Appendix A

Site History

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Terms

bgs	below ground surface
Cr(VI)	hexavalent chromium
CSM	conceptual site model
CY	calendar year
DOE	U.S. Department of Energy
DOE-RL	DOE Richland Operations Office
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FSB	fuel storage basin
gpm	gallons per minute
ISRM	in situ redox manipulation
LIDAR	Light Detection and Ranging
OU	operable unit
P&T	pump-and-treat
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
PRB	permeable reactive barrier
RI/FS	remedial investigation/feasibility study
ROD	record of decision
RPO	remedial process optimization
RUM	Ringold upper mud
Tri-Party Agreement	*Hanford Federal Facility Agreement and Consent Order*
UPR	unplanned release

A Site History

Information on the site history for the 100-HR-3, 100-KR-4, and 100-NR-2 Operable Units (OUs) is provided in this appendix.

A1 100-HR-3 Operable Unit History

In September 1994, DOE/RL-93-43, *Limited Field Investigation Report for the 100-HR-3 Operable Unit*, including a qualitative risk assessment, was completed. Hexavalent chromium (Cr(VI)) was identified as a contaminant of concern for ecological receptors in the Columbia River. In August 1995, DOE/RL-94-67, *100-HR-3 Operable Unit Focused Feasibility Study*, and DOE/RL-94-102, *Proposed Plan for Interim Remedial Measure at the 100-HR-3 Operable Unit*, were finalized. The Proposed Plan (DOE/RL-94-102) recommended the use of a pump-and-treat (P&T) system to mitigate chromium migration to the Columbia River. In 1994, a pilot-scale P&T system was deployed, and DOE/RL-95-83, *The Pilot-Scale Treatability Test Summary for the 100-HR-3 Operable Unit*, was issued in December 1995. The report indicated that removing Cr(VI) from extracted groundwater in the 100-HR-3 OU using a resin treatment (ion exchange) system was viable.

In April 1996, EPA/ROD/R10-96/134, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington*, was issued for the 100-HR-3 OU P&T system. The interim record of decision (ROD) specified installation of a P&T system in the 100-HR-3 and 100-KR-4 OUs to intercept portions of the Cr(VI) plumes that affect the Columbia River. Full-time operation of the HR-3 treatment system began on July 1, 1997, with a treatment capacity of 1,136 L/min (300 gallons per minute [gpm]). On August 5, 1998, the P&T system was modified to permit groundwater from the 100-D Area to be treated separately from 100-H Area groundwater.

In October 1999, EPA/AMD/R10-00/122, *Interim Remedial Action Record of Decision Amendment for the 100-HR-3 Operable Unit, Hanford Site, Benton County, Washington*, was approved, which modified the selected remedial action by deploying an innovative treatment technology, in situ redox manipulation (ISRM), to address the groundwater chromium plume located southwest of the D/DR Reactors. This plume is not within the established treatment zone for the P&T system for the interim action. The initial phase of the ISRM remedial action was implemented in 2000.

An additional P&T system was installed in 2004 at the 100-D Area (DR-5, with a 189 L/min [50 gpm] treatment capacity) to extract and treat high Cr(VI) concentrations in the central portion of the 100-D Area. The two P&T systems operated to remediate Cr(VI) in the 100-HR-3 OU groundwater. The HR-3 system extracted contaminated groundwater from the 100-D and 100-H Areas; the groundwater was then treated and injected in the 100-H Area. The DR-5 system extracted, treated, and injected groundwater in the 100-D Area.

Monitoring of these systems over time provided significant additional information on the nature and extent of contamination and revealed that the Cr(VI) footprint in groundwater was much larger than anticipated. A remedial process optimization (RPO) study began in 2008 to determine how to optimize the remediation of Cr(VI) in groundwater at the 100-HR-3 OU by 2012. The study included cleanup of groundwater within the Horn area based on field investigations conducted in 2007 and 2008 that further delineated the extent of Cr(VI) in the area (DOE/RL-2008-42, *Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit*). Two new, expanded P&T systems (the DX system in the 100-D Area, and the HX system in the 100-H Area) were constructed and increased the treatment capacity for groundwater cleanup by 2,273 L/min and 3,030 L/min (600 gpm and 800 gpm), respectively, in the 100-HR-3 OU. Table A-1 provides a summary of treatment capacities

for the 100-HR-3 OU P&T systems. The DR-5 and HR-3 P&T systems were phased out in calendar year (CY) 2011 by the expanded systems.

The DX P&T system, which came online in December 2010, focuses on Cr(VI) contamination in groundwater underlying the 100-D Area and the northwestern portion of the Horn. The HX P&T system came online in September 2011 and focuses on Cr(VI) contamination in groundwater underlying 100-H Area and the southeastern portion of the Horn.

Additional detailed site characterization and background information on the 100-HR-3 OU and P&T activity are provided in DOE/RL-2008-46-ADD1, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*. Further information on the P&T system design and operation is provided in DOE/RL-2009-56, *Remedial Design/Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit Interim Actions*. The groundwater monitoring requirements are described in DOE/RL-96-90, *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units*.

The ongoing characterization and remediation of waste sites in the 100-D and 100-H Areas began in 1996 under the authority provided by the interim action RODs and *Resource Conservation and Recovery Act of 1976* closure and monitoring plans. Remediation primarily consists of removing and disposing soil, debris, and waste material, and then backfilling the remediated waste site. A portion of the 100-D and 100-H Area waste sites (i.e., trenches, pits, and burial grounds) have already been remediated and dispositioned. The remediation status of each waste site is described in detail in DOE/RL-2008-46-ADD1.

The remedial investigation/feasibility study (RI/FS) field effort, implemented in 2010, targeted several waste sites located in the 100-D and 100-H Areas for additional characterization. The objectives were to define the nature and extent of contaminants more accurately and to identify any remaining potential sources of contamination. The following 17 waste sites were investigated:

- 100-D-12 French drain associated with the sodium dichromate/acid railcar and truck unloading station (where highly concentrated sodium dichromate solutions may have been drained during railcar unloading operations)
- 100-D-4 Sludge Pit
- 100-D-56 Pipelines
- 116-D-1A Trench
- 116-D-1B Trench
- 116-D-4 Crib
- 116-D-7 Retention Basin
- 116-DR-1&2 Trenches
- 116-DR-9 Retention Basin
- 118-D-6 Fuel Storage Basin (FSB)
- 116-H-1 Trench
- 116-H-2 Trench
- 116-H-4 Crib
- 116-H-6 (183-H) Solar Evaporation Basins
- 116-H-7 Retention Basin
- 118-H-6 FSB
- 1607-H4 Septic System

Fieldwork as part of the River Corridor RI/FS characterization was completed in 2011. Draft A of DOE/RL-2010-95, *Remedial Investigation/Feasibility Study for the 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*, was issued in December 2012.

A1.1 Origin of Contaminants in the 100-HR-3 Operable Unit

The 100-D Area reactors operated between 1944 and 1967, and the 100-H Area reactor operated between 1949 and 1965. Each reactor required at least 95,000 L/min (25,000 gpm) of water for cooling in the process tubes. The primary sources of groundwater contamination in the 100-HR-3 OU are associated with reactor operations. Most of the groundwater contamination is associated with various activities involved in the cooling water cycle for the reactors. One of the most important factors in reactor operations was the control of corrosion in the process tubes inside the reactor at high temperatures. Sodium dichromate dihydrite was added to cooling water as a corrosion inhibitor prior to passing through the reactors. Sodium dichromate dihydrite was used, first in a dry, granular form delivered in bags and was later delivered as a concentrated liquid solution via railcar. Sodium dichromate dihydrite was initially used at 2 parts per million (ppm) in the cooling water but was later reduced to 1 ppm. The primary mechanism for Cr(VI) contamination to groundwater is leaching through the soil from unplanned releases of concentrated solutions of sodium dichromate dihydrite to the ground and discharges of reactor cooling water to retention basins and trenches. Other significant sources are the water-filled FSBs on the back side of the reactor where the fuel slugs were allowed to cool before being transported to the 200 Areas for processing. Both the cooling water and the FSB water could become contaminated with radionuclides as a result of fuel-cladding failures and be diverted to trenches and cribs to protect the river from radionuclides.

The groundwater contamination in the 100-HR-3 OU is primarily the result of operations at the three water-cooled nuclear reactors (D, DR, and H Reactors), the associated support structures (e.g., FSBs), and waste disposal processes. These operations generated large quantities of liquid and solid waste contaminated with radionuclides and/or hazardous chemicals. Most contaminant sources can be characterized as high-volume, low-concentration waste emplaced under high hydraulic head or as low-volume, high-concentration waste emplaced under low hydraulic head. Waste released to the environment created potential secondary sources of contamination beneath ponds, ditches, cribs, burial grounds, and unplanned release (UPR) sites. Contaminants from these sites can be retained in the vadose zone and released to the aquifer over extended periods.

A1.2 Conceptual Site Model

Data from wells drilled in 2011 were evaluated and combined with historical information, and data from wells drilled since the 1996 ROD (EPA/ROD/R10-96/134), to support the interim actions. The new data have improved the understanding of the nature and extent of contamination.

Several borehole summary reports were published in 2011. A series of 70 wells was drilled and constructed in the 100-HR-3 OU to support enhanced P&T operations at the new DX and HX P&T systems. These wells were drilled according to the RPO sampling and analysis plan (DOE/RL-2009-09, *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells*). Details on well construction, sampling, and geology are described in SGW-48612, *Borehole Summary Report for the Installation of 70 Remedial Process Optimization, Pump-and-Treat Expansion Wells, for the 100-HR-3 Operable Unit*. In addition, a characterization campaign was conducted to support an RI/FS at the 100-D and 100-H Areas. This characterization included 10 vadose zone characterization boreholes (SGW-50131, *Borehole Summary of Ten Characterization Boreholes in the 100-DR-1, 100-DR-2 and 100-HR-1, 100-HR-2 Source Operable Units in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit*) and 17 groundwater characterization wells (SGW-49912, *Borehole Summary Report for the Installation of 16 Resource Protection Wells in the 100-HR-3*

Groundwater Operable Unit in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit; SGW-51502, *Borehole Summary Report for the Installation of Well C8668 at 100-D-12 in FY2012*).

The information has been integrated to form an updated interpretation of geology in the 100-D and 100-H Areas. The following subsections provide a brief summary of the geologic and hydrogeologic setting and the groundwater contaminants that are the basis for the conceptual site model (CSM). Additional details are provided in DOE/RL-2008-46-ADD1.

A1.3 Geologic/Hydrogeologic Setting

The 100-D and 100-H Areas are located in the north central portion of the Hanford Site within the 100-HR-3 Groundwater OU. The 100-D/H Area is the operational name for the area that contained the D, DR, and H Reactor buildings and associated support facilities. It is bordered by the Columbia River and is located approximately 45 km (28 mi) north-northwest of Richland, Washington. The 100-D and 100-H Areas are geographically connected by the intervening Horn area. On the northern border of the Horn, the Columbia River turns from the northeastern path and flows to the southeast.

