5  100-KR

This chapter presents information for the 100-KR groundwater interest area, which includes the 100-KR-4 OU and an adjacent region to the east. This chapter includes an overview, a discussion of CERCLA- and AEA-related groundwater activities conducted in 2016, and a summary of 2016 groundwater monitoring results.

5.1  Overview

Groundwater in 100-KR was contaminated by waste releases associated with past operations of the KE and KW Reactors and from associated support facilities. At the end of 2016, 56 percent of the waste sites were classified as closed, interim closed, no action, or not accepted or rejected. Removing contaminants from the vadose zone eliminates secondary sources of contamination that could migrate to groundwater and reduces the risk of direct exposure at the surface.

Table 5-1 lists key facts about 100-KR. Additional details about 100-KR history, waste sites, and hydrogeology are provided in Chapters 1 and 3 of the 100-K RI/FS (DOE/RL-2010-97, Remedial Investigation/Feasibility Study for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units). Waste sites known or suspected to have contributed to groundwater contamination include 183-KE and 183-KW head house tank farms, 116-KE-1 and 116-KW-1 gas condensate cribs, 116-KE-3 and 116-KW-2 fuel storage basin (FSB) cribs/reverse wells, 116-K-1 Crib, 116-K-2 Trench, and 118-K-1 Burial Ground.

Characterization beneath the footprint of the former K East FSB (i.e., UPR-100-K-1) confirmed that historical releases did impact groundwater in that area. Figure 5-1 shows the locations of key features in 100-KR along with groundwater sample locations used during 2016. Section 1.5 provides plume mapping details, including descriptions of terms in figure legends (e.g., Type 1 control point).

The unconfined aquifer in 100-KR ranges from 5.2 m to more than 32 m (17.1 to 105 ft) thick. This aquifer is primarily present in the Ringold unit E sand and gravel (Figure 5-2). This unit is overlain by the gravels and interbedded sand and silt of the Hanford formation, which comprise the bulk of the vadose zone. The vadose zone ranges from less than 1 m (3.3 ft) thick near the Columbia River to 32 m (105 ft) thick inland. The uneven surface of the silt- and clay-rich RUM forms the bottom of the unconfined aquifer. Contaminant concentrations are generally highest within the uppermost portion of the aquifer near the water table; however, mobile contaminants (e.g., Cr(VI)) have been detected over the entire aquifer thickness, particularly near source areas.

The natural groundwater flow direction in 100-KR is generally to the northwest toward the Columbia River, which forms a discharge boundary for the unconfined aquifer. Operation of P&T systems as an interim remedial action for Cr(VI) changes the groundwater flow direction and velocity. These changes are expressed as depressions and mounds in the water table, affecting the flow direction (Figure 5-3). Larger mounds (e.g., those produced by the combined discharges from the KR4 and KX P&T systems near the middle of the 116-K-2 Trench) create conditions of radial flow away from the mound. This creates local diversion of groundwater flow direction away from the natural patterns. Groundwater farther inland of the 100-K Area generally flows to the north and northeast toward the 100-N and 100-D Areas. The flow direction and apparent velocity in this inland area are somewhat uncertain due to sparse groundwater elevation measurements in the area.
Table 5-1. 100-KR at a Glance

**Reactor operations:** KE Reactor, 1955 to 1971; KW Reactor, 1955 to 1970

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Water Quality Standard</th>
<th>Maximum Concentration</th>
<th>Plume Area&lt;sup&gt;a&lt;/sup&gt; (km&lt;sup&gt;2&lt;/sup&gt;)</th>
<th>Shoreline&lt;sup&gt;b&lt;/sup&gt; (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hexavalent chromium</td>
<td>48/10 µg/L</td>
<td>330 µg/L (199-K-111A)</td>
<td>0.11/1.7&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0/311</td>
</tr>
<tr>
<td>Tritium</td>
<td>20,000 pCi/L</td>
<td>730,000 pCi/L (199-K-207)</td>
<td>0.12</td>
<td>0</td>
</tr>
<tr>
<td>Nitrate</td>
<td>45 mg/L</td>
<td>75.3 mg/L (199-K-185)</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>Strontium-90</td>
<td>8 pCi/L</td>
<td>164 pCi/L (199-K-200)</td>
<td>0.03</td>
<td>0</td>
</tr>
<tr>
<td>Carbon-14</td>
<td>2,000 pCi/L</td>
<td>40,100 pCi/L (199-K-106A)</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>5 µg/L</td>
<td>9.48 µg/L (199-K-185)</td>
<td>0.10</td>
<td>0</td>
</tr>
</tbody>
</table>

**Remediation**

**Waste sites:** 56 percent complete.<sup>d</sup>

Groundwater interim action for hexavalent chromium 1997 through present.

Final record of decision is currently planned for December 2019.

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<sup>a.</sup> Estimated area at a concentration greater than the listed water quality standard.
<sup>b.</sup> Length of shoreline intersected by plume above listed water quality standard
<sup>c.</sup> Includes about 0.2 km<sup>2</sup> of the plume that has migrated into the 100-NR interest area. The groundwater plume area exceeding the interim groundwater target concentration of 20 µg/L at 100-K is 0.59 km<sup>2</sup>.
<sup>d.</sup> Sites with status of closed, interim closed, final closed, no action, not accepted, or rejected as of December 31, 2016.
2016 Sample Locations
- Groundwater Well
- Aquifer Tube
- Well Installed 2016
- KR-4 Extraction Well
- KR-4 Injection Well
- KW Extraction Well
- KW Injection Well
- KX Extraction Well
- KX Injection Well

Well prefix '160-' and '600-' omitted.

Figure 5-1. 100-KR Sampling Locations, 2016
Figure 5-2. 100-KR Geology

Figure 5-3. 100-KR Water Table, March 2016
Daily and seasonal fluctuations in the river stage also affect groundwater flow in 100-KR. As would be expected, longer term changes in the river stage produce more extensive and longer lived changes in the water levels, hydraulic gradient, and flow directions in the unconfined aquifer. Transport of river water into the aquifer during high river stage can lower contaminant concentrations in aquifer tubes and in some near-river wells. The highest river stage period in 2016 was observed in mid-April to early May, with the maximum river-stage elevation occurring on April 22, 2016 at an elevation of 121.08 m (397.23 ft). The seasonal high river stage that typically occurs in June through July was substantially reduced in 2016 due to continued regional drought conditions. The low river-stage period for 2016 was observed from late August through December.

Contaminants in the 100-KR unconfined aquifer were identified in the RI/FS and include chromium (total and Cr(VI)), tritium, nitrate, strontium-90, carbon-14, and TCE. Figure 5-4 shows how the plume areas have changed since 2003. Chromium in groundwater at some locations has historically been and continues to be measured as total chromium (in filtered and/or unfiltered aliquots) instead of (or in addition to) Cr(VI). Anthropogenic chromium in groundwater at 100-KR is understood to be present as Cr(VI), so total chromium in filtered aliquots and Cr(VI) are discussed as Cr(VI) for purposes of this report.

On May 16, 2016, the KW P&T system was shut down to initiate a rebound study. By January 2016, all groundwater monitoring locations associated with the KW P&T system exhibited Cr(VI) concentrations below the 20 µg/L interim remedial action groundwater target concentration. A SAP (DOE/RL-2016-42, Sampling and Analysis Plan for KW Pump and Treat System Rebound Study) was prepared to evaluate the potential for contaminant concentrations to remain below cleanup levels and determine if continuing secondary source material exists in the deep vadose zone by measuring the amount of rebound in Cr(VI) concentrations. For 2016, contaminant plumes depicted in the vicinity of the KW Reactor use the maximum detected concentrations of a specific constituent instead of the annual average used in previous years. In the case of Cr(VI), a pre- and post-KW P&T shutdown was used to show conditions as they existed during P&T operations and the maximum extent of rebound observed after the shutdown.
Discussion of observations made during the course of the rebound study is included in the following sections as appropriate.

5.2 Hexavalent Chromium – Low River Stage

Cr(VI) is a mobile contaminant at 100-KR, and its presence resulted from historical releases of two different types of wastewater contaminated with Cr(VI). The first type of release included spills, leaks, and limited intentional discharge of concentrated sodium dichromate dihydrate solutions used as feed chemicals for conditioning reactor cooling water. The second type of release included spent reactor cooling water from retention basin leaks and intentional discharges to the 116-K-1 Crib and 116-K-2 Trench. The plumes from these sources are associated with three general areas: (1) a plume originating at or near the 183-KW head house chemical storage tank farm and extending riverward, (2) a plume originating at or near the 183-KE head house chemical storage tank farm and extending riverward, and (3) a plume originating at the 116-K-1 Crib and 116-K-2 Trench and extending radially away from those sites. These plumes have been reshaped and/or dissected by operation of the groundwater P&T systems at 100-K (Figures 5-5 and 5-6 during low river stage; Figures 5-7 and 5-8 during high river stage), which have substantially reduced the observed groundwater Cr(VI) concentrations since 1996. Based on aquifer tube sampling and near-river wells, the extent of Cr(VI) at the river shore continues to decline.

