6 100-NR

6.1 Overview

The 100-NR groundwater interest area encompasses the 100-NR-2 OU and the surrounding area, located adjacent to the Columbia River (Figure 6-1). Among the Hanford Site plutonium-production reactors, the design of N Reactor was unique. The N Reactor, which operated in the 100-N Area from 1963 to 1987, was a dual-purpose reactor that produced plutonium for defense purposes and steam for commercial electrical power generation. Groundwater contamination in 100-NR is primarily associated with waste formerly produced by the reactor and associated processes. Approximately 92 percent of the waste sites in 100-NR have been remediated or classified as not requiring remediation under an interim action ROD. A summary of 100-NR, including key contaminants, is shown in Table 6-1. Additional details about 100-NR history and waste sites are provided in Section 1.3 of DOE/RL-2012-15, Draft A. Section 1.3 of this document provides details about plume mapping, including descriptions of terms in figure legends (e.g., Type 1 Control Point).

Strontium-90 is the principal groundwater contaminant. Other contaminants include nitrate, total petroleum hydrocarbon (TPH) diesel, hexavalent chromium, and tritium. Strontium-90 and TPH-diesel are being remediated under a CERCLA interim action ROD (EPA/ROD/R10-99/112, as amended). An apatite permeable reactive barrier (PRB) was installed between 2006 and 2011 to enhance attenuation of the strontium-90 in groundwater moving toward the Columbia River. TPH-diesel free product is being removed from groundwater in one well (199-N-18). A bioventing system began full-scale operations in 2012 to remediate TPH-diesel in the deep vadose zone. Groundwater is monitored at four waste sites to meet requirements of RCRA and WAC 173-303. Figure 6-2 illustrates how estimates of plume areas in the 100-NR groundwater interest area have changed since 2003.

The vadose zone in 100-NR is 0 to 23 m (76 ft) thick and is composed of gravels and sands of the Hanford formation and upper Ringold Formation unit E (Figure 6-3). The unconfined aquifer is approximately 6.5 to 14 m (21 to 46 ft) thick and primarily located within the Ringold Formation unit E. When the Columbia River stage is high, the water table can rise into the Hanford formation in wells near the shoreline. The RUM forms the base of the unconfined aquifer.

Groundwater in 100-NR generally flows northwest toward the Columbia River. As shown in Figure 6-1, the magnitude of the difference in groundwater hydraulic head across 100-NR in March 2014 was about 2 m (6.6 ft). Groundwater flow was influenced in 2014 by groundwater extraction and injection for the KX P&T remediation system located in the southwest portion of 100-NR. A groundwater mound approximately 1 m (3.3 ft) high surrounding KX injection Wells 199-K-159, 199-K-160, and 199-K-164 creates local radial flow (Figure 6-1).

In 2014, the high river stage lasted from mid-March through early August (Figure 5-7). Water levels in Well 199-N-146 near the river rose approximately 2 m (6.6 ft) between late February and mid-April. There is a lag time of a few days between the rise in water levels in wells near the river and in wells further inland (e.g., between 199-N-146 and 199-N-2, 170 m [560 ft] inland from the river) (DOE/RL-2014-32). Changing river stage can influence groundwater elevations over 1 km (0.6 mi) inland from the river (Section 3.6 of DOE/RL-2012-15).

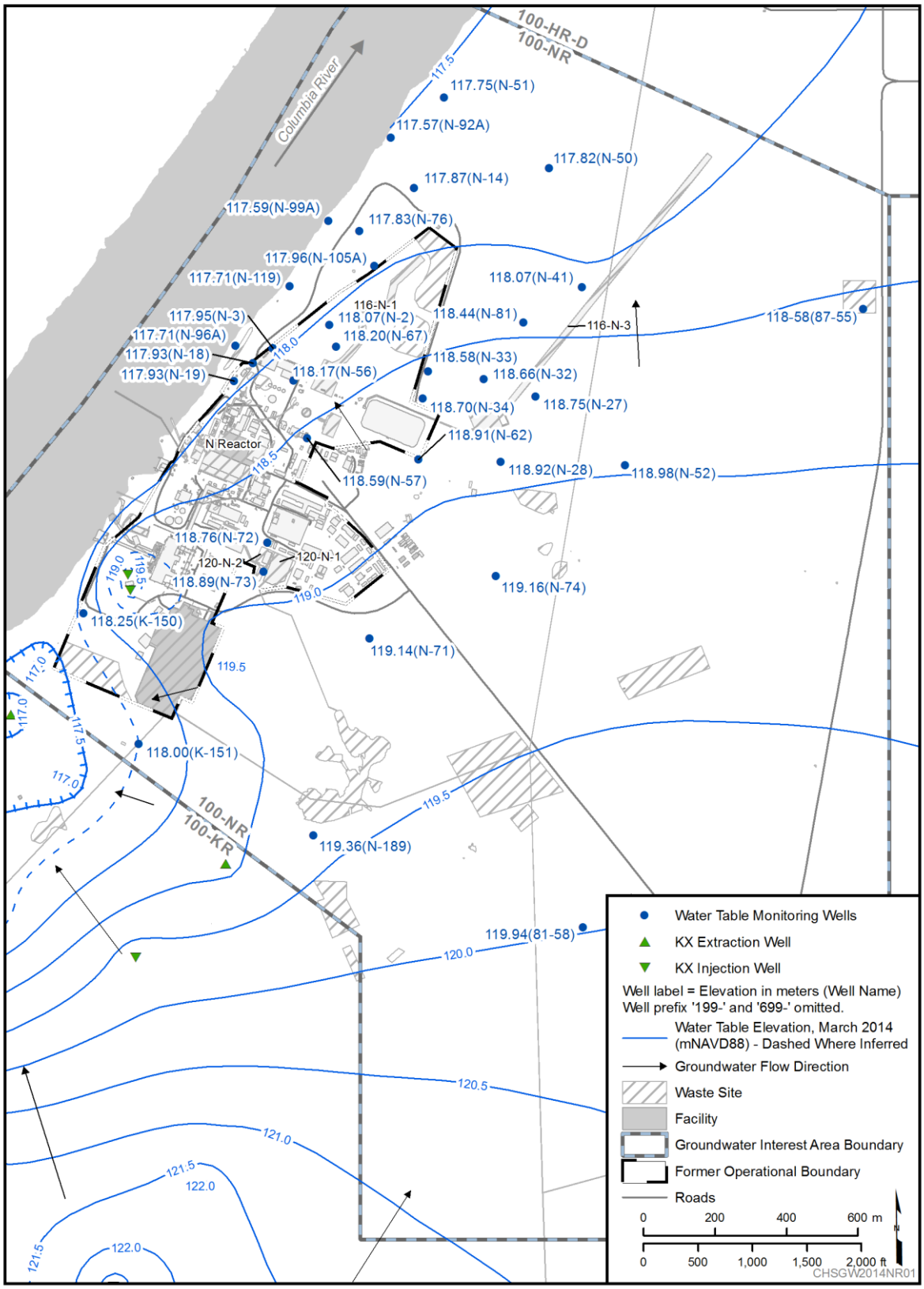

Figure 6-1. 100-NR Overview Map with Groundwater Flow

Table 6-1. 100-NR at a Glance

N Reactor operations: 1963–1987				
2014 Groundwater Monitoring				
Contaminants	**Water Quality Standard**	**Maximum Concentration**	**Plume Area[a]**	**Shoreline Impact (m)**
Strontium-90	8 pCi/L[b]	15,500 pCi/L (199-N-67)	0.61 km^2	600
Nitrate	45 mg/L[c]	186 mg/L (199-N-67)	0.53 km^2	100
Diesel (as total petroleum hydrocarbons)	0.5 mg/L[d]	18 mg/L (199-N-346)	0.01	60
Hexavalent Chromium	48 µg/L/ 10 µg/L[e]	193 µg/L (199-N-80)	0 / 0.81 km^2 [f]	0
Tritium	20,000 pCi/L[b]	761,000 (C7934)	NC[g]	NC[g]
Remediation				
Waste sites (interim action): 92 percent complete[h] Groundwater (interim action): • P&T: 1995-2006, 1.8 Ci strontium-90 removed • Apatite PRB: 2006-2014 Final ROD anticipated in 2015.				

a. Estimated area at a concentration greater than the listed water quality standard.

b. Drinking water standard

c. 45 mg/L as NO_3 is equivalent to the drinking water standard of 10 mg/L as N.

d. MTCA Method A for TPH-diesel range organics?

e. 48 µg/L MTCA standard, 10 µg/L surface water standard

f. Hexavalent chromium in 100-NR unconfined aquifer is believed to have origins in 100-KR

g. Plume area not calculated due to infrequent detection of tritium greater than 20,000 pCi/L. Shoreline impact not calculated since tritium only detected above 20,000 pCi/L in one aquifer tube cluster.

h. Sites with status of closed, interim closed, no action, not accepted, or rejected.

COCs = contaminants of concern
MTCA = Model Toxics Control Act
P&T = pump and treat
PRB = permeable reactive barrier
ROD = Record of Decision

