Appendix D

Confined Aquifers
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Contents

D1  Ringold Confined Aquifers ................................................................................................. D-1
  D1.1  Groundwater Flow in Ringold Confined Aquifers ..................................................... D-1
  D1.2  Groundwater Quality in Ringold Confined Aquifers .............................................. D-4

D2  Upper Basalt-Confined Aquifer ......................................................................................... D-6
  D2.1  Groundwater Flow in Upper Basalt-Confined Aquifer ........................................... D-7
  D2.2  Groundwater Quality in Upper Basalt-Confined Aquifer ....................................... D-9

D3  References ....................................................................................................................... D-12

Figures

Figure D-1.  Ringold Confined Monitoring Wells ................................................................. D-2
Figure D-2.  Potentiometric Surface for Ringold Unit A, March 2016 ................................. D-3
Figure D-3.  Cr(VI) in Selected 100-HR-3 RUM Wells ......................................................... D-6
Figure D-4.  Basalt-Confined Monitoring Wells ................................................................. D-8
Figure D-5.  Potentiometric Surface for Upper Basalt-Confined Aquifer, March 2016 ....... D-10

Tables

Table D-1.  Groundwater Quality in Ringold Confined Aquifers ........................................... D-5
Table D-2.  Groundwater Quality in Upper Basalt-Confined Aquifer ................................... D-11
### Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr(VI)</td>
<td>hexavalent chromium</td>
</tr>
<tr>
<td>DWS</td>
<td>drinking water standard</td>
</tr>
<tr>
<td>RUM</td>
<td>Ringold upper mud unit</td>
</tr>
<tr>
<td>TCE</td>
<td>trichloroethene</td>
</tr>
</tbody>
</table>
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D Confined Aquifers

This appendix describes groundwater flow and groundwater quality in confined aquifers within the Ringold Formation and the upper portion of the Columbia River Basalt Group. The U.S. Department of Energy monitors groundwater quality in the confined aquifer systems because of the potential for downward migration of contaminants from the overlying unconfined aquifer in areas where confining units are absent or fractured.

D1 Ringold Confined Aquifers

Numerous wells at the Hanford Site monitor the confined water-bearing units in the Ringold Formation (Figure D-1). The most widespread Ringold confined aquifer is where the Ringold lower mud unit confines the underlying sediment of Ringold unit A (Figure 1-7). Approximately 40 wells are screened in Ringold unit A, although not all of the wells have been sampled in recent years. Most of the wells are located in or near the Central Plateau; others are located in the southern Hanford Site (including the 300 Area), and one well is in the 100 Area.

Local water-bearing units in or beneath the Ringold upper mud unit (RUM) exist in the northern Hanford Site (Figure 1-5). These units are not believed to be interconnected into a regionally confined aquifer. Twenty-one wells in the 100 Area are screened in water-bearing units within or beneath this unit.

D1.1 Groundwater Flow in Ringold Confined Aquifers

This section describes groundwater flow in the confined aquifer of Ringold unit A in the region near the 200 Areas and farther south. The elevation of this Ringold confined aquifer varies from 34 m (111.5 ft) (NAVD88, North American Vertical Datum of 1988) southwest of the 200 West Area (Plate 3 of PNNL-13858, Revised Hydrogeology for the Suprabasalt Aquifer System, 200-West Area and Vicinity, Hanford Site, Washington) to more than 128 m (420 ft) northeast of the 200 East Area (Plate 3 of PNNL-12261, Revised Hydrogeology for the Suprabasalt Aquifer System, 200-East Area and Vicinity, Hanford Site, Washington). Insufficient data are available from unit A in the northern part of the Hanford Site to interpret groundwater flow directions. Groundwater flow in the RUM is not characterized.