In addition to measurements collected from the near-river environment at aquifer tubes, river shore seeps at the 100-KR Area were also sampled in 2016. The seeps are discrete areas of groundwater discharge to the ground surface near the river shore that appear during the low river stage and are most apparent during the falling portion of the river-stage cycle. Seeps represent a surface expression of groundwater leaving the aquifer in areas where the groundwater elevation remains higher than the river elevation for some period of time. At the 100-KR Area, four seeps were sampled during 2016, all during September and October. The seep measurements provide useful information regarding near-shore surface water conditions. For information purposes, the results of Cr(VI) measurement of the 2016 seep samples are posted on the Cr(VI) plume maps for both low and high river stages in this report.

The Columbia River is a discharge boundary for groundwater beneath the 100-KR Area. When river stage is low (generally from September through March [Figure 5-9]), groundwater flows readily toward the river and discharges into the river through areas of interaction in the hyporheic zone where the aquifer meets the surface water. During the high river stage period, the groundwater elevation increases in response to the change in boundary condition, and the gradient toward the river decreases somewhat. The low river-stage period has been selected for collecting water samples from the aquifer tubes placed into the near-river environment at 100-KR. During 2016, six aquifer tube locations exceeded the 10 µg/L ambient water quality criterion. The inferred distribution of Cr(VI) at 100-KR during the low river-stage period is shown in Figures 5-5 and 5-6.

Cr(VI) concentrations greater than 10 µg/L are observed in isolated wells east and northeast of the 100-K Area: 699-87-55, 699-77-54, and two wells farther east in the 100-FR groundwater interest area (Figure 1-3). The origin of this contamination is unknown, but it may be related to historical releases in the 100-K or 100-D Areas.
2016 Hexavalent Chromium Plume, September - December

- Well Sampled in 2016
- Well Sampled in 2015
- Well Sampled in 2014
- Type 1 Control Point
- Type 3 Control Point

- Seep
- October 2016 Groundwater Contour
- Groundwater Interest
- Area Boundary
- Former Operational Boundary
- Roads

Hexavalent Chromium Plume
- Concentration ≤10 µg/L
- Concentration 10-20 µg/L
- Concentration 20-40 µg/L
- Concentration 40-80 µg/L
- Concentration >80 µg/L


Figure 5-5. 100-KR Cr(VI) Plume, KE and KW Reactor Vicinity (2016 Low River Stage)

Figure 5-6. 100-KR Cr(VI) Plume, 116-K-2 Trench and 100-N Area (2016 Low River Stage)

Figure 5-7. 100-KR Cr(VI) Plume, KE and KW Vicinity (2016 High River Stage)

Figure 5-8. 100-KR Cr(VI) Plume, 116-K-2 Trench and 100-N Area (2016 High River Stage)
5.2.1 K West Associated Plume

In recent years the K West Cr(VI) plume has been depicted as a narrow band with relatively high concentration starting near the 183-KW head house and extending toward the river. Since 2013, river-stage effects have had less influence on plume geometry than in earlier years. Instead, changes between high and low river stage appear to reflect P&T progress made over the calendar year. Figure 5-10 shows the high and low river-stage Cr(VI) plumes for 2013 through 2015. At the end of 2015, all groundwater wells (including extraction and monitoring wells) in the vicinity of the KW P&T system exhibited concentrations below the interim remedial action groundwater remediation target of 20 µg/L. A statistical trend analysis was performed using data collected from June 2011 through March 2016 to confirm that groundwater Cr(VI) concentrations were exhibiting downward trends. The results of this analysis indicated that it was appropriate to conduct a Cr(VI) rebound test to assess the potential for a Cr(VI) concentration rebound due to potential continuing contribution from secondary sources in the PRZ and overlying vadose zone. The high river-stage Cr(VI) plume at K West (Figure 5-7), which for 2016 represents Cr(VI) data collected between January 1 and May 16, confirmed the trend analysis performed (DOE/RL-2016-42). These conditions supported the decision to shut down the KW P&T system on May 16, 2016.
Figure 5-10. 100-KR KW High and Low River-Stage Cr(VI) Plumes, 2013 through 2015
During the KW rebound study, groundwater samples were collected on a schedule based on the relative proximity of monitoring locations to the apparent secondary source areas. Monitoring locations within the source areas were sampled the most frequently (e.g., every other week), and locations more distant from the source areas were sampled less frequently (e.g., monthly, bimonthly, quarterly). Over the course of the rebound study, wells and aquifer tubes located between the KW Reactor and the Columbia River exhibited very little change in concentration of Cr(VI) (including filtered total chromium). The K West plume depiction in Figure 5-5 shows the maximum concentration of Cr(VI) (measured as Cr(VI) or total chromium in filtered samples) detected during the rebound study period at all monitoring locations. The extent of the contamination (greater than 10 µg/L) downgradient of the reactor is attributed to the migration of low concentration Cr(VI) that existed between operating P&T wells and continues to migrate toward the river under natural flow conditions. The highest concentration downgradient of the reactor was 19.4 µg/L at well 199-K-132. Figure 5-11 shows trend plots of monitoring well locations downgradient of the KW Reactor. In the top panel of Figure 5-11, wells 199-K-132, 199-K-138, 199-K-185, and 199-K-196 are the monitoring wells closest to the river. The bottom panel shows select wells immediately downgradient of the reactor.

Aquifer tubes in the vicinity of K West exhibited minimal change from previous years’ Cr(VI) concentrations. Aquifer tube 17-D exhibited 9.2 µg/L in a filtered total chromium sample; however, Cr(VI) concentrations reported at this aquifer tube were consistent with previous measurements. This was the largest reported value in aquifer tubes near K West.

The area between the KW Reactor and the 183-KW head house exhibited a much different rebound response. Prior to shutting off the KW P&T, the maximum concentration of Cr(VI) was 16 µg/L at well 199-K-137. Between June 1 and September 1, following KW system shutdown, wells 199-K-173 and 199-K-205 both increased from less than 15 µg/L to maximum concentrations of 56 and 48 µg/L, respectively. From September 1 through December 31, former extraction wells 199-K-137, 199-K-165, 199-K-173, and 199-K-205 and monitoring well 199-K-166 exhibited increases in Cr(VI) concentrations. Table 5-2 shows the initial concentrations of Cr(VI) prior to the KW P&T shutdown as well as the maximum rebound concentration detected as of December 31, 2016. These six locations exhibited increases ranging from 200 to 2,200 percent (21.9 µg/L to 168 µg/L) in Cr(VI) concentrations over a 7-month period. The rebound effects in Cr(VI) concentrations at these wells indicate that continuing contributions from secondary source material within the overlying vadose zone or PRZ exist and will continue to cause groundwater contamination above the DWS.

Based on the magnitude and locations of observed Cr(VI) rebound, it is likely that multiple areas of secondary source material within the vadose zone and/or PRZ exist between the reactor and the head house (Figure 5-5). Well 199-K-205, located at the 183-KW head house, with a maximum concentration of 3,280 µg/L in 2014, has shown dramatic decreases due to extraction efforts at this location. Since well 199-K-205 became an extraction well in September 2014, concentrations of Cr(VI) have decreased from 1,020 µg/L to 12 µg/L in May 2016. However, based on the observed concentration increase during the rebound study, secondary source material continues to feed the plume at this location. Likewise, at well 199-K-173 the observed increase at this location is similar to well 199-K-205, suggesting a similar condition to 199-K-205.
Figure 5-11. 100-KR Cr(VI) Data for Monitoring Wells Downgradient of the KW Reactor
Table 5-2. Cr(VI) Concentrations in Wells between the KW Reactor and the 183-KW Head House

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Well Purpose</th>
<th>Pre-Rebounda</th>
<th>Maximum Reboundb</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>199-K-137</td>
<td>Extraction well</td>
<td>13</td>
<td>40</td>
<td>+208%</td>
</tr>
<tr>
<td>199-K-165</td>
<td>Extraction well</td>
<td>7</td>
<td>28.9c</td>
<td>+313%</td>
</tr>
<tr>
<td>199-K-166</td>
<td>Monitoring well</td>
<td>1</td>
<td>23</td>
<td>+2,200%</td>
</tr>
<tr>
<td>199-K-173</td>
<td>Extraction well</td>
<td>6</td>
<td>98</td>
<td>+1,533%</td>
</tr>
<tr>
<td>199-K-205</td>
<td>Extraction well</td>
<td>12</td>
<td>180</td>
<td>+1,400%</td>
</tr>
</tbody>
</table>

a. The reported pre-rebound result was taken before the KW P&T system was shut off on May 16, 2016.
b. The reported maximum rebound result was taken between May 16, 2016 and December 31, 2016 for the top of the aquifer.
c. Reported result is a filtered total chromium measurement.

