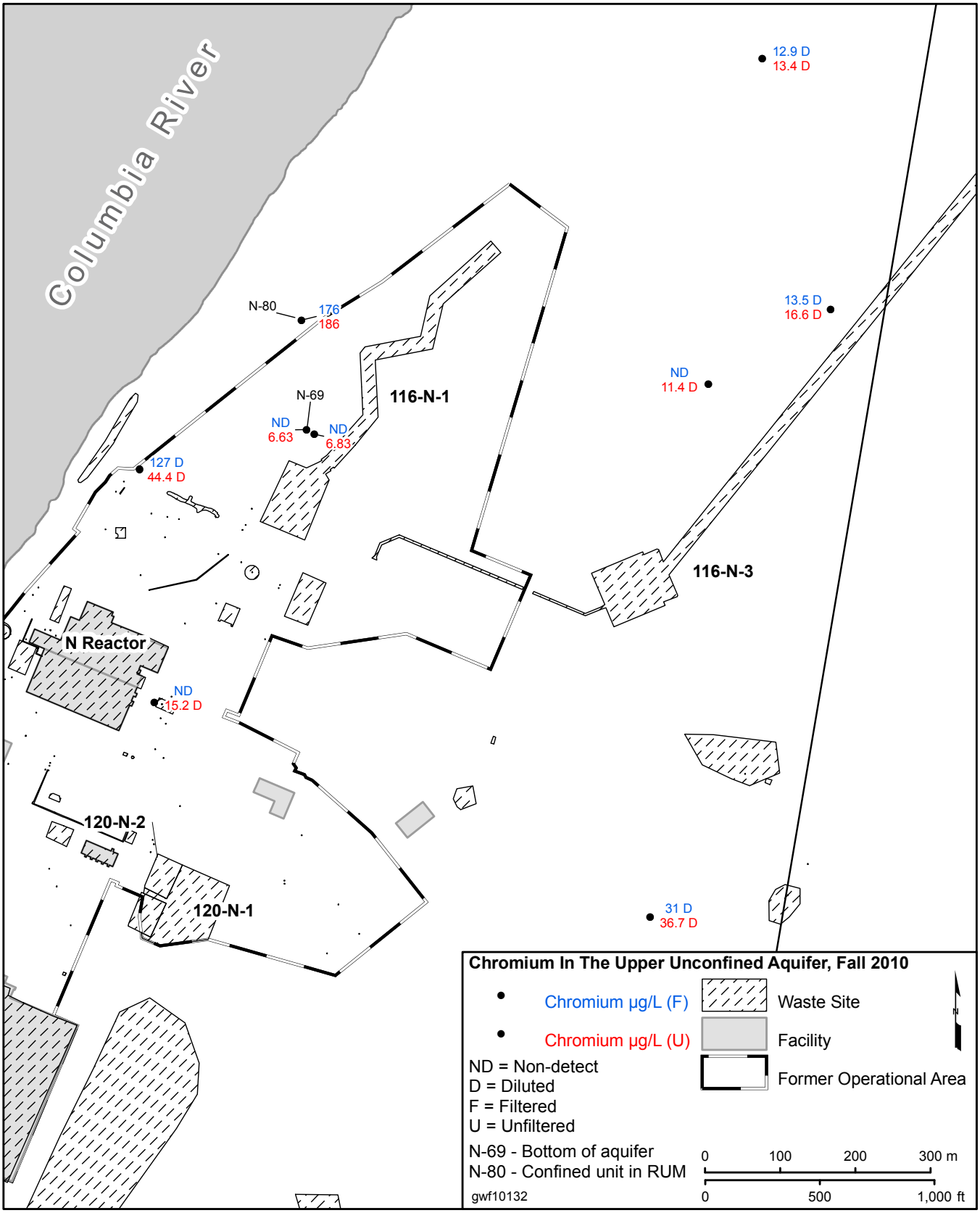

Figure 6-24. Gross Beta Trend Plot for Middle Upper Section of Apatite Permeable Reactive Barrier

