2.4 100-NR-2

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This section describes the groundwater conditions and contaminant distributions in the 100-NR-2 Operable Unit, which includes groundwater affected by contaminant releases from facilities and waste sites in the 100-N Area. Figure 2.4-1 shows the facilities and wells in 100-NR-2. Figures 2.4-2, 2.4-3, and 2.4-4 show details for the shoreline monitoring locations and sites related to the original 300-foot apatite permeable reactive barrier installed from 2006 through 2008, and the upriver and downriver extension barriers installed in fall 2011.

Sections 2.4.1 through 2.4.7 discuss the contaminant plumes and concentration trends in the vicinity of 100-NR-2. Strontium-90 and petroleum hydrocarbons are the contaminants of concern for a 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 activities will contribute to the development of a final ROD. The CERCLA activities completed during 2011 are discussed in Section 2.4.8. Section 2.4.9 identifies the groundwater monitoring activities at the four RCRA facilities for 2011.

DOE has identified 191 waste sites in the 100-N Area. Approximately 30 percent of the sites have been remediated or are classified as not needing to be remediated under an interim record of decision. 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.

Strontium-90 is the principal contaminant of concern in 100-NR-2. The areal extent of the strontium-90 plume has remained relatively unchanged from 1996 to 2012. Strontium-90 contamination is found in portions of the vadose zone that were saturated during discharge operations and also in the underlying aquifer extending to the Columbia River. Other groundwater contaminants include tritium, nitrate, petroleum hydrocarbons, sulfate, and chromium.

### 100-NR-2 at a Glance

**N Reactor Operations: 1963–1987**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Drinking Water Standard</th>
<th>Maximum Concentration</th>
<th>Plume Areaa</th>
<th>Shoreline Impact (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strontium-90</td>
<td>8 pCi/L</td>
<td>13,500 pCi/L</td>
<td>0.57 km²</td>
<td>620</td>
</tr>
<tr>
<td>Nitrate</td>
<td>45 mg/L</td>
<td>394 mg/L</td>
<td>0.57 km²</td>
<td>150</td>
</tr>
<tr>
<td>TPH</td>
<td>N/A</td>
<td>48 mg/L</td>
<td>0.003b</td>
<td>0</td>
</tr>
<tr>
<td>Tritium</td>
<td>20,000 pCi/L</td>
<td>16,500 pCi/L</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Remediation**

- Waste Sites (interim action): >30% completec
- Groundwater (interim action):
  - Pump-and-treat: 1995-2006, 1.8 Ci strontium-90 removed
  - Apatite sequestration barrier: 2006-2011
- Final record of decision anticipated in 2013

a. Estimated area above drinking water standard.
b. Area at 200 µg/L.
c. Waste sites with status of closed, interim closed, no action, not accepted, or rejected.

TPH = Total petroleum hydrocarbons
N/A = Not applicable
The 100-N Area is underlain by the Hanford formation, the Ringold Formation unit E, 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 because of excavation and fill that was placed to build the road. Unit E of the Ringold Formation underlies the entire area and is 5 to 20 meters thick. The Ringold Formation upper mud unit forms the base of the unconfined aquifer and is 17 to 29 meters thick. Most of the monitoring wells in 100-NR-2 were completed in the upper portion of the unconfined aquifer, which is predominantly in the Ringold Formation unit E. 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, was completed in a fine-grained sandy unit in the Ringold Formation upper mud unit, approximately 12 meters below the water table. Chapters 2.0 and 4.0 of the RI study/work plan provide further information about the geology and hydrology of 100-NR-2 (DOE/RL-2008-46-ADD5).

Groundwater flow in 2011 was influenced by groundwater extraction and injection for the KX remediation system in 100-KR-4 (Section 2.3). Figure 2.4-5 provides the March 2011 water table map for 100-NR-2. A groundwater mound at least 1 meter high creates the potential for radial flow in the southernmost part of 100-NR-2. The water table beneath the rest of the area was nearly flat in March 2011 when the river stage was higher than normal for that time of year. The river stage can change daily (plus or minus 1.5 meters) and seasonally (plus or minus 2.4 meters) for sustained periods, which changes the saturated zone thickness and causes flow reversals (Section 1.1 of PNNL-16891, Hanford 100-N Area Apatite Emplacement: Laboratory Results of Ca-Citrate-PO4 Solution Injection and Sr-90 Immobilization in 100-N Sediments). In 2011, the river stage peaked in late May and early June, and remained high into early July. Water levels in well 199-N-2, 170 meters from the river, rose more than 1.5 meters with a lag time of a few days. Water levels in 199-N-34, 500 meters from the river, rose more than 0.5 meter with a lag time of approximately two months. The changes affected groundwater flow directions. Section 2.4.9 provides more information about groundwater flow.

The 100-KR-4 pump-and-treat system began injecting treated water into wells between the 100-K and 100-N Areas. The injections changed the direction of groundwater flow in the southern part of 100-NR-2 in 2011.

Vertical hydraulic gradients are difficult to measure in the unconfined aquifer at 100-NR-2. 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 2011—within measurement error. The screen depths differ by approximately 5 to 6 meters.

### 2.4.1 Strontium-90

The majority of the strontium-90 remaining in the subsurface of 100-NR-2 is in the vadose zone above the aquifer. Strontium-90 tends to sorb to sediment grains, so its rate of transport in groundwater is slower than the groundwater flow rate. The relative rate of the velocity of strontium-90 to groundwater is approximately 1 to 100.