New wells 199-K-223 and 199-K-224 exhibit different conditions (Table 5-3). Well 199-K-224, which is located 86 m (282 ft) upgradient from well 199-K-173, exhibited 160 µg/L Cr(VI) in a characterization sample collected during drilling. However, over the course of the rebound study, concentrations of Cr(VI) collected at the water table ranged from 100 to 138 µg/L. Well 199-K-223, located upgradient of 199-K-224, exhibited concentrations of Cr(VI) consistently at or below 10 µg/L. It is possible that well 199-K-223 was affected by clean effluent water injected at well 199-K-206 and other injection wells. Elevated Cr(VI) observed at well 199-K-205 would not have had sufficient time to migrate from the vicinity of 199-K-205 over the rebound study time period. These condition will be further evaluated in the KW rebound study report, which is planned to be written and issued in FY 2018.

Along with samples collected at the water table, several wells were sampled at multiple depths within the well screened interval to better understand the vertical extent of contamination immediately downgradient of suspected secondary source areas. Wells 199-K-137, 199-K-165, 199-K-173, 199-K-205, and new wells 199-K-223 and 199-K-224 were all initially sampled on a bi-weekly schedule that included up to two additional samples collected at specific depths within the aquifer screened interval, using a low-flow purge and sample technique. With the exception of well 199-K-165, which exhibited low and slowly increasing Cr(VI) concentrations, and 199-K-223, which exhibited consistently low concentrations, these wells all exhibited increasing Cr(VI) greater than the interim action groundwater remediation target of 20 µg/L. Figures 5-12 and 5-13 show the average Cr(VI) concentration detected over the vertical profile samples collected at wells 199-K-205 and 199-K-224. The vertical distribution in well 199-K-205, suggests the contamination continues to leach from the PRZ (as evident from the maximum concentration at the water table) and is contaminated above the interim action groundwater remediation target at depth. The vertical distribution in well 199-K-224 suggests that in this area, the full thickness of the aquifer (27 m [90 ft]) is contaminated with Cr(VI) at levels above the 100 µg/L DWS for total chromium.
Table 5-3. CERCLA Wells Drilled During 2016

<table>
<thead>
<tr>
<th>Well Name (Well ID)</th>
<th>Purpose and Justification</th>
<th>Contaminant Observations</th>
<th>Construction Depth, m (ft) bgs</th>
<th>Drilled Depth, m (ft) bgs</th>
<th>Acceptance Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>199-K-223 (C9595)</td>
<td>KW P&amp;T Extraction well; targets Cr(VI) mass removal downgradient of the 183-KW head house. It was also placed in preparation for a potential soil-flushing activity to address secondary source material in the deep vadose zone.</td>
<td>Soil samples indicate copper and mercury above soil cleanup levels for groundwater protection (DOE/RL-96-17). Cr(VI) was detected at a maximum concentration of 45 µg/L in groundwater during drilling; however, subsequent samples have detection around &lt;10 µg/L.</td>
<td>53.9 (176.95)</td>
<td>54.1 (177.34)</td>
<td>9/13/2016</td>
</tr>
<tr>
<td>199-K-224 (C9596)</td>
<td>KW P&amp;T Extraction well; targets Cr(VI) mass removal downgradient of the 183-KW head house. It was also placed in preparation for a potential soil-flushing activity to address secondary source material in the deep vadose zone.</td>
<td>Soil samples indicate mercury above the soil cleanup level for groundwater protection (DOE/RL-96-17). Cr(VI) was detected at a maximum concentration of 160 µg/L in groundwater during drilling. Subsequent samples are further discussed in Section 5.2.1.</td>
<td>55.9 (183.29)</td>
<td>56.7 (185.89)</td>
<td>8/30/2016</td>
</tr>
<tr>
<td>199-K-225 (C9597)</td>
<td>KX P&amp;T Extraction well; targets Cr(VI) mass removal downgradient of the 183-KE head house. It was also placed in preparation for a potential soil-flushing activity to address secondary source material in the deep vadose zone.</td>
<td>Soil samples indicate total chromium above the soil cleanup level for groundwater protection (DOE/RL-96-17). Cr(VI) was detected at a maximum concentration of 2 µg/L in groundwater during drilling. Subsequent samples are further discussed in Section 5.2.2.</td>
<td>50.2 (164.69)</td>
<td>50.3 (165.15)</td>
<td>8/9/2016</td>
</tr>
<tr>
<td>199-K-226 (C9598)</td>
<td>KX P&amp;T Extraction well; targets Cr(VI) mass removal downgradient of the 118-K-1 Burial Ground.</td>
<td>Soil samples indicate total chromium above the soil cleanup level for groundwater protection (DOE/RL-96-17). Cr(VI) and tritium were detected at a maximum concentrations of 193 µg/L and 29,500 pCi/L, respectively, in groundwater during drilling. Subsequent samples are further discussed in Section 5.4.</td>
<td>44.9 (147.36)</td>
<td>45.4 (148.79)</td>
<td>10/20/2016</td>
</tr>
</tbody>
</table>

Figure 5-12. 100-KR Average Cr(VI) Concentration in Vertical Profile Samples at Well 199-K-205

Figure 5-13. 100-KR Average Cr(VI) Concentration in Vertical Profile Samples at Well 199-K-224
5.2.2 K East Associated Plume

For 2016, as with 2014 and 2015, the K East Cr(VI) plume is inferred to be the commingling of Cr(VI) contamination from the 116-K-1 Crib, 116-K-2 Trench, and the 183-KE head house (Figure 5-5), caused by operation of the KR4 and KX P&T systems and the apparent east-to-west groundwater gradient caused by the injection wells in this area.

In 2016, the K East plume extends from the 183-KE head house toward the Columbia River through the KE Reactor area (Figure 5-5). The apparent source is near the 183-KE head house chemical storage tank farm, similar to the condition observed at K West. In 2015, the K East Cr(VI) plume was inferred to extend northwest toward the 118-K-1 Burial Ground and wells 199-K-111A and 199-K-207. This apparent change is caused by the addition of KX P&T extraction well 199-K-225, with an average concentration of 16.7 µg/L and the increase in concentration at well 199-K-186. Also, for wells 199-K-221 and 199-K-222, the January 2017 concentrations were applied at both wells due to a change in the sample collection method to obtain water from the upper portion of the aquifer near the water table. It is still possible that contamination continues to migrate from the head house area towards the 118-K-1 Burial Ground. Monitoring wells are planned to be drilled in 2017 to better understand the plume distribution in this area. Upgradient (inland) of the 183-KE head house, well 199-K-187 had a maximum concentration of 5.3 µg/L (filtered total chromium) in 2016. This location has consistently had low concentrations and appears to define the inland extent of this plume.

Cr(VI) concentrations in the vicinity of 183-KE head house continue to exceed the groundwater remediation target. Well 199-K-36, located at the former 183-KE head house, has exhibited Cr(VI) concentrations ranging from 115 to 403 µg/L between 2011 and 2015. Over the course of 2016, concentrations dropped as low as 18 µg/L; however, by the end of 2016, concentrations had increased to 45 µg/L. Downgradient monitoring wells and extraction wells between the head house and the river show concentrations ranging from less than 10 µg/L to greater than 30 µg/L.

The Cr(VI) plume segment on the northeast side of the KE Reactor, which is inferred to be related to previous releases from the 116-K-1 Crib, 116-K-2 Trench, or possible releases from the 118-K-1 Burial Ground, continue to exhibit elevated Cr(VI) at a number of locations. In well 199-K-111A, Cr(VI) concentrations increased from 2015, ranging from 285 to 350 µg/L. Examination of the concentration time series for co-contaminants, however, continues to indicate that the Cr(VI) at this location is related to contamination that originated at the 116-K-2 Trench and moved westward coincidentally with tritium from the 118-K-1 Burial Ground. Along with these observation, new well 199-K-226, which is located downgradient of 199-K-111A, also showed elevated concentrations of both Cr(VI) and tritium.