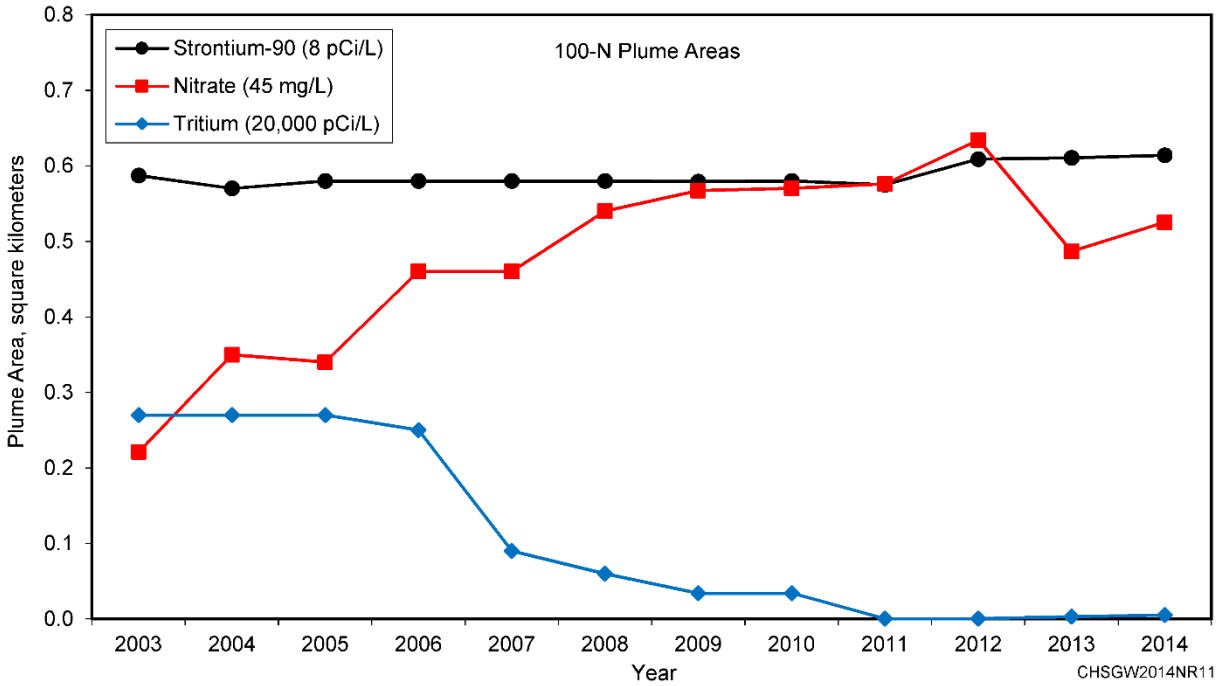

Figure 6-2. 100-NR Plume Areas

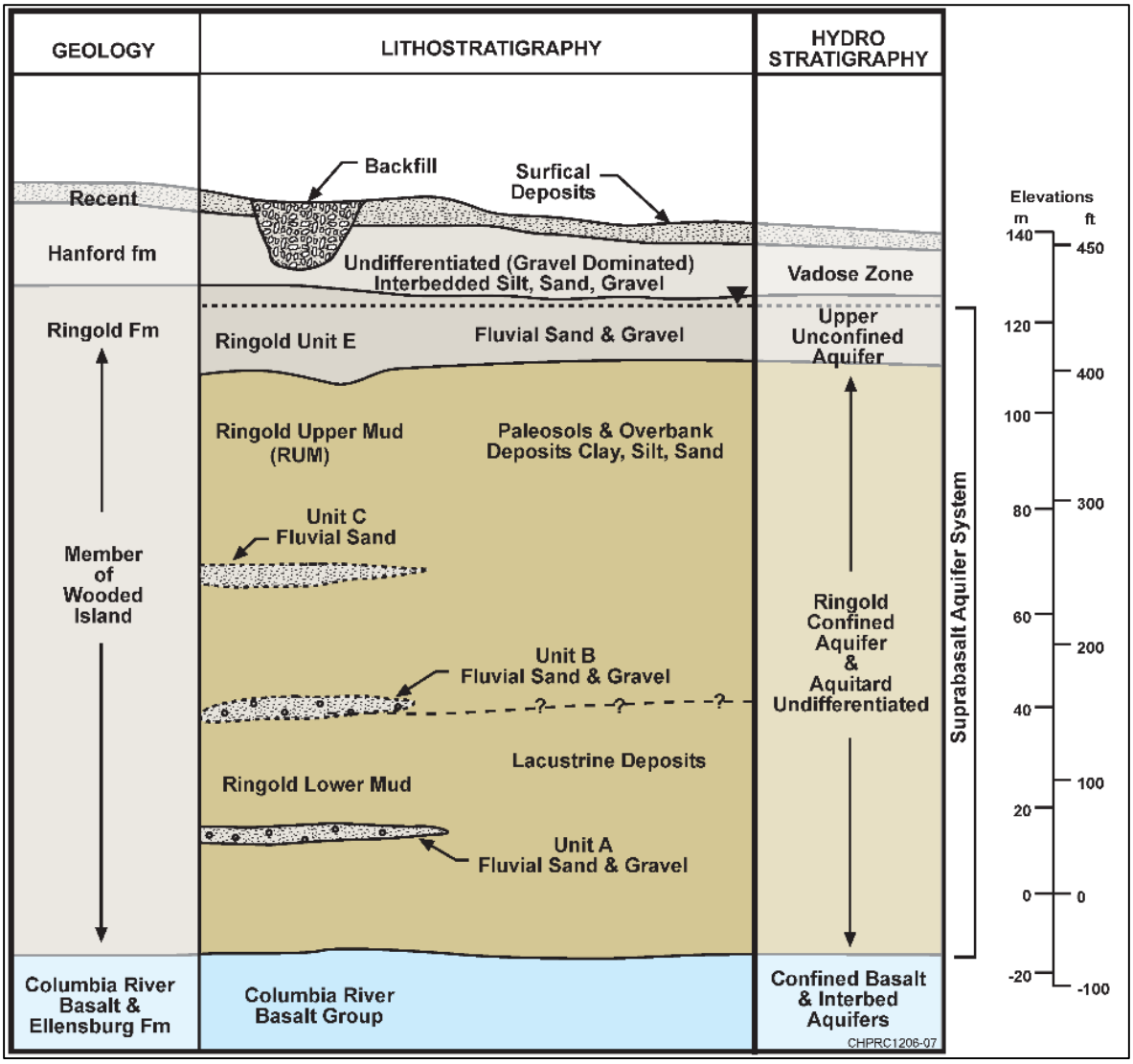

Figure 6-3. 100-NR Geology

6.2 CERCLA Activities

In 2014, CERCLA activities in 100-NR included routine groundwater monitoring, completion of the remedial design report/remedial action work plan (RD/RA WP; DOE/RL-2001-27, Rev. 1), beginning revision of Draft A of the RI/FS report (DOE/RL-2012-15) in response to comments, and continued interim remediation of strontium-90 and TPH-diesel contamination.

6.2.1 Groundwater Monitoring

Routine groundwater monitoring for October through December 2014 is described in the RDR/RA WP (DOE/RL-2001-27, Rev. 1), which was approved in September 2014. From January through September 2014, groundwater monitoring was described in the previous version of the work plan (DOE/RL-2001-27, Rev. 0, as modified by TPA-CN-256 and TPA-CN-569). From January through September 2014, groundwater sampling also was conducted in accordance with the RI/FS work plan (DOE/RL-2008-46 ADD5) and associated SAP (DOE/RL-2009-42, as modified by

TPA-CN-478). During CY 2014, aquifer tubes were monitored in accordance with the SAP for aquifer tubes (DOE/RL-2000-59, as modified by TPA-CN-353). The sampling locations for 100-NR are shown in Figure 6-4.

CERCLA sampling is conducted primarily in September, with selected wells also monitored in March. Table A-4 of Appendix A lists the wells and constituents monitored. Aquifer tubes in 100-NR were sampled in September 2014, and some were sampled more frequently (Appendix C).

One river shore seep at 100-NR was sampled in September 2014 during low river stage. Seeps occur when the groundwater elevation locally is higher than the river elevation causing groundwater to drain from the aquifer along the shoreline above the river. The results of the seep analyses for hexavalent chromium, nitrate, strontium-90, and tritium are shown as information on their respective plume maps but are not used during preparation of the plume configurations.

6.2.2 Remedial Design/Remedial Action Work Plan

The revised RDR/RA WP (DOE/RL-2001-27, Rev. 1) presents the approach for implementing the interim remedial actions selected for the 100-NR-2 Groundwater OU, as specified in the *Interim Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units* (EPA/ROD/R10-99/112). The RDR/RA WP includes the activities necessary to install and maintain an apatite PRB for the 100-NR-2 OU, as specified in the interim action ROD, as amended (EPA, 2010, *100-NR-1 and NR-2 Operable Units Hanford Site – 100 Area Benton County, Washington Amended Record of Decision, Decision Summary and Responsiveness Summary*). Appendix A of the RDR/RA WP is the SAP for interim remedial actions and routine groundwater monitoring. The revised RDR/RA WP was prepared to fulfill *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) Milestone M-015-60.

6.2.3 Remedial Investigation/Feasibility Study

Draft A of the RI/FS report (DOE/RL-2012-15) was submitted to Ecology, the lead regulatory agency for the 100-NR-1 and 100-NR-2 OUs, in June 2013 for review. The document was revised during 2014 in response to Ecology's comments. The RI/FS information will be used to make decisions for remediation of waste sites and groundwater. The ROD for these OUs, which will specify the remedies for cleanup of waste sites and groundwater, is anticipated in 2016.

6.2.4 Groundwater Remediation

Interim actions are being conducted for cleanup of strontium-90 and TPH-diesel contamination in 100-NR-2 OU groundwater. The activities and results for 2014 are summarized in Section 6.8. Additional details are available in DOE/RL-2015-05, *Calendar Year 2014 Annual Summary Report for the 100-HR-3 and 100-KR-4 P&T Operations, and 100-NR-2 Groundwater Remediation*.

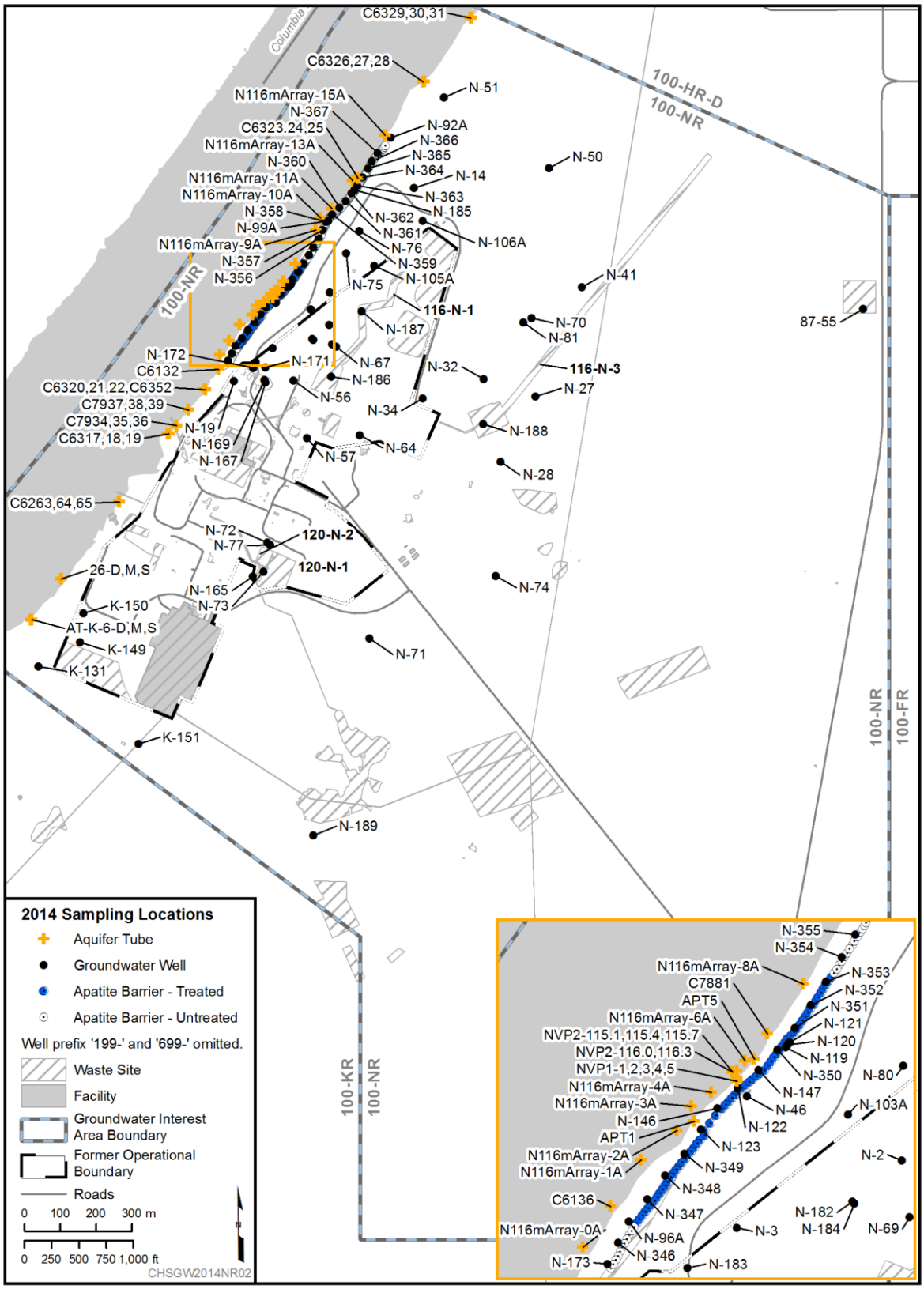

Figure 6-4. 100-NR Sample Locations, 2014

6.3 Strontium-90

The primary source of the strontium-90 contamination in 100-NR was liquid waste disposal to the 116-N-1 Crib and Trench and the 116-N-3 Crib and Trench. The size and shape of the strontium-90 plume changes very little from year to year, except near the apatite PRB (Figure 6-5). The low-mobility strontium-90 plume extends from beneath the 116-N-1 Crib and Trench and 116-N-3 Crib waste site sources to the Columbia River at concentrations exceeding the DWS (8 pCi/L). The highest concentration portion of the strontium-90 groundwater plume (i.e., the area with concentrations exceeding 800 pCi/L) is found beneath the 116-N-3 Crib and beneath and downgradient of the 116-N-1 Trench. The lateral distribution of the groundwater plume with concentrations between 8 and 80 pCi/L is found peripheral to the highest concentration area in a distribution consistent with historical radial flow away from the 116-N-1 and 116-N-3 Cribs and Trenches and elongated toward the river.

The highest strontium-90 groundwater concentration detected at 100-NR in 2014 was 15,500 pCi/L in a sample from Well 199-N-67, which is downgradient of the 116-N-1 Trench. Because of strontium-90's low mobility in groundwater, concentrations exceeding 100 pCi/L are limited to the very upper portion of the aquifer. Strontium-90 contamination is either not detected or is detected at very low concentrations in wells monitoring the base of the unconfined aquifer or the RUM. The highest strontium-90 concentration at the base of the aquifer in 2014 was 3.25 pCi/L at Well 199-N-69, adjacent to 199-N-67.

Water levels in the unconfined aquifer were significantly higher beneath the 116-N-1 and 116-N-3 waste sites when discharges were occurring. As the water level declined, strontium-90 remained sorbed to sediment in the lower vadose zone. When the current water table rises beneath these former waste sites, residual strontium-90 from the vadose zone may be temporarily remobilized, increasing the concentrations in groundwater. As the water table subsequently declines, strontium-90 sorbs back to the surrounding sediment. Strontium-90 concentrations in Well 199-N-81 downgradient of the 116-N-3 Trench have declined since the late 1990s. However, higher water levels in this well over the last 3 years correspond to a slight increase in the strontium-90 concentration that continues into the fall 2014 sample (Figure 6-6). Well 199-N-67 near the 116-N-1 Crib was sampled twice in 2014, with concentrations of 11,000 and 15,500 pCi/L in March and September, respectively. Strontium-90 concentrations in this well show no obvious long-term decline, but generally increase when the water level is elevated and decrease when it is lower (Figure 6-7). The positive variation of concentration with water level is more pronounced at this well near the 116-N-1 waste site, which received a much larger mass of strontium-90 than the 116-N-3 waste site and presumably has more residual strontium-90 in the lower vadose zone.

Strontium-90 concentrations in several wells within the untreated portion of the appatite barrier were also elevated. Wells 199-N-99A, 199-N-357, 199-N-280, and 199-N-281 had values that exceeded 800 pCi/L. This localized high concentration area has been interpreted to extend upgradient toward the 116-N-1 main portion of the high concentration plume (Figure 6-5).

Strontium-90 concentrations at the apatite PRB are discussed in Section 6.8. Strontium-90 concentrations in aquifer tubes are consistent with those seen in near-shore monitoring wells.