A1.3.1 Geology

The surficial deposits at the 100-D and 100-H Areas consist of recent backfill sand and gravel overlying Holocene aeolian deposits (Figure A-1). Construction backfill varies in depth depending on the excavated depth of waste sites and building foundations, and backfill material may cover larger graded areas to a depth up to 4.6 m (15 ft) below ground surface (bgs). Where not disrupted by construction activities, Holocene surficial deposits form a thin (0.3 m [1 ft]) veneer and consist of fine-grained aeolian deposits (loess) and Columbia River deposits of silt, sand, and gravel (WHC-SD-EN-TI-155, *Geology of the 100-K Area, Hanford Site, South-Central Washington*).

These surface deposits are underlain, in descending order, by the Hanford formation, the Ringold Formation, and bedrock consisting of the Columbia River Basalt Group. The Hanford formation and the Ringold Formation are described in the following paragraphs. Figure A-1 illustrates the hydrostratigraphic units located in the 100-HR-3 OU.

Geologic data from the new RI wells and the new RPO wells improved the knowledge of 100-D/H stratigraphic relationships. Prior to installation of the new wells, the trace line of where the unconfined aquifer matrix transitions from the Ringold unit E to the Hanford formation was not well defined. The location of this trace line (east of the 100-D Area) is important because the Hanford formation is more transmissive than the Ringold unit E, which can affect groundwater flow. Data from the new wells also provided better delineation of the Ringold upper mud (RUM) surface.

Hanford formation. The informally named Hanford formation consists of boulders, gravel, sand, and silt deposited by the cataclysmic floodwaters released from glacial Lake Missoula during the Pleistocene epoch (DOE/RW-0017, *Draft Environmental Assessment for Reference Repository Location, Hanford Site, Washington*). The Hanford formation is the dominant material in the 100 Area vadose zone, ranging in thickness from 2 to 30 m (6.6 to 98 ft) beneath the 100-D and 100-H Areas. The Hanford formation can be loosely divided into three facies: gravel-dominated, sand-dominated, and slackwater (WHC-SD-EN-TI-011, *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas*). The gravel-dominated matrix of the Hanford formation generally contains greater than 40 percent basalt (sand-size fraction), displaying a salt-and-pepper or gray coloring (WHC-SD-EN-TI-132, *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*). The Hanford formation is unconsolidated and has low cementation, allowing for faster infiltration through the vadose zone. Discrete sand lenses are present in the 100-D and 100-H Areas, which may form preferential flow paths or collection zones for vadose zone contaminants.

Ringold Formation. Disconformably underlying the Hanford formation, the Ringold unit E is composed of fluvial, matrix-supported gravels and sands, with intercalated fine to coarse sand and silt lenses. The contact between the Hanford formation and the Ringold unit E can be difficult to distinguish. Unit E lithology is between 35 percent and 90 percent felsic, consisting of mainly metamorphic, intermediate volcanic, and felsic volcanic clasts (WHC-SD-EN-TI-011). In general, Ringold unit E gravels are more rounded and more cemented, and they show a distinct oxidized reddish-brown color as compared to the Hanford formation. Silica and carbonate cementation are highly variable depending on depth and location (WHC-SD-EN-TI-132). Hydraulic conductivities vary locally, but the Ringold unit E is generally regarded as a low-conductivity unit.

The Ringold unit E had been considered absent east of the 100-D Area. The borehole logs from wells drilled in 2010 and 2011 as part of both the RI/FS and RPO provide data for additional geologic interpretation across the 100-HR-3 OU, which was conducted in 2012, with significantly more coverage across the Horn. The new geologic information showed Ringold unit E was present in several pockets across the Horn. The presence of Ringold unit E can influence groundwater flow since it has a lower hydraulic conductivity and water moves through it slower than through the overlying Hanford formation.

Several paleochannels were also shown to be present, coinciding roughly with surface expressions indicated on Light Detection and Ranging (LIDAR) imagery. The paleochannels appear to coincide with areas where the Ringold unit E is not present, as it had been scoured away. The pockets of the Ringold unit E and presence of paleochannels, along with the undulating surface of the RUM, combine to exhibit some control on the groundwater flow across the 100-HR-3 OU.

The RUM is primarily composed of variably cemented overbank flood deposits and paleosols. Primarily composed of silt and clay, the RUM is typically described as various shades of brown to olive-brown. Within the RUM, thin sand-to-gravel lenses form discontinuous confined to semi-confined aquifers. At some locations in the 100-HR-3 OU, the lower Hanford formation contains isolated but numerous rip-up clasts of the RUM (WHC-SD-EN-TI-132). The RUM marks the base of the unconfined aquifer.

A1.3.2 Hydrogeology

Groundwater generally enters the 100-HR-3 OU from the south, with most of the flow moving toward the lower elevations of the 100-H Area. A much smaller portion of the regional flow moves directly toward the 100-D Area. Underlying the 100-D Area, groundwater generally flows toward the Columbia River. Northeast of the 100-D Area, groundwater flow is parallel to the river, thereby flowing east-northeast across the horn area and toward the 100-H Area. Groundwater below the 100-H Area discharges northeast and east to the Columbia River.

Groundwater flow in the 100-HR-3 OU is significantly influenced by the Columbia River stage. The river stage fluctuates regularly in seasonal and shorter cycles (e.g., daily river stage change) due to a combination of natural (e.g., spring snowmelt and runoff) and anthropogenic influences (e.g., dam releases). During periods of the year when the river stage is relatively low (typically during the fall), natural groundwater flow is toward the river; when river stage is relatively high (typically in the late spring/early summer), groundwater can flow away from the river and/or parallel to the river. Depending on operations at the upstream Priest Rapids Dam, river stage can fluctuate by greater than 3 m (9.8 ft) annually, with changes of 1 m (3 ft) or more over short time periods (i.e., hours to days).

Other influences on groundwater flow are leakage from the 182-D reservoir and drawdown or mounding from the groundwater extraction and injection well network. The zone of uncontaminated groundwater near the 182-D facility suggests that long-term contaminant mixing and diversion of contaminated groundwater from the mounding caused by the leaks. In response to the reservoir leakage, a specific issue

was included in DOE/RL-2006-20, *The Second CERCLA Five-Year Review Report for the Hanford Site*, for the U.S. Department of Energy (DOE) to provide direction to its operating contractor to conduct changes to the operation of the reservoir to minimize leakage. These actions were completed and documented in the closeout of the 5-year review issue. These leaks and resulting impacts to groundwater flow have significantly diminished since the reservoir water level was reduced in 2004, to the point that influences on groundwater flow from reservoir leakage are much less noticeable.

In 2009, wells 199-H4-12C, 199-H3-2C, and 199-H4-15CS were used for a series of aquifer tests to gather data on the presence of deep chromium in the RUM in the 100-H Area (SGW-47776, *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation*). The Cr(VI) concentrations in the RUM rose slightly due to pumping during the test. The aquifer tests indicated that the RUM at well 199-H3-2C is connected to the upper aquifer.

The erosional forces that removed the Ringold unit E at the 100-H Area may have scoured off portions of the RUM, which exhibits an undulating surface typical of erosion. A discontinuous RUM in the 100-H Area would have allowed reactor cooling water that mounded up during operations to be driven into the RUM near the retention basins. The intrusion of cooling water into the lower aquifer (first water-bearing unit in the RUM) resulted in relatively high concentrations along this zone, near the Columbia River. Extraction of water from this water-bearing unit has not yet resulted in a decrease in concentrations, as noted by the stable levels in well 199-H4-12C.

A2 100-KR-4 Operable Unit History

In July 1994, DOE/RL-93-79, *Limited Field Investigation Report for the 100-KR-4 Operable Unit* (including a qualitative risk assessment), was completed. The report concluded that an interim remedial measure was not warranted based on human health risk, but an interim remedial measure could be justified for ecological concerns related to Cr(VI). In October 1995, DOE/RL-94-48, *100-KR-4 Operable Unit Focused Feasibility Study*, and DOE/RL-94-113, *Proposed Plan for Interim Remedial Measure at the 100-KR-4 Operable Unit*, were completed. The Proposed Plan (DOE/RL-94-113) recommended using a P&T interim remedial measure to mitigate Cr(VI) migration into the Columbia River.

In April 1996, an interim remedial action ROD (EPA/ROD/R10-96/134) was issued for the 100-KR-4 P&T system. The ROD specified installation of a P&T system in the 100-HR-3 and 100-KR-4 OUs to intercept portions of the Cr(VI) plumes that affect the Columbia River. Full-time operation of the treatment system began on October 1, 1997.

Detailed site characterization and background information for the 100-KR-4 OU and P&T activities is provided in the focused FS (DOE/RL-94-48) and the Proposed Plan (DOE/RL-94-113). Further information on P&T system design and operation is provided in DOE/RL-96-84, *Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action*, and DOE/RL-97-96, *100-HR-3 and 100-KR-4 Operable Units Interim Action Performance Evaluation Report*. Groundwater monitoring requirements are described in the interim action monitoring plan (DOE/RL-96-90). Additional background information is available in DOE/RL-2013-22, *Hanford Site Groundwater Monitoring Report for 2012*.

The KR4 P&T system treats groundwater downgradient of the 116-K-2 Trench (also referred to as the Mile-Long Trench) and has a treatment capacity of 1,136 L/min (300 gpm). The KX P&T system came online in CY 2009 and added 2,271 L/min (600 gpm) treatment capacity. For the Cr(VI) plumes associated with the 116-K-2 Trench, DOE/RL-2006-75, *Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump-and-Treat System*, describes the changes made with the addition of the KX system.

The KW P&T system came online in CY 2007 with a 387 L/min (100 gpm) treatment capacity and was expanded to a 757 L/min (200 gpm) capacity in 2009. The system continued operation in 2011 near the groundwater treatment capacity of 757 L/min (200 gpm). For the Cr(VI) plume associated with the KW Reactor, DOE/RL-2006-52, *The KW Pump-and-Treat System Remedial Design and Remedial Action Work Plan, Supplement to the 100-KR-4 Groundwater Operable Unit Interim Action*, describes the changes made with the addition of the P&T system. The combined groundwater treatment capacity of the three P&T systems (i.e., KR4, KX, and KW) for the 100-KR-4 OU is 4,167 L/min (1,100 gpm). Table A-2 provides a summary of treatment capacities for the 100-KR-3 OU P&T systems.

In 2011, the ion-exchange resin was changed from Dowex[1] 21K to SIR-700 resin, implementing recommendations from SGW-46621, *100 Area Groundwater Chromium Resin Management Strategy for Ion Exchange Systems*, which is implemented at both the DX and HX P&T systems. The KW P&T facility was selected to test the implementation of SIR-700 resin at a mildly acidic pH (5.5 [±0.5]) to determine if the pH would cause any system lining degradation and aquifer effect, and whether any negative effects to the aquifer would result from injecting lower pH water. The results are documented in SGW-51721, *100-KW Pump and Treat ResinTech SIR-700 Test Results and Recommendations for Use Across 100-KR-4 Operable Unit*. The test objectives were met, and the KW P&T system continues to operate using SIR-700 resin.