Figure D-2 presents the March 2016 potentiometric surface for a portion of the confined aquifer in Ringold unit A. This map is subject to uncertainty because only a few wells monitor this aquifer. However, generalized flow patterns can be inferred from available data when the hydrogeologic framework (i.e., the extent of the confined unit, presence of basalt subcrops, and influence of the May Junction Fault) is considered.

Groundwater flow in the Ringold confined aquifer is generally west to east near the 200 West Area and west to east along the southern boundary of the aquifer near the Rattlesnake Hills. This flow pattern indicates that recharge occurs west of the 200 West Area in upgradient areas within the Cold Creek Valley, as well as in the Dry Creek Valley, and possibly the Rattlesnake Hills. Near the 200 East Area, flow in the Ringold confined aquifer converges from the west, south, and east before discharging to the unconfined aquifer where the Ringold lower mud is absent (Section 4.2.3 of PNNL-12261). This water is thought to flow southeast over the top of the confining unit (Section 2.4.3 of DOE/RL-2008-59, Interim Status Groundwater Monitoring Plan for the 216-B-3 Pond).

The head in confined wells in 200 West Area declined up to 0.3 m (1 ft) between 2015 and 2016 in response to declining head in the overlying unconfined aquifer. A smaller decline was observed east of 200 West Area near five pump-and-treat injection wells that are screened beneath the Ringold lower mud. A bend in the 128 m (420 ft) contour in Figure D-2 illustrates the impact of the injection wells.

Figure D-2. Potentiometric Surface for Ringold Unit A, March 2016
The head in confined wells near 200 East Area were stable or declined only a few centimeters between 2015 and 2016. Artificially elevated water levels are present northeast of the 216-B-3 Pond (B Pond). The high water levels reflect mounding from past wastewater discharges and cause southwest flow beneath B Pond where mounding is not as prevalent. Eastward flow away from the region of elevated water levels does not occur due to the north-south trending May Junction Fault, located east of the B Pond area (Section 2.4.3 of DOE/RL-2008-59). Hydraulic head and water chemistry differences across this fault indicate that it is a barrier to groundwater flow in the confined aquifers (Sections 4.2.3 and 4.3.2 in PNNL-12261). While impermeable units have been juxtaposed against permeable units along part of the fault, the mud units may also have smeared along the fault zone and sealed it (Plates 8 and 9 in PNNL-12261). South of the B Pond area, the water flow divides, with some flow moving northwest toward the 200 East Area and some flow moving east or southeast. The exact location of the flow divide is not known because of a lack of water-level data in this area and uncertainty regarding the southward extent of the May Junction Fault.

The potentiometric contours for the Ringold confined aquifer (Figure D-2) are similar to the potentiometric surface contours for the upper basalt-confined aquifer system, indicating that flow patterns in the central portion of the Hanford Site are similar in both aquifers. Basalt bedrock from the topographic low area at Gable Gap near the 200 East Area was eroded significantly by late Pleistocene catastrophic flooding (Section 7.0 of PNNL-19702, Hydrogeologic Model for the Gable Gap Area, Hanford Site), which facilitates intercommunication between the unconfined and confined aquifers. The 200 East Area is a discharge area for both of the confined aquifers, which explains the similar flow patterns.

### D1.2 Groundwater Quality in Ringold Confined Aquifers

Wells monitoring Ringold confined aquifers are sampled in accordance with the objectives of the groundwater operable units in which they are located. The main text of this report discusses the monitoring results, and highlights of the monitoring are summarized in the following discussion.

With few exceptions, groundwater in the RUM is not contaminated (Table D-1). Twenty wells screened in this unit were sampled at least once between 2014 and 2016. Hexavalent chromium (Cr(VI)) concentrations are greater than the 48 µg/L WAC 173-340, “Model Toxics Control Act—Cleanup,” standard in some RUM wells in 100-HR-H (Figure D-3). It appears that portions of this unit east of the 100-D Area were eroded, allowing contaminated cooling water into water-bearing units within the mud from the overlying unconfined aquifer. This water moves more slowly than unconfined groundwater so the contamination persists.