Soil data have been collected from wells and borings at the 116-N-1 (1301-N) and 116-N-3 (1325-N) LWDFs, and 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 E. This contaminated layer is thickest beneath the LWDFs (up to 12.2 meters) and thins toward the Columbia River (1.5 to 6.1 meters). Strontium-90 concentrations in soil near the LWDFs decrease with distance and depth. 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 between 2000 and
2005, and contaminated concrete and soil were removed to a depth of 4.5 to 6.5 meters depending on location. The sites were backfilled in 2006 (Section 4.1 of CVP-2002-00002, *Cleanup Verification Package/Clean Closure Report for the Soil Column of the 116-N-3 Trench and 100-N-63:1 Pipeline*; Section 3.1 of CVP-2006-00004, *Cleanup Verification Package/Clean Closure Report for the Soil Column of the 116-N-1 Crib and Trench*).

Strontium-90 concentrations in soil samples collected from the wells and borings farther from the LWDFs along the 100-NR-2 shoreline indicate that the majority of strontium-90 is in the top of the Ringgold Formation unit E and the bottom of the Hanford formation. The water table near the Columbia River is in the top of the Ringgold Formation unit E during low river-level conditions (late July through March), but the water table can rise up into the Hanford formation when river levels are elevated (April to June). This causes the strontium-90 contamination to smear vertically within the areal extent of the plume (Section 1.1 of PNNL-16891). The majority of the contamination in soil along the Columbia River is in the immediate vicinity of the original apatite permeable reactive barrier, between wells 199-N-123 and 199-N-121 (Section 5.2 of 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 the groundwater have varied little over the years because of the way strontium and strontium-90 behave in the environment (Figures 2.4-6 and 2.4-7). The plume currently has nearly the same areal extent and shape as it had in 1996, before the startup of the 100-NR-2 pump-and-treat operations. 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 of 8 pCi/L. Concentrations in several wells and aquifer tubes exceeded the DOE’s derived concentration standard of 1,100 pCi/L. Concentrations exceeding 100 pCi/L are limited to the upper approximately 3 meters of the aquifer (Section 2.4.1 of PNNL-16436, *Hanford Site Groundwater Monitoring for Fiscal Year 2006*). Wells monitoring the base of the unconfined aquifer or in the Ringold upper mud unit are essentially free of strontium-90 contamination (that is, it is either not detected or is at levels barely above detection limits).

DOE estimates that the amount of strontium-90 discharged to the ground in 100-N, corrected for radioactive decay through 2010, is approximately 1,325 Ci (DOE/RL-2008-46-ADD5). In planning documents for remediation of the 116-N-1 and 116-N-3 crib and trench sediments (BHI-00368, *Data Quality Objectives Workshop Results for 1301-N and 1325-N Characterization*), it was estimated in 1995 that approximately 560 Ci of the strontium-90 inventory would be removed by the remedial action. Based on these estimates, approximately 850 Ci (corrected for radioactive decay through 2010) of the strontium-90 inventory remains. Of the inventory remaining, approximately 99 percent is absorbed on the soil in the vadose zone and upper aquifer, and 1 percent is in the groundwater (Section 1.1 of PNNL-16891).

The 116-N-3 LWDF was in use from 1983 through 1991. The highest concentration at this site in 2011 was 3,320 pCi/L in a characterization sample from the top of the aquifer at new characterization well 199-N-188, which was drilled through the former crib. Concentrations declined sharply with depth in this well (to 338 pCi/L at 3 meters below the shallowest sample).

Strontium-90 levels in well 199-N-81 near the 116-N-3 LWDF have declined since the late 1990s (Figure 2.4-8). A high water table in 2011 did not create a large increase in strontium-90 concentrations in 199-N-81 in the fall 2011 sample. Delayed effects may become evident in 2012.
The 116-N-1 LWDF was in use from 1963 to 1985. Strontium-90 concentrations in 199-N-67 show no obvious long-term decline, but concentrations vary in relation to water levels (Figure 2.4-9). Water levels were higher beneath 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. Therefore, when the water table rises beneath the former LWDFs, strontium-90 from the vadose zone is remobilized, and the concentrations in groundwater increase.

Well 199-N-187 was drilled through the 116-N-1 LWDF in 2011. Characterization samples show that strontium-90 concentrations decline sharply with depth. At the water table, concentrations were 17,300 and 13,700 pCi/L in duplicate samples. At 1.8 meters below the water table, the concentration was 8,100 pCi/L; at 3.5 meters below the water table, the concentration was 1,600 pCi/L.

Seven wells downgradient from the 116-N-LWDF show increasing strontium-90 concentrations since the pump-and-treat system was shut down in 2006. These wells are as follows:

- Former extraction wells 199-N-75, 199-N-103A, 199-N-105A, and 199-N-106A (Figure 2.4-10)
- Wells 199-N-14, 199-N-67, and 119-N-76 downgradient from the 116-N-1 LWDF
- Well 199-N-119, located near one of the most contaminated portions of the shoreline

The strontium-90 concentration in former extraction well 199-N-105A increased four-fold in 2011. This increase may have been caused by a high water table and changes in groundwater flow directions.

The increases are partially attributable to a rebound effect after pump-and-treat operations ceased. However, some of the wells exhibited higher concentrations in 2011 than in 1996, before the pump-and-treat system was started, and concentrations increased four-fold in well 199-N-105A in 2011. The increase in well 199-N-105A may have been caused by the high water table in June 2011, which mobilized strontium-90 from contaminated sediments in the lower vadose zone. Another explanation is that the increases reflect a change in groundwater flow directions because of the groundwater mound in the southern part of 100-NR-2, caused by 100-KR-4 injection wells. Future groundwater monitoring will determine whether the changes persist and whether they are linked to changes in the river stage.

The highest strontium-90 concentrations in soil and groundwater along the Columbia River are found near the original apatite permeable reactive barrier and immediately downriver to the northeast. This area is the focus of increased monitoring and remediation activities. Figure 2.4-11 depicts the strontium-90 concentrations at the 100-NR-2 shoreline in the area affected by the original apatite barrier.