The process test demonstrated the superior performance of the SIR-700 resin to the Dowex 21K resin. TPA-CN-505, *Change Notice for Modifying Approved Documents/Workplans In Accordance with the Tri-Party Agreement Action Plan, Section 9.0, Documentation and Records: Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump and Treat System, DOE-RL-2006-75 REISSUE, Rev. 1*, to modify DOE/RL-2006-75, was approved to use SIR-700 resin at the 100-KR-4 OU P&T systems. The Dowex 21K resin was replaced with SIR-700 resin at the KX and KR4 P&T systems in April and June 2012, respectively.

A2.1 Origin of Contaminants in the 100-KR-4 Operable Unit

The groundwater contamination in 100-KR-4 OU is primarily the result of the operation of two now inactive, water-cooled nuclear reactors (KE and KW Reactors), associated structures (e.g., FSBs), and waste disposal processes associated with reactor operations. During operation of these reactors, large quantities of liquid and solid waste (e.g., contaminated reactor cooling water, FSB water, and decontamination solutions) were generated and released to the environment, resulting in contamination of 100-K Area groundwater by a range of constituents.

A2.2 Conceptual Site Model

Data from wells drilled in 2011 were evaluated and combined with historical information and data from older wells and boreholes. The new data have improved the understanding of the nature and extent of contamination, as wells as the geology, hydrology, and major ion geochemistry that forms the basis of the CSM, which is described in detail in DOE/RL-2010-97, *Remedial Investigation/Feasibility Study for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units*.

Borehole summary reports published in 2011 present the details of the wells and boreholes (SGW-49459, *Borehole Summary Report for the Drilling and Installation of RI/FS Wells in the 100-KR-4 Operable Unit*).

[1] Dowex® is a registered trademark of the Dow Chemical Company, Midland, Michigan.

A2.3 Geologic/Hydrogeologic Setting

The 100-K Area is the operational name for the area that contained the KE and KW Reactor buildings and associated support facilities located in the north central portion of the Hanford Site. It is bordered by the Columbia River to the north and is located approximately 45 km (28 mi) north-northwest of Richland, Washington. The two 100-K Area reactors, KE and KW, operated in tandem from 1955 to 1971. In addition to its operational history, the reactor FSBs were used to store spent fuel from N Reactor from 1975 until 2007. The primary sources of groundwater contamination in the 100-KR-4 OU are associated with reactor operations.

A2.3.1 Geology

The surficial deposits at the 100-K Area consist of recent backfill sand and gravel overlying Holocene aeolian deposits (Figure A-2). Construction backfill varies in depth depending on the excavated depth of waste sites and building foundations, and backfill material may cover larger graded areas to a depth of up to 4.6 m (15 ft). Where not disturbed by construction activities, Holocene surficial deposits form a thin (0.3 m [1 ft]) veneer and consist of fine-grained aeolian deposits (loess) and Columbia River deposits of silt, sand, and gravel (WHC-SD-EN-TI-155).

These surface deposits are underlain, in descending order, by the Hanford formation, the Ringold Formation, and bedrock consisting of Columbia River Basalt Group. The Hanford formation and the Ringold Formation are described in the following paragraphs. Figure A-2 presents a generalized cross section of the geology beneath the 100-K Area.

Hanford formation. The informally named Hanford formation overlies the late Miocene to middle Pliocene Ringold Formation in the 100-K Area. The formation consists of boulders, gravel, sand, and silt deposited by cataclysmic glacial Lake Missoula Ice Age floods that occurred during the Pleistocene epoch (DOE/RW-0017). The Hanford formation is comprised of gravel-dominated, sand-dominated, and silt-dominated sequences of which only the upward-fining, gravel-dominated unit occurs along the Columbia River (DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Post-Ringold Formation Sediments Within the Central Pasco Basin*). The Hanford formation is the dominant material in the 100 Area vadose zone, ranging in thickness from less than 1 m (3.3 ft) near the river shoreline to 20 m (65 ft) along the southern edge of the K Reactor area, approximately 30 m (100 ft) near the southeastern boundary of the 100-K Area (WHC-SD-EN-TI-011). The unit thins near the shoreline of the Columbia River and becomes mixed with terrace gravel deposits laid down by the ancestral Columbia River. The Hanford formation underlying the 100-K Area essentially comprises a sand and gravel wedge that generally coarsens eastward (DOE/RL-2002-39). The Hanford formation has been eroded in locations to where the underlying Ringold Formation is exposed along the riverbank and up to 366 m (1,200 ft) inland (EPA/ROD/R10-96/134).

Ringold Formation. The Miocene-Pliocene Ringold Formation disconformably underlies the Hanford formation and overlies the Columbia River Basalt Group (Figure A-2). It has a maximum thickness of approximately 185 m (600 ft) in the Pasco Basin and a maximum thickness of 161 m (527 ft) in the 100-K Area. During the Pleistocene flood events that produced the Hanford formation in the 100-K Area, the Ringold Formation experienced widespread erosion that resulted in an irregular contact between the two units. This contact presents a contrast between the loose, permeable, coarse Hanford deposits and the denser, less permeable, locally cemented Ringold unit E gravels.

The Ringold Formation in the 100-K Area consists of four water-bearing, stratigraphic intervals dominated by fluvial gravels and sand. These lower Ringold units are designated, in descending stratigraphic order, as units E, C, B, and A; unit D is missing locally. These units are separated by, and

interbedded with, two widespread mud and silt deposits of overbank and lacustrine origin (BHI-00184, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*).

Ringold unit E is the uppermost coarse-grained unit of the Ringold Formation present in the 100-K Area, and it comprises the majority of the shallow unconfined aquifer. This unit is composed of loose to semi-indurated clay, silt, fine- to coarse-grained sand, gravel, and cobbles. Hydraulic conductivities vary locally, but the Ringold unit E is generally regarded as a low-conductivity unit.

The Ringold unit E is underlain by the low-permeability, silt-rich and clay-rich RUM. The RUM is up to 60 m (200 ft) thick in the 100-K Area and marks the base of the shallow unconfined aquifer. In general, the RUM has an undulating surface and dips toward the Columbia River. The RUM/Ringold unit E contact is also disconformable with evidence of erosion by the ancestral Columbia River system that deposited the Ringold unit E.

A2.3.2 Hydrogeology

Long-term groundwater flow near the 100-K Area is toward the Columbia River and occurs primarily in the low to moderately permeable sands and gravels of the Ringold unit E. The saturated thickness of the Ringold unit E ranges from 5.2 m (17 ft) to more than 32 m (105 ft) in the 100-K Area. The mean transmissivity value obtained from constant discharge tests in 100-KR-4 OU injection wells was approximately 90 m^2/d (969 ft^2/d). The underlying silt-rich and clay-rich RUM is considered an aquitard rather than an aquiclude. Measurements of hydraulic conductivity of the Ringold unit E ranged from approximately 0.98 to 44.2 m/d (3 to 145 ft/d) in monitoring wells 199-K-108A and 199-K-37, respectively. Along the 116-K-2 Trench, hydraulic conductivities ranged between 0.9 and 34 m/d (3 and 111 ft/d), with the greatest conductivity value near the center of the trench.

Columbia River water stage is controlled at Priest Rapids Dam and is strongly influenced by fluctuations in flow rates due to both natural and anthropogenic effects (e.g., spring snowmelt and runoff). These fluctuations in river stage similarly affect the water table elevation and groundwater flow direction within the aquifer proximal to the river. Even short-term fluctuations in the discharge rates from Priest Rapids Dam are known to cause river elevations to change by as much as 2.7 m (9 ft) in a single day (PNL-9437, *Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River*). Longer term seasonal changes in the river stage produce longer term increases in the water table elevation that gradually extend further inland over time (up to several thousand meters) from the river, while the magnitude of the increase progressively decreases with distance from the river.

In response to the seasonal changes in river stage, the groundwater flow gradients in the 100-KR-4 OU steepen toward the Columbia River during seasonal periods of low river flow (i.e., in the fall and winter). Conversely, the groundwater gradient flattens as river water pushes into the aquifer during the spring when the river stage is high.

A3 100-NR-2 Operable Unit History

On September 23, 1994, the Washington State Department of Ecology (Ecology) and the U.S. Environmental Protection Agency (EPA) issued an action memorandum to the DOE Richland Operations Office (DOE-RL) to initiate groundwater remedial actions immediately in the 100-N Area (Ecology and EPA, 1994, “Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy Hanford Site, Richland, Washington”). The requested remedial actions included the design, construction, and operation of a groundwater P&T system and the construction of a sheet-pile barrier wall at N Springs. However, in a letter dated March 1995 (CCN 012354, “RE: U.S. Department of Energy Request to Change N-Springs Action Memorandum”), Ecology and

EPA concurred with DOE-RL that installation of the sheet-pile wall could not be achieved in the manner specified. This conclusion was based on a construction test conducted in December 1994.

Ecology and EPA subsequently directed DOE-RL to proceed with installing a P&T system as an expedited response action. The N Springs P&T system was completed by August 1995 and began full operation by September 1995, meeting *Hanford Federal Facility Agreement and Consent Order* (Tri-Party Agreement) (Ecology et al., 1989) Milestone M-16-12D.

From system startup in September 1995 through November 8, 1996, the N Springs P&T system operated at a nominal rate of 189 L/min (49.9 gpm). During this period, the system consisted of four extraction wells (199-N-75, 199-N-103A, 199-N-106A, and 199-N-105A, with three wells operating and one well serving as a backup) and two injection wells (199-N-29 and 199-N-104A).

Based on recommendations in DOE/RL-95-110, *N-Springs Expedited Response Action Performance Evaluation Report*, and DOE/RL-97-34, *N-Springs Pump and Treat System Optimization Study*, the system was shut down and upgraded to operate at 227 L/min (60 gpm) between November 8 and December 17, 1996. The P&T system was brought back online on December 17, 1996, and continued to operate until it was shut down and placed in cold-standby status in March 2006 (interim action status change are documented in Tri-Party Agreement Change Request M-16-06-01. The historical configuration of the P&T network consisted of three extraction wells (199-N-75, 199-N-103A, and 199-N-106A) and two injection wells (199-N-29 and 199-N-104A), with well 199-N-105A serving as a backup extraction well.

Additional information regarding progress of the 100-NR-2 OU P&T operations is provided in previous annual Sitewide groundwater monitoring reports (e.g., DOE/RL-2010-11, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 and 2*). Additional current background information is available in DOE/RL-2013-22.