The Cr(VI) concentrations in RUM well 199-H4-12C (an extraction well for 100-HR-3) showed sudden downward spikes in 2015 (Figure D-3). These spikes were attributed to influence of the overlying unconfined aquifer, where Cr(VI) concentrations are lower. A reduced pumping rate in 2016 eliminated subsequent changes.

Tritium and Cr(VI) concentrations are elevated in Ringold mud well 199-N-80 (see 100-NR discussion in Chapter 6), although tritium levels are below the drinking water standard (DWS) and are declining. This is the only well in 100-NR screened in the mud. Attempts to install another well in a similar water-bearing zone in 2011 were unsuccessful; no water-bearing zone was encountered during drilling.

Strontium-90 was detected at 6 pCi/L in RUM well 199-H4-12C in November 2015. The sample was reanalyzed and the result was confirmed. No strontium-90 was detected in any of three 2016 samples.
Table D-1. Groundwater Quality in Ringold Confined Aquifers

<table>
<thead>
<tr>
<th>Groundwater Interest Area</th>
<th>Wells Sampled</th>
<th>Groundwater Contamination (DWS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wells Screened in Ringold Upper Mud Unit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-BC</td>
<td>199-B2-12</td>
<td>None</td>
</tr>
<tr>
<td>100-FR</td>
<td>199-F5-43B and 199-F5-53</td>
<td>None</td>
</tr>
<tr>
<td>100-HR-D and 100-HR-H</td>
<td>199-D5-134, 199-D5-141, 199-D8-54B, 199-H2-1, 199-H3-10, 199-H3-2C, 199-H3-9, 199-H4-12C, 199-H4-15CS, 199-H4-90, 199-H4-91, 699-97-43C, 699-97-45B, and 699-97-48C</td>
<td>Hexavalent chromium (48 µg/L): up to 144 µg/L Nitrate (45 mg/L): up to 23.5 mg/L Strontium-90 (8 pCi/L): up to 6.05 pCi/L</td>
</tr>
<tr>
<td>100-KR-4</td>
<td>199-K-32B and 199-K-192</td>
<td>None</td>
</tr>
<tr>
<td>100-NR</td>
<td>199-N-80</td>
<td>Hexavalent chromium (48 µg/L): up to 181 µg/L Tritium (20,000 pCi/L): up to 11,400 pCi/L</td>
</tr>
<tr>
<td><strong>Well Screened in Ringold Unit B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-HR-H</td>
<td>199-H4-15CR</td>
<td>None</td>
</tr>
<tr>
<td><strong>Wells Screened in Ringold Unit A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100-HR-H</td>
<td>199-H4-15CQ</td>
<td>None</td>
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<tr>
<td>300-FF</td>
<td>399-1-16C, 399-1-17C, 399-1-18C, 399-1-9, 399-8-5C, and 699-S29-E16C</td>
<td>None</td>
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<tr>
<td>200-BP</td>
<td>699-42-40A, 699-43-41G, and 699-45-42</td>
<td>Iodine-129 (1 pCi/L): up to 3.41 pCi/L Tritium (20,000 pCi/L): up to 42,000 pCi/L</td>
</tr>
<tr>
<td>200-UP</td>
<td>299-W22-24P</td>
<td>Iodine-129 (1 pCi/L): up to 1.39 pCi/L (Q flag)</td>
</tr>
<tr>
<td>200-ZP</td>
<td>699-43-69, 699-45-69C, and 699-47-80AQ</td>
<td>Carbon tetrachloride (5 µg/L): up to 220 µg/L Hexavalent chromium (48 µg/L): up to 32 µg/L Nitrate (45 mg/L): up to 217 mg/L</td>
</tr>
</tbody>
</table>

a. Evaluation based on data from 2014 through 2016. Listed contaminants present at levels one-half the DWS or more.
b. May include total chromium results from filtered samples as well as hexavalent chromium results.
c. Other wells in 200-ZP are screened in unit A, where the lower mud is not present: 299-W6-6, 299-W7-3, 299-W11-88, 299-W12-2, 299-W12-3, 299-W14-73, and 299-W14-74. The aquifer is not confined at these locations, and results are not reported here.
DWS = drinking water standard
Q flag = associated quality control sample is out of limits
TCE = trichloroethene
Figure D-3. Cr(VI) in Selected 100-HR-3 RUM Wells