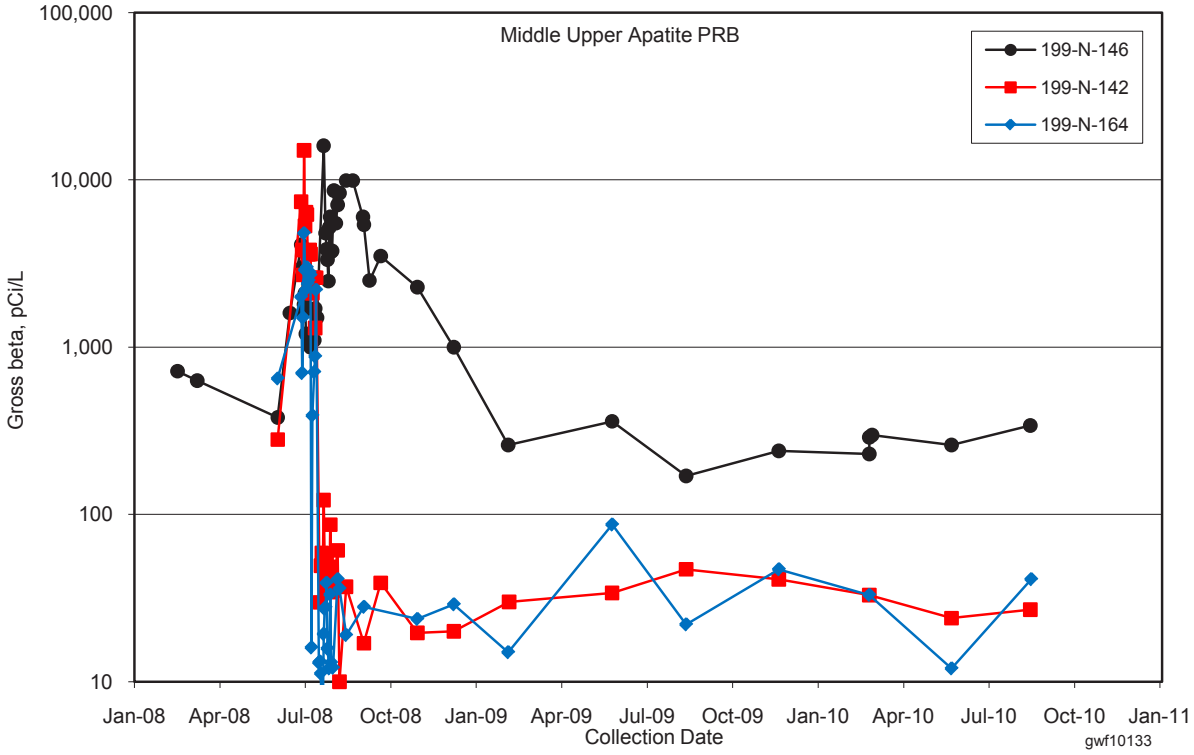

Figure 6-25. Gross Beta Trend Plot for Middle Lower Section of Apatite Permeable Reactive Barrier

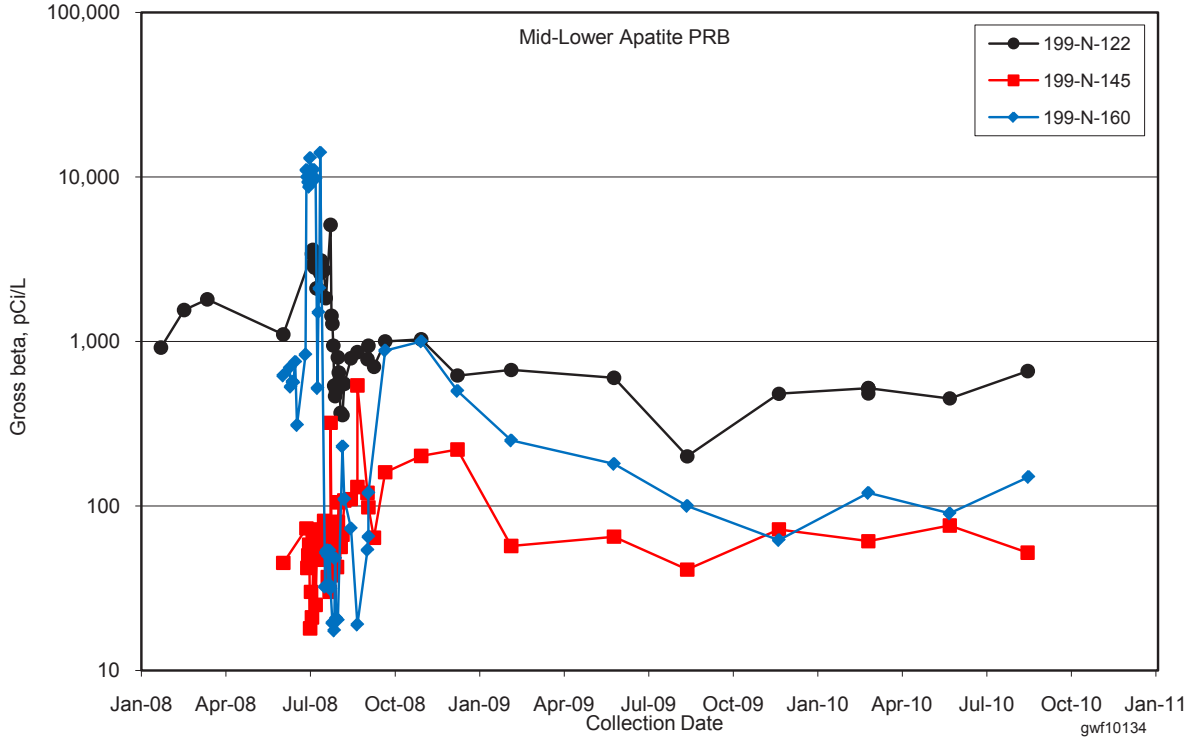

Figure 6-26. Gross Beta Trend Plot for the Highest Strontium-90 Concentration Portion of Apatite Permeable Reactive Barrier