Figure 2.4-12 shows the effects of the original apatite barrier on strontium-90 concentrations (as represented by gross beta activity). Following initial injections in 2006, the barrier helped to reduce strontium-90 concentration in its immediate vicinity, including the wells within the barrier itself, on both sides of the injection wells on each end of the barrier, and the monitoring wells downgradient from the barrier.

Figure 2.4-12 also includes one well upgradient of the barrier; 199-N-46 has shown a decrease in strontium-90 concentrations. While most locations remain at 90 percent reduction in strontium-90 since injections began in 2006, some areas appear to be candidates for additional apatite treatment (Section 2.4.8.2). Concentrations in all but two monitoring points are below 1,000 pCi/L. Well 199-N-123 exhibited a strontium-90 increase to 1,770 pCi/L in September, and aquifer tube NVP2-116.0 showed an increase to 1,100 pCi/L in August. Concentrations subsequently decreased at both sites. The increase at well 199-N-123 was caused by the upstream barrier extension injections in September 2011. Variability in concentration is affected by the depth of well completion and local geology; but, overall, the values are
well below pre-treatment levels. Effects of the apatite barrier are discussed in greater detail in DOE/RL-2012-02.

Strontium-90 concentrations in aquifer tubes are consistent with those seen in monitoring wells. Levels greater than the drinking water standard are present only above approximately 115 meters in elevation (that is, the top 2 to 3 meters of the aquifer), so this is where most of the aquifer tubes are screened. 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 that the adjacent areas along the river shore will also be free of strontium-90.

The only strontium-90 detections in aquifer tubes outside the area where the strontium-90 plume intersects the Columbia River (Figure 2.4-6) are at aquifer tube cluster C7934/35/36. These tubes are in the engineered fill around the 1908-N Outfall, which indicates that outfall construction created a preferential pathway in the fill. The potential sources of strontium-90 contamination at this location are from the 105-N Reactor Building/Fuel Storage Basin, the 1909-N Waste Disposal Valve Pit, the 107-N Basin Recirculating Cooling Facility, the 1304-N Emergency Dump Tank, the 1300-N Emergency Dump Basin, and/or other associated structures (Section 4.2 of SGW-49370, Columbia River Pore Water Sampling in 100-N Area, December 2010).

### 2.4.2 Nitrate

A nitrate plume (Figure 2.4-13) lies under the former 116-N-1 and 116-N-3 LWDFs, under portions of the southwestern 100-N Area (the reactor and associated buildings), and extends to the Columbia River below well 199-N-21. The 2011 plume has a more limited extent to the southwest than in previous years because of the impact of treated water entering the aquifer through 100-KR-4 injection wells in this region. The highest concentrations (>100 mg/L) are observed beneath the 116-N-1 LWDF. The highest concentration in 2011 was 394 mg/L in well 199-N-67 in January. The concentration dropped sharply to 55.8 mg/L in September 2011. Nitrate was not documented as a waste source disposed to the LWDFs, but the sites are implicated as the primary nitrate source based on the persistent plume beneath them.

Figures 2.4-14 and 2.4-15 provide nitrate trend plots for wells near the former 116-N-1 and 116-N-3 LWDFs, respectively. At both sites, nitrate concentrations were high in the mid to late 1980s, declined sharply in the early 1990s, and increased between 2002 and 2010. Concentrations decreased in 2011. Continued monitoring will show whether the decrease will persist.

Figure 2.4-16 shows the nitrate concentrations for three wells near the 120-N-1 Percolation Pond. (Note that well 199-N-59 went dry and was replaced by well 199-N-165 in 2008.) Nitrate concentrations at this location were very low when the facility was in use, but began to increase in the mid-1990s. Concentrations in groundwater increased between 2010 and 2011. During the 120-N-1 Percolation Pond’s period of use from 1977 to 1990, only low levels of nitrate (approximately 1 mg/L) were detected in the pond’s effluent stream (Section 2.4.4 of DOE/RL-96-39, 100-NR-1 Treatment, Storage, and Disposal Units Corrective Measures Study/Closure Plan). These factors suggest the pond was not the source of the nitrate plume in this region. However, the distribution of the contaminant implicates the pond as its source.

Well 199-N-18 has anomalously low nitrate concentrations related to chemical reduction and biodegradation of hydrocarbons (Section 15.2.3 of DOE/RL-2010-11). The lower concentrations are caused by the chemical reduction of nitrate from the biodegradation of petroleum hydrocarbons near the wells (Section 2.4.3). Other chemical constituents and parameters that support the interpretation of
chemical reduction in and around 199-N-18 include low dissolved oxygen, lower pH, detectable nitrite,\(^1\) and elevated concentrations of iron and manganese.

Nitrate concentrations are highest in the upper part of the unconfined aquifer. Wells 199-N-69 and 199-N-70, screened near the bottom of the aquifer, consistently have lower concentrations than the adjacent, shallow wells. Well 199-N-80, screened in the Ringold upper mud unit, also has concentrations below the drinking water standard.

Nitrate concentrations in aquifer tubes in southwestern 100-NR-2 exceeded the drinking water standard of 45 mg/L in 2010 and in January 2012 (sampling delayed from fall 2011).