Twenty wells screened in Ringold unit A were sampled at least once between 2014 and 2016. The region just east of the 200 West Area is contaminated with carbon tetrachloride, chromium, and nitrate.

These contaminants apparently reached Ringold unit A in a region of the 200 West Area where the lower mud is absent. As the groundwater continues to flow toward the east where the lower mud is present, it becomes confined. Chapter 12 (200-ZP section of this report) discusses contaminant distribution with depth in the 200 West Area.

Well 299-E25-28 in the 200-PO groundwater interest area had the highest iodine-129 concentration in the Ringold confined aquifer in 2016, at 4.63 pCi/L. Tritium and nitrate concentrations are well below their DWS in this well.

The Ringold confined aquifer (unit A) is the uppermost aquifer in a region east of the 200 East Area (200-BP and 200-PO groundwater interest areas). Regional contaminants nitrate, iodine-129 and tritium are detected in wells monitoring this aquifer (Table D-1). Contamination has not been observed in wells located downgradient of the contaminated wells, indicating that it is of limited extent.

D2 Upper Basalt-Confined Aquifer

The upper basalt-confined aquifer groundwater system occurs within basalt fractures and joints, interflow contacts, and sedimentary interbeds within the upper Saddle Mountains Basalt. The thickest and most widespread sedimentary unit in this system is the Rattlesnake Ridge interbed, which is present beneath much of the Hanford Site. Groundwater also occurs within the Levey interbed, which is present only in the southern portion of the Hanford Site. A small interflow zone occurs within the Elephant Mountain Member of the upper Saddle Mountains Basalt and may be significant to the lateral transmission of water.
The upper basalt-confined aquifer system is confined by the dense, low-permeability interior portions of the overlying basalt flows and in some places by silt and clay units of the lower Ringold Formation that overlie the basalt. Approximately 40 wells screened in the upper basalt-confined aquifer have been sampled or had water levels measured in recent years (Figure D-4).

An area of intercommunication between the unconfined and upper basalt-confined aquifers exists near the 200 East Area where the confining layers are eroded away or fractured. Several basalt-confined wells have shown evidence of intercommunication with the overlying unconfined aquifer (Section 3.0 of PNL-10817, Hydrochemistry and Hydrogeologic Conditions within the Hanford Site Upper Basalt Confined Aquifer System).

D2.1 Groundwater Flow in Upper Basalt-Confined Aquifer

Figure D-5 presents the interpreted March 2016 potentiometric surface for the upper basalt-confined aquifer system south of Gable Butte and Gable Mountain, based on measurements from 34 monitoring wells. The region to the north of Gable Butte and Gable Mountain was not contoured because of an insufficient number of wells in this area. Plate 1 of PNL-8869, Preliminary Potentiometric Map and Flow Dynamic Characteristics for the Upper-Basalt Confined Aquifer System, provides a generalized potentiometric surface map of this area. The upper basalt-confined aquifer system does not exist in the Cold Creek Valley and along the west portion of the Gable Mountain and Gable Butte structural area because of the absence of the Rattlesnake Ridge interbed.