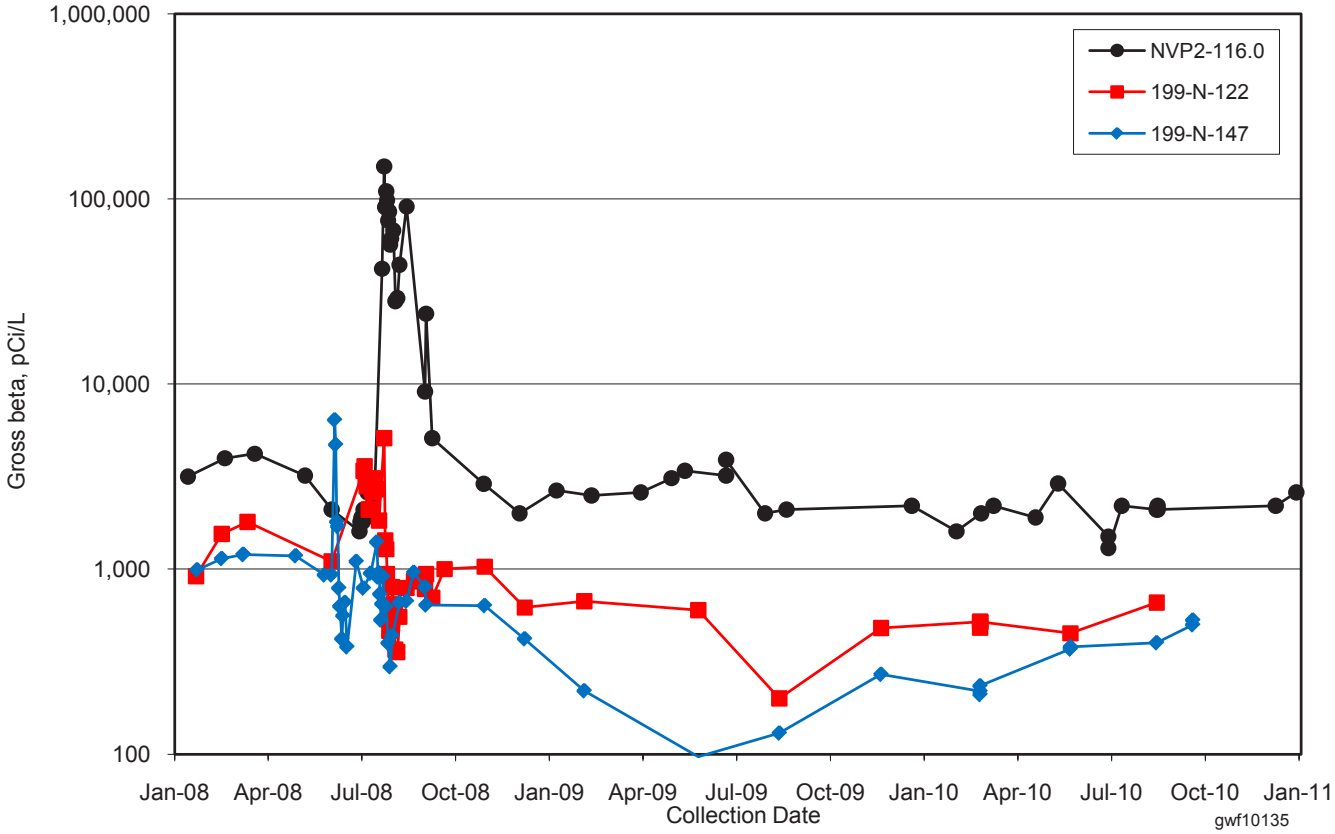

Figure 6-27. Location of Core Wells at the Pilot Test #2 Site, Apatite Permeable Reactive Barrier