5.2.3 116-K-2 Trench Associated Plume

The current Cr(VI) groundwater plume associated with the 116-K-2 Trench occurs in multiple, isolated plume segments at the 10 µg/L contour (Figure 5-6). This plume, which was initially inferred in the mid-1990s (see historical monitoring reports) as being continuous over the length of the 116-K-2 Trench, has been dissected by operation of the P&T systems. The Cr(VI) plume associated with the head end (southwest end) of the 116-K-2 Trench (e.g., wells 199-K-111A and 199-K-226) may be continuous with Cr(VI) originating at the 183-KE head house area and is discussed in Section 5.2.2.
A central plume segment exhibiting concentrations greater than 10 µg/L extends from the 116-K-2 Trench inland to well 199-K-193 (Figure 5-6). The highest concentrations in this plume segment occur in the immediate vicinity of the 116-K-2 Trench. Well 199-K-201, which was installed in 2010, has exhibited persistently elevated concentrations of Cr(VI). At the beginning of 2016, the maximum observed concentration at this well was 83.6 µg/L in a filtered total chromium sample. By the end of 2016, concentrations were as low as 28.5 µg/L. This is most likely caused by the pumping scheme at KX P&T extraction well 199-K-163. This well operated at reduced flows (95 to 114 L/min [25 to 30 gal/min]) instead of the potential 208 to 227 L/min (55 to 60 gal/min) for 75 percent of 2016 to allow the inferred stagnation zone between well 199-K-163 and downgradient KR4 and KX P&T extraction wells 199-K-115A, 199-K-161, and 199-K-212 to be drawn downgradient. Well 199-K-154, which is located upgradient from the 116-K-2 Trench and is an extraction well for the KX P&T system, continued to exhibit decreasing Cr(VI) concentrations, ranging from 21 to 39 µg/L in 2016. In 2015 Cr(VI) concentrations ranged from 34 to 40 µg/L. Operation of injection wells for the KR4 and KX P&T systems has further dissected the Cr(VI) plume in the central portion of the trench.

Along the river, aquifer tube measurements at all but one location were at or below detection limits in 2016, indicating the KR4 and KX P&T extraction wells located inland are providing capture of the Cr(VI) (Figure 5-6). There is an area of potential shoreline concern in the central Cr(VI) plume segment. Aquifer tube 22-D, which is located downgradient of KR4 P&T extraction well 199-K-114A, continued to exhibit an increase in Cr(VI) concentration in 2016 compared to 2015 (Figure 5-14). This observation along with a specific conductance greater than 200 µS/cm, higher than the typical river specific conductance, suggests that groundwater is continuing to discharge at this location. This condition will be further evaluated in the 2016 annual P&T report (DOE/RL-2016-68).

The northeastern portion of the 116-K-2 Trench plume extends northeast into the 100-NR-2 OU. Well 199-N-189 was not sampled in 2016; therefore, the 2015 value was used for the plume depictions. Well 199-K-182 (a KX system extraction well) continued to exhibit a downward trend in concentrations, ranging from 16 to 31 µg/L in 2016. Well 199-N-74, which is located 2 km (1.2 mi) from the end of the trench, exhibited an average filtered total chromium concentration of 46.2 µg/L in 2016. Cr(VI) concentrations in extraction wells downgradient of this plume segment near the Columbia River continued the 2015 decreasing trend in response to P&T system operation (Figure 5-15).

Cr(VI) continues to be detected in wells farther northeast within the footprint of 100-NR (Figure 5-6). This includes average filtered total chromium results above 10 µg/L at several wells (e.g., 199-N-41, 199-N-57, 199-N-27, and 199-N-81). The actual extent of the Cr(VI) plume in this region is uncertain due to the sparse quantity and frequency of measurements in nearby locations.

### 5.3 Hexavalent Chromium – High River Stage

As described in Section 5.1, the high river stage period in 2016 was observed in mid-April to early May, with the maximum river-stage elevation occurring on April 22, 2016 at an elevation of 121.08 m (397.23 ft) above NAVD88 at 100-K. The seasonal high river stage that typically occurs in June through July was substantially reduced in 2016 due to continued regional drought conditions.
Figure 5-14. 100-KR Cr(VI) Data for Aquifer Tube 22-D and Inland Extraction Wells 199-K-113A, 199-K-114A, and 199-K-161

Figure 5-15. 100-KR Cr(VI) Data for Wells 199-K-130, 199-K-131, and 199-K-148 (Near-River Extraction Wells in Northern Portion of 100-KR)
Coincident with the drought-induced river-stage behavior, groundwater in the 100-K Area also did not exhibit typical seasonal elevation transients. After examining the groundwater contaminant concentrations based on the river-stage elevation trends as well as the actual sample collection frequency for 2016, the same time period that has historically been identified as the typical high river-stage period was selected for 2016 data analysis (i.e., April 15 through July 31), with the exception of the K West plumes. Based on concentrations of Cr(VI) in groundwater samples collected during the 2016 high river-stage period, the distribution of plumes in 100-KR in early summer 2016 (Figures 5-7 and 5-8) are not dramatically different from those observed during the low river period (fall). During the high river stage, river water may intrude into the aquifer, causing displacement and/or dilution of the aquifer water in the near-shore environment. During 2016, the apparent bank storage condition was substantially reduced from previous years based on evaluation of groundwater elevation maps.

Due to increased pumping rates at groundwater extraction wells, particularly those riverward of the distal portion of the 116-K-2 Trench, groundwater gradient reversal near the river appears to have occurred at some locations. In particular, wells 199-K-112A and 199-K-129 exhibited specific conductance measurements consistently below 200 µS/cm during 2016 (Figure 5-16). This specific conductance is consistent with the influence of mixing of groundwater with river water. The Columbia River water typically exhibits specific conductance of 130 to 140 µS/cm. Inspection of the groundwater elevation contours for 2016 indicate that the P&T systems imposed hydraulic capture of groundwater along the affected shoreline over most of the year, consistent with the specific conductance observations. Cr(VI) concentrations observed in the aquifer tubes were deemed to be representative of the near-river boundary condition for plume interpolation in 2016.

Some inland wells (e.g., greater than 200 m [660 ft] from the river) exhibit transient increases in Cr(VI) concentration during periods of seasonal high groundwater elevation. An example of this effect is well 199-K-189, located near the KE Reactor (Figure 5-17). This well has consistently exhibited seasonal concentration transients that appear to be directly proportional to changes in groundwater elevation (i.e., as groundwater elevation rises, Cr(VI) concentration rises). This correlation indicates that this well may be located close to a secondary source in the vadose zone or PRZ.

5.4 Tritium

Tritium is mobile in 100-KR groundwater and is present at levels above the 20,000 pCi/L DWS. The major historical sources of tritium contamination included the following:

- Releases of reactor gas dryer condensate to the 116-KE-1 and 116-KW-1 Cribs (tritium activity concentrations up to $1 \times 10^{10}$ pCi/L in the condensate per HW-76258, Reactor Gas Drier Condensate Waste – Decontamination Studies)

- Release of FSB water to the 116-KE-3 and 116-KW-2 Cribs, and to UPR-100-K-1 (tritium activity concentrations up to $6 \times 10^{9}$ pCi/L in the basin water per WHC-EP-0877, K Basin Corrosion Program Report)

- Contaminated solid waste disposed at the 118-K-1 Burial Ground (tritium activity concentrations up to 13,400 pCi/g in deep vadose zone soil remaining after surface remediation per CVP-2013-00002, Cleanup Verification Package for the 118-K-1 Burial Ground)

Another source of tritium was the release of contaminated reactor cooling water to the retention basins, 116-K-1 Crib, and 116-K-2 Trench.
Figure 5-16. 100-KR Specific Conductance (2016 Low River Stage)
At 100-KR, seven wells had tritium concentrations exceeding 20,000 pCi/L in 2016: 199-K-106A, 199-K-111A, 199-K-189, 199-K-202, 199-K-207, 199-K-221, and new well 199-K-226. The highest measured tritium concentration in groundwater during 2016 (730,000 pCi/L) was in well 199-K-207, located within the footprint of the former 118-K-1 Burial Ground. The tritium distribution in groundwater in 2016 shows three plumes with concentrations above the DWS (Figure 5-18).