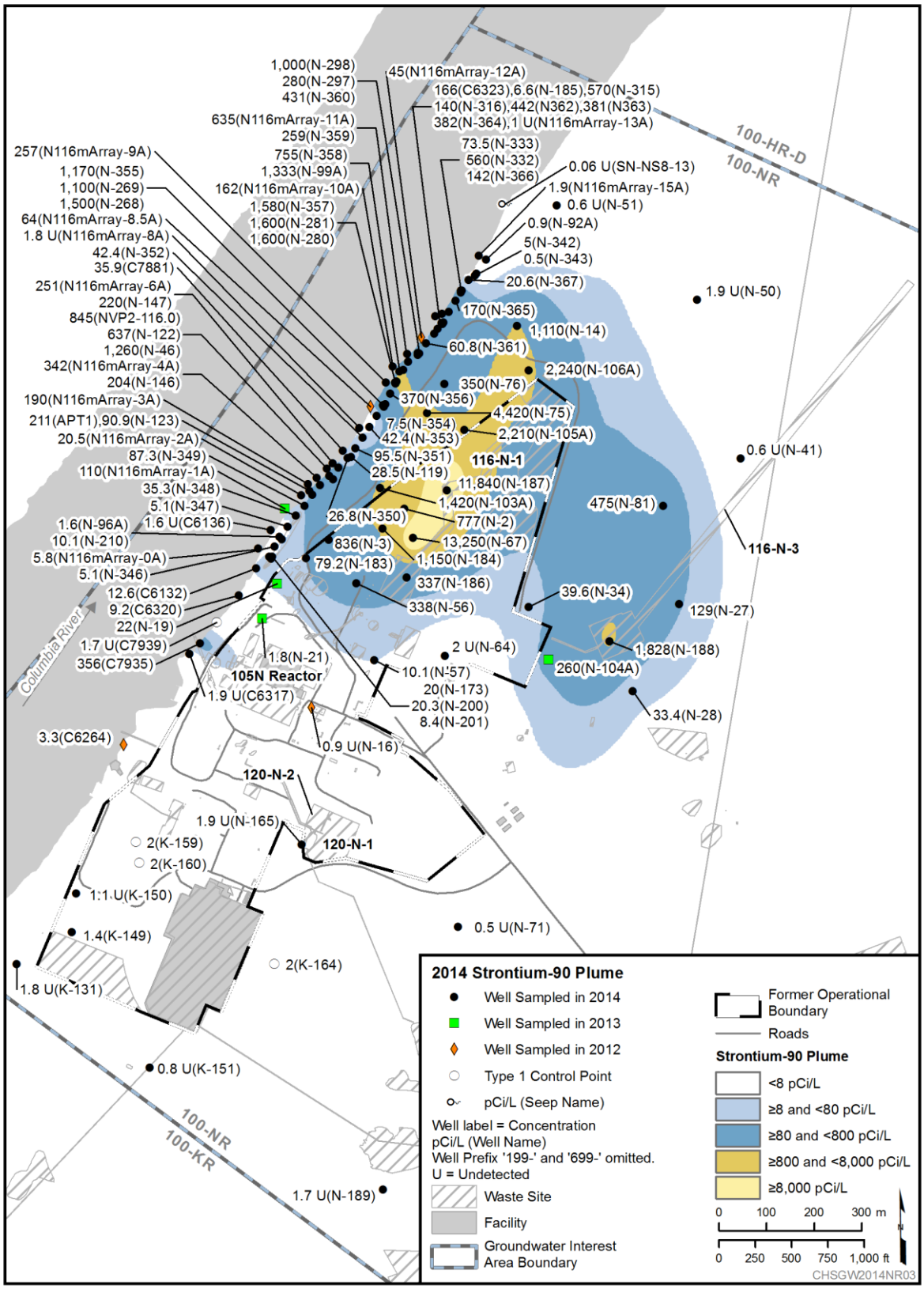

Figure 6-5. 100-NR Strontium-90 Plume, 2014

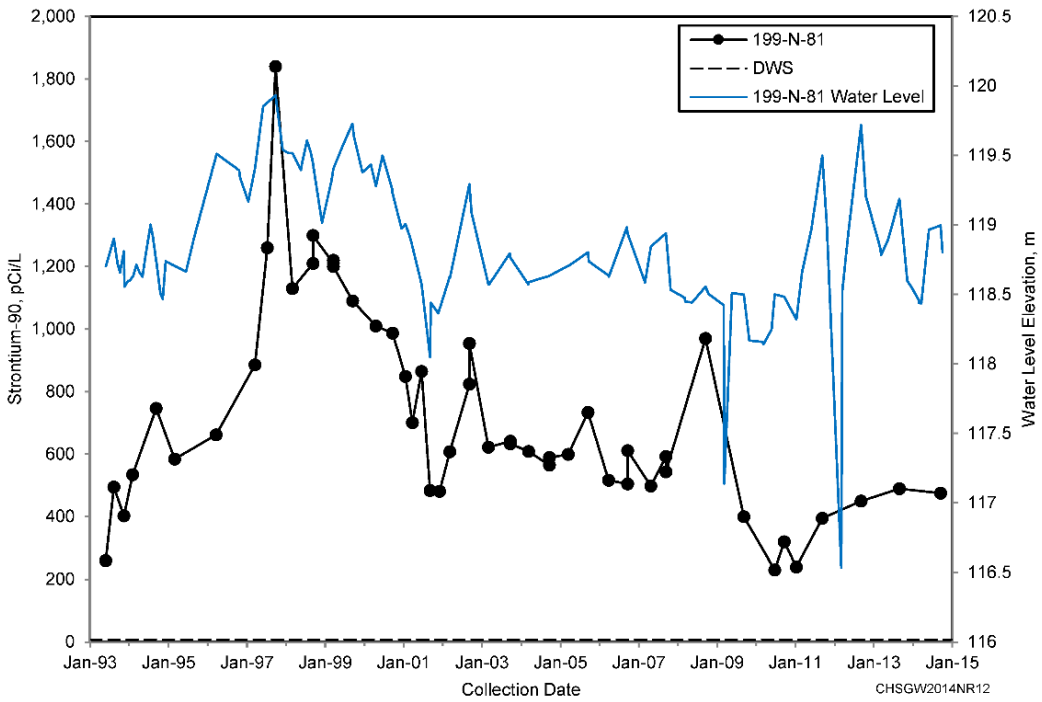

Figure 6-6. 100-NR Strontium-90 Data for Well 199-N-81

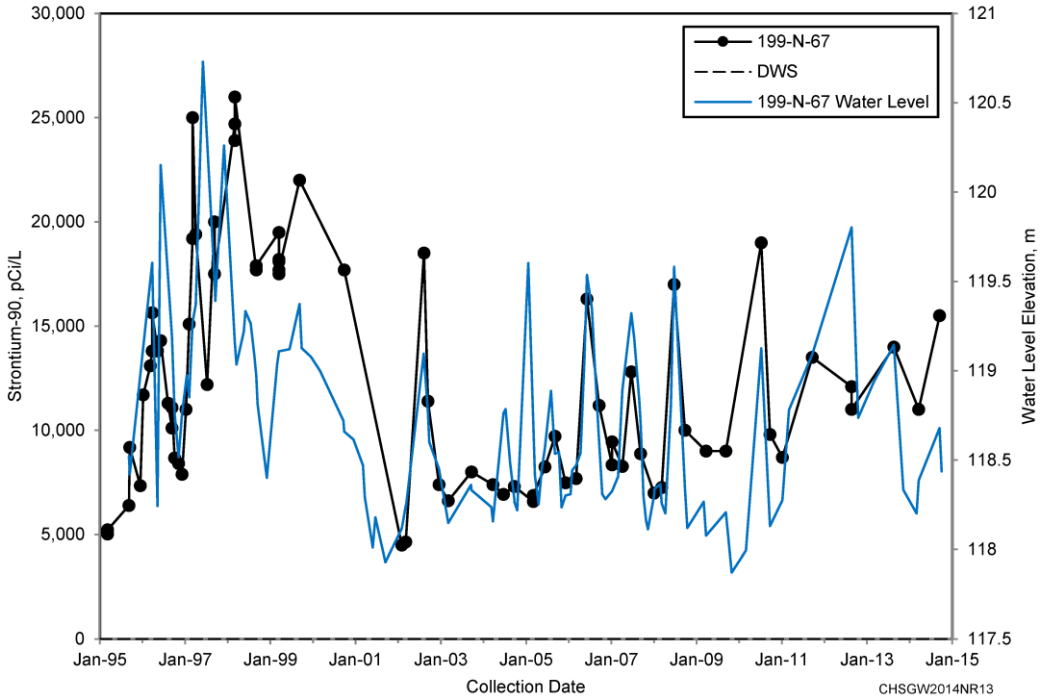

Figure 6-7. 100-NR Strontium-90 Data for Well 199-N-67

Strontium-90 is also detected in groundwater at aquifer tube cluster C7934/C7935/C7936 (Figure 6-8) located upriver from the main strontium-90 plume (Figure 6-5). When these aquifer tubes were first sampled in July 2010, strontium-90 concentrations were above the DWS. Strontium-90 concentrations have remained elevated but relatively stable through 2014, suggesting the presence of a small isolated area of low mobility strontium-90. These aquifer tubes are located close to the engineered fill around the 1908-N Outfall, which suggests that outfall construction created a preferential pathway in the fill for migration of contaminated groundwater to the river (Section 4.2 of SGW-49370). Leaks from the fuel storage basin and associated facilities and pipelines between the N Reactor and the river may be the source of the elevated strontium-90 concentrations at the aquifer tube cluster. Three new wells are planned to be drilled to evaluate the source.

Seep 100-N SPRING 8-13, on the river shore near aquifer tube 116mArray-16A, was sampled on September 24, 2014. The strontium-90 result (undetected) is posted on the strontium-90 plume map (Figure 6-5).

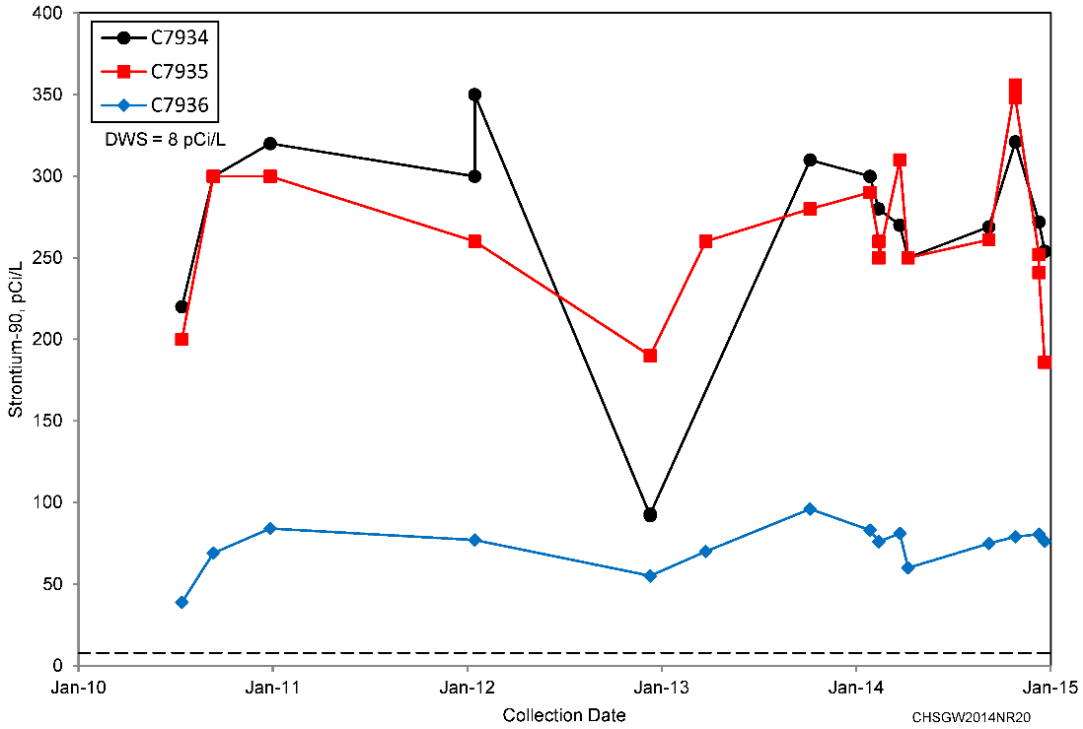

Figure 6-8. 100-NR Strontium-90 Data for Aquifer Tubes C7934, C7935, and C7936

6.4 Tritium

Tritium concentrations were elevated above the DWS in 2014 at aquifer tube cluster C7934/C7935/C7936 (Figure 6-9). Concentrations continued to increase in 2014, peaking at over 700,000 pCi/L. December 2014 results suggest that concentrations had begun to decline. The increasing tritium concentrations did not fluctuate with river stage, suggesting that a slug of tritium was moving through this area. Based on its high mobility, the tritium concentration increases are likely a result of the recent deep excavation and addition of dust suppression water at waste sites between the reactor and the river. The 1908-N Outfall construction likely created a preferential pathway in the fill for migration of contaminated groundwater to the river.

Tritium concentrations also exceeded the DWS (20,000 pCi/L) in Well 199-N-186 in 2014 (the maximum value was 35,100 pCi/L). The well was drilled through the 116-N-1 Crib in 2011. The 116-N-1 waste site was a source of tritium contamination in 100-NR groundwater. This was the only monitoring well in 100-NR with tritium concentrations above the DWS in 2014.