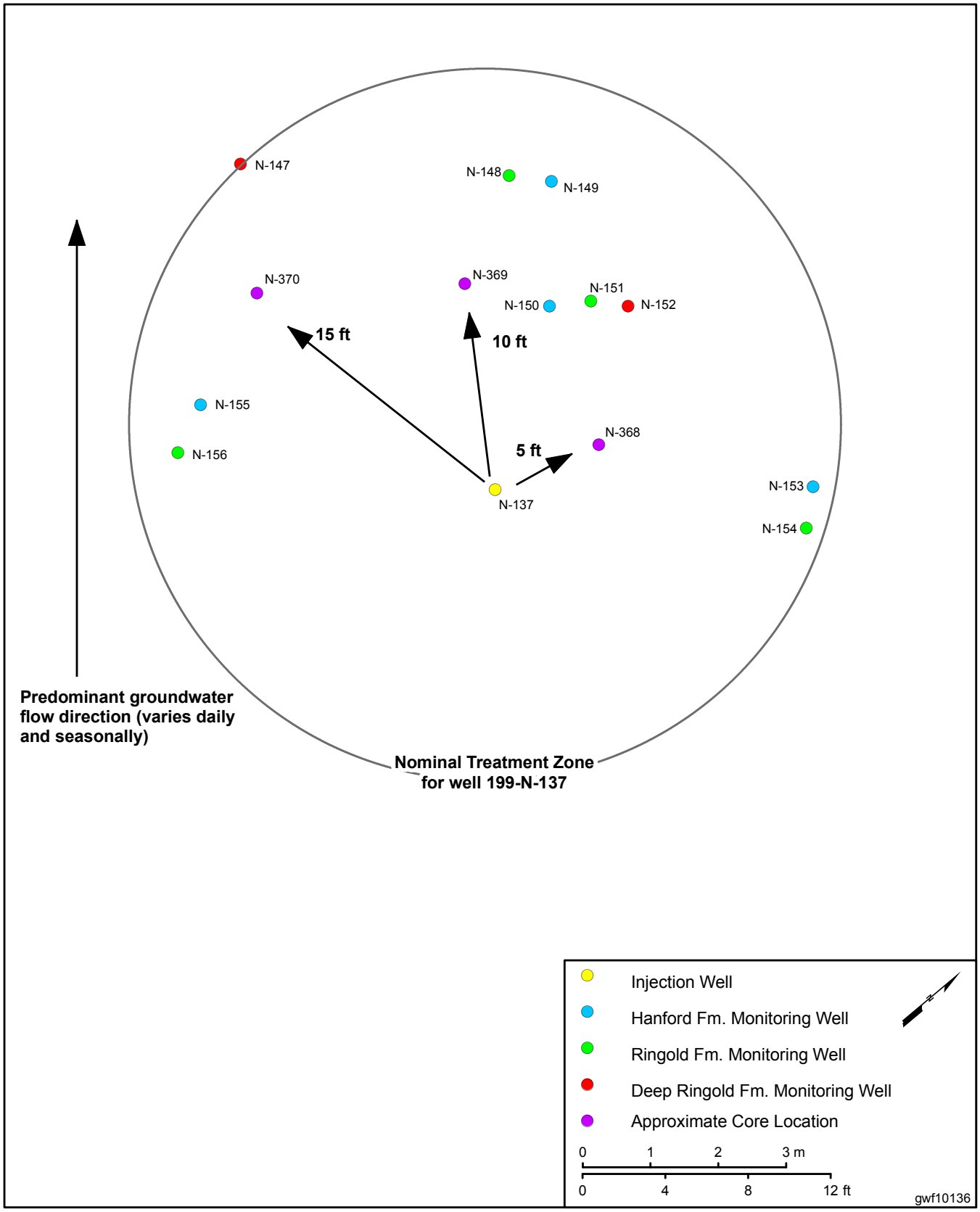

Figure 6-28. Location of Jet Injection Test Plots and Core Wells Along 100-N Area Shoreline