Groundwater near the 118-K-1 Burial Ground continued to exhibit changing tritium concentrations. In 2015 and 2016 tritium concentrations in well 199-K-111A increased from below the DWS to 379,000 pCi/L, then declined to 233,000 pCi/L in November 2016 (Figure 5-19). At well 199-K-207 (within the footprint of the 118-K-1 Burial Ground), tritium concentrations declined from 730,000 pCi/L in January 2016 to 400,000 pCi/L in October. New monitoring well and future KX system extraction well 199-K-226, located downgradient of 199-K-111A, exhibited tritium concentrations at 28,600 pCi/L during well development, showing migration of the tritium plume toward downgradient KX extraction wells. Tritium in well 199-K-157 (upgradient of well 199-K-207) remained below 3,000 pCi/L during 2016 (Figure 5-18). The known historical release points (e.g., 118-K-1 Burial Ground and 116-KE-1 Crib) may also be continuing secondary sources in the vadose zone and/or PRZ.
Figure 5-18. 100-KR Tritium Plume, 2016
A portion of the K East tritium plume appears to have originated at the 116-KE-1 Crib, with contribution from waste at the 118-K-1 Burial Ground (Figure 5-18). Well 199-K-189 (downgradient of the 116-KE-1 Crib) had a maximum tritium concentration of 47,500 pCi/L in 2016. Since the end of 2014, tritium concentrations rose steadily in well 199-K-189 but started to decline in 2016, suggesting plume migration from an upgradient secondary source. During the KW rebound study, tritium concentrations in K West were below the DWS at most monitoring locations. However, tritium concentrations at well 199-K-106A increased from 24,200 pCi/L in February to a peak concentration of 91,900 pCi/L by August (Figure 5-20). Along with tritium, carbon-14 and chloride both increased with the rise in the water table at this location. This transient indicates that contamination in the deep vadose zone at or near the 116-KW-1 gas condensate crib remains a continuing source of groundwater contamination. Tritium increased in downgradient monitoring well 199-K-204 to a maximum of 6,040 pCi/L by the end of 2016. This suggests that well 199-K-204 is at the head end of a migrating tritium plume originating from 116-KW-1.

Extraction wells for active Cr(VI) remediation also capture tritium, but because tritium is present primarily as tritiated water, it passes through the treatment system and is returned to the aquifer via inland injection wells. Based on the design of the P&T system, much of this water will be recaptured by the downgradient extraction wells, and the tritium will be recirculated and continue to decay. Tritium was detected in effluent water from the KW, KX, and KR4 P&T systems. The average effluent concentration of the KR4 P&T system for 2016 was 3,560 pCi/L, which is below the DWS. The tritium concentration in the effluent from the KX system was 3,543 pCi/L. Effluent samples from the KW system were not collected because the system was turned off for the rebound study. Tritium contamination is not currently reaching the river above the DWS (based on data from aquifer tubes).
Nitrate concentrations continued to exceed 45 mg/L in several 100-KR wells in 2016 (Figure 5-21). The nitrate observed in 100-KR is attributed primarily to oxidation of high concentrations of ammonia in reactor gas dryer condensate (i.e., up to 36,000 mg/L) that was discharged to the 116-KE-1 and 116-KW-1 Cribs. Additional nitrate contributions to groundwater may have come from sanitary waste drain fields at various locations in 100-KR.

Near K East, only well 199-K-207 had a maximum nitrate concentration above the 45 mg/L DWS equivalent in 2016, at 48.7 mg/L. Well 199-K-189, which is downgradient of the 116-KE-1 gas condensate crib, has exhibited an increasing trend since the end of 2014. However, at the end of 2016 the maximum concentration was still below the DWS at 43.4 mg/L.

During the rebound study at K West, three wells had nitrate concentrations above 45 mg/L (199-K-106A, 199-K-132, and 199-K-185, with maximum concentrations during 2016 of 70.8, 53.1, and 75.3 mg/L, respectively) (Figure 5-22). Well 199-K-106A, which increased in concentration in late 2015, continued that trend for most of 2016, exhibiting its maximum concentration in September. This increase along with increased tritium, carbon-14, and chloride indicate a continued release of contamination from the 116-KW-1 gas condensate crib, a known historical source of contamination. Well 199-K-204, which is located downgradient of 199-K-106A, saw a similar increase but was just below the 45 mg/L standard at 44.3 mg/L. Concentrations observed at wells 199-K-132 and 199-K-185 are most likely related to higher concentrations of nitrate previously observed at well 199-K-106A, which have migrated riverward toward the downgradient extraction wells.
Figure 5-21. 100-KR Nitrate Plume, 2016
Aquifer tubes C6241 and 17-D (downgradient from K West) historically exhibited nitrate concentrations above 45 mg/L but have been below that level since 2013 and 2011, respectively. During 2016, 17-D and 17-M exhibited a slight increase, but concentrations were below 30 mg/L. Seep SK-063-1 (near the K West nitrate plume) had a nitrate concentration of 1.6 mg/L in September. Nitrate concentrations in aquifer tubes and seeps may increase as the nitrate plume continues to migrate towards the river.

5.6 Strontium-90

Strontium-90 is a fission product generated within the reactor fuel during nuclear reactor operation. It was historically released during fuel failure events and resulted in contamination of reactor cooling water. Contaminated cooling water, along with irradiated fuel fragments, could be released to the 116-K-2 Trench under off-normal conditions, as well as to the reactor FSBs during discharge of irradiated fuel from the reactors. Cooling water contaminated by fuel rod failure fission products (including strontium-90) was held in the KE or KW retention basins and was subsequently discharged to the 116-K-2 Trench. The highest strontium-90 concentrations in groundwater are associated with historical releases from the FSBs and their associated drainage systems. The FSBs also contained cooling water contaminated with strontium-90. Discharges of reactor cooling water to the 116-K-2 Trench are apparent sources of strontium-90 in 100-KR groundwater. Strontium-90 has also been historically released to groundwater via discharges to the 116-KW-2 and 116-KE-3 FSB cribs and reverse wells, and by direct leakage from the 105-KE FSB (e.g., UPR-100-K-1 at the K East FSB).
Strontium-90 was detected in 30 monitoring wells and 6 aquifer tubes in 100-KR during 2016. Quantifiable activity concentrations in monitoring wells ranged from 0.86 pCi/L up to 164 pCi/L. Detections in aquifer tubes ranged from 0.96 up to 6.48 pCi/L.

In 2016, strontium-90 contamination in 100-KR groundwater was found in three localized plumes and several isolated wells at concentrations exceeding the 8 pCi/L DWS (Figure 5-23). These plumes are relatively small and are not inferred to extend to the Columbia River at levels above the DWS as contiguous plumes, except at the northeast end of the 116-K-2 Trench, where aquifer tube 22-M exhibited a maximum strontium-90 concentration of 6.48 pCi/L in 2016 (similar to the 6.36 pCi/L observed in 2015 and down from 7.16 pCi/L in 2014). This condition appears to represent downgradient migration of strontium-90 toward the river from the distal end of the trench.

Many of the wells monitoring the 116-K-2 Trench have detectable strontium-90, but most concentrations are below the 8 pCi/L DWS. The highest concentration during 2016 was 164 pCi/L at well 199-K-200 (Figure 5-24), which was drilled through the former trench near its proximal (southwest) end. Concentrations in other wells in the 116-K-2 Trench region were consistently less than 20 pCi/L. Downgradient wells 199-K-19, 199-K-20, 199-K-21, and 199-K-161 each had at least one result exceeding the DWS during 2016, showing the apparent downgradient migration of strontium-90 toward the river.

A high-concentration strontium-90 plume is present near the KE Reactor. The highest concentration portion of the plume formerly was represented by well 199-K-109A, with a concentration of 1,120 pCi/L the last time the well was sampled in 2008 and a historical maximum of 18,600 pCi/L. This well historically exhibited strontium-90 concentrations greater than 5,000 pCi/L from 1996 to 2000. The well was decommissioned to facilitate KE Reactor demolition activities. About 120 m (390 ft) directly downgradient from well 199-K-109A, strontium-90 concentration continued to increase in extraction well 199-K-141 to a maximum of 75 pCi/L by mid-2016 (Figure 5-25). The increased concentration in extraction well 199-K-141 indicates that part of the leading edge of the K East strontium-90 plume continued migrating downgradient in 2016.

Well 199-K-202, downgradient of the KE Reactor, helps delineate the strontium-90 plume in that area. This well has not detected strontium-90 to date, providing a bounding measurement for the high-concentration strontium-90 plume historically defined by decommissioned well 199-K-109A. It appears that the strontium-90 plume is migrating from the location of former well 199-K-109A toward extraction well 199-K-141. This plume movement is consistent with the current interpretation of groundwater gradient in this area. The decrease in strontium-90 concentration observed at well 199-K-109A was substantially faster than could be accounted for by radioactive decay, and the change is attributed to downgradient migration of the strontium-90 plume in the direction of extraction well 199-K-141.