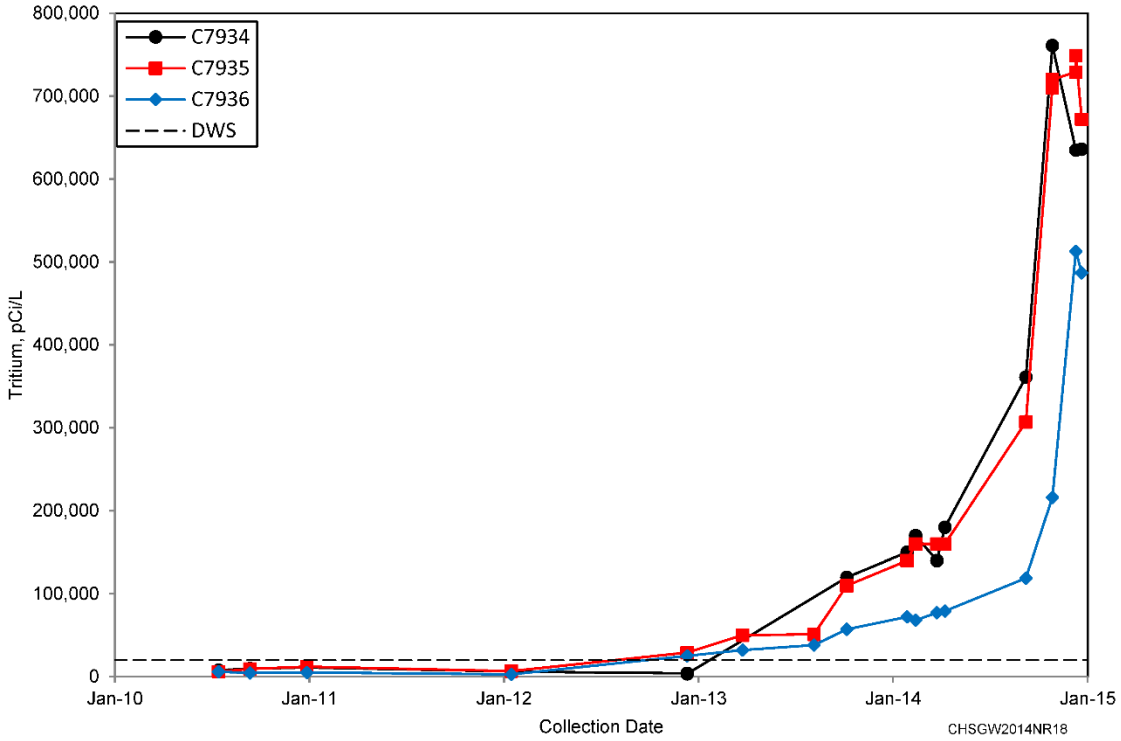

Figure 6-9. 100-NR Tritium Data for Aquifer Tubes C7934, C7935, and C7936

6.5 Nitrate

Nitrate exceeds 45 mg/L in groundwater beneath the 116-N-1 and 116-N-3 waste sites and the N Reactor area to the southwest (Figure 6-10). The highest concentration detected in 2014 was 186 mg/L in Well 199-N-67 downgradient of the 116-N-1 Crib. The 116-N-1 and 116-N-3 waste sites are implicated as the primary source of nitrate based on the persistent plume beneath them.

Nitrate concentrations were relatively low during disposal operations at the 116-N-1 and 116-N-3 waste sites (Figures 6-11 and 6-12). The highest nitrate concentrations were detected following remediation activities at these two sites from 2000 to 2006, which included excavation; application of dust suppression water and soil fixatives; and backfill. Increases in nitrate concentrations in 2014 may be due to delayed drainage from the deep vadose zone caused by additional surface water applied during waste site remediation several years ago.

Nitrate concentrations near the 120-N-1 waste site were very low when the waste site was in use but began to increase in the mid-1990s (Figure 6-13). Only low levels of nitrate (approximately 1 mg/L) were detected in the 120-N-1 effluent (Section 2.4.4 of DOE/RL-96-39). These factors suggest that the 120-N-1 waste site was not the source of the nitrate plume in the southwest region of 100-NR. The increase in nitrate concentrations since the mid-1990s may be a delayed or ongoing response to dust suppression water applied during past and ongoing waste site remediation activities in the area southwest of N Reactor. A new well is planned to be drilled in 2015 to evaluate the source.

The nitrate plume in 2011 through 2014 has a more limited extent to the southwest than in previous years because of the impact of treated water entering the aquifer through nearby 100-K injection wells.

Nitrate concentrations are anomalously low in wells in the area of the TPH-diesel groundwater plume (Figure 6-16). The lower concentrations are caused by the chemical reduction of nitrate during biodegradation of the TPH-diesel contamination. Low dissolved oxygen levels, lower pH, detectable nitrite, and elevated concentrations of iron and manganese support the interpretation of reducing conditions in this part of the aquifer.

Nitrate concentrations are highest in the upper part of the unconfined aquifer but are fairly well dispersed throughout the unconfined aquifer. Wells 199-N-69, 199-N-70, and 199-N-182, screened near the bottom of the aquifer, consistently have lower concentrations than the adjacent shallow wells. Concentrations have increased in deep Well 199-N-77 (maximum in 2014 was 35 mg/L), but remained lower than in nearby shallow Wells 199-N-72 and 199-N-73 (~50 mg/L).

Nitrate concentrations in several aquifer tubes in southwestern 100-NR exceeded the DWS in 2014 (Figure 6-10).

Seep 100-N SPRING 8-13, on the river shore near aquifer tube N116mArray-16A, was sampled on September 24, 2014. The nitrate result (16.6 mg/L) is posted on the nitrate plume map (Figure 6-10).