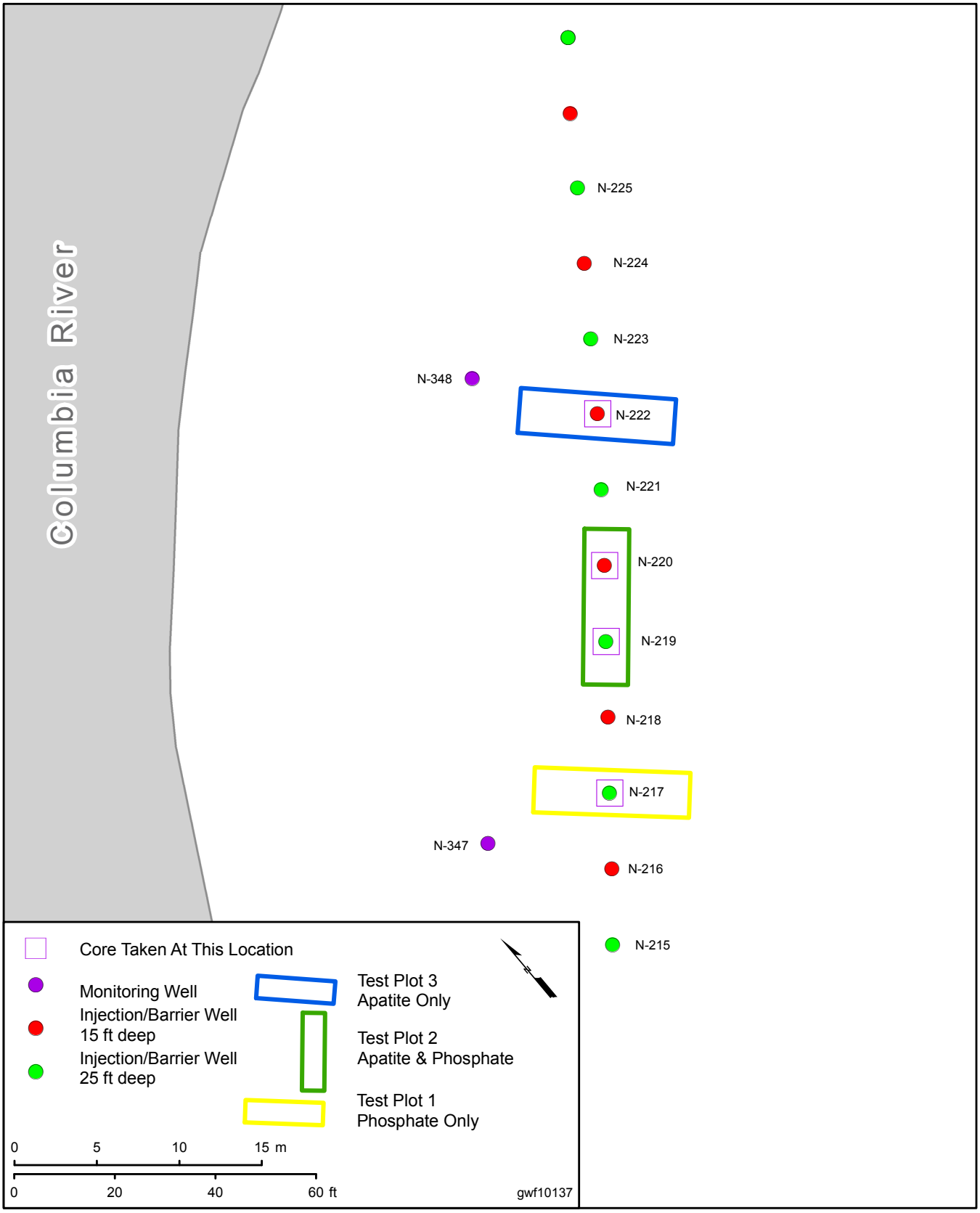

Figure 6-29. 100-N Area Follow-Up River Porewater Sampling Locations, November/December 2010