### 2.4.3 Petroleum Hydrocarbons

Petroleum hydrocarbon from a 1960s diesel fuel tank spill (site code UPR-100-N-17) continues to be detected in 100-NR-2 groundwater. The full nature and extent of subsurface hydrocarbon impacts in the UPR-100-N-17 waste site have not been determined (WCH-490, \textit{UPR-100-N-17: Bioventing Pilot Plant Performance Report}). During the drilling of well 199-N-173, vertical profile samples were collected from the vadose zone and groundwater. If present in large enough quantities, the diesel in groundwater is found in the very top of the aquifer or floating on top of the water table (Section 4.4 of DOE/RL-2011-25, \textit{Calendar Year 2010 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump-and-Treat Operations, and 100-NR-2 Groundwater Remediation}). The petroleum hydrocarbon plume in groundwater (Figure 2.4-17) is confined to a relatively small region and is centered on well 199-N-18, with a concentration of 7,700 µg/L in 2011. This is a substantial decrease from the 2010 value of 420,000 µg/L. Fewer wells detected petroleum hydrocarbons in 2011 than in 2010. This reduction may be partly attributable to the high-volume bioventing test on the vadose zone that Washington Closure Hanford performed in 2010 and 2011, summarized in Section 2.4.8.3. Introduction of large amounts of air may have temporarily displaced the diesel in the vicinity of the well screens. Additional testing and monitoring are planned for 2012.

\[\text{The diesel plume in 100-NR-2 has a limited extent. It stems directly from spills in and around the former 166-N Tank Farm facility.}\]

In 2011, DOE continued passive remedial actions to remove free product from well 199-N-18 in accordance with the interim action ROD (EPA/541/R-99/112). 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 two 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 2.4-1 shows the results of this remediation activity since it began in 2003. Removal of product from well 199-N-18 continued in 2011.

As part of the RI/FS process, well 199-N-183 was drilled to replace 199-N-18 as a monitoring well (Section 4.7 of DOE/RL-2008-46-ADD5). This decision was made for two reasons: (1) the low water level in well 199-N-18 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 (Section 6.1.4 of DOE/RL-2011-01). Well 199-N-18 was kept for continued product removal because that particular process is not affected by the residual smart-sponge material on the well casing.

\(^1\) The presence of nitrite (NO\(_2^–\)) is indicative of a reducing environment because this compound is rapidly converted to nitrate (NO\(_3^–\)) in the presence of oxygen.
Aquifer tubes near wells 199-N-173 and 199-N-96A along the 100-NR-2 shoreline are sampled for petroleum hydrocarbons. In 2011, two of four aquifer tubes sampled near the intersect of the plume and the Columbia River showed detections of total petroleum hydrocarbon-diesel (Figure 2.4-17). These samples were collected in mid-September 2011 when the river level was low. Diesel contamination is more likely to be upwelling into the river under these conditions because groundwater flows into the river.

### 2.4.4 Tritium

The source of the tritium in groundwater at 100-NR-2 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. When effluent was discharged to the 100-N Area LWDFs, tritium was highly mobile and migrated through the vadose zone with the wastewater. Because it is part of the water molecule, tritium does not sorb to sediment grains.

In 2011, all tritium concentrations in 100-NR-2 groundwater were below the 20,000 pCi/L drinking water standard. At concentrations below the drinking water standard, the plume currently covers the area beneath the 116-N-1 and 116-N-3 LWDFs and extends to the Columbia River shoreline (Figure 2.4-18). The highest tritium concentration in 2011 was 16,500 pCi/L in well 199-N-32. Figure 2.4-19 shows tritium concentrations declining in wells 199-N-14 and 199-N-32 near the 116-N-1 and 116-N-3 LWDFs. The tritium plume has diminished since 1991, when effluent discharge to the 116-N-3 LWDF ceased, because of radioactive decay, advection, and dispersion (Figure 2.4-7).

Unlike strontium-90, tritium occurs 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. The tritium concentration in well 199-N-80, completed in a confined aquifer in the Ringold Formation, was 13,000 pCi/L in 2011 (unchanged from 2010).

### 2.4.5 Chromium

Chromium was present in the effluent discharged to the 116-N-1 LWDF, but was never detected in samples of the effluent waste stream (Section 3.1.1.4 of DOE/RL-90-22, RCRA Facility Investigation/Corrective Measures Study Work Plan for the 100-NR-1 Operable Unit, Hanford Site, Richland, Washington). The dangerous waste discharged to the LWDFs collectively made up only 0.002 percent of the total volume of waste, 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 levels in wells monitoring the unconfined aquifer were low when the facility was in use. Sodium dichromate was only used in 100-NR-2 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 (such as zircaloy) in the fuel and facility (Section 4.3.4 of DOE/RL-2008-46-ADD5). The chromium fraction of the sodium dichromate used in the 100-N Area was approximately 24,704 kilograms. Given the mobility and nonsorbing nature of chromium in solution, the high continuous discharge rates and high temperatures 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 (Section 4.3.4 of DOE/RL-2008-46-ADD5).

Continued monitoring of wells in 100-NR-2 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. The 100-N RI/FS borehole samples were taken from the vadose zone, Hanford formation, Ringold Formation, and from the Ringold Formation upper mud unit at several locations. Sampling results will be addressed in the 100-N RI report.
One well in the 100-NR-2 had dissolved (filtered) chromium concentrations above the drinking water standard of 100 µg/L. Well 199-N-80, which was completed in a thin, water-bearing zone in the Ringold upper mud unit, had a filtered chromium concentration of 200 µg/L in 2011, consistent with previous results. Attempts to drill other wells into this water-bearing zone were unsuccessful, indicating it is not laterally continuous.

### Chromium concentrations above the 100 µg/L drinking water standard occur in only one well in 100-NR-2. Most wells show chromium levels near the detection limit.

A down-hole camera survey performed in 2001 showed visible corrosion along the length of the well screen (33.7 to 42.7 meters deep) in well 199-N-80. 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 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. Soil and groundwater samples were taken from wells drilled near 199-N-80 as part of the RI/FS process.

In 2011, chromium continued to be detected in well 199-N-74, increasing to a maximum of 34 µg/L. Samples collected during drilling of new well 199-N-189 (see Figure 2.3-1 in Section 2.3 for location) had hexavalent chromium concentrations ranging from 29 to 39 µg/L. Hexavalent chromium contamination from 100-KR-4 migrated inland while the 100-K-2 Trench was in use and a groundwater mound was present. A portion of the plume has migrated northward into 100-NR-2. Figure 2.3-4 in Section 2.3 illustrates the chromium plume in 100-KR-4. DOE will continue to monitor well 199-N-89 and other wells in this region for chromium in 2012.