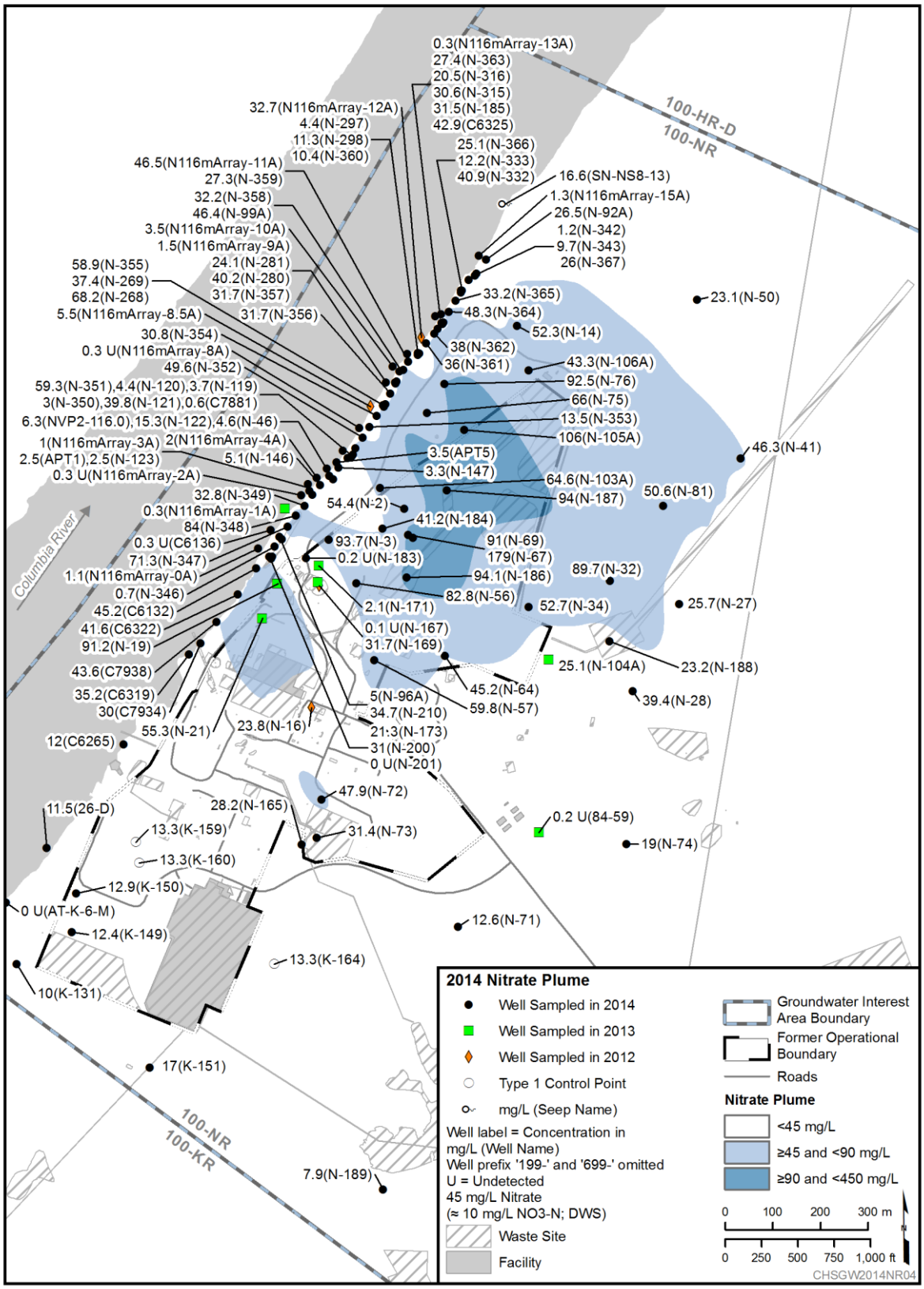

Figure 6-10. 100-NR Nitrate Plume, 2014

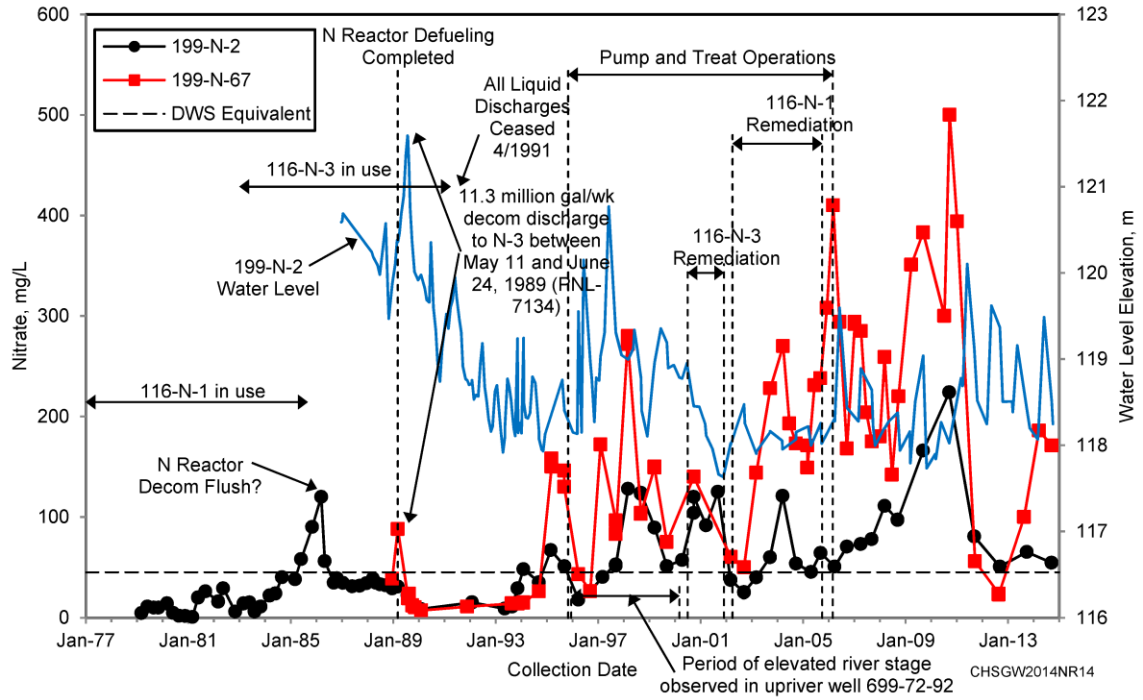

Figure 6-11. 100-NR Nitrate Data for Wells 199-N-2 and 199-N-67

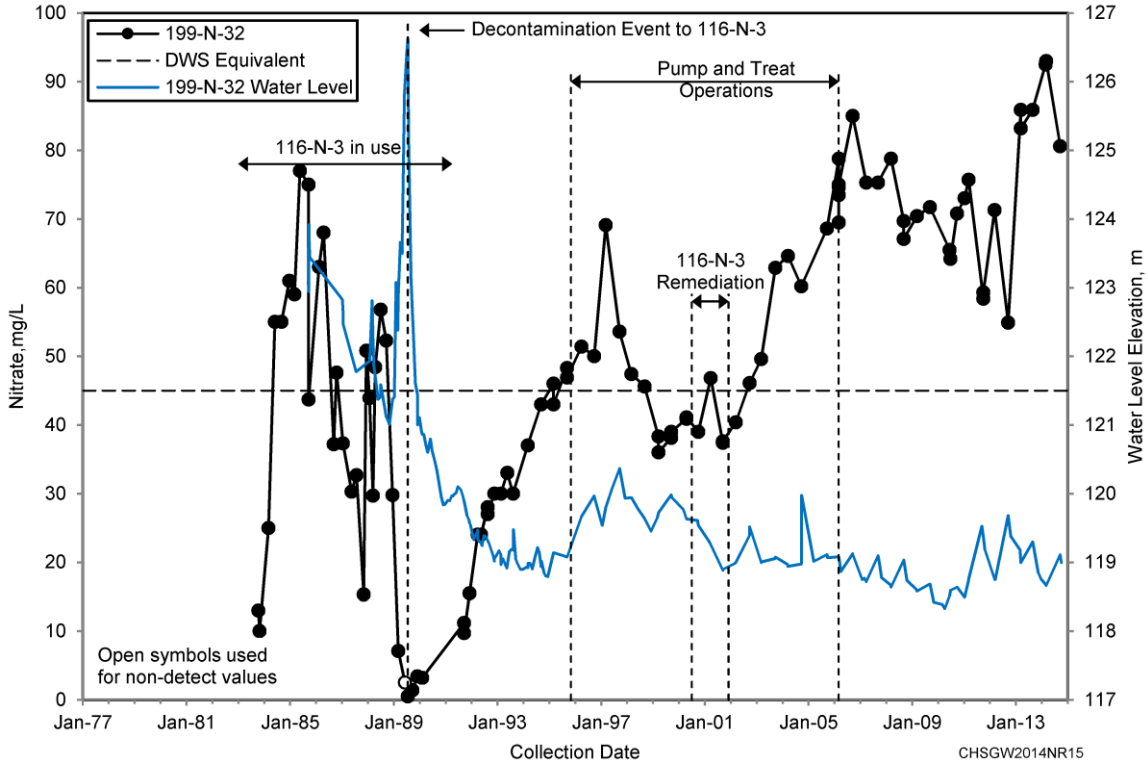

Figure 6-12. 100-NR Nitrate Data for Well 199-N-32

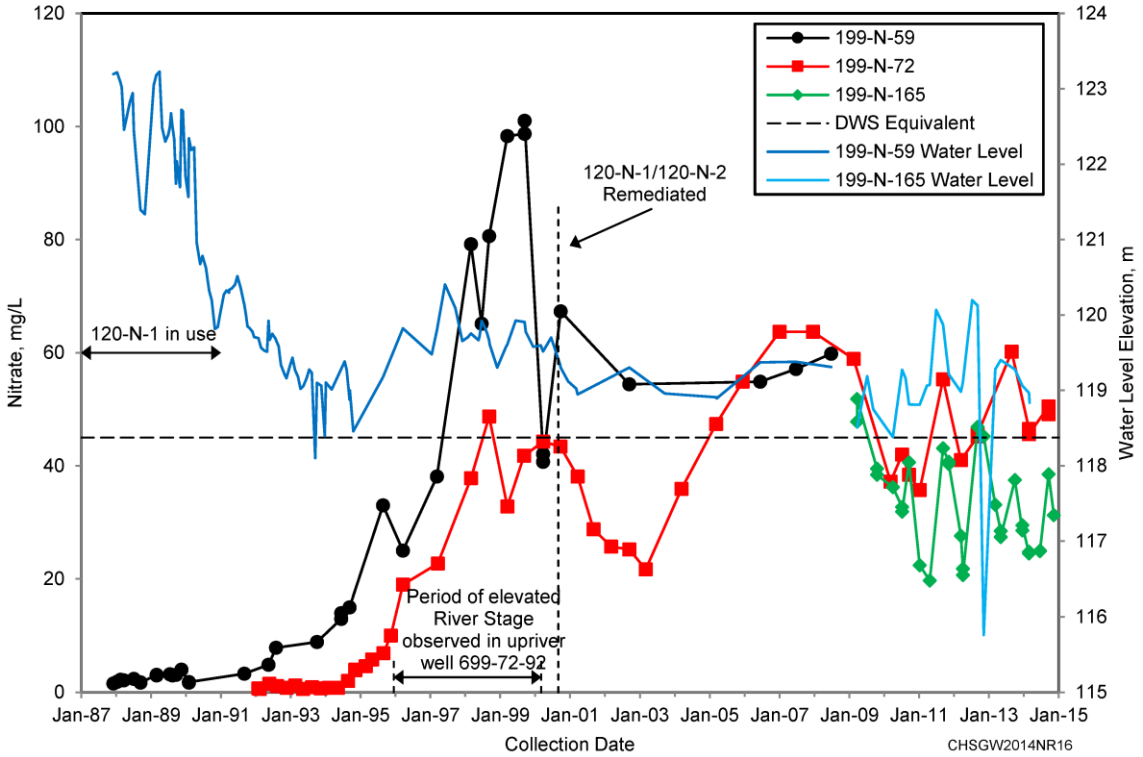

Figure 6-13. 100-NR Nitrate Data for Wells 199-N-59, 100-N-72, and 199-N-165

6.6 Total Petroleum Hydrocarbons – Diesel

The primary source of the TPH-diesel groundwater contamination is a 1966 diesel fuel spill (UPR-100-N-17). A small, relatively narrow groundwater plume extends downgradient from the spill location to the river (Figure 6-14). The highest groundwater concentration in 2014 was 18,000 µg/L (199-N-346), which was a substantial decrease from the 2011 and 2010 maximum concentrations of 48,000 and 420,000 µg/L, respectively (199-N-18), but an increase from the 2013 maximum concentration (199-N-171) of 9,450 µg/L. The overall plume reduction in concentration in 2012 through 2014 is attributed primarily to the bioventing conducted during that time for remediation of diesel in the deep vadose zone at UPR-100-N-17 (WCH-600).

In-situ bioventing introduces oxygen to promote in situ aerobic biodegradation of the TPH-diesel in the deep vadose zone to carbon dioxide and water. The data from the bioventing pilot test (2010–2011) were used to support the design of a full-scale bioventing system. Full-scale bioventing system operations began at UPR-100-N-17 in December 2012 using two vadose zone injection wells (199-N-167 and 199-N-172) and two vadose zone gas monitoring wells (199-N-169 and 199-N-171). Groundwater is monitored in eight monitoring wells (199-N-3, 199-N-19, 199-N-56, 199-N-96A, 199-N-169, 199-N-171, 199-N-173, and 199-N-183) (Appendix H of DOE/RL-2005-93).

Some natural biodegradation of diesel occurs in groundwater, as shown by the anomalously low nitrate groundwater concentrations in this area (discussed in Section 6.5).

In 2014, the two aquifer tubes near the intersection of the groundwater plume and the Columbia River showed detections of TPH-diesel (C6132 and N116mArray-0A [Figure 6-14]). A third aquifer tube (C6135) sampled in previous years was broken and could not be sampled in 2013 or 2014; a replacement is planned.

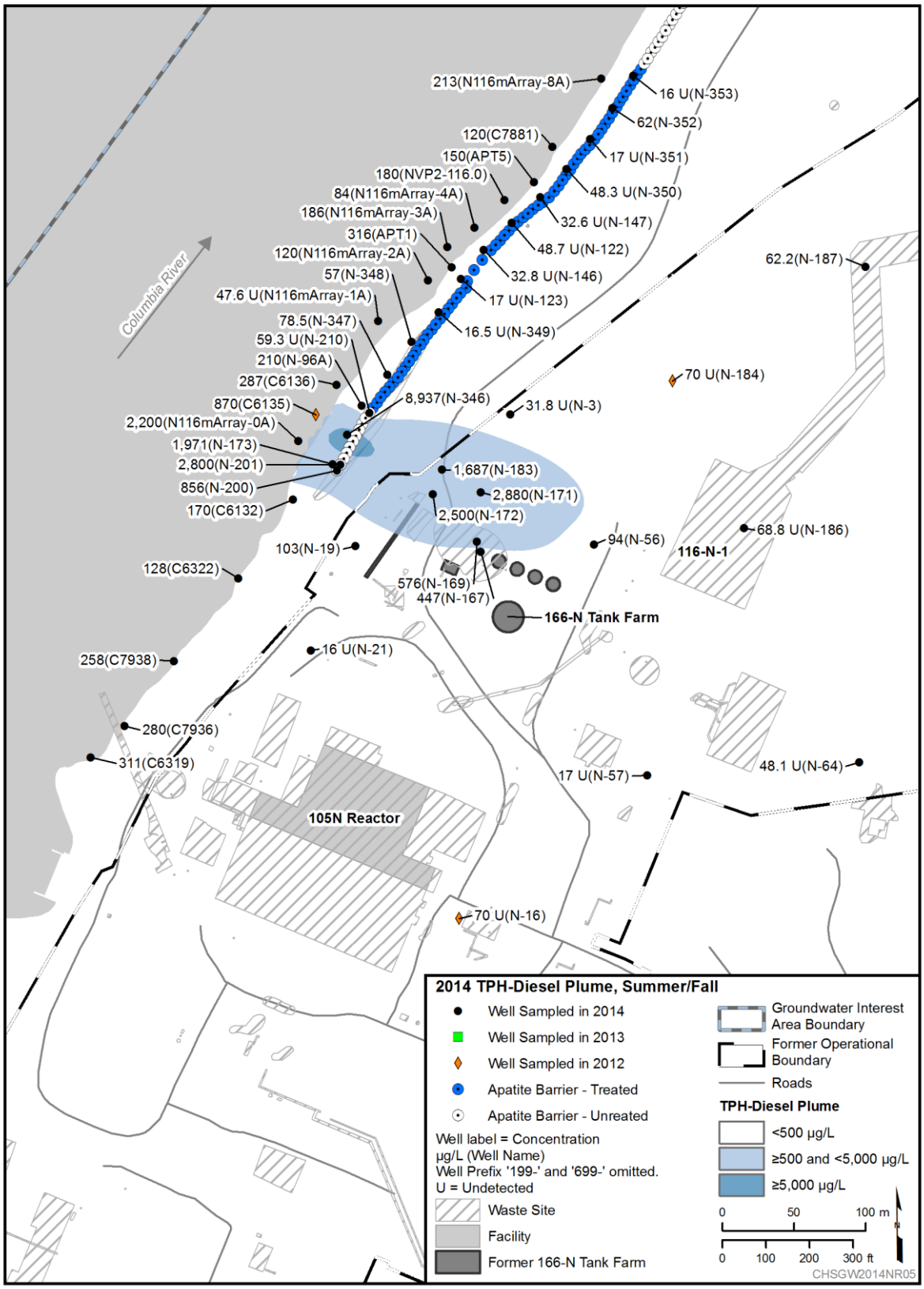

Figure 6-14. 100-NR TPH-Diesel Plume, 2014

If present as a nonaqueous phase (free product), the TPH-diesel in groundwater is found in the shallowest portion of the aquifer or floating on top of the water table (Section 4.4 of DOE/RL-2011-25). Removal of free product from Well 199-N-18 continued in 2014 in accordance with the interim action ROD (EPA/ROD/R10-99/112). The diesel is removed using a polymer "smart sponge" that selectively absorbs petroleum products from the surface of the water within the well. Approximately every 2 months, two sponges are lowered to the surface of the aquifer in Well 199-N-18 and left to soak up the diesel. 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 diesel fuel removed from the well. In 2014, 550 g of diesel were removed from Well 199-N-18 (Table 6-2). Removal of petroleum product from Well 199-N-18 will continue in 2015.

Table 6-2. 100-NR Hydrocarbon Product Removal from Well 199-N-18, 2003–2013

Year	Product Removed (gram)	Notes
2003[a]	~1,200[b]	Estimate provided per information given in table note; 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
2011	500	Changed every 2 months
2012	600	Changed in January, April, June, and August 2012
2013	750	Changed in January, March, May, July, September, and November 2013
2014	550	Changed in February, April, June, August, and October 2014
	Total	**13,044.5 grams (approximately 13 kg) removed through end of 2014**

a. 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.

b. 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 fiscal year 2004 (October 2003 through October 2004) was approximately 0.4 kg/month; therefore, an estimate is provided for the 3 months missing in 2003.

6.7 Hexavalent Chromium

Sodium dichromate was only used in N Reactor operations from 1964 to 1972 and in lesser amounts than in 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 (Section 1.3.2 of DOE/RL-2012-15). Although chromium was present in the effluent discharged to the 116-N-1 waste site, it was never detected in samples of the effluent (Section 3.1.1.4 of DOE/RL-90-22). Hexavalent chromium is mobile in solution and while chromium was being delivered to the 116-N-1 waste site, discharge rates and effluent temperatures were high. Liquid discharges to 116-N-1 continued for another 10 years after use of sodium dichromate had ceased. Because of these factors, the mobile portion of chromium was thoroughly flushed from the vadose zone and into the unconfined aquifer. Because a groundwater mound was present, the diluted effluent spread radially, with some portion going into the Columbia River by the end of the N Reactor's operational period (Section 4.8.1.4 of DOE/RL-2012-15). Dissolved chromium in Hanford Site groundwater is present in hexavalent form.

The maximum dissolved chromium concentration in 100-NR in 2014 was in Well 199-N-80, located downgradient from the 116-N-1 Trench and screened in a thin, confined, water-bearing zone in the upper portion of the RUM. The well was not sampled for hexavalent chromium,but the concentration of total chromium in a filtered sample was 193 µg/L, consistent with previous results and relatively unchanged since monitoring began (Figure 6-15). This water-bearing zone has not been detected in surrounding wells and boreholes and is not believed to be laterally continuous (Section 4.4.3 of DOE/RL-2012-15).

The chromium detected in Well 199-N-80 is likely the result of high-volume past disposal of chromium-bearing liquid waste into the nearby 116-N-1 waste site that was driven into this relatively shallow confined interval during extremely high unconfined aquifer heads and today remains trapped and relatively stagnant in this locally confined interval (Section 4.8.1.4 of DOE/RL-2012-15). Well maintenance activities in 2001 confirmed stainless-steel well screen corrosion was occurring, which could also release chromium into this well. However, other components of stainless steel (nickel, manganese, and iron) are present only at low or undetectable concentrations.

In 2014, hexavalent chromium continued to be detected below the 48 µg/L MTCA standard in wells approximately 750 m (2,500 ft) inland from the N Reactor and northeast around the upgradient portion of the 116-N-3 waste site. These chromium detections are not believed to be associated with a 100-NR waste site (Figure 5-6). This chromium contamination migrated inland while the 116-K-2 Trench was in use and a groundwater mound was present. A portion of this 100-KR chromium plume has migrated northward into 100-NR near Wells 199-N-74 and 199-N-189.