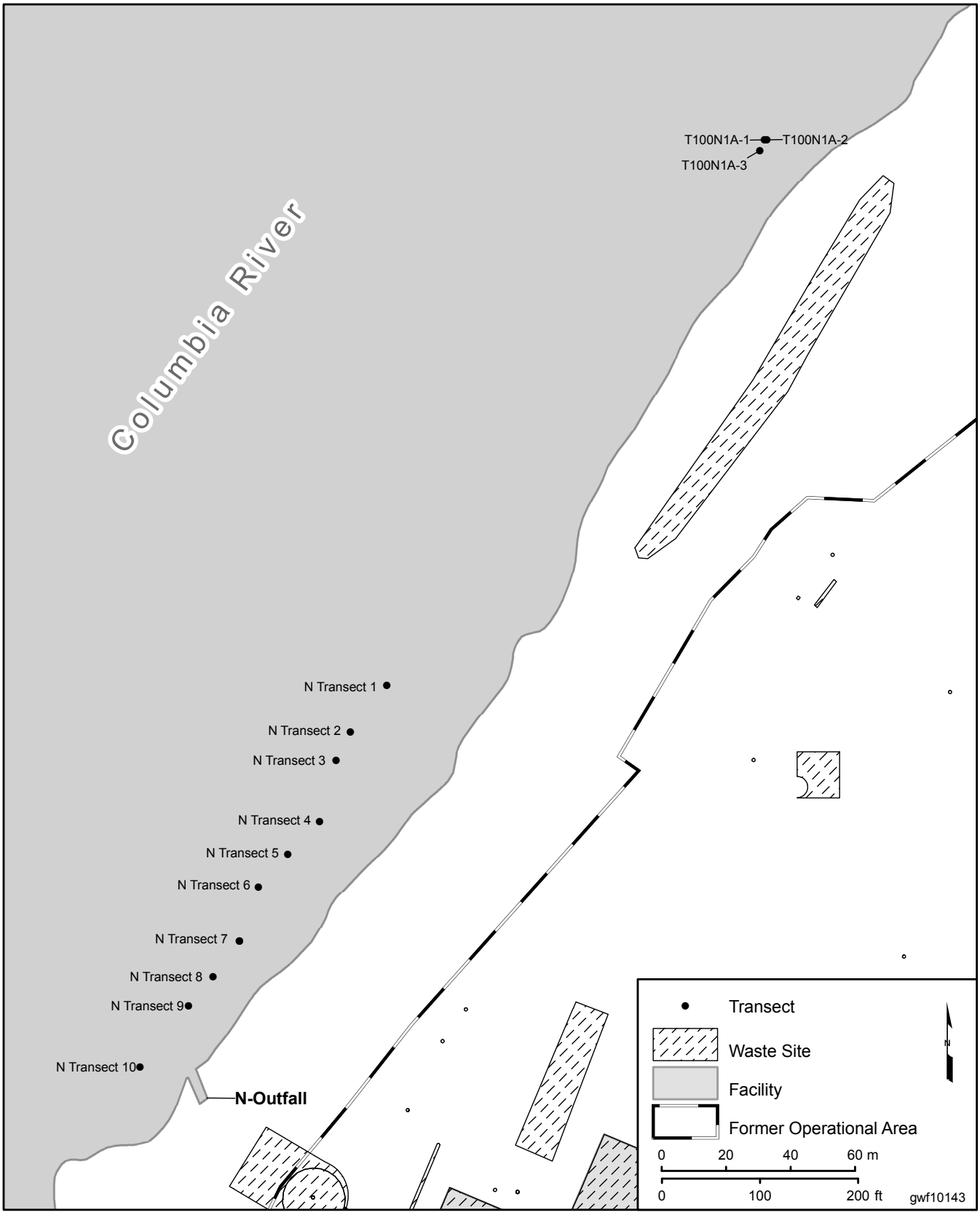

Figure 6-30. Potential Contaminant Source Pathways for 100-N Outfall Structure Strontium-90