Data from two wells near the 116-KE-3 and UPR-100-K-1 waste sites (leakage from the former K East FSB) show the presence of strontium-90 in groundwater. Samples collected from these two new wells during 2016 exhibited modest strontium-90 concentrations (i.e., 8.69 and 38.2 pCi/L maxima observed at wells 199-K-221 and 199-K-222, respectively). However, much higher concentrations were observed at well 199-K-222 located in the former FSB footprint during drilling in 2015. The reduced concentration in 2016 is attributed to a change in sample collection technique. The sample collection method has been revised to obtain water from the upper portion of the aquifer near the water table where the highest concentration was measured during drilling (4,000 pCi/L).
Figure 5-23. 100-KR Strontium-90 Plume, 2016
Figure 5-24. 100-KR Strontium-90 Data for Well 199-K-200 (Located in the Former 116-K-2 Trench)

Figure 5-25. 100-KR Strontium-90 Data for Wells 199-K-32A, 199-K-141, and 199-K-178 (Located Downgradient of the KE Reactor)
In 2016, three K West wells exhibited strontium-90 concentrations above the DWS (199-K-107A, 199-K-34, and 199-K-139) (Figure 5-26). At well 199-K-34, the maximum concentration of 41.5 pCi/L was slightly higher than the 33.8 pCi/L observed in 2015. The concentration at well 199-K-107A ranged from 12 to 26 pCi/L in 2016, an increase from 2015. The 2016 plume is inferred to be similar in size to the 2015 plume. The 2016 strontium-90 measurements indicate continued migration from the vicinity of well 199-K-107A (near the 199-KW-2 Crib/reverse well) toward nearby extraction wells (e.g., well 199-K-139). Fluctuating concentrations observed in well 199-K-107A are attributed to changes in water table elevation associated with shut down of the KW P&T system and performance of the associated rebound test. Concentrations are near detection limits in wells farther downgradient. Strontium-90 was not detected in 100-KR seep samples during 2016.

Figure 5-26. 100-KR Strontium-90 Data for Wells 199-K-107A, 199-K-34, and 199-K-139 (Located Downgradient of the KW Reactor)
5.7 Carbon-14

Most of the carbon-14 in 100-KR groundwater originated from historical discharges of reactor gas dryer regeneration condensate to the 116-KE-1 and 116-KW-1 gas condensate cribs. Carbon-14 in gas dryer condensate collected during operation ranged from $2.9 \times 10^8$ pCi/L at the KW Reactor to $1.04 \times 10^9$ pCi/L at the KE Reactor. The gas condensate stream contained tritium ranging from $3 \times 10^9$ pCi/L to $1 \times 10^{10}$ pCi/L and ammonia ranging from 9,000 to 36,000 mg/L (HW-76258).

In previous years, to estimate the extent of carbon-14 in groundwater more accurately, extrapolations of historical carbon-14 concentrations from KE well 199-K-30 and KW well 199-K-106A were evaluated. The highest residual carbon-14 concentrations in groundwater are associated with the KW Reactor, with an estimated maximum (derived from the extrapolation) of 39,500 pCi/L. The KE Reactor extrapolated concentrations are slightly lower, with an estimated maximum of 22,900 pCi/L. For the 2016 carbon-14 plume at the KW Reactor, the migrated point was removed due to similar concentrations occurring at well 199-K-204, which is located at the approximate location of the migrated value. For the KE East carbon-14, the migrated point based on well 199-K-30 was used.

Over the course of 2016 and the KW rebound study, concentrations of carbon-14 throughout most of the KW Reactor area remained consistent with previous years (Figure 5-27), ranging from 400 to 1,000 pCi/L at monitoring locations in the vicinity of the KW Reactor. Concentrations increased sharply, however, in wells downgradient of the 116-KW-1 gas condensate crib. Well 199-K-106A, which is located 32 m (105 ft) downgradient of 116-KW-1, had a maximum concentration of 40,100 pCi/L, similar to the historic maximum in 1997, which was used as the migrated concentration in previous annual reports (Figure 5-28). This release indicates that a secondary source below the 116-KW-1 Crib is a continuing source of carbon-14, along with nitrate and tritium.

Monitoring wells 199-K-204 and 199-K-185, and KW extraction well 199-K-132, located farther downgradient of 199-K-106A, showed similar concentration increases during 2016 (Figure 5-29). Well 199-K-204, which is immediately downgradient of well 199-K-106A, showed a similar in magnitude change in concentrations, but the increase started in June and peaked in September at a maximum concentration of 25,500 pCi/L. This increase is likely due to carbon-14 contamination migrating downgradient from the 116-KW-1 gas condensate crib.

A lower concentration carbon-14 plume exists in the K East region. It was formerly defined by wells 199-K-29 and 199-K-30, which have been decommissioned. In 2010, wells 199-K-29 and 199-K-30 had maximum concentrations of 3,120 and 6,900 pCi/L, respectively, which are above the DWS. These wells monitored conditions downgradient of the 116-KE-1 Crib. As with conditions near the KW Reactor, the carbon-14 plume near the KE Reactor appears to be migrating downgradient from the source area. The extrapolated concentrations likely exceed 20,000 pCi/L in the downgradient area where effective monitoring currently does not exist. The carbon-14 plume at K East may not lie completely within the capture zone of the operating KX extraction wells. Well 199-K-202 exhibited a carbon-14 concentration of about 2,000 pCi/L in 2016. Well 199-K-189, located between wells 199-K-202 and 199-K-203, exhibited a large range in carbon-14 concentrations from 163 to 2,480 pCi/L during 2016, exhibiting a decreasing trend from 2015.

Similar to the KW Reactor area, carbon-14 continued to be detected at relatively low concentrations in aquifer tubes near the KE Reactor area (below 500 pCi/L).
Figure 5-27. 100-KR Carbon-14 Plume, 2016
Figure 5-28. 100-KR Historic Carbon-14 Data for Well 199-K-106A

Figure 5-29. 100-KR Carbon-14 Data for Wells Downgradient of the 116-KW-1 Gas Condensate Crib
5.8 Trichloroethene

TCE continues to be detected in some 100-KR wells, primarily in the K West region (Figure 5-30). As with the other contaminant plumes at KW, the TCE plumes use the maximum concentration detected since the KW rebound study was initiated in May. Several wells exhibited TCE at concentrations above the 5 µg/L DWS in at least one sample in 2016. The highest concentrations in samples collected in 2016 were from wells 199-K-11, 199-K-185, and 199-K-190 (6.0, 9.48, and 5.92 µg/L, respectively) (Figure 5-31). Historical maximum concentrations were larger than currently observed (e.g., 35 µg/L at well 199-K-106A measured in 1995). The sources of TCE at 100-KR are likely related to the use of solvents during equipment maintenance activities, but specific TCE release points have not been identified. The TCE plume is poorly defined by the available measurements, and there are relatively few wells in the vicinity of the exceedance; this provides an element of uncertainty in the interpolation of plume contours. Unlike previous years, where the KW effluent concentration was applied at injection wells, measured values were taken over the course of the KW rebound study. These measurements are consistent with previous observations that the KW P&T has been injecting TCE at levels below the 5 µg/L DWS and has created a relatively dispersed TCE plume in groundwater near the KW Reactor (Figure 5-30).

TCE was detected in aquifer tubes 17-D and 17-M, located downgradient of the K West plume, at estimated concentrations around 1.0 µg/L. Seep SK-063-1, located riverward of well 199-K-132, had TCE at concentrations below 1.0 µg/L during 2016. Detection of TCE also occurred in aquifer tubes outside the primary K West plume at cluster C6236, C6237, and C6238. This condition is likely due to KW P&T operations and the injection of low concentration TCE into the injection wells. Similar concentrations are exhibited inland at monitoring wells 199-K-31 and 199-K-183.

5.9 CERCLA Remediation and Monitoring

CERCLA groundwater activities at 100-KR included groundwater sampling and analysis at monitoring well locations and the operation of three interim groundwater remediation systems focusing on removing Cr(VI) (Figure 5-1; Table A-5 in Appendix A). CERCLA groundwater sampling includes monitoring interim remedial actions for effectiveness and monitoring wells throughout 100-KR to track Cr(VI) and co-contaminants carbon-14, nitrate, strontium-90, TCE, and tritium. These constituents, which have been identified as groundwater COCs through the RI/FS process, may be captured and extracted incidentally by the interim remedial action P&T system. However, these constituents are not treated by the interim action and are, therefore, considered to be co-contaminants of the Cr(VI), which is the primary target of the interim action. Another contaminant related to historical reactor operations at 100-KR is technetium-99. In 2016, technetium-99 was detected in groundwater within 100-KR at concentrations consistently less than 100 pCi/L, which is much less than the DWS equivalent concentration of 900 pCi/L. Technetium-99 has not been identified as a COC at 100-K.