Interest was renewed in strontium stabilization by phosphate injection (chemical injection) based on reports of successful bench testing at Sandia National Laboratory. Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratory scientists presented the merits of apatite sequestration and phytoextraction at a workshop in August 2003. Because of the potential for these technologies to remove or sequester strontium-90 from the riverbank sediments, DOE funded two laboratory studies at PNNL in fiscal year 2004 to determine the appropriateness of these technologies at the 100-NR-2 OU:

- Phytoextraction of strontium-90 at the 100-N Area
- Strontium-90 sequestration by apatite at the 100-N Area

In 2006, under the existing interim action ROD (EPA/ROD/R10-99/112, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*) and Tri-Party Agreement Change Control Form M-16-06-01 (*Federal Facility Agreement and Consent Order Change Control Form: Establish Interim Milestone M-016-14, Complete Construction of a Permeable Reactive Barrier at 100-N*), DOE agreed to construct and evaluate the effectiveness of a permeable reactive barrier (PRB) for strontium-90 using apatite sequestration technology as part of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* RI/FS process. From 2006 through 2008, the first apatite PRB was installed along 91.5 m (300 ft) of the most contaminated section of 100-N Area shoreline. Since 2008, this section has been in performance monitoring to track the formation of apatite within the vadose zone and groundwater and to determine the effectiveness of the PRB in attenuating strontium-90 and preventing its release to the Columbia River. To date, the PRB has shown a 90 percent reduction of strontium-90 concentrations at the river's edge (PNNL-19572, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ*

Strontium-90 Immobilization, Final Report). In response to the success of the existing PRB, 146 new injection wells and 25 new monitoring wells were drilled and installed along the remainder of the 100-N Area shoreline in late 2009 to early 2010, both upriver and downriver of the existing PRB.

In September 2011, additional injections were performed at two sections of apatite PRB, expanding the original barrier upstream and downstream, and increasing the current treated portion of 100-N Area shoreline to 290 m (950 ft) in length. The formulation for these injections was the high-concentration calcium-citrate-phosphate solution amendment that was tested in 2008 (PNNL-19572).

A3.1 Conceptual Site Model

The 100-N Area is underlain by the Hanford formation, the Ringold unit E, and the RUM, in descending order. The uppermost unit, the Hanford formation, is 6 to 23 m (19.7 to 75.5 ft) thick and underlies most of the area. In a few places along the shoreline lower road, the Hanford formation is absent because of the excavation and fill that were placed to build the roadway. The Ringold Formation underlies the entire area and is 5 to 20 m (16.4 to 65.6 ft) thick. Based on borehole information, the RUM underlies the entire decision unit and is 17 to 29 m (55.8 to 95.1 ft) thick; it is a relatively low-permeability unit and forms the base of the unconfined aquifer.

Most of the monitoring wells in the 100-N Area are completed in the upper portion of the unconfined aquifer, which is predominantly in the Ringold unit E. At high Columbia River levels, the aquifer can rise into the Hanford formation in wells along the shoreline and nearby inland wells. Five wells monitor the base of the unconfined aquifer in the lower Ringold unit E. One well is completed in a fine-grained, sandy unit in the RUM, approximately 12 m (39 ft) below the water table. The properties of these formations influence the distribution and behavior of contamination in the subsurface. Within the 100-N Area, the vadose zone is composed mainly of the Hanford formation, with portions of the Ringold unit E in some areas. Figure A-3 provides a generalized geologic cross section of the 100-N Area.

The surface of the Hanford formation/Ringold unit E contact has a topographic high near the 116-N-1 facility (Figure A-4), and the Ringold unit E/RUM contact has a topographic low beneath and to the southwest of the Hanford formation/Ringold unit E high spot (Figure A-5). This depression or trough (2 to 2.5 m [6.6 to 8.2 ft] lower than surrounding area) in the RUM runs from adjacent to the head end of the 116-N-1 facility to the river shoreline. It has created a preferential pathway at the base of the aquifer that closely mirrors where higher concentrations of contaminants from the disposal units have been found on the shoreline. Liquid wastes disposed to the ground in the 100-N Area quickly migrated downward through the gravels of the Hanford formation, with very little lateral spreading until reaching groundwater. During operations, the water table was much higher and was located in the Hanford formation, forming mounds under the disposal facilities. Once in groundwater and the Ringold Formation, the wastes moved radially outward from the disposal sites and eventually followed groundwater flow and geologic structure to the Columbia River. The surface of the Hanford/Ringold contact and the RUM contributed to a preferential pathway to the Columbia River shoreline. The first seeps along the shoreline were discovered in 1983 in this location on the shoreline between current wells 199-N-123 and 199-N-119 (PNL-5289, *Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River*). When discharges ceased, the groundwater mounds dissipated and left residual contamination in the vadose zone above groundwater. Chapters 2 and 4 in DOE/RL-2008-46-ADD5, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units*, provide further details on the hydrogeologic conditions and the manner in which contaminants migrated through the vadose zone and groundwater.

A4 Historical Plume Maps

Figures A-6 through A-10 show the historical shape and extent of the Cr(VI) plumes in the 100-D, 100-H, and 100-K Areas.

A5 References

BHI-00184, 1995, *Miocene- to Pliocene-Aged Suprabasalt Sediments of the Hanford Site, South-Central Washington*, Rev. 00, Bechtel Hanford, Inc., Richland, Washington.

CCN 012354, 1995, "RE: U.S. Department of Energy Request to Change N-Springs Action Memorandum" (letter to S.H. Wisness, U.S. Department of Energy, Richland Operations Office, from Roger Stanley, Washington State Department of Ecology, and Doug Sherwood, U.S. Environmental Protection Agency), Washington State Department of Ecology, Olympia, Washington, March 23.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 USC 9601, et seq., Pub. L. 107-377, December 31, 2002. Available at: http://epw.senate.gov/cercla.pdf.

DOE/RL-93-43, 1994, *Limited Field Investigation Report for the 100-HR-3 Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196060716.

DOE/RL-93-79, 1994, *Limited Field Investigation Report for the 100-KR-4 Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196074933.

DOE/RL-94-48, 1995, *100-KR-4 Operable Unit Focused Feasibility Study*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196006899.

DOE/RL-94-67, 1995, *100-HR-3 Operable Unit Focused Feasibility Study*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196006763.

DOE/RL-94-102, 1995, *Proposed Plan for Interim Remedial Measure at the 100-HR-3 Operable Unit*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196007187.

DOE/RL-94-113, 1995, *Proposed Plan for Interim Remedial Measure at the 100-KR-4 Operable Unit*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196007167.

DOE/RL-95-83, 1995, *The Pilot-Scale Treatability Test Summary for the 100-HR-3 Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D197188558.

DOE/RL-95-110, 1996, *N-Springs Expedited Response Action Performance Evaluation Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196188281.

DOE/RL-96-84, 2003, *Remedial Design and Remedial Action Work Plan for the 100-HR-3 and 100-KR-4 Groundwater Operable Units' Interim Action*, Rev. 0-A, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D1348764.

DOE/RL-96-90, 1997, *Interim Action Monitoring Plan for the 100-HR-3 and 100-KR-4 Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D197194770.

DOE/RL-97-34, 1997, *N-Springs Pump and Treat System Optimization Study*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D198059793.

DOE/RL-97-96, 1998, *100-HR-3 and 100-KR-4 Operable Units Interim Action Performance Evaluation Report*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D198088271.

DOE/RL-2002-39, 2002, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://media.wix.com/ugd/12afd0_9dbdbd7be68232c47fabe26b53360660.pdf.

DOE/RL-2006-20, 2006, *The Second CERCLA Five-Year Review Report for the Hanford Site*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=DA04570094.

DOE/RL-2006-52, 2009, *The KW Pump-and-Treat System Remedial Design and Remedial Action Work Plan, Supplement to the 100-KR-4 Groundwater Operable Unit Interim Action*, Rev. 2 Draft, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0906100518.

DOE/RL-2006-75, 2008, *Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump-and-Treat System*, Rev. 1, Reissue, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0812030152.

DOE/RL-2008-42, 2009, *Hydrogeological Summary Report for 600 Area Between 100-D and 100-H for the 100-HR-3 Groundwater Operable Unit*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0911161139.

DOE/RL-2008-46-ADD1, 2010, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 1: 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0084374.

DOE/RL-2008-46-ADD5, 2010, *Integrated 100 Area Remedial Investigation/Feasibility Study Work Plan, Addendum 5: 100-NR-1 and 100-NR-2 Operable Units*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1005130011.

DOE/RL-2009-09, 2010, *Sampling and Analysis Plan for Installation of 100-HR-3 Groundwater Operable Unit Remedial Process Optimization Wells*, Rev. 2, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0084448.

DOE/RL-2009-56, 2011, *Remedial Design/Remedial Action Work Plan for the 100-HR-3 Groundwater Operable Unit Interim Actions*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE/RL-2010-11, 2010, *Hanford Site Groundwater Monitoring and Performance Report for 2009: Volumes 1 & 2*, Rev. 1, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0084237.

DOE/RL-2010-95, 2012, *Remedial Investigation/Feasibility Study for 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*, Draft A, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1102231040.

DOE/RL-2010-97, 2011, *Remedial Investigation/Feasibility Study for the 100-KR-1, 100-KR-2, and 100-KR-4 Operable Units*, Draft A, U.S. Department of Energy, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0093615.

DOE/RL-2013-22, 2013, *Hanford Site Groundwater Monitoring Report for 2012*, Rev. 0, U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0087974.

DOE/RW-0017, 1984, *Draft Environmental Assessment for Reference Repository Location, Hanford Site, Washington*, U.S. Department of Energy, Washington, D.C.

Ecology and EPA, 1994, "Action Memorandum: N-Springs Expedited Response Action Cleanup Plan, U.S. Department of Energy Hanford Site, Richland, Washington" (letter to R. Izatt, U.S. Department of Energy, Richland Operations Office) from D. Butler (Washington State Department of Ecology) and R.F. Smith (U.S. Environmental Protection Agency), Olympia, Washington, September 23. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196063443.

Ecology, EPA, and DOE, 1989, *Hanford Federal Facility Agreement and Consent Order*, 2 vols., as amended, Washington State Department of Ecology, U.S. Environmental Protection Agency, and U.S. Department of Energy, Olympia, Washington. Available at: http://www.hanford.gov/?page=81.

EPA/AMD/R10-00/122, 2000, *Interim Remedial Action Record of Decision Amendment for the 100-HR-3 Operable Unit, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Region 10, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: http://www.epa.gov/superfund/sites/rods/fulltext/a1000122.pdf.

EPA/ROD/R10-96/134, 1996, *Record of Decision for the 100-HR-3 and 100-KR-4 Operable Units Interim Remedial Actions, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Washington. Available at: http://www.epa.gov/superfund/sites/rods/fulltext/r1096134.pdf.

EPA/ROD/R10-99/112, 1999, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*, U.S. Environmental Protection Agency, Region 10, Washington State Department of Ecology, and U.S. Department of Energy, Olympia, Seattle, Washington. Available at: http://www.epa.gov/superfund/sites/rods/fulltext/r1099112.pdf.

PNL-5289, 1984, *Investigation of Ground-Water Seepage from the Hanford Shoreline of the Columbia River*, Pacific Northwest Laboratory, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196018566.

PNL-9437, 1994, *Monitoring Groundwater and River Interaction Along the Hanford Reach of the Columbia River*, Pacific Northwest Laboratory, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196088721.