Total and hexavalent chromium concentrations were near or below detection limits in 100-NR-2 aquifer tube samples in 2011. All were below the 10 µg/L ambient water quality standard.

### 2.4.6 Sulfate

Wastewater from the former 120-N-1 Percolation Pond introduced sulfate and sodium into 100-NR-2 groundwater (Figure 2.4-20). The highest sulfate concentrations in 2011 were in wells 199-N-72 and 199-N-73, where results exceeded the 250 mg/L secondary drinking water standard at least once in 2011. Wells downgradient (north and northwest) from the Percolation Pond also had elevated sulfate levels, but concentrations were below the standard. Several wells near the 116-N-3 LWDF also have elevated sulfate concentrations. The contamination beneath this facility 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 (Section 15.2.5 of DOE/RL-2010-11).

Well 199-N-172, in the northern part of the sulfate plume, also had concentrations above the secondary drinking water standard in 2011 (261 mg/L). This was an order of magnitude higher than in 2010, and the change may relate to the enhanced bioventing test conducted upgradient of the well (Section 2.4.8.3).

### 2.4.7 Manganese and Iron

Manganese and iron concentrations are elevated in some 100-NR-2 wells, but originated from well screens or aquifer sediments, not from waste sites. The high concentrations are observed primarily in areas affected by petroleum hydrocarbon contamination. Biodegradation of the organic contaminant
creates chemically reducing conditions in the aquifer, increasing the solubility of manganese, iron, and some other metals found in aquifer sediments or well screens and casings.

Eight wells in the region of the current diesel plume had manganese concentrations exceeding the secondary drinking water standard of 50 µg/L in 2011. The highest concentration in 2011 in a filtered sample was 7,870 µg/L in 199-N-18, which was lower than the peak value in 2010. This well also had the highest filtered iron concentration, 33,600 µg/L. The secondary drinking water standard for iron is 300 µg/L.

Well 199-N-16 also has elevated levels of manganese and iron. This well shows the effects of diesel degradation from three separate diesel spills that occurred in the area of the well in 1987. In 2007 and 2010, this well had detectable levels of total petroleum hydrocarbon-diesel; it did not have detectable levels in 2008, 2009, or 2011.

Well 199-N-32, which is not near diesel contamination sites, also continued to show elevated manganese (485 µg/L) and iron (316 µg/L) in 2011. These metals are probably a result of screen corrosion, which was noted during a 2001 borehole camera survey.

Manganese and iron concentrations were elevated in numerous aquifer tubes in 2011. Tubes in southwestern 100-NR-2 are affected by petroleum hydrocarbon contamination and related chemical reduction effects. Tubes located northeast are affected by injection of chemicals for the apatite barrier (Section 2.4.8.2).

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

2.4.8 CERCLA Groundwater Activities

CERCLA groundwater activities in 100-NR-2 in 2011 included progress on an RI/FS and interim groundwater remediation of the strontium-90 in groundwater.

Wells and constituents monitored for 100-NR-2 are defined in the following documents:


The CERCLA sampling is conducted mainly in September, with selected wells monitored in March. During 2011, three wells were not sampled as scheduled (Appendix A).

#### 2.4.8.1 Remedial Investigation/Feasibility Study

DOE issued an RI/FS work plan (DOE/RL-2008-46-ADD5) and sampling and analysis plan (DOE/RL-2009-42, *Sampling and Analysis Plan for the 100-N Decision Unit Remedial Investigation Feasibility Study*) for 100-N in March 2011 and December 2010, respectively.
In 2011, eight boreholes were drilled and completed as wells as part of the RI. Soil and water samples were collected from each of the boreholes during drilling. Data collected as part of this effort will better define the extent of contamination in the vadose zone, groundwater, and groundwater plumes. The upcoming RI/FS report will provide detailed results. This information will be used to make decisions for remediation of waste sites and groundwater.

2.4.8.2 Groundwater Remediation

A groundwater pump-and-treat system operated from 1995 until March 2006 in 100-NR-2 as part of the CERCLA interim action (EPA/541/R-99/112). 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 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 M-16-06-01, Federal Facility Agreement and Consent Order Change Control Form: Establish Interim Milestone M-016-14, Complete Construction of a Permeable Reactive Barrier at 100-N, in 2006, which required placing the pump-and-treat system in cold-standby status and constructing a permeable reactive barrier. Based on the treatability test results, the apatite technology showed promise as a remediation option. As a result, DOE proposed in June 2009 to amend the existing interim remedial action ROD for the 100-NR-1 and 100-NR-2 Operable Units (EPA/541/R-99/112) to include expansion of the existing apatite barrier to approximately 762 meters in the aquifer and the vadose zone. DOE issued DOE/RL-2009-54, Proposed Plan for Amendment of 100-NR-1/NR-2 Interim Action Record of Decision, in June 2010. Ecology approved the amendment to the interim action ROD in September 2010 to allow for expansion of the apatite barrier and permanent decommissioning of the 100-NR-2 pump-and-treat facility.

The amended, interim action remedy for strontium-90 (EPA, 2010, Amended Record of Decision, Decision Summary and Responsiveness Summary, 100-NR-1 and NR-2 Operable Units, Hanford Site – 100 Area, Benton County, Washington) includes the following actions:

- Extend the existing apatite permeable reactive barrier from 90 to approximately 760 meters.
- Apply one round of additional apatite injections within 5 years of all first-round apatite injections.
- Decommission the existing 100-NR-2 pump-and-treat building and components.
- Use monitored natural attenuation.
- Maintain existing institutional controls.
- Perform periodic groundwater monitoring.