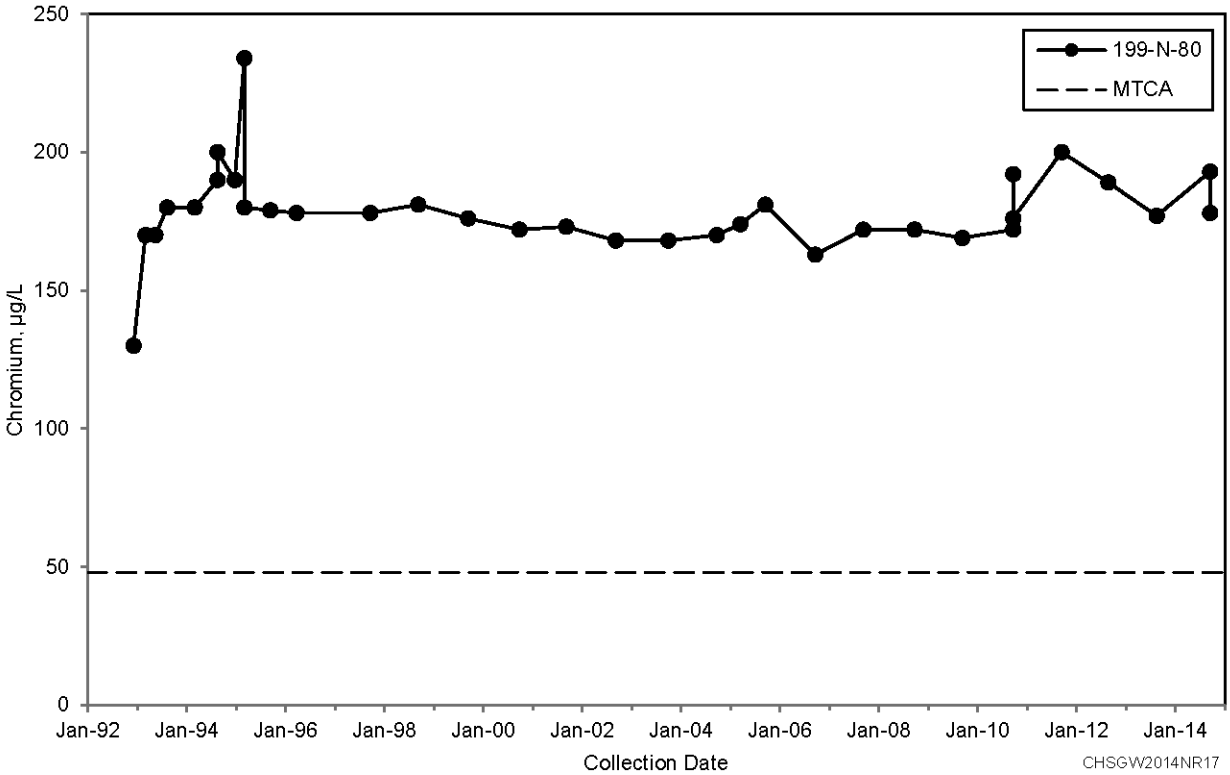

Figure 6-15. 100-NR Chromium Data for Well 199-N-80

The 2014 plume maps (Figures 5-5 and 5-6) suggest another area of chromium contamination within NR-2 may exist surrounding Well 199-N-41 and upgradient of the 116-N-3 waste site. Well 199-N-41 had a filtered chromium detection of 51 µg/L in June 2014 (Figure 5-13). However this result was 4 to 5 times higher than previous or subsequent results (including September 2014) and was flagged as a suspected error. Sparse and limited historical chromium concentration data, recent chromium increases, and limited well control in this region limit the ability to confidently map the chromium extent. None of these inland wells detected hexavalent chromium above the 48 µg/L MTCA standard, but several have had detections above the 10 µg/L ambient water quality standard. Future groundwater monitoring, as defined in the 100-NR-2 and 100-KR-4 OU groundwater SAPs, will provide additional data from an expanded list of monitoring wells. These results will be used to assess the presence and extent of hexavalent chromium contamination in this region of 100-NR and farther upgradient.

Hexavalent chromium concentrations were near or below detection limits in 100-NR aquifer tube samples in 2014. All were below the 10 µg/L ambient water quality standard.

Seep 100-N SPRING 8-13, on the river shore near aquifer tube 116mArray-16A, was sampled on September 24, 2014, with a hexavalent chromium result of 7.06 µg/L.

6.8 100-NR-2 Remedies

Interim actions are being conducted for cleanup of strontium-90 and TPH-diesel contamination in the 100-NR-2 OU (Figure 6-16). The activities and results for 2014 are summarized in this section. Additional details are available in DOE/RL-2015-05, *Calendar Year 2014 Annual Summary Report for the 100-HR-3 and 100-KR-4 P&T Operations, and 100-NR-2 Groundwater Remediation*.

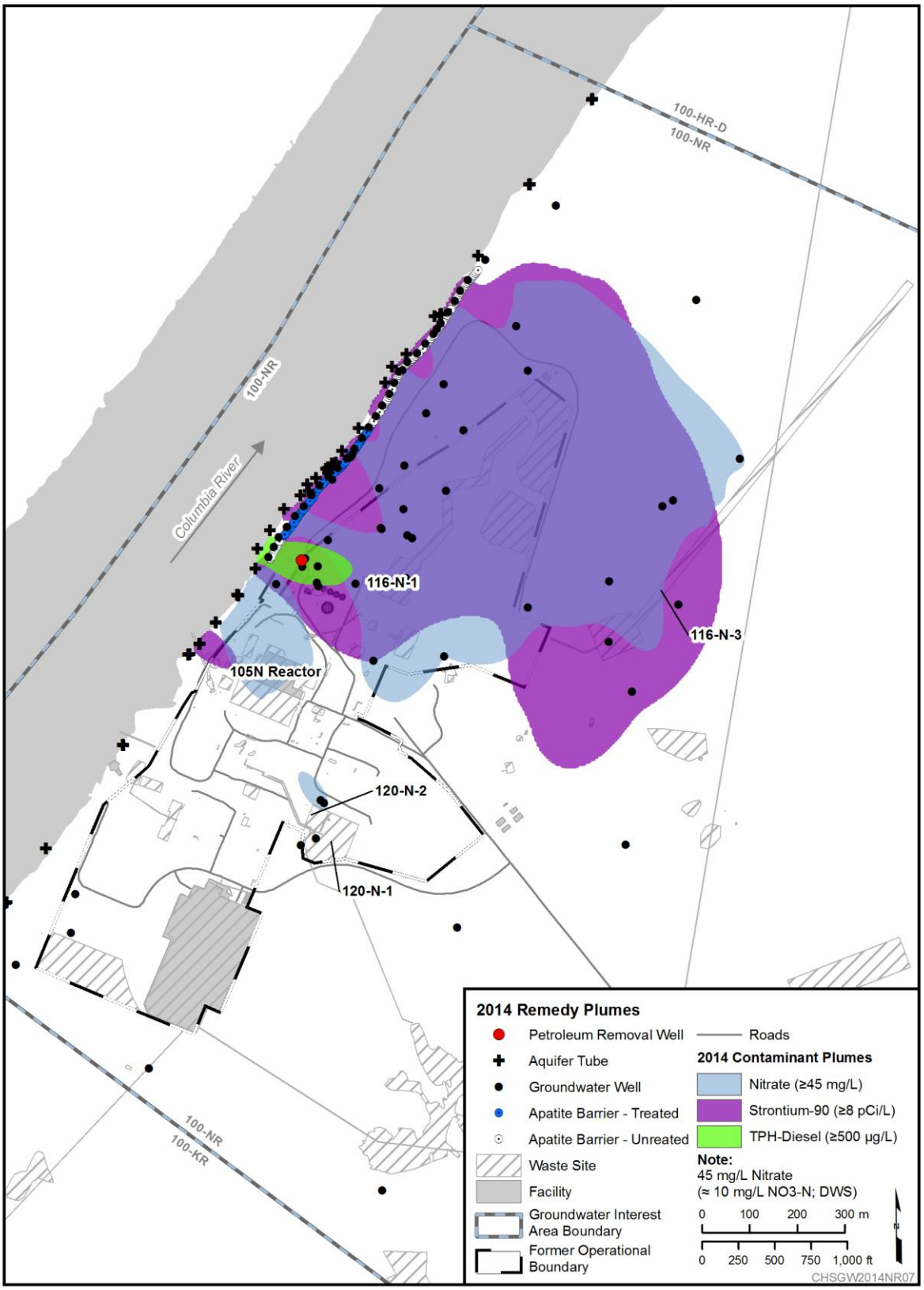

Figure 6-16. 100-NR Remedy Plumes

The CERCLA remediation of strontium-90 in groundwater is identified in the interim action ROD (EPA/ROD/R10-99/112). When the interim action ROD was issued in 1995, the interim action for remediation of strontium-90 in groundwater was P&T. The 100-NR-2 groundwater P&T system operated from 1995 until 2006. The system removed approximately 1.8 Ci of strontium-90 from the aquifer, which was less than the amount removed by radioactive decay during the same period. Because strontium-90 binds strongly to the sediment, the P&T system was not effective in the cleanup of strontium-90 from the aquifer.

One of the requirements of the interim action ROD was to evaluate alternative technologies for groundwater cleanup. Therefore, in 2006, Ecology, EPA, and DOE approved placing the P&T system in cold standby status and constructing a PRB. A 90 m (300 ft) long apatite PRB was completed as a treatability test in accordance with DOE/RL-2005-96. Based on the treatability test results (PNNL-17429; PNNL-SA-70033), the apatite technology showed promise as a remediation option. As a result, the interim action ROD was amended in 2010 to allow for expansion of the apatite barrier and permanent decommissioning of the 100-NR-2 P&T system.

The CERCLA interim action for remediation of TPH-diesel in groundwater is identified in the interim action ROD (EPA/ROD/R10-99/112). The interim action ROD specifies that petroleum hydrocarbons (free product) will be removed if observed in a monitoring well. The removal of the TPH-diesel is discussed in Section 6.6.

6.8.1 Apatite Barrier

The original, 90 m (300 ft) long apatite PRB was created by injection of apatite-forming solutions into 16 wells from 2006 through 2008 (PNNL-19572). The expanded apatite PRB well network was installed between late 2009 and early 2010, extending the original barrier well network upriver and downriver for a total length of 760 m (2,500 ft) (Figure 6-17). In September 2011, two segments of the extended well network, one upriver and one downriver of the original barrier, were injected with apatite-forming solution to extend the length of the apatite PRB to approximately 300 m (1,000 ft). The barrier was expanded in accordance with the design optimization study (DOE/RL-2010-29), which had seven objectives for evaluating barrier implementation and effectiveness. Data from the injections and subsequent performance monitoring are used to evaluate these objectives.

6.8.1.1 Apatite Permeable Reactive Barrier Technology

The apatite PRB is formed by injecting a calcium citrate phosphate solution into the aquifer through a network of vertical wells (i.e., the barrier well network). After the solution is injected, biodegradation of the citrate releases the calcium, which results in formation of apatite (a calcium phosphate mineral [$Ca_{10}(PO_4)_6(F, Cl, OH)_2$]). Strontium ions (including strontium-90) in groundwater substitute for calcium ions in the apatite via cation exchange and eventually become trapped as part of the mineral matrix during apatite crystallization (Section 1.3 of PNNL-16891). The strontium-90 in groundwater is sequestered within the apatite PRB as contaminated groundwater flows through the barrier. The PRB design assumes an average groundwater flow rate of 0.3 m/day. Based on data collected from batch laboratory tests, the calculated average incorporation rate for the PRB design apatite content of 0.96 mg apatite/g of sediment is 2 to 200 times greater than the estimated strontium flux through the barrier (PNNL-23367). At the design apatite content, strontium and strontium-90 would be incorporated into apatite more rapidly than the average groundwater flow rate and most high-flow events. The sequestered strontium-90 continues to decay in place within the barrier.

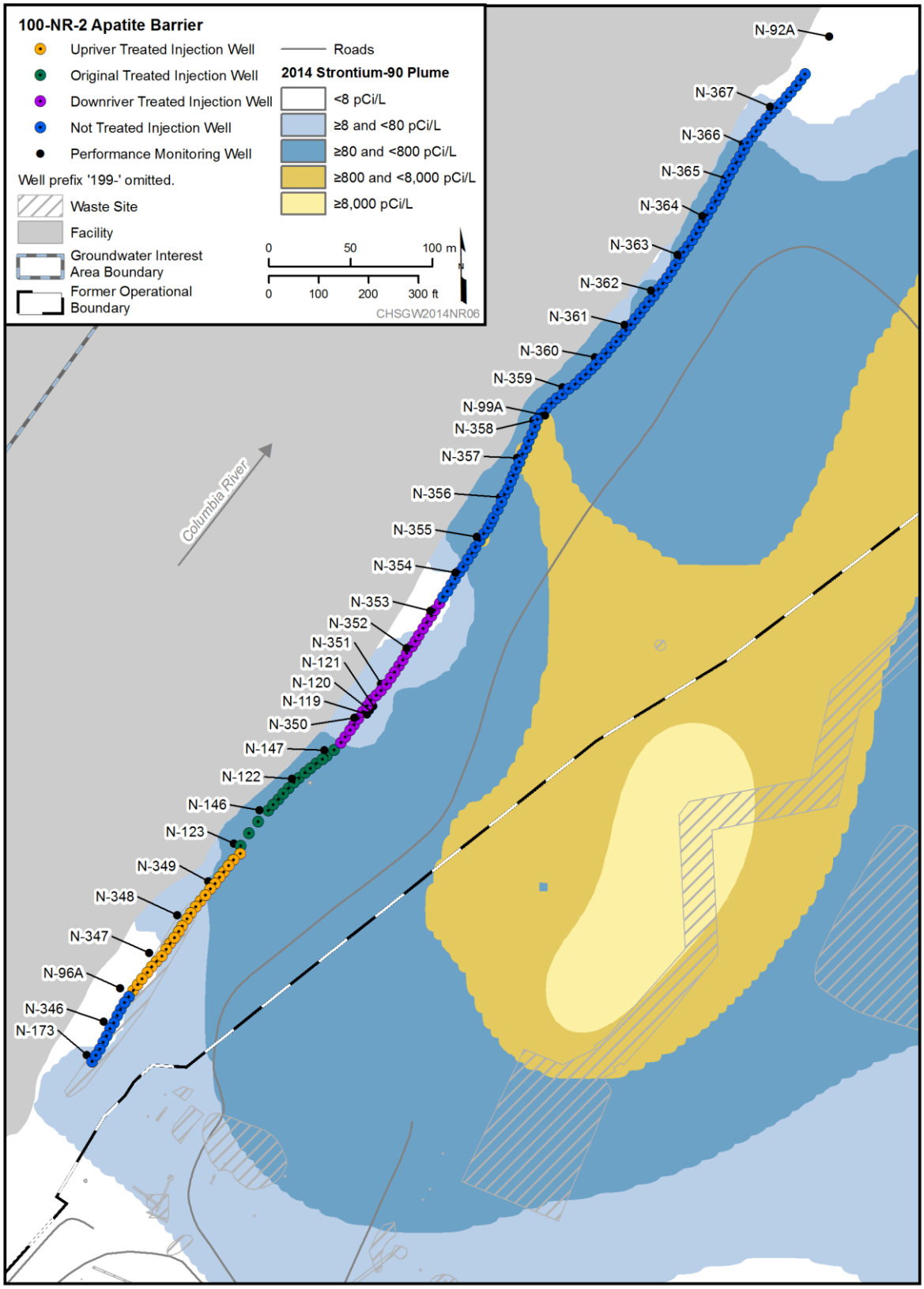

Figure 6-17. 100-NR Apatite Barrier

6.8.1.2 Apatite Permeable Reactive Barrier Performance Monitoring

Performance monitoring at the apatite barrier was conducted twice in 2014. Groundwater samples were collected from performance monitoring wells and aquifer tubes during high river stage in June and during low river stage in September. A comparison of 2014 data to baseline conditions is shown in Table 6-3. Semiannual performance monitoring (high and low river stages) will continue for the apatite PRB in 2015.