Recharge to the upper basalt-confined aquifer system likely occurs from upland areas along the margins of the Pasco Basin and results from the infiltration of precipitation and surface water where the basalt and interbeds are exposed at or near ground surface. Recharge may also occur from the overlying aquifers (i.e., the unconfined aquifer or confined aquifer in the Ringold Formation) in areas where the hydraulic gradient is downward and from deeper basalt aquifers where an upward gradient is present. The Yakima River may also be a source of recharge to this aquifer system. The Columbia River represents a discharge area for this aquifer system in the southeastern portion of the Hanford Site where the river has a lower head than the upper basalt-confined aquifer, but not for the northern portion of the Site where the river head is higher (Section 3.2 of PNL-8869). Discharge also occurs to the overlying aquifers in areas where the hydraulic gradient is upward. Discharge to the overlying unconfined aquifer near the Gable Butte and Gable Mountain structural area is believed to occur through windows eroded in the basalt.

South of Gable Butte and Gable Mountain, groundwater in the upper basalt-confined aquifer system generally flows from west to east across the Hanford Site, toward the Columbia River. The north-south trending May Junction Fault, located east of B Pond, acts as a barrier to groundwater flow in the unconfined aquifer and the confined aquifer within the Ringold Formation (Section 2.4.3 of DOE/RL-2008-59). It may also impede the movement of water in the upper basalt-confined aquifer system by juxtaposing permeable units opposite impermeable units. As with the Ringold confined aquifer, a flow divide is interpreted to exist southeast of the 200 East Area and B Pond in the upper basalt-confined aquifer system, but the exact location of this divide is uncertain because of a lack of wells in the area.
Figure D-4. Basalt-Confined Monitoring Wells
Groundwater flow rates within the Rattlesnake Ridge interbed have been estimated between 0.7 and 2 m/yr (2.3 and 6.6 ft/yr) (Section 4.2 of PNL-10817), which is a considerably lower flow rate than most estimates for the overlying unconfined aquifer system. The sediment comprising the interbed consists mostly of sandstone (with silts and clays) and is much less permeable than the sediment in the unconfined aquifer. In addition, the magnitude of the hydraulic gradient is generally lower than in the unconfined aquifer.

The vertical hydraulic gradient between the upper basalt-confined aquifer system and the overlying aquifer varies spatially, as shown by comparison of observed heads depicted for 2014 in Figure D-5 of DOE/RL-2015-07, Hanford Site Groundwater Monitoring Report for 2014. An upward gradient exists beneath most of the Hanford Site. A downward gradient exists in the western portion of the Hanford Site and near the B Pond recharge mound, as well as in regions north and east of the Columbia River. Near B Pond, the vertical head gradient between the unconfined aquifer system and the upper basalt-confined aquifer system has diminished in recent years but remains downward. An area of upward gradient beneath a portion of the 200 West Area is caused by groundwater extraction, which reduced heads in the unconfined aquifer.

In the 200 East Area, the potentiometric surface (Figure D-5) is similar to the potentiometric surface for the Ringold confined aquifer (Figure D-2). The basalt in this area was significantly eroded by late Pleistocene catastrophic flooding, which facilitates aquifer intercommunication (Section 7.0 of PNNL-19702). In the 200 East Area and to the immediate north, the vertical hydraulic gradient between the upper basalt-confined aquifer system and the overlying aquifer is upward. It is likely that the upper basalt-confined aquifer system currently discharges to the overlying aquifer in this region.

The 2016 potentiometric surface map (Figure D-5) shows flexures in the contours beneath the 200 West Area and the region to the east. This interpretation shows the influence of groundwater mounds (injection) and depressions (extraction) in the overlying unconfined and Ringold confined aquifers.

Water levels have been declining in most of the basalt-confined wells in the 200 East and 200 West Areas in response to reduced loading of the confined aquifer (i.e., a reduction in external stress) caused by water-level declines in the overlying unconfined aquifer and Ringold confined aquifer. The largest decline between 2015 and 2016 was 0.33 m (1.1 ft) in piezometer 699-47-80AP in the 200 West Area. Hydraulic head in the 200 East Area wells declined up to 0.1 m (0.33 ft).