The primary objective is protection of the Columbia River with a remedial action goal of 8 pCi/L for surface and groundwater. Successful implementation will support the goal of achieving a strontium-90 concentration of 8 pCi/L in the hyporheic and Columbia River water column by 2016. The interim remedial action is not intended to address aquifer restoration.
Implementation of the interim remedy apatite barrier expansion will be conducted under a revision to the 100-NR-2 Operable Unit 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 before full-scale expansion will initially move forward under two approved design optimization studies: the barrier expansion design optimization study (DOE/RL-2010-29), and the jet injection design optimization study (DOE/RL-2010-68, Jet Injection Design Optimization Study for 100-NR-2 Groundwater Operable Unit). DOE/RL-2012-02 provides detailed results of 2011 remediation activities.

**Original Apatite Permeable Reactive Barrier**

DOE agreed to construct and evaluate the effectiveness of a permeable reactive barrier for strontium-90 using apatite sequestration technology as part of the CERCLA RI/FS process, which is consistent with the interim remedial action ROD for the 100-NR-1 and 100-NR-2 Operable Units (EPA/541/R-99/112) and the 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 \([\text{Ca}_5(\text{PO}_4)_3(\text{F, Cl, OH})]\)) precipitation. Strontium-90 (and strontium) ions in groundwater substitute for calcium ions via cation exchange and eventually become trapped as part of the mineral matrix during apatite crystallization (Section 1.3 of PNNL-16891).

The original apatite treatability test site covers approximately 90 meters along the Columbia River shoreline (Figure 2.4-2). A total of 45 monitoring points are associated with this site, including injection/barrier wells, monitoring wells, and aquifer tubes. A total of 16 wells comprise the actual permeable reactive barrier. Four monitoring wells are parallel to the barrier between the river and the injection/barrier wells. Two pilot test sites (PT#1 and PT#2) are at each end of the barrier (around the two end injection/barrier wells) and contain smaller diameter monitoring wells surrounding the individual end injection/barrier wells.

**Gross beta concentrations have declined 90 percent three years after injections of apatite-forming chemicals ceased.**

Strontium-90 contamination in the 100-N Area is primarily absorbed to sediments by ion exchange (99 percent absorbed and 1 percent in solution in the groundwater) in the lower vadose zone and upper portion of the unconfined aquifer. Although primarily absorbed, some strontium-90 is mobilized by seasonal water level increases that remove strontium-90 from sediments not previously in contact with groundwater (PNNL-16891). DOE injected apatite-forming solutions into the Hanford and Ringold formations over a period of 3 years (from 2006 through 2008). Performance monitoring at the existing apatite barrier was performed twice in 2011, with high river stage sampling in May and June, and low river stage sampling in November. Since injections ceased in July 2008, strontium-90 and gross beta concentrations have declined steadily in the sampled wells, with very few exceptions. As of November 2011, the strontium-90 and gross beta values were considerably less in all wells and aquifer tubes monitored along the barrier than before the injections started. All of the wells have shown an approximately 90 percent decline in gross beta from the measured pre-injection values, meeting established test criteria. However, concentrations remain above the 8 pCi/L drinking water standard (remedial action goal).
Figure 2.4-11 provides the strontium-90 contours for the apatite permeable reactive barrier. Figure 2.4-12 shows the gross beta\textsuperscript{2} concentrations in the most contaminated portion of the 100-N shoreline. The scale on Figure 2.4-12 is logarithmic to make it easier to see the 90 percent decrease that has occurred in the treated wells and monitoring well 199-N-122. This set of four wells consists of a monitoring well (199-N-122) and two injection wells (well 199-N-162 screened only in the Ringold Formation, well 199-N-144 screened across the Hanford formation and Ringold Formation), and one monitoring well located behind the barrier (199-N-46, screened in the top of the unconfined aquifer). All four wells showed high strontium-90 concentrations following the injections in 2008. The high-concentration apatite injection solution had a higher ionic strength than groundwater. When the fluid was initially injected, it temporarily mobilized cations and anions, causing their concentrations in groundwater to increase. Over time, the concentration of gross beta began to decline, which is most evident in injection well 199-N-162. The injection wells show more fluctuation in gross beta values, but all four wells show much lower concentrations of gross beta than concentrations before injections in 2008. Well 199-N-46, which has historically had high levels of gross beta, is starting to slowly trend downward since treatments began.

Concentrations of strontium-90 and gross beta began to increase slightly in 2010 (Figure 2.4-12). This trend was occurring in more locations in 2011. Additional injections are needed in the existing permeable reactive barrier, based on data presented in the two reports on the initial low-concentration and high-concentration injections (PNNL-17429, Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injections for In Situ Strontium-90 Immobilization; PNNL-19572, 100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization, Final Report) and the follow-up report on barrier performance progress (PNNL-20252, 100-NR-2 Apatite Treatability Test: An Update on Barrier Performance). These additional injections are discussed in further detail in DOE/RL-2012-02.

Injections for the existing barrier will occur as budget and schedule allow within the next few years. The planned jet injections in the vadose zone should satisfy the retreatment needs in the near term. Semiannual performance monitoring (high and low river stages) will continue for the existing barrier until those injections occur, at which time a revised performance monitoring schedule will be initiated.

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\textit{Apatite barrier extensions have increased the length of 100-N Area shoreline treated to sequester strontium-90, from 90 to approximately 290 meters.}

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\textbf{Extension of Apatite Permeable Reactive Barrier}

Apatite barrier extensions were installed in fall 2011 and included injecting wells along an additional 100 meters on each end of the original barrier. DOE performed the work under a design optimization study (DOE/RL-2010-29) and an upcoming remedial design/remedial action work plan.

The injections were performed using a two-step process, where the deeper Ringold Formation wells are injected first and then the overlying Hanford formation wells are injected second. These staggered injections overlay each other and maximize the coverage in the upper unconfined aquifer and lower vadose zones. The formulation for these injections was the high-concentration calcium-citrate-phosphate solution amendment that was tested in 2008.