Petroleum hydrocarbons (measured as total petroleum hydrocarbons [TPH]) have been encountered in the vadose zone during drilling of wells 199-K-167 (decommissioned), 199-K-173, and 199-K-186. Low levels of petroleum hydrocarbons (all less than 100 µg/L of diesel, gasoline, kerosene, and motor-oil range hydrocarbons) were detected in groundwater during 2016. At well 199-K-23, located downgradient of the old KE underground fuel oil storage tank, a maximum concentration of 203 µg/L of TPH-motor oil was detected in early 2016. TPH-diesel range was also detected at a concentration of 139 µg/L. A second sample was collected at the end of 2016 that indicated nondetects for both contaminants. Detections of TPH were found at three locations downgradient of the KE Reactor and at seven locations near the KW Reactor. All detections were downgradient of the reactor underground fuel oil storage tanks.
Figure 5-30. 100-KR TCE Plume, 2016
Figure 5-31. 100-KR Trichloroethene Data for Wells 199-K-11, 199-K-185, and 199-K-190, Located in the Vicinity of the KW Reactor

The 100-KR aquifer tubes are generally scheduled for annual sampling in the fall. This sampling provides information about conditions near the river during the period of the most rapid movement of groundwater toward the river. Aquifer tubes provide samples of water from the near-river environment and hyporheic zone. Analysis of near-river samples is assumed to provide a representation of conditions in potential exposure points for aquatic organisms, although the aquifer tubes may not be completed within the biologically active portions of the hyporheic zone. In total, 109 sample trips were performed from 100-KR aquifer tubes during 2016 (Table A-6).

In 2016, 43 extraction wells and 19 injection wells were in use for P&T groundwater remediation operations. The three systems are capable of treating a combined total of more than 7.9 million L (2.1 million gal) of groundwater per day. The combined P&T systems in 100-KR removed 31 kg of Cr(VI) from groundwater in 2016. Since 1997, the P&T systems have removed 867 kg of Cr(VI) from the aquifer. Section 5.9.2 provides additional information, and DOE/RL-2016-68 provides details.

In 2016, four wells were drilled and constructed at 100-K to support ongoing remedial process optimization activities (DOE/RL-2013-36-ADD3, 100-KR-4 Groundwater Operable Unit Well Installation Sampling and Analysis Plan, Addendum 3: Wells 199-K-223, 199-K-224, 199-K-225, and 199-K-226). Table 5-3 lists the intended use and technical justification for all four wells, as well as any significant findings during or after drilling.
5.9.1 CERCLA Decision Documents and Plans

DOE submitted Draft A of an RI/FS (DOE/RL-2010-97) and proposed plan (DOE/RL-2011-82, Proposed Plan for Remediation of 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units) to EPA in 2011. EPA reviewed the documents in 2012, and DOE is conducting studies of contaminant sources. The final RI/FS report will present results of RI studies and evaluate alternatives for cleanup of the vadose zone and groundwater. Based on the observed efficacy of the P&T systems at the 100-KR-4 OU, it seems likely that the proposed plan for this OU will include P&T as a major element of a preferred alternative.

In December 2016, DOE finalized updates to the supporting interim remedial action documents. These included an operations and maintenance plan, RD/RAWP, and SAP. The RD/RAWP describes how the interim remedies are designed, installed, and operated to meet the remedial action objectives (RAOs) identified in the interim action ROD (EPA/ROD/RL-10-96/134). The groundwater monitoring described in DOE/RL-2013-29, Sampling and Analysis Plan for the 100-KR-4 Groundwater Operable Unit Monitoring, is designed to supersede all previous sampling document as well as track the changing conditions, the performance of the remedy, and the effectiveness of the interim remedial action in meeting performance criteria required by EPA/ROD/RL-10-96/134. The operations and maintenance plan (DOE/RL-2013-48, Operation and Maintenance Plan for the 100-KR-4 Pump and Treat Systems) describes the remedial system operation to meet remedy performance goals. The revised SAP will be implemented in 2017.

In May 2016, DOE finalized and issued the KW rebound study SAP (DOE/RL-2016-42). The purpose of this SAP was to define the sampling requirements for wells in the area affected by the KW P&T to assess the completion of the interim action. The original performance period was scheduled to end September 30, 2016. However, TPA-CN-0752, Tri-Party Agreement Change Notice Form: DOE/RL-2016-42, Sampling and Analysis Plan for KW Pump and Treat System Rebound Study, Rev. 0, signed on September 29, 2016, modified the sample requirements for some locations and extended the period of performance through the end of March 2017. The results of this effort through the end of 2016 are discussed in Sections 5.2 through 5.8.

5.9.2 Pump and Treat

An interim action ROD for the 100-KR-4 OU was issued in April 1996 (EPA/ROD/RL-96/134). One of the RAOs is to protect aquatic receptors in the Columbia River from groundwater contaminants. The interim action ROD included a preliminary estimated dilution factor of 1:1 for groundwater entering the Columbia River at the 100-K, 100-D, and 100-H Areas under the assumption that dilution of groundwater with river water is expected before the groundwater would reach the aquatic receptor point of concern within the river substrate. This established an operational target for Cr(VI) treatment system effluent at 20 µg/L. For purposes of managing the interim remedial action, the working assumption is that groundwater at 20 µg/L at onshore, near-river monitoring locations will achieve the surface water standard of 10 µg/L at the point where groundwater discharges to the river (EPA et al., 2009).

Since the interim action ROD was published, DOE has implemented three P&T systems to remediate Cr(VI) contamination in 100-KR-4 OU groundwater and to protect the Columbia River. All of the following systems operated in 2016. A total of 38 compliance and performance monitoring wells are identified for these systems:

- The original P&T system (KR-4) began operating in 1997 and focuses on contamination originating beneath the 116-K-2 Trench.
• The KX P&T system is focused on two areas: the northeastern end of the 116-K-2 Trench, where the Cr(VI) plume historically migrated toward 100-NR-2; and near the KE Reactor facilities. The KX system began operating in 2009.

• The KW P&T system began operating in 2007 and focuses on the Cr(VI) plume at the KW Reactor facilities. The system was shut down on May 16, 2016 to initiate a rebound study (Section 5.2.1).

Groundwater P&T systems will continue to operate in the 100-KR-4 OU. These systems provide protection of the Columbia River from release of Cr(VI)-contaminated groundwater that would cause an exceedance of the 10 µg/L surface water quality criterion and help maintain hydraulic containment of remaining Cr(VI) plumes.

As of December 2016, 43 extraction wells and 19 injection wells were available for service (Figure 5-32). Combined, the three P&T systems are capable of treating about 7.9 million L (2.1 million gal) of groundwater per day, and removed 31 kg of Cr(VI) from groundwater in 2016. Since 1997, the 100-KR-4 P&T systems have removed 867 kg of Cr(VI) from the aquifer. DOE/RL-2016-68 provides additional details.

Under the current configuration, the 100-KR-4 P&T systems are demonstrating progress toward the interim RAOs (Table 5-4; Figure ES-6). Operation of the systems and containment of the plumes address the first and third RAOs defined by the ROD:

• RAO #1: Protect aquatic receptors in the river bottom from contaminants in groundwater entering the Columbia River.

• RAO #3: Provide information that will lead to a final remedy.

As defined in the RD/RAWP (DOE/RL-2013-33, Remedial Design/Remedial Action Work Plan for the 100-KR-4 Groundwater Operable Unit Interim Action), one of the steps that will be taken to evaluate the completion of the interim action is a rebound study. At the beginning of 2016, the concentrations of Cr(VI) at the extraction and monitoring wells in the vicinity of the KW P&T were below the interim action remediation target. As discussed in Section 5.9.1, a rebound study SAP (DOE/RL-2016-42) was written to determine whether contaminant concentrations will remain below cleanup levels when the aquifer is no longer under the influence of active remediation. The results of the study through the end of 2016 are discussed in Sections 5.2 through 5.8.

Table 5-5 summarizes Cr(VI) concentrations in compliance and performance evaluation wells during 2016. In 2016, 17 of the 38 compliance and performance evaluation wells exceeded the 10 µg/L Cr(VI) surface water quality criterion, and 6 wells exceeded 20 µg/L. Plume containment and institutional controls meet the second RAO:

• RAO #2: Protect human health by preventing exposure to contaminants in the groundwater.

During 2015, two characterization borings were advanced near the KE Reactor, and both were completed as groundwater monitoring wells. Groundwater monitoring provides ongoing information regarding the nature, extent, and dynamic behavior of the groundwater plumes at the 100-KR-4 OU.
Figure 5-32. 100-KR P&T Well Locations
### Table 5-4. 100-KR-4 P&T Summary

#### 2016 100-KR-4 P&T Systems

<table>
<thead>
<tr>
<th>P&amp;T System</th>
<th>KW(^a)</th>
<th>KR4</th>
<th>KX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design capacity (L/min [gal/min])</td>
<td>758 (200)</td>
<td>1,136 (300)</td>
<td>2,273 (600)</td>
</tr>
<tr>
<td>Extraction wells (post-realignment)(^b)</td>
<td>11(^c)</td>
<td>11</td>
<td>21</td>
</tr>
<tr>
<td>Injection wells (post-realignment)(^b)</td>
<td>4(^c)</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Average flow rate (L/min [gal/min])</td>
<td>1,229(^d) (325)</td>
<td>1,116 (295)</td>
<td>3,121 (825)</td>
</tr>
<tr>
<td>Volume treated (million L [million gal])</td>
<td>242 (64)</td>
<td>580 (153)</td>
<td>1,636 (432)</td>
</tr>
<tr>
<td>Cr(VI) mass removed (kg)</td>
<td>2.9</td>
<td>2.5</td>
<td>25.6</td>
</tr>
<tr>
<td>Average Cr(VI) influent concentration (µg/L)</td>
<td>12.4</td>
<td>4.8</td>
<td>16.9</td>
</tr>
<tr>
<td>Average Cr(VI) effluent concentration (µg/L)</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>

#### All 100-KR-4 P&T Systems, 1997-2016

| Volume treated (million L [million gal]) | 21,297 (5,622) |
| Cr(VI) mass removed (kg) | 867 |

---

\(a\). The KW P&T system placed on standby in May 2016 for rebound test.