PNNL-19572, 2010, *100-NR-2 Apatite Treatability Test: High-Concentration Calcium-Citrate-Phosphate Solution Injection for In Situ Strontium-90 Immobilization, Final Report*, Pacific Northwest National Laboratory, Richland, Washington. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19572.pdf.

Resource Conservation and Recovery Act of 1976, 42 USC 6901, et seq. Available at: http://www.epa.gov/epawaste/inforesources/online/index.htm.

SGW-46621, 2010, *100 Area Groundwater Chromium Resin Management Strategy for Ion Exchange Systems*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-47776, 2010, *Aquifer Testing and Rebound Study in Support of the 100-H Deep Chromium Investigation*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://www.osti.gov/bridge/servlets/purl/1038045/.

SGW-48612, 2011, *Borehole Summary Report for the Installation of 70 Remedial Process Optimization, Pump-and-Treat Expansion Wells, for the 100-HR-3 Operable Unit*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1301110180.

SGW-49459, 2011, *Borehole Summary Report for the Drilling and Installation of RI/FS Wells in the 100-KR-4 Operable Unit*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-49912, 2011, *Borehole Summary Report for the Installation of 16 Resource Protection Wells in the 100-HR-3 Groundwater Operable Unit in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1301110181.

SGW-50131, 2011, *Borehole Summary of Ten Characterization Boreholes in the 100-DR-1, 100-DR-2 and 100-HR-1, 100-HR-2 Source Operable Units in Support of the Integrated 100 Areas RI/FS: 100-D/H Decisional Unit*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1301110179.

SGW-51502, 2012, *Borehole Summary Report for the Installation of Well C8668 at 100-D-12 in FY2012*, Rev. 0, CH2M HILL Plateau Remediation Company, Richland, Washington.

SGW-51721, 2012, *100-KW Pump and Treat ResinTech SIR-700 Test Results and Recommendations for Use Across 100-KR-4 Operable Unit*, Rev. 1, CH2M HILL Plateau Remediation Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=0091796.

TPA-CN-505, 2012, *Change Notice for Modifying Approved Documents/Workplans In Accordance with the Tri-Party Agreement Action Plan, Section 9.0, Documentation and Records: Supplement to the 100-HR-3 and 100-KR-4 Remedial Design Report and Remedial Action Workplan for the Expansion of the 100-KR-4 Pump and Treat System, DOE-RL-2006-75 REISSUE, Rev. 1*, dated February 22, U.S. Department of Energy, Richland Operations Office, and U.S. Environmental Protection Agency, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=1204020501.

Tri-Party Change Control Form M-16-06-01, 2006, *Federal Facility Agreement and Consent Order Change Control Form: Establish Interim Milestone M-016-14, Complete Construction of a Permeable Reactive Barrier at 100-N*, dated February 15, U.S. Environmental Protection Agency, Washington State Department of Ecology, and U.S. Department of Energy, Richland Operations Office, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/pdf.cfm?accession=DA01967035.

WHC-SD-EN-TI-011, 1992, *Geology of the Northern Part of the Hanford Site: An Outline of Data Sources and the Geologic Setting of the 100 Areas*, Rev. 0, Westinghouse Hanford Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196090817.

WHC-SD-EN-TI-132, 1993, *Geologic Setting of the 100-HR-3 Operable Unit, Hanford Site, South-Central Washington*, Rev. 0, Westinghouse Hanford Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196126259.

WHC-SD-EN-TI-155, 1993, *Geology of the 100-K Area, Hanford Site, South-Central Washington*, Rev. 0, Westinghouse Hanford Company, Richland, Washington. Available at: http://pdw.hanford.gov/arpir/index.cfm/viewDoc?accession=D196129512.