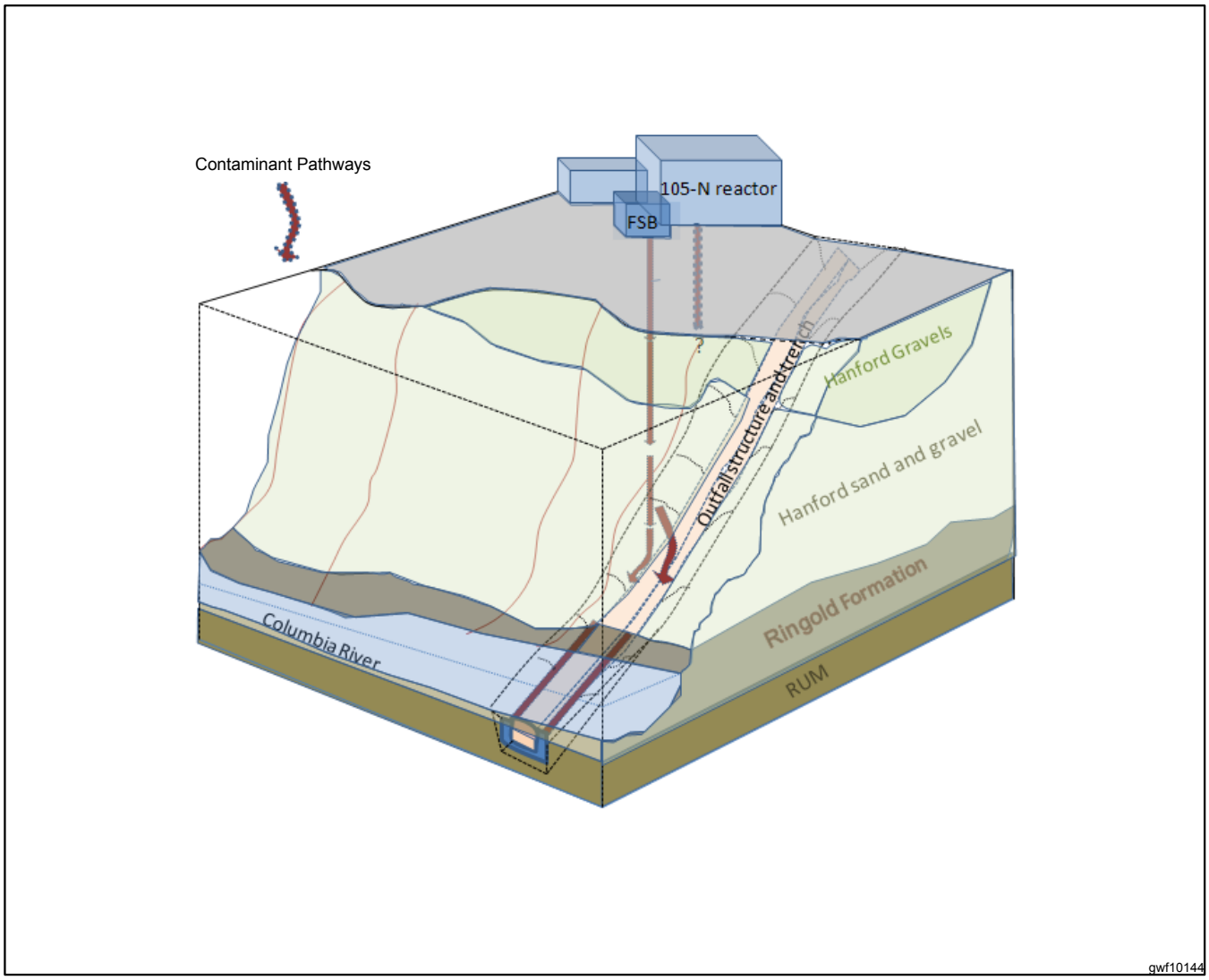

Figure 6-31. Remedial Investigation/Feasibility Study Aquifer Tube Sampling Locations