\(b\). The number of extraction and injection wells does not include those that are not operational.

\(c\). KW extraction and injection wells were disconnected from the KW P&T system in May 2016 for rebound test.

\(d\). Average flow rate while KW P&T system was operating prior to standby.

---

### Table 5-5. Summary of Cr(VI) Concentrations in 100-KR-4 OU Compliance and Performance Evaluation Wells for 2016

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Current Use</th>
<th>Maximum Cr(VI) (µg/L)</th>
<th>Well Name</th>
<th>Current Use</th>
<th>Maximum Cr(VI) (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>199-K-18</td>
<td>Monitoring well</td>
<td>3.7</td>
<td>199-K-144</td>
<td>KX Extraction well</td>
<td>32</td>
</tr>
<tr>
<td>199-K-19</td>
<td>Monitoring well</td>
<td>3.9*</td>
<td>199-K-145</td>
<td>KR4 Extraction well</td>
<td>8</td>
</tr>
<tr>
<td>199-K-20</td>
<td>Monitoring well</td>
<td>4.58</td>
<td>199-K-146</td>
<td>KX Extraction well</td>
<td>9</td>
</tr>
<tr>
<td>199-K-32A</td>
<td>Monitoring well</td>
<td>17*</td>
<td>199-K-147</td>
<td>KX Extraction well</td>
<td>17</td>
</tr>
<tr>
<td>199-K-114A</td>
<td>KR4 Extraction well</td>
<td>6</td>
<td>199-K-152</td>
<td>KX Extraction well</td>
<td>32</td>
</tr>
<tr>
<td>199-K-115A</td>
<td>KR4 Extraction well</td>
<td>5</td>
<td>199-K-161</td>
<td>KX Extraction well</td>
<td>19</td>
</tr>
<tr>
<td>199-K-117A</td>
<td>Monitoring well</td>
<td>2.8*</td>
<td>199-K-171</td>
<td>KX Extraction well</td>
<td>19</td>
</tr>
<tr>
<td>199-K-119A</td>
<td>Monitoring well</td>
<td>1.8</td>
<td>199-K-178</td>
<td>KX Extraction well</td>
<td>24</td>
</tr>
</tbody>
</table>
Table 5-5. Summary of Cr(VI) Concentrations in 100-KR-4 OU Compliance and Performance Evaluation Wells for 2016

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Current Use</th>
<th>Maximum Cr(VI) (µg/L)</th>
<th>Well Name</th>
<th>Current Use</th>
<th>Maximum Cr(VI) (µg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>199-K-120A</td>
<td>KR4 Extraction well</td>
<td>5</td>
<td>199-K-181</td>
<td>KX Extraction well</td>
<td>17</td>
</tr>
<tr>
<td>199-K-125A</td>
<td>Monitoring well</td>
<td>3</td>
<td>199-K-182</td>
<td>KX Extraction well</td>
<td>31</td>
</tr>
<tr>
<td>199-K-130</td>
<td>KX Extraction well</td>
<td>9</td>
<td>199-K-208</td>
<td>KX Extraction well</td>
<td>19</td>
</tr>
<tr>
<td>199-K-131</td>
<td>KX Extraction well</td>
<td>4</td>
<td>199-K-210</td>
<td>KX Extraction well</td>
<td>29.9*</td>
</tr>
<tr>
<td>199-K-132</td>
<td>KW Extraction well</td>
<td>19.4*</td>
<td>199-K-212</td>
<td>KX Extraction well</td>
<td>15</td>
</tr>
<tr>
<td>199-K-138</td>
<td>KW Extraction well</td>
<td>12*</td>
<td>199-K-220</td>
<td>KX Extraction well</td>
<td>18</td>
</tr>
<tr>
<td>199-K-141</td>
<td>KX Extraction well</td>
<td>25</td>
<td>199-K-225</td>
<td>KX Extraction well</td>
<td>19</td>
</tr>
</tbody>
</table>

* Reported value represents a result from a filtered total chromium sample.

5.10 Atomic Energy Act Monitoring

AEA monitoring at 100-KR includes Hanford Sitewide monitoring under DOE/RL-2015-56. This new SAP now addresses monitoring in the vicinity of the 100-K Area FSBs previously performed under PNNL-14033, *Groundwater Monitoring and Assessment Plan for the 100-K Area Fuel Storage Basins*. AEA groundwater monitoring was conducted at 56 groundwater wells and aquifer tubes in the 100-KR groundwater interest area in accordance with the SAP issued in December 2015 (DOE/RL-2015-56). The primary AEA constituents for 100-KR are carbon-14, nitrate, strontium-90, and tritium. One well was not sampled as scheduled (Table C-5 in Appendix C). Minor exceptions to planned monitoring occurred because of maintenance issues and scheduling constraints. Appendix C lists the sampling frequencies, types of laboratory analyses, and sample status for 2016 AEA monitoring of the 100-KR groundwater wells.

Concentrations of radionuclides in groundwater samples from 133 wells and aquifer tubes were used to estimate the cumulative TED and to compare the cumulative beta/photon emitters, alpha emitters, and uranium mass to DWSs, as described in Section 1.2.4. The estimated TED did not exceed the 100 mrem/yr standard at any groundwater wells in 100-KR. The DWSs for cumulative alpha emitters and uranium mass were not exceeded. The cumulative drinking water dose from beta/photon emitters exceeded the 4 mrem/yr standard at 21 locations in this interest area (Table 5-6). Some of these locations are adjacent to the Columbia River, which is the primary potential pathway for offsite exposure to Hanford Site contaminated groundwater. Members of the public are protected from exposure to groundwater through the implementation of institutional controls that restrict access to groundwater and through remedial action measures to control the migration of contaminated groundwater to exposure points.
Table 5-6. Cumulative Total Effective Doses and Groundwater Concentrations that Exceeded Standards at Groundwater Monitoring Locations in 100-KR in 2016

<table>
<thead>
<tr>
<th>Monitoring Location/Well Name</th>
<th>Cumulative Drinking Water Dose (Beta/Photon) ≥4 mrem/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>199-K-106A</td>
<td>4.84</td>
</tr>
<tr>
<td>199-K-107A</td>
<td>6.56</td>
</tr>
<tr>
<td>199-K-111A</td>
<td>45.40</td>
</tr>
<tr>
<td>199-K-132</td>
<td>4.28</td>
</tr>
<tr>
<td>199-K-139</td>
<td>5.46</td>
</tr>
<tr>
<td>199-K-141</td>
<td>33.62</td>
</tr>
<tr>
<td>199-K-161</td>
<td>4.71</td>
</tr>
<tr>
<td>199-K-185</td>
<td>4.32</td>
</tr>
<tr>
<td>199-K-189</td>
<td>10.60</td>
</tr>
<tr>
<td>199-K-19</td>
<td>7.52</td>
</tr>
<tr>
<td>199-K-20</td>
<td>6.17</td>
</tr>
<tr>
<td>199-K-200</td>
<td>68.74</td>
</tr>
<tr>
<td>199-K-201</td>
<td>5.60</td>
</tr>
<tr>
<td>199-K-202</td>
<td>7.06</td>
</tr>
<tr>
<td>199-K-204</td>
<td>7.92</td>
</tr>
<tr>
<td>199-K-207</td>
<td>80.37</td>
</tr>
<tr>
<td>199-K-21</td>
<td>13.62</td>
</tr>
<tr>
<td>199-K-221</td>
<td>7.22</td>
</tr>
<tr>
<td>199-K-222</td>
<td>6.96</td>
</tr>
<tr>
<td>199-K-226</td>
<td>5.90</td>
</tr>
<tr>
<td>199-K-34</td>
<td>16.66</td>
</tr>
</tbody>
</table>

Source: ECF-HANFORD-17-0022, Calculation of Radiological Dose based on Calendar Year 2016 Atomic Energy Act Groundwater Monitoring at Hanford.

Note: No wells in 100-KR had total effective dose ≥100 mrem/yr, cumulative alpha activity ≥15 pCi/L, or cumulative uranium mass ≥30 µg/L.
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