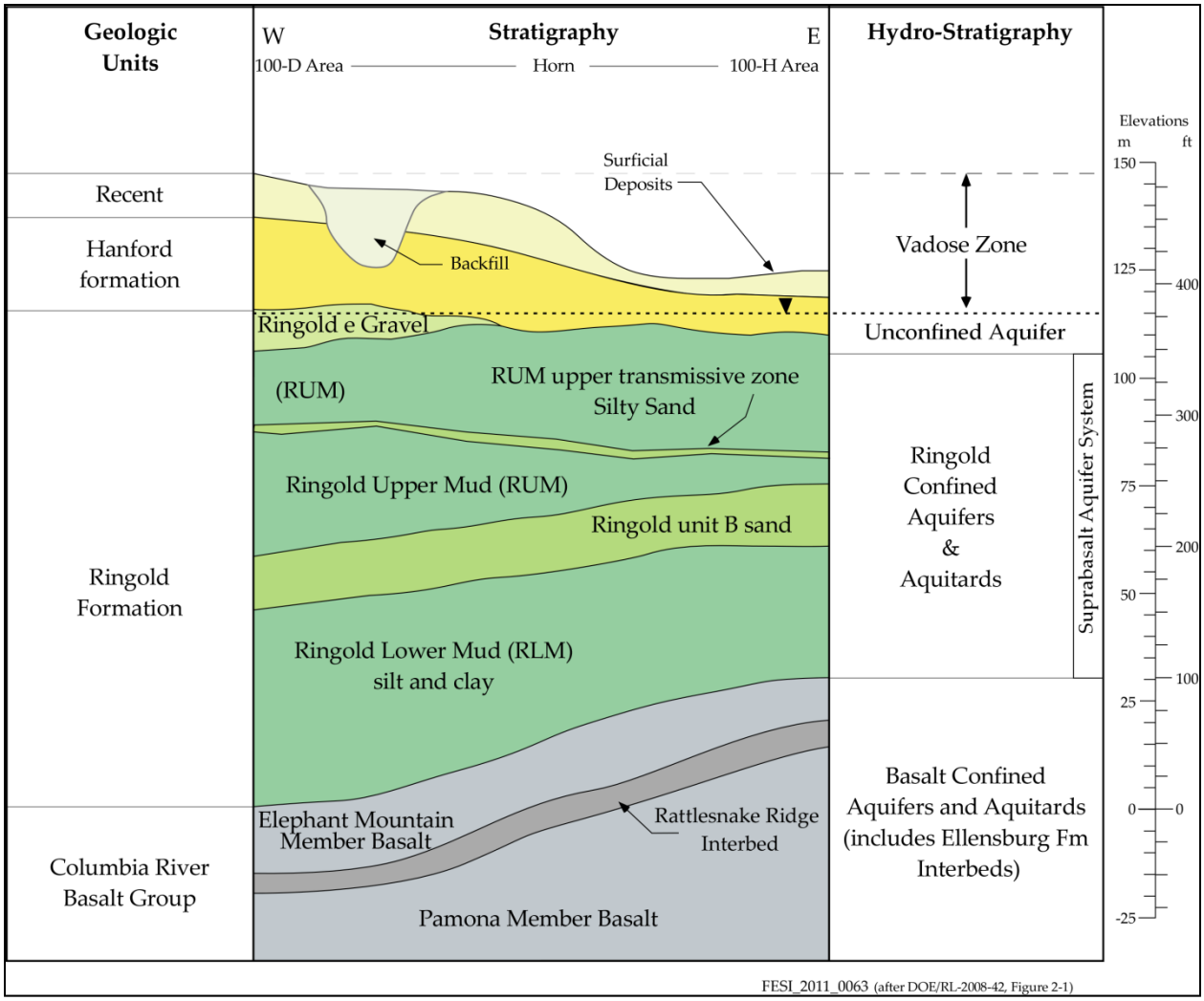

Figure A-1. Conceptual Cross Section of the 100-D and 100-H Areas

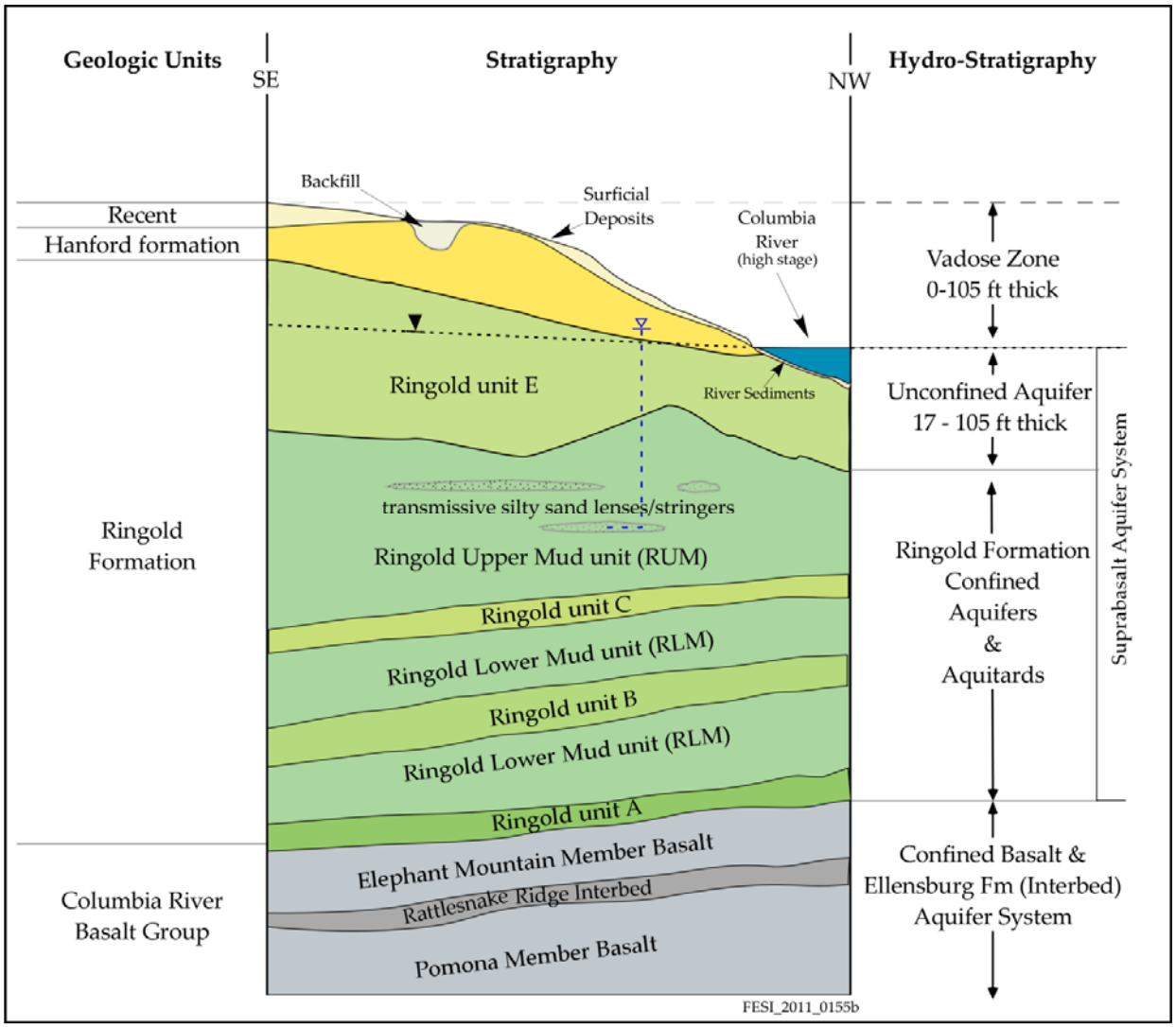

Figure A-2. Generalized Stratigraphic Column at the 100-KR-4 OU

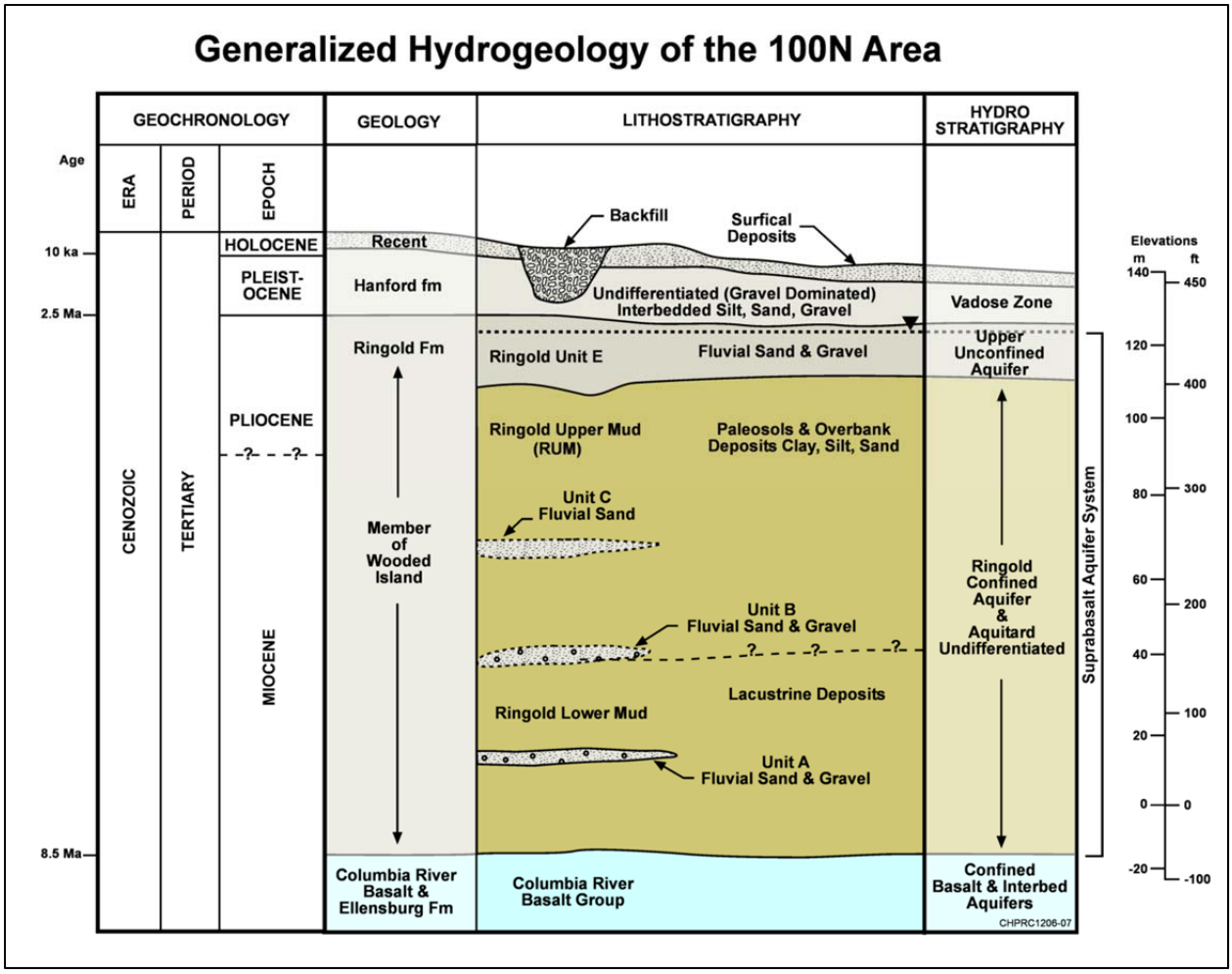

Figure A-3. Generalized Geologic Cross Section of the 100-NR-2 OU