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\textsuperscript{2} Strontium-90 is a beta-emitter. Gross beta concentrations are approximately two times the strontium-90 concentrations.
The goals of the study were as follows (DOE/RL-2010-29):

1. Refine the application of high-concentration calcium-citrate-phosphate solution over a large scale.
2. 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.
3. Test the new well design installed under DOE/RL-2009-32 to evaluate the adequacy of injection solution delivery to the target zone.
4. 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.
5. Determine whether 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.
6. Further evaluate the high-concentration calcium-citrate-phosphate solution impact on the release of strontium-90 and other metals from previously untreated sediments to groundwater.
7. Evaluate whether the permeable reactive barrier can achieve up to a 90 percent reduction in strontium-90 flux to the Columbia River.

The first five objectives were adequately tested; to date, they have been met (DOE/RL-2012-02). The sixth objective is being tested in 2012 as samples are collected to determine how long the release of strontium-90 and other metals occurs after injections. Initial samples were collected for one month after injections, with the first set collected immediately after injections ceased, the second set collected after two weeks, and the third set collected after one month. At the end of a month, the strontium-90 and metal levels were almost back to pre-injection levels. The spring 2012 sampling event will happen more than six months after the end of 2011 injections. The last objective will require the collection of data over the next few years to determine whether the 90 percent reduction of strontium-90 has occurred in the permeable reactive barrier monitoring wells.

Other Strontium-90 Treatment Technologies

Several different types of strontium-90 treatment technologies are being evaluated at 100-NR-2 in addition to the current permeable reactive barrier. Several types of treatment are needed to treat the entire zone of contamination effectively. The existing barrier has treated groundwater and the lower vadose zone, but it has not treated the upper vadose zone and near-shore riparian zone. No additional work on these technologies occurred in 2011. The following reports provide additional information on other technologies that have been investigated previously:

- **Jet Injection** – SGW-47062, *Treatability Test Report for Field-Scale Apatite Jet Injection Demonstration for the 100-NR-2 Operable Unit*
- **Infiltration Gallery** – PNNL-20322, *100-NR-2 Apatite Treatability Test: Fall 2010 Tracer Infiltration Test*
- **Phytoextraction** – PNNL-19120, *100-N Area Strontium-90 Treatability Demonstration Project: Phytoextraction Along the 100-N Columbia River Riparian Zone – Field Treatability Study*

2.4.8.3 Deep Vadose Zone Remediation

In situ bioremediation was chosen as the remedial technology for addressing petroleum contamination in selected subsurface areas at 100-N Area. Bioremediation uses naturally-occurring bacteria in the soil to remove contaminants from the vadose zone or aquifer. To enhance the population of bacteria, oxygen is added by forcing air through the vadose zone soils, a process known as bioventing.
Washington Closure Hanford conducted a bioventing pilot test at the UPR-100-N-17 waste site between February 2010 and May 2011 (WCH-490). The pilot test included collection of baseline measurements in the vadose zone at seven bioremediation wells, a respirometry test to determine bacterial oxygen use, an air injection test to determine radius of influence, and a 6-month operational test. Results from the pilot testing indicate that the technology is a promising method of remediating hydrocarbon contamination in the deep vadose zone. The data from the pilot test will support the design of full-scale bioventing systems for UPR-100-N-17 and similar waste sites.

2.4.9 RCRA Facility Monitoring

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. Sections 2.4.1 and 2.4.4 discuss monitoring results for radionuclides. 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-NR-2 RCRA units.

2.4.9.1 116-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 effluent contained small quantities of dangerous waste in addition to the large volume of radioactive waste. 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.

The direction of groundwater flow beneath the 116-N-1 LWDF changed in 2011 under the influence of groundwater injection in 100-KR-4 to the south and the high river stage. In March 2011, the river stage was higher than normal for early spring. The water table beneath the 116-N-1 LWDF sloped to the northeast at $3.5 \times 10^{-5}$, and estimates of the groundwater flow rate ranged from 0.01 to 0.13 meter per day. In September 2011, when the river stage was lower, the water table sloped to the northwest at $2.3 \times 10^{-3}$, and flow rate estimates ranged from 0.05 to 0.84 meter per day (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 LWDF (Appendix B). No changes to the monitoring network are planned until implementation of an integrated groundwater monitoring program (CERCLA, RCRA, and AEA) for 100-NR-2 is completed.

This 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, 100-N Pilot Project: Proposed Consolidated Groundwater Monitoring Program. 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”).
Upgradient and downgradient wells are scheduled for sampling twice each year for RCRA contamination indicator parameters (that is, 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 2011, and there were no critical mean exceedances.

### 2.4.9.2 120-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 of corrosive, nonradioactive waste from 1977 to 1990. Both facilities have been remediated and backfilled.

Both of these units 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 (waste management area) 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 Percolation Pond and 120-N-2 Surface Impoundment. Well 199-N-77 is screened at the base of the unconfined aquifer, and statistical comparisons are not performed on data from this well. During 2011, 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).

New 100-KR-4 injection wells south and west of 1324-N/NA affected groundwater flow in 2011 (Figure 2.4-5). In March 2011, the hydraulic gradient sloped toward the northeast at $5.9 \times 10^{-4}$, and estimated flow rates ranged from 0.01 to 0.22 meter per day. In September 2011, the gradient sloped to the east-northeast at $9.1 \times 10^{-4}$, and flow estimates ranged from 0.02 to 0.34 meter per day. The groundwater monitoring network was designed for a northwestern flow direction. The network should be evaluated for revision in conjunction with development of an integrated groundwater monitoring program for 100-NR-2 and changes in the water table observed in 2011. 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 785 µS/cm at least once in 2011. 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).