Following the apatite injections in 2008 in wells in the central (original) segment of the barrier, strontium-90 concentrations declined in the performance monitoring wells (Figure 6-18). The wells showed temporary, higher strontium-90 concentrations immediately following the injections of the apatite solution, which had a higher ionic strength than groundwater and temporarily mobilized cations and anions, causing their concentrations in groundwater to increase. Strontium-90 concentrations in Wells 199-N-122 and 199-N-123, which are near the upriver and downriver ends of the central barrier segment, temporarily increased following injections into the nearby barrier extension wells in 2011.

As of fall 2014, the strontium-90 concentrations were still considerably lower in the wells monitored along the central segment of the barrier than before the injections started in 2006. The treatability test plan objective was a 90 percent reduction in strontium-90 concentrations in the performance monitoring wells (Section 4.4.3 of DOE/RL-2005-96). The 2014 data indicate that the strontium-90 concentrations in groundwater have been reduced by approximately 90 percent in three of the four performance monitoring wells (Table 6-3). The percent reduction in strontium-90 concentrations ranged from 74 percent (199-N-146) to 90 percent (199-N-123) in spring 2014 and 85 percent (199-N-146) to 95 percent (199-N-123) in fall 2014.

In the performance monitoring wells along the upriver barrier extension, the percent reduction in strontium-90 concentrations in September 2014 (3 years following the injections) ranged from 10 percent (199-N-347) to 98 percent (199-N-96A). The relatively low percent reduction in Well 199-N-347 reflects comparison to the low baseline strontium-90 concentration. Both the baseline and the September 2014 sample concentrations were below the DWS (8 pCi/L). Strontium-90 concentration at Well 199-N-349 have trended up since the initial reduction following the 2011 injections. The reduction from baseline strontium-90 concentrations were 80 percent and 44 percent in spring and fall 2014 samples, respectively.

In the performance monitoring wells along the downriver barrier extension, the percent reduction in strontium-90 concentrations in September 2014 ranged from 54 percent (199-N-351) to 95 percent (199-N-353). Stronium-90 concentrations measured in samples collected in the spring from Well 199-N-351 do not indicate an increasing trend since injections in 2011. The strontium-90 concentration reduction from baseline values at Well 199-N-351 was 91 percent from the spring 2014 sample. Ongoing monitoring will allow the determination of the continued effectiveness of the apatite barrier and support decisions regarding additional future apatite treatments.

Table 6-3. Performance Monitoring at the Apatite PRB, 100-NR-2 OU

Well Name	Baseline Sample					2014 results			
	Sample Dates	Number of Samples	Number of Nondetects	Minimum Sr-90 (pCi/L)	Max imum Sr-90 (pCi/L)	June 4-5 Sr-90 (pCi/L)	Sept. 10-11 Sr-90 (pCi/L)	% Reduction June [a]	% Reduction Sept. [a]
Upriver Apatite PRB									
199-N-96A	1995-2007[a]	56	8	1.54[b]	37.9[b]	1.1	0.8	97	98
199-N-347	4/6/2010[b]	1	1	7[c]	7[c]	3.9	6.3	44	10
199-N-348	4/6/2010	1	0	1,800	1,800	10	60	99	97
199-N-349	4/6/2010	2	0	220	230	45.5	129	80	44
Central (Original) Apatite PRB									
199-N-122	2005-2007[d, e]	10	0	657	4,630	388	886	92	81
199-N-123	2005-2006[d, e]	6	0	689	1,180	61.7	120	95	90
199-N-146	2006-2007[d, e]	4	0	318	985	151	256	85	74
199-N-147	2006[d, e]	3	0	522	1,842	231	209	87	89
Downriver Apatite PRB									
199-N-350	7/29/2010	1	0	240	240	13.2	40.3	95	83
199-N-351	7/28/2010	1	0	350	350	30.9	160	91	54
199-N-352	7/28/2010	1	0	580	580	21.6	63.2	96	89
199-N-353	7/28/2010	1	0	83	83	3.8	4.3	95	95

a. The percent reduction in strontium-90 concentration is calculated as:

(([maximum baseline value] – [2014 value])/[baseline value]) × 100.

b. Between 1995 and 2011, the maximum baseline was measured on 12/06/1995; the minimum detected baseline was measured on 06/13/2006 and 06/22/2007.

c. Strontium-90 estimated from gross beta. Gross beta concentrations are approximately two times the strontium-90 concentrations. The strontium-90 concentration was 1.1 U pCi/L. The gross beta concentration, 14 pCi/L, was divided by two to approximate the strontium-90 concentration of 7 pCi/L.

d. From Table 8.1 in PNNL-17429.

e. From Table 4.1 in PNNL-19572,

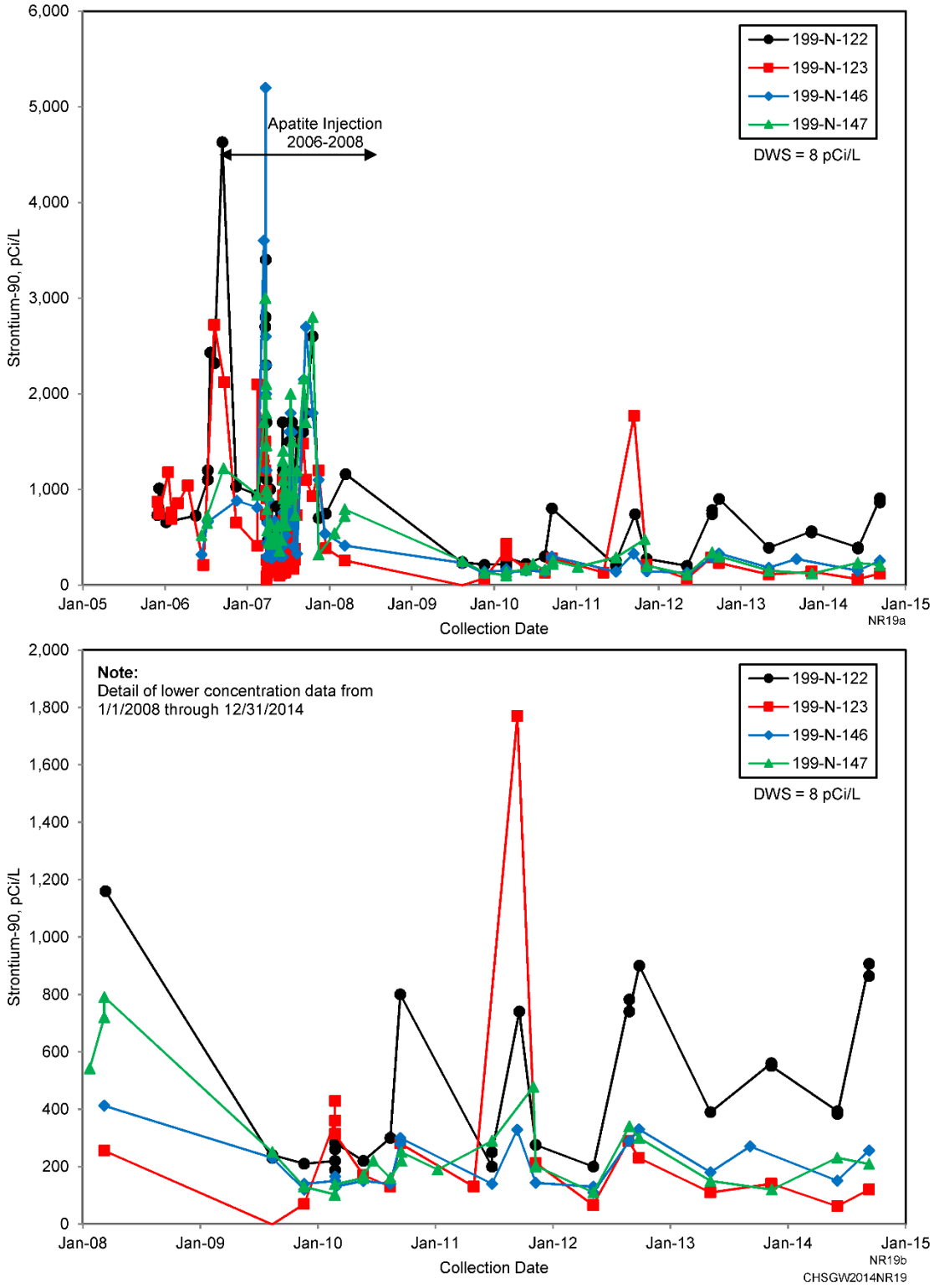

Figure 6-18. 100-NR Strontium-90 Data for Performance Monitoring Wells along the Central Segment of the Apatite PRB

6.9 RCRA Monitoring

This section describes the monitoring results for the following four RCRA facilities in 100-NR: the 116-N-1 Crib and Trench, the 116-N-3 Crib and Trench, the 120-N-1 Percolation Pond, and the 120-N-2 Surface Impoundment (Figure 6-1). Groundwater is monitored at these facilities to meet the requirements of RCRA and WAC-173-303 for dangerous waste constituents. Groundwater data for these facilities are available in the HEIS database and in the data files accompanying this report. Appendix B includes well and constituent lists, flow rates, and statistical tables for the four RCRA units in 100-NR.

6.9.1 116-N-1 Crib and Trench

The 116-N-1 waste site (Figure 6-19) was an unlined crib and trench used for disposal of liquid effluent from the 1960s through 1985. The effluent contained small quantities of dangerous waste in addition to the large volume of radioactive waste. The waste site excavation varied from 4.6 to 6.1 m (15 to 20 ft) below ground surface depending on location to remove shallow vadose zone sediment (where most of the radionuclide contamination resided) and was backfilled with clean fill.

The direction of groundwater flow beneath the 116-N-1 site in 2014 remained the same as in 2013; the area is not likely affected by the influence of groundwater injection in 100-KR-4 to the south (Figure 6-1). On February 28, 2014, the water table gradient beneath the 116-N-1 site was to the north at 1.9×10^{-3} m/m, and estimates of the groundwater flow rate ranged from 0.04 to 0.69 m/d (0.13 to 2.3 ft/d) (Table B-1, Appendix B).

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 waste site (Table B-2, Appendix B). No changes to the monitoring network were made in 2014.

The 116-N-1 facility is included in the Hanford Facility RCRA Permit (WA7890008967), which states that RCRA monitoring during closure activities will follow the requirements of BHI-00725. That plan, 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 and downgradient wells are scheduled for sampling twice each year for RCRA contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and turbidity, and once for groundwater quality and supporting parameters (chloride, iron, manganese, sodium, sulfate, and alkalinity). The wells were sampled as scheduled during 2014, and there were no critical mean exceedances (Table B-4, Appendix B).