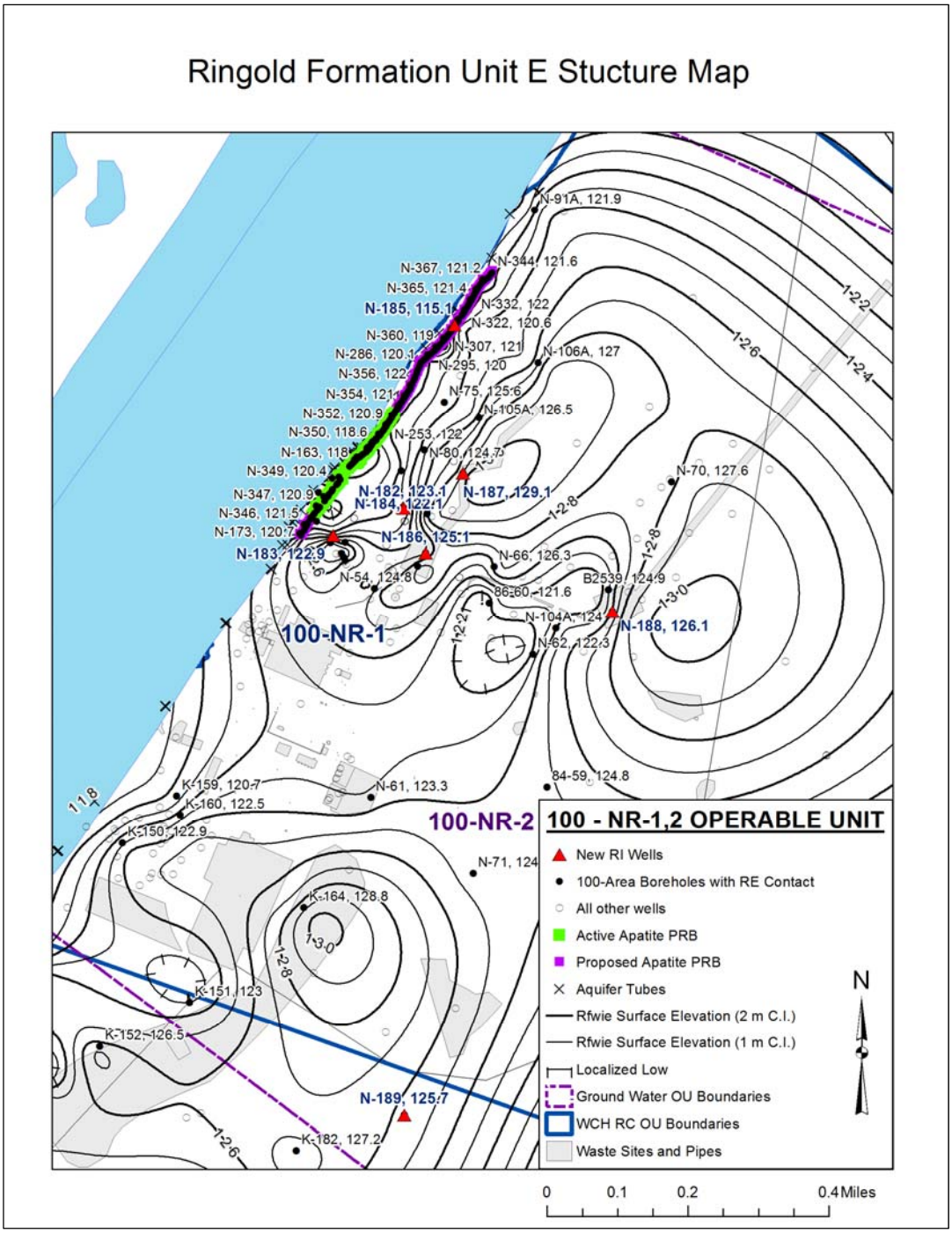

Figure A-4. Surface of the Hanford Formation/Ringold Unit E Contact

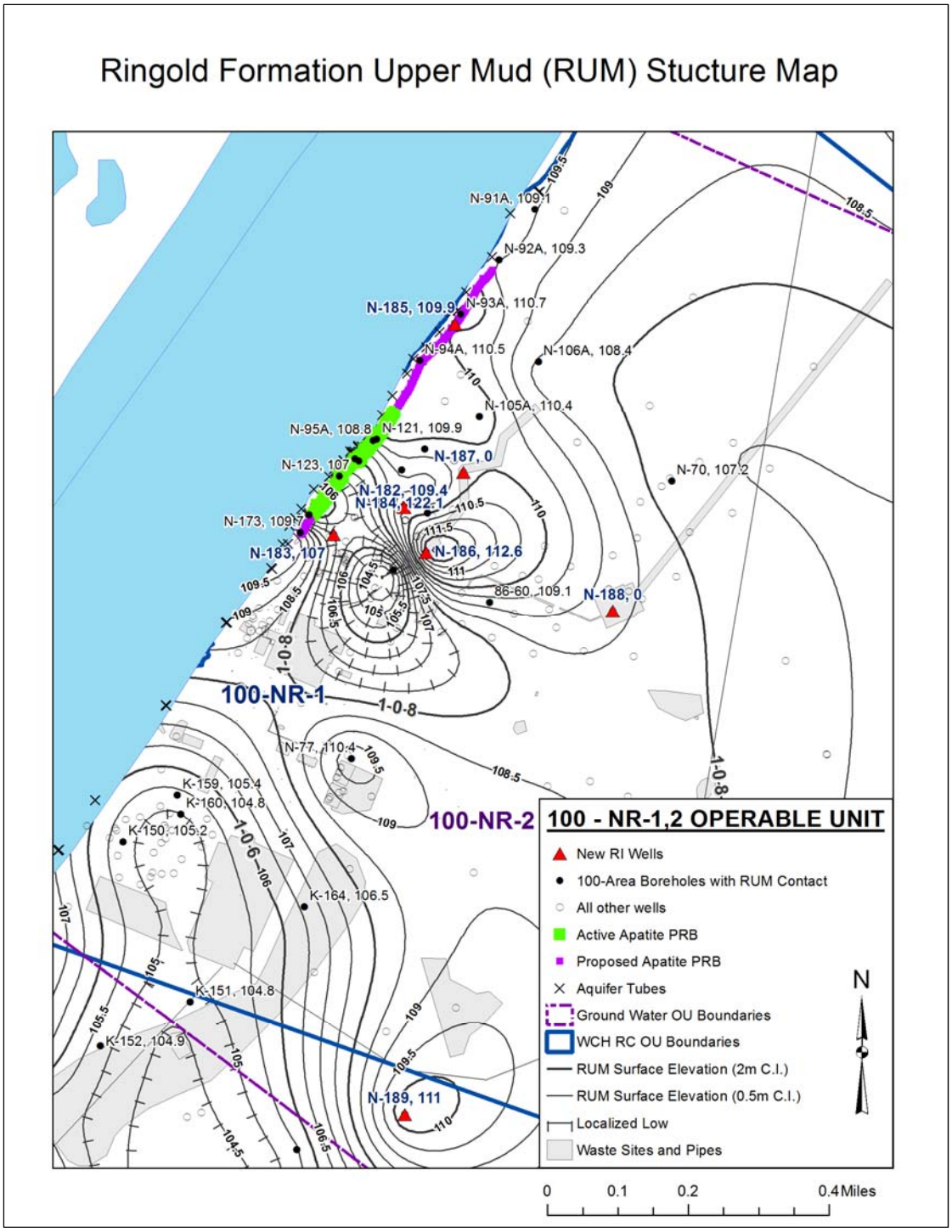

Figure A-5. Surface of the Ringold Unit E/RUM Contact

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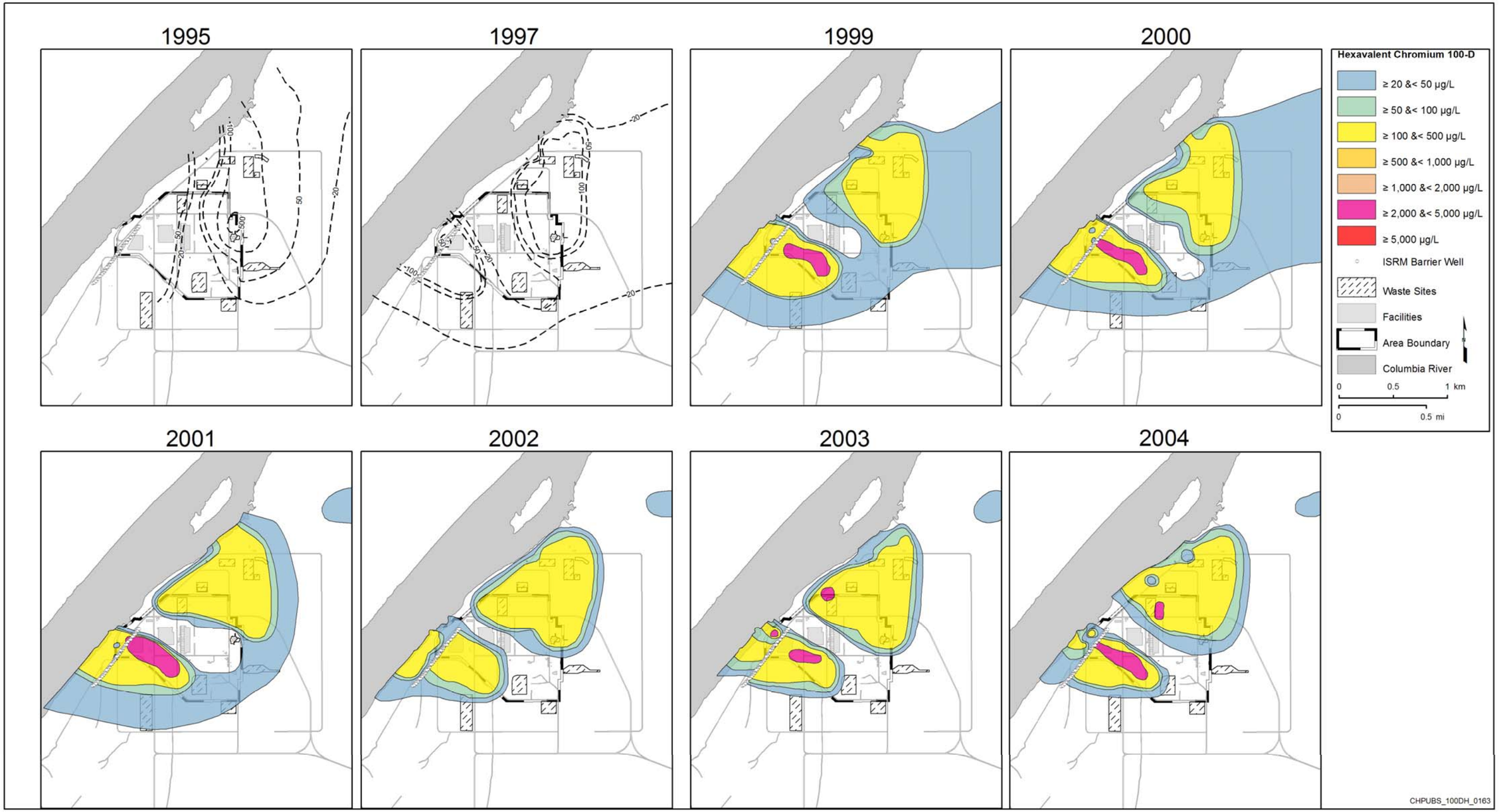