**Total organic carbon concentrations exceeded the critical mean value at the 120-N-1 site in 2011. The contamination is not from the RCRA facility, and DOE is investigating its source.**

The average total organic carbon concentration exceeded the critical mean value of 860 µg/L in well 199-N-165 in September 2011, and was above the limit of quantitation of 1,000 µg/L. Confirmation samples were collected in November 2011, and the results were higher than the September samples.
Because there is no record of organic waste discharged to these facilities, it is believed the exceedance was not caused by releases from 1324-N/NA. DOE informed Ecology of the exceedance and recommended that additional sampling be performed to determine the source of the elevated total organic carbon. Plans are underway to perform this sampling in 2012 and will include all five RCRA wells for this location and two additional nearby 100-KR-4 wells. Several additional analytes have been added to the sampling event for all wells. No other critical mean exceedances occurred during 2011.

Specific conductance increased sharply in wells 199-N-72, 199-N-77, and 199-N-165 in September 2011. A similar increase was seen in 2010 in well 199-N-72. The changes were caused by increases in calcium, sodium, nitrate, sulfate, and other ions. The cause of the change is unknown. This will also be investigated by the additional 2012 sampling.

2.4.9.3 116-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 of liquid effluent from 1983 through 1991. The effluent contained small quantities of dangerous waste in addition to the large volume of radioactive waste. 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 2011 sloped to the north-northwest at $5.1 \times 10^{-4}$, with the groundwater flow rate estimated between 0.01 and 0.19 meter per day (Appendix B). Water levels in September 2011 were unusually high beneath the 116-N-3 LWDF as the effects of high river stage in May and June reached the inland monitoring wells. The gradient sloped toward the east-northeast at $8.0 \times 10^{-4}$, and flow estimates ranged from 0.02 to 0.30 meter per day.

The 116-N-3 LWDF 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 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-NR-2 is completed.

All five wells in the RCRA network were sampled as planned during 2011, twice for RCRA contamination indicator parameters (that is, pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters.

Average specific conductance values in downgradient well 199-N-41 continued to exceed the critical mean value of 520 µS/cm in 2011, which is a continuation of previous exceedances noted from 1999 through 2010. 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.
### Table 2.4-1. Hydrocarbon Product Removal from Well N-18 (2003 to 2011)

<table>
<thead>
<tr>
<th>Year</th>
<th>Product Removed (gram)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>~1,200&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Estimate provided per information given in table note; data records lost when original work package was lost in the field.</td>
</tr>
<tr>
<td>2004</td>
<td>3,475</td>
<td>Changed out twice per month.</td>
</tr>
<tr>
<td>2005</td>
<td>780</td>
<td>Changed approximately every two months.</td>
</tr>
<tr>
<td>2006</td>
<td>1,370</td>
<td>Changed every two months.</td>
</tr>
<tr>
<td>2007</td>
<td>1,294</td>
<td>Changed every two months.</td>
</tr>
<tr>
<td>2008</td>
<td>920</td>
<td>Changed every two months.</td>
</tr>
<tr>
<td>2009</td>
<td>1,380</td>
<td>Changed approximately every two months.</td>
</tr>
<tr>
<td>2010</td>
<td>225.5</td>
<td>Changed only twice prior to June 2010; smart sponge broke apart in well. No removal for second half of 2010.</td>
</tr>
<tr>
<td>2011</td>
<td>500</td>
<td>Changed every two months.</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>11,414.5 g (approximately 11.41 kg) removed through end of 2011</strong></td>
</tr>
</tbody>
</table>

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<sup>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.</sup>

<sup>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 kilogram per month; therefore, an estimate is provided for the 3 months missing in 2003.</sup>
Figure 2.4-1. Facilities and Groundwater Monitoring Wells in 100-NR-2
Figure 2.4-2. Groundwater Monitoring Wells in the Original Apatite Permeable Reactive Barrier
Figure 2.4-3. Groundwater Monitoring Wells in the Upriver Extension—Apatite Permeable Reactive Barrier
Figure 2.4-4. Groundwater Monitoring Wells in the Downriver Extension—
Apatite Permeable Reactive Barrier
Figure 2.4-5. 100-NR-2 Water Table, March 2011
Figure 2.4-6. Average Strontium-90 Concentrations in 100-NR-2, Upper Part of Unconfined Aquifer, 2011
Figure 2.4-7. Changes in 100-NR-2 Plume Areas

Figure 2.4-8. Strontium-90 and Water Level Trend in Well 199-N-81
Figure 2.4-11. Average Strontium Concentrations in the 100-N Area, Apatite Permeable Reactive Barrier Study Area, Upper Part of Unconfined Aquifer, 2011
Figure 2.4-12. Gross Beta Trends in Wells near Apatite Barrier
Figure 2.4-13. Average Nitrate Concentrations in 100-NR-2, Upper Part of Unconfined Aquifer, 2011
Figure 2.4-14. Nitrate Trends in wells 199-N-2 and 199-N-67 near the 116-N-1 LWDF

Figure 2.4-15. Nitrate Trend in Well 199-N-32 near the 116-N-3 LWDF
Figure 2.4-16. Nitrate Trends in Wells near the 120-N-1 Percolation Pond

Replicate data averaged.
Figure 2.4-17. Total Petroleum Hydrocarbon-Diesel Concentrations in 100-NR-2, Upper Part of Unconfined Aquifer, Summer/Fall 2011
Figure 2.4-18. Average Tritium Concentrations in 100-NR-2, Upper Part of Unconfined Aquifer, 2011
Figure 2.4-19. Tritium Trends in Wells 199-N-14 and 199-N-32

- **199-N-14**
- **199-N-32**
- **DWS**

Replicate data averaged

Tritium, pCi/L

Collection Date

Jan-87  Jan-89  Jan-91  Jan-93  Jan-95  Jan-97  Jan-99  Jan-01  Jan-03  Jan-05  Jan-07  Jan-09  Jan-11
Figure 2.4-20. Average Sulfate Concentrations in 100-NR-2, Upper Part of Unconfined Aquifer, 2011