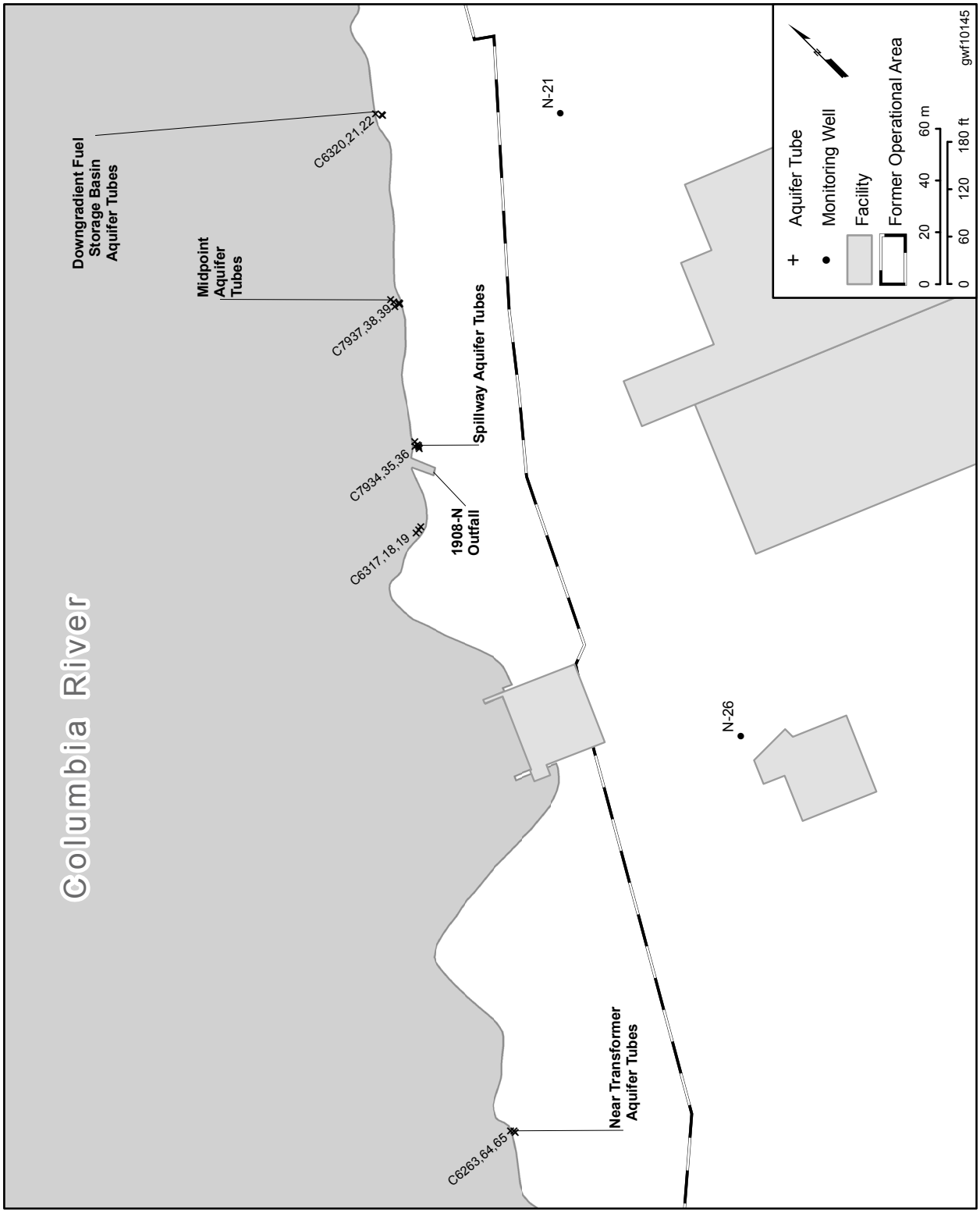
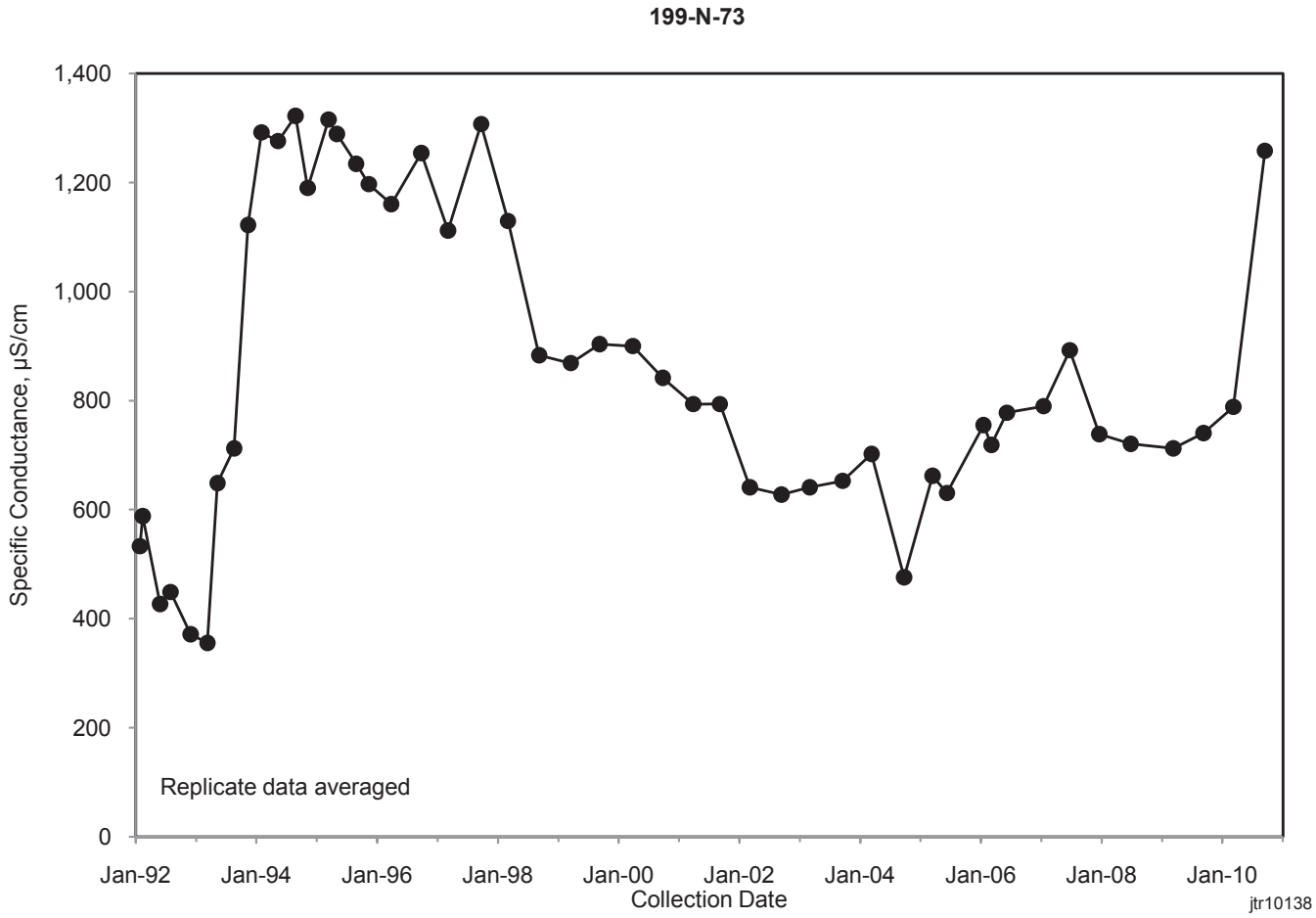
Figure 6-32. Specific Conductance in Well 199-N-73