Figure A-6. 100-D Area Chromium Plumes, 1995 to 2004

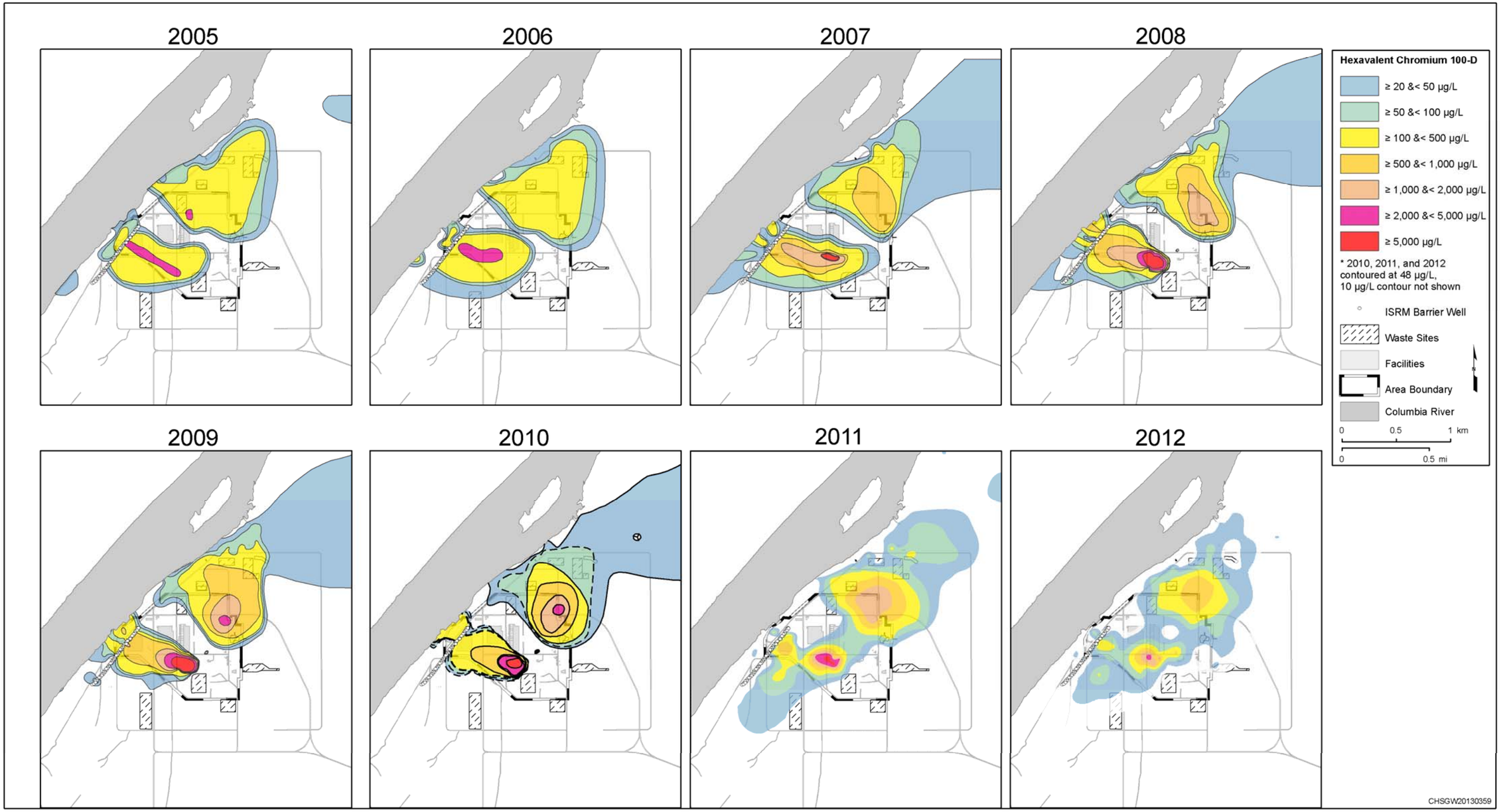

Figure A-7. 100-D Area Chromium Plumes, 2005 to 2011

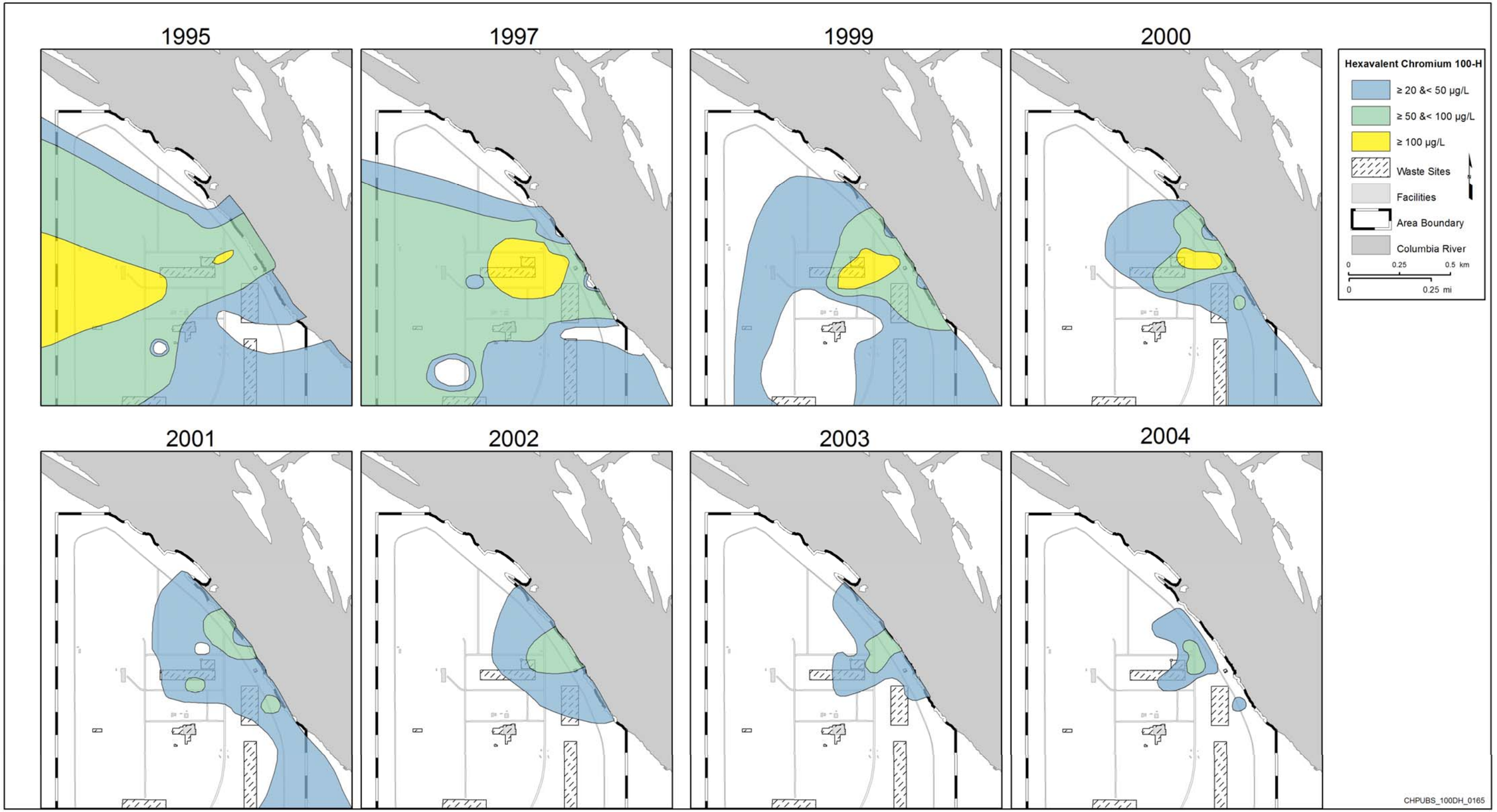

Figure A-8. 100-H Area Chromium Plume, 1995 to 2004

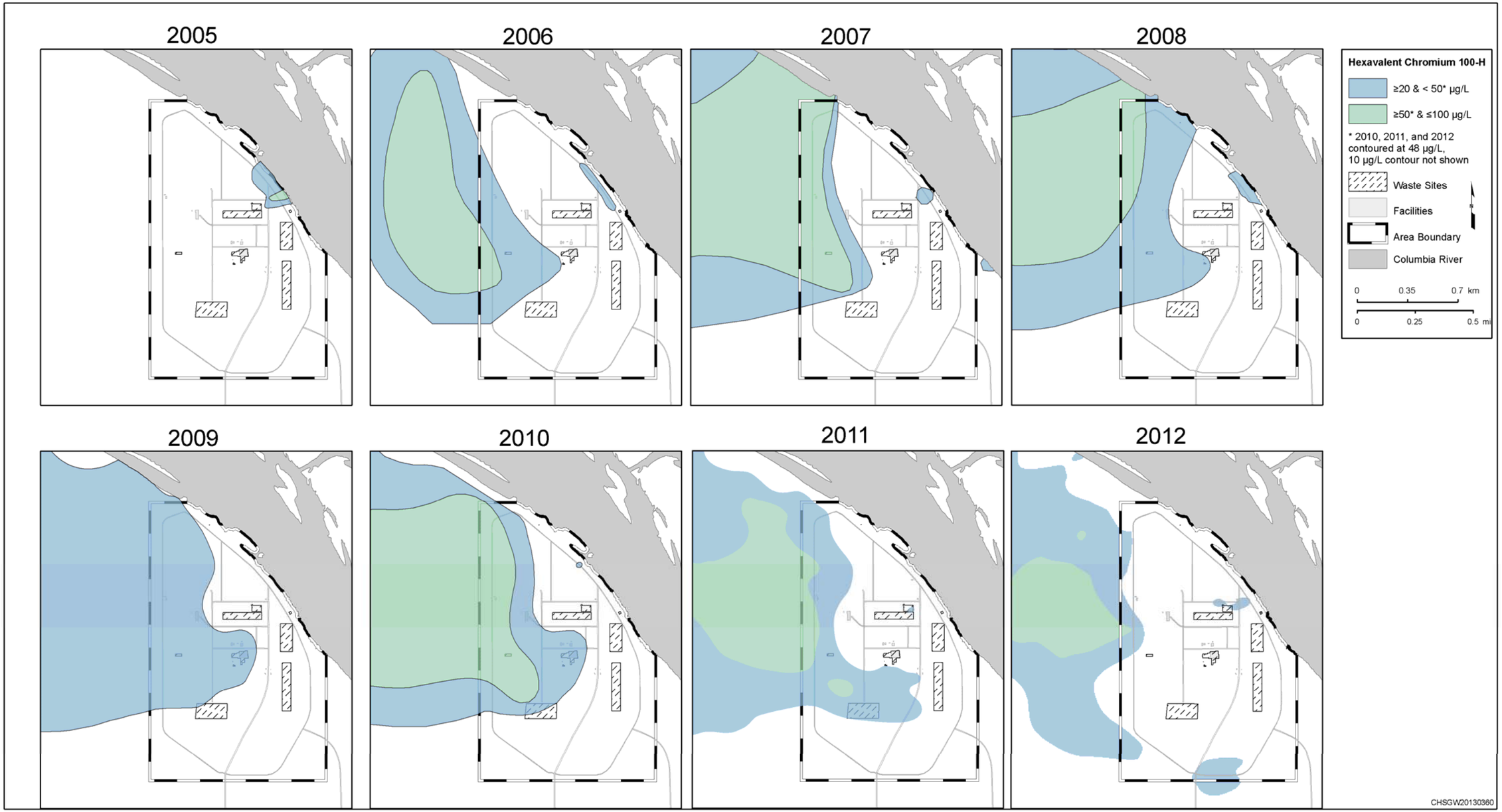

Figure A-9. 100-H Area Chromium Plume, 2005 to 2011

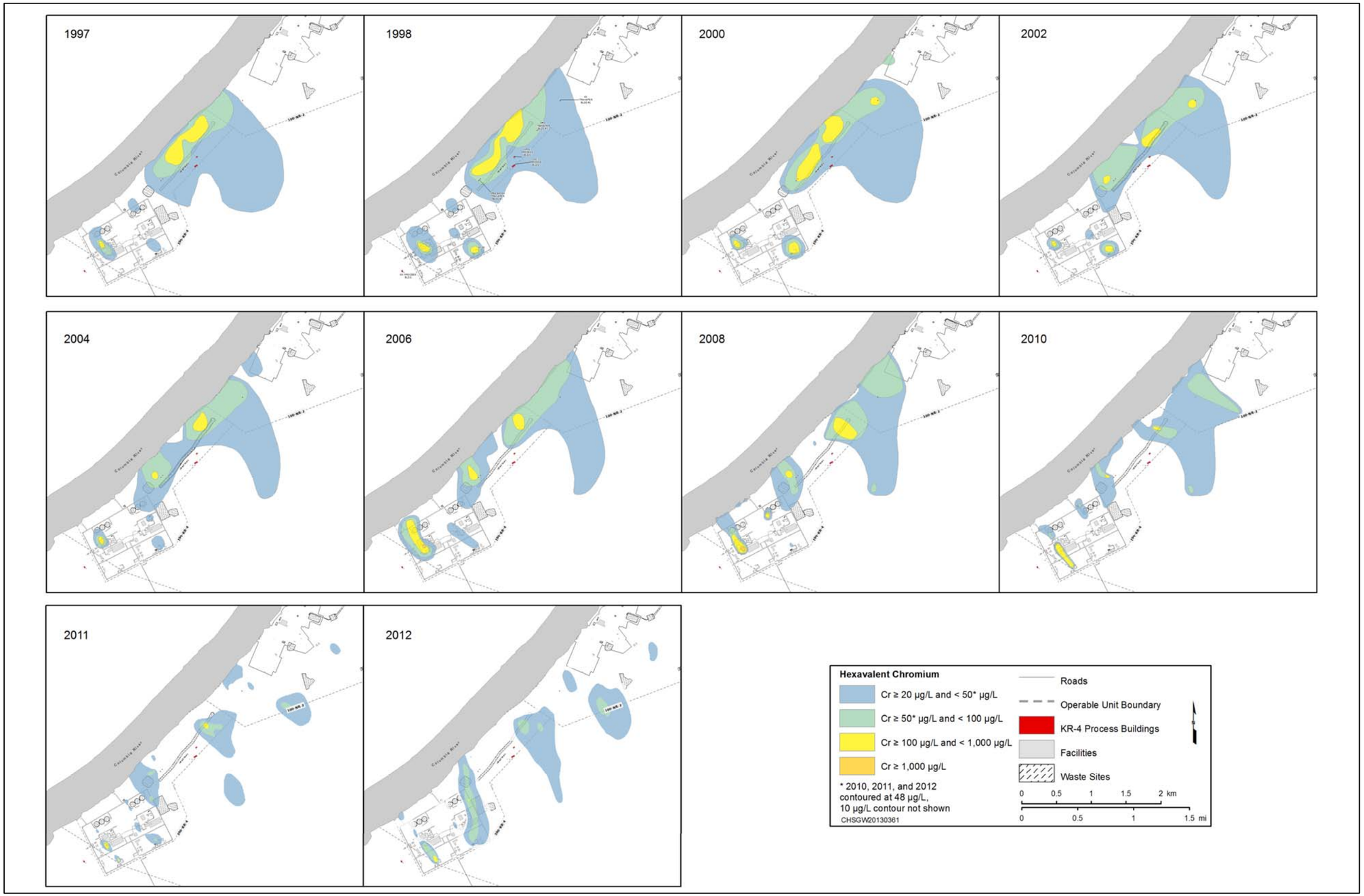

Figure A-10. 100-K Area Chromium Plume, 1997 to 2011

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Table A-1. Treatment Capacity Summary of P&T Systems in the 100-HR-3 OU

P&T System	Actual/Scheduled Operation	Design Capacity (L/min [gpm])	Number of Extraction Wells in the Current Network	Number of Injection Wells in the Current Network
HR-3[a]	June 1997 to May 2011	1,136 (300)	10	4
DR-5[b]	July 2004 to March 2011	189 (50)	5	2
DX	December 2010 to Present	2,273 (600)	37	14
HX	September 2011 to Present	3,030 (800)	31	15

a. The HR-3 P&T system was shutdown in May 2011, and the extraction and injections wells were realigned to the HX P&T system.

b. The DR-5 P&T system was shutdown in March 2011, and the extraction and injections wells were realigned to the DX P&T system.

gpm = gallons per minute

P&T = pump-and-treat

Table A-2. Treatment Capacity Summary of P&T Systems in the 100-KR-4 OU

P&T System	Actual/Scheduled Operation	Design Capacity (L/min [gpm])	Number of Extraction Wells in the Current Network	Number of Injection Wells in the Current Network
KR-4	September 1997 to Present	1,136 (300)	10	5
KX	February 2009 to Present	2,273 (600)	14	9
KW	January 2009 to Present	757 (200)	8	3

gpm = gallons per minute

P&T = pump-and-treat

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