D2.2 Groundwater Quality in Upper Basalt-Confined Aquifer

The upper basalt-confined aquifer system is not affected by contamination as much as the unconfined aquifer. Contamination in the upper basalt-confined aquifer system is most likely to occur in areas where the confining units have been eroded away or were never deposited, and where past disposal of large amounts of wastewater resulted in downward hydraulic gradients. Researchers have identified areas of intercommunication between the contaminated unconfined aquifer and the upper basalt-confined aquifer by geochemical signatures and the presence of nitrate and tritium in groundwater in some basalt-confined wells near the 200 East Area (Chapter 3.0 of PNL-10817). However, groundwater monitoring data do not indicate that contamination has migrated into the upper basalt-confined aquifer. Because of poor seals in wells constructed prior to implementation of WAC 173-160, “Minimum Standards for Construction and Maintenance of Wells,” intercommunication between aquifers has permitted groundwater flow from the unconfined aquifer to the underlying confined aquifer in the past, increasing the potential to spread contamination (e.g., at well 299-E33-12, as discussed below). Section 2.14.2 of DOE/RL-2008-01, Hanford Site Groundwater Monitoring for Fiscal Year 2007, further discusses communication between the upper basalt-confined aquifer system and the overlying aquifers.
Figure D-5. Potentiometric Surface for Upper Basalt-Confined Aquifer, March 2016

Seventeen wells screened in the upper basalt-confined aquifer were sampled between 2014 and 2016. Concentrations of contaminants are far below DWSs in the basalt-confined aquifer (Table D-2), except in well 299-E33-12, where past drilling practices and well construction allowed migration of groundwater from the overlying unconfined aquifer. The highest concentrations of contaminants continued to be observed in well 299-E33-12 in the northwestern 200 East Area. This well was drilled in 1953 and was uncased from just above the bottom of the unconfined aquifer through the Rattlesnake Ridge interbed. Contamination is believed to have migrated from the unconfined aquifer, down the open borehole, and to the Rattlesnake Ridge interbed (Section 2.14.2 of DOE/RL-2008-01). The well was sealed from the unconfined aquifer in 1979, with an additional seal placed in the well in 1990 to shorten the open interval. Concentrations of nitrate and technetium-99 continued to be elevated in samples from this well, and possibly in a small area of the confined aquifer. Well 299-E33-50, located near 299-E33-12, consistently shows levels of technetium-99 between 25 and 50 pCi/L. Other confined wells in this region showed no contamination. The hydraulic gradient is upward in this region.

Tritium is detected at a concentration below the DWS in well 699-42-40C, located east of the 200 East Area (Section 10.3), and concentrations are generally declining (3,200 pCi/L in 2014). The strong, downward hydraulic gradient formerly present in this region, and partial erosion of the basalt confining unit allowed communication between the unconfined and basalt-confined aquifers (RHO-RE-ST-12P, An Assessment of Aquifer Intercommunication in the B Pond-Gable Mountain Pond Area of the Hanford Site). The hydraulic gradient in this region remains downward.

Groundwater in basalt-confined wells in other regions of the Hanford Site is uncontaminated based on data from a small number of available wells that were sampled in recent years (Table D-2).

<table>
<thead>
<tr>
<th>Groundwater Interest Area</th>
<th>Wells Sampled</th>
<th>Groundwater Contamination&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-H</td>
<td>199-H4-15CP</td>
<td>None</td>
</tr>
</tbody>
</table>
Technetium-99: up to 1,000 pCi/L<sup>b</sup> |
| 300-FF                    | 699-13-1C and 699-S11-E12AP | None                                 |
| Offsite                   | 699-42-E9B  | None                                 |

<sup>a</sup> Evaluation based on data 2014 through 2016. Listed contaminants present at levels one-half the drinking water standard or more.

<sup>b</sup> Not representative of basalt-confined aquifer. Migrated down wellbore from unconfined aquifer (see text discussion).
D3 References