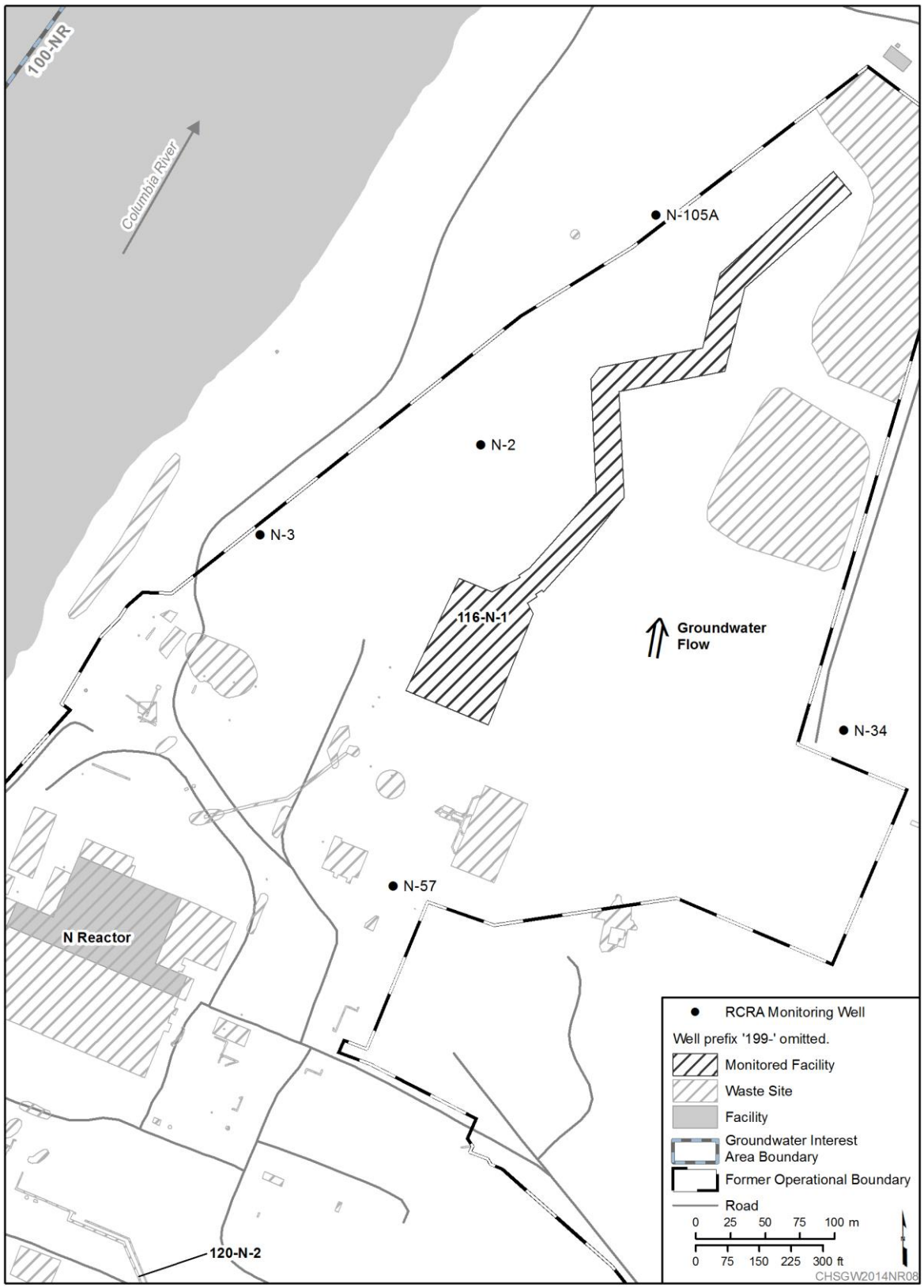

Figure 6-19. RCRA 116-N-1 Monitoring Well Locations

6.9.2 116-N-3 Crib and Trench

The 116-N-3 waste site (Figure 6-20) was an unlined crib and trench used to dispose of liquid effluent from 1983 through 1991. N Reactor was on cold standby beginning in 1987, but effluent was generated and disposed at a reduced rate until 1991. The effluent contained small quantities of dangerous waste in addition to the large volume of radioactive waste. The waste site was excavated to 1.5 m (5 ft) below the engineered structure to remove vadose zone material (which contained the highest concentrations of radionuclides) and was backfilled.

Groundwater flows to the north beneath the 116-N-3 site, turns to the northwest, and discharges to the Columbia River. The hydraulic gradient in February 2014 was to the north at 1.3×10^{-3} m/m with the groundwater flow rate estimated from 0.03 to 0.47 m/d (0.10 to 1.5 ft/d) (Table B-1, Appendix B).

The 116-N-3 facility is included in the Hanford Facility RCRA Permit (WA7890008967), which 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 downgradient Wells 199-N-32, 199-N-41, and 199-N-81 monitor the 116-N-3 waste site. Well 199-N-28 is monitored for supporting information; it previously reflected potential impacts of treated groundwater injected into a nearby well during operation of the 100-N P&T. Data from Well 199-N-28 are not evaluated statistically. No changes to the monitoring network were made in 2014.

All five wells in the RCRA network were sampled twice for RCRA contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and turbidity, and once for groundwater quality and supporting parameters (chloride, iron, manganese, sodium, sulfate, and alkalinity) in 2014. All five wells were sampled successfully as planned in 2014.

Average specific conductance values in all three of the downgradient wells (199-N-41, 199-N-81, and 199-N-32) and upgradient Well 199-N-74 exceeded the 2014 critical mean of 465 µS/cm (Table B-10, Appendix B). This is a continuation of previous exceedances noted from 1999 through 2013.
The assessment report for the original 1999 exceedance (at Well 199-N-41) concluded that the exceedance was caused by past discharges of nonregulated contaminants (sulfate and sodium) to the 120-N-1 site (00-GWVZ-054). During operation of the 120-N-1 percolation pond, a groundwater mound was present, pushing groundwater inland from the site. Recent data indicate that the conclusion of the 1999 assessment report (00-GWVZ-054) remains valid and the site remains in interim status monitoring.

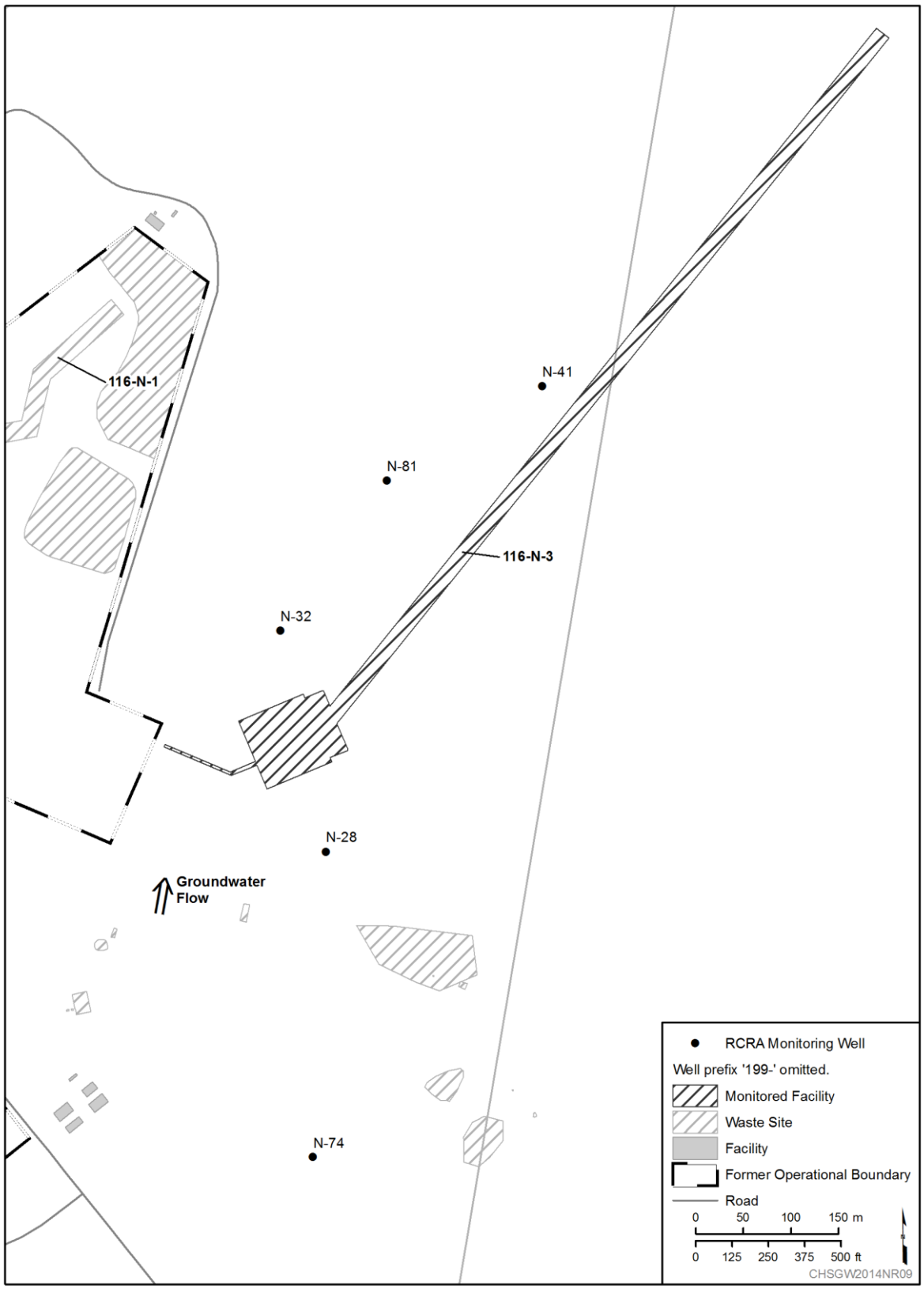

Figure 6-20. RCRA 116-N-3 Monitoring Well Locations

6.9.3 120-N-1 Percolation Pond and 120-N-2 Surface Impoundment

The 120-N-1 waste site and the 120-N-2 waste site were used to treat and dispose of corrosive, nonradioactive waste from 1977 to 1990. Both facilities have been remediated and backfilled. The remediation consisted of the removal and disposal of the miscellaneous site structures, including the 120-N-2 liner system, a small sampling shed, fencing, and other miscellaneous debris.

The 120-N-1 and 120-N-2 facilities (Figure 6-21) are included in the Hanford Facility RCRA Permit (WA7890008967), which 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 (WMA) because of their proximity and similar waste types.

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 and 120-N-2 waste sites. 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 were made in 2014.

All five of the monitoring wells for these sites were sampled as planned during 2014, twice for RCRA contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and turbidity, and once for groundwater quality and supporting parameters (chloride, iron, manganese, sodium, sulfate, and alkalinity) (Table B-2, Appendix B).

The 100-KR-4 injection wells south and west of the 120-N-1 and 120-N-2 sites have raised the water table and continued to affect groundwater flow in 2014 (Figure 6-1). Due to the injection mound, the water table slopes to the north-northwest. The hydraulic gradient was estimated to be 9.6×10^{-4} m/m in February 2014, and flow rates ranged from 0.02 to 0.36 m/d (0.07 to 1.2 ft/d) (Table B-1, Appendix B). The direction of flow has varied from north-northeast to north-northwest over the past three years.

Average specific conductance values in downgradient wells continued to exceed the critical mean value of 596 µS/cm in 2014. 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). These constituents, along with calcium, nitrate, other ions, and the indicator specific conductance, increased during the time of unusually high water levels in the aquifer in 2011 and 2012.
The concentrations dropped coincident with lower water table levels in 2013 and 2014. These data suggest that residual contamination of the constituents identified above may be present in the lower vadose zone near the water table beneath 120-N-1 and 120-N-2 and is released into the aquifer during unusually high water levels that saturated the normally unsaturated lower vadose zone. Recent data indicate that this conclusion in the 1992 assessment report (WHC-SD-EN-EV-003) remains valid and the site remains in interim status monitoring.

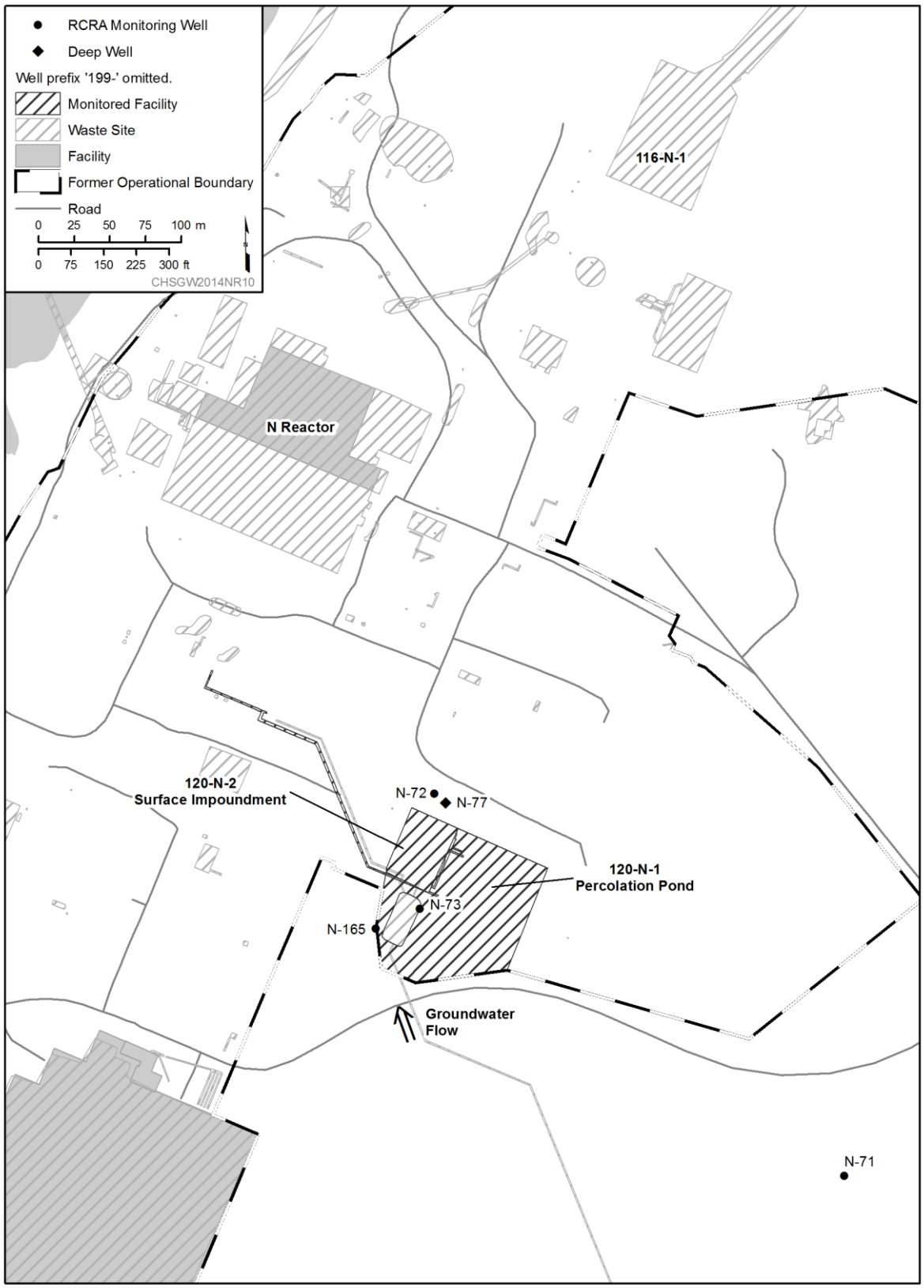

Figure 6-21. RCRA 120-N-1 and 120-N-2 Monitoring Well Locations