Monitoring Hexavalent Chromium in the Columbia River Hyporheic Zone - 16405

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ABSTRACT

Concentrations of hexavalent chromium in groundwater at the 100-BC reactor area, located on the U.S. Department of Energy's Hanford Site, exceed the State of Washington's surface water quality criterion of 10 µg/L. Groundwater discharge to the Columbia River is the primary pathway for contaminants to reach potential receptors. Additional monitoring was needed in order to make an informed decision about groundwater remediation.

An array of 23 hyporheic sampling points (HSPs) was installed and monitored. The HSPs consist of stainless-steel tubing with 15-cm long mesh screens at depths ranging from 0.15 to 1 meter in the riverbed. The HSPs, which are fully submerged at all river stages, were installed and sampled from a boat using low-flow pumping.

The HSPs provided permanent sampling points to obtain samples of hyporheic zone water. They were equally suitable for high-frequency sampling, with up to 48 samples collected from each HSP over a 4-day period, and long-term monitoring, with monthly grab samples collected over a 2-year period. The HSPs could be sampled at any river stage, which varied up to 3 meters daily and 4 meters seasonally. Pumping rates were kept low to ensure representative sampling and avoid hydraulic short-circuiting.

Short-term increases in river stage did not suppress hexavalent chromium concentrations. Monthly sampling showed that hexavalent chromium concentrations and specific conductance did decline during periods of sustained, seasonally high river stage. Concentrations varied from <2 µg/L during high river stage to 25 µg/L during moderate to low river stage, compared to 50 to 60 µg/L in near-river monitoring wells.

INTRODUCTION

The Hanford Site, part of the U.S. Department of Energy's nuclear weapon complex, is located on the Columbia River in southeastern Washington State. During World War II and through the 1980s, the government built and operated a total of nine nuclear reactors for the production of nuclear materials. Operation of the reactors created liquid waste containing radionuclides and chemical contaminants, including hexavalent chromium. This waste contaminated soil and groundwater beneath the reactor areas.

The 100-BC Area of the Hanford Site is home to B Reactor, the world's first full-scale plutonium nuclear reactor, now a portion of the new Manhattan Project

National Historic Park. DOE completed most of the remediation of 100-BC Area waste sites and contaminated soil by 2013. Figure 1 illustrates the two largest remediation sites, excavations that extended to the water table at a depth of 24 meters. These sites were sources of hexavalent chromium. Remediation activities, which included application of water to control fugitive dust, mobilized contamination and caused a temporary increase in chromium concentration in groundwater. The excavations were backfilled and revegetated in 2013 and 2014.

Fig. 1. Looking North at 100-BC Area, Showing Excavated Waste Sites in 2011. The Columbia River flows west to east at this location.

The water table in 100-BC Area lies at a depth of 18 to 24 meters. The unconfined aquifer comprises unconsolidated gravels and sands. The aquifer is 32 to 48 meters thick, underlain by a fine grained sediment unit, additional sandy units, and the Columbia River Basalts.

The direction of groundwater flow beneath the southern part of 100-BC Area, the location of the recently excavated waste sites, is generally northeastward. The hydraulic gradient is very small (10^{-5} to 10^{-4} m/m) due to the aquifer's high transmissivity. The gradient steepens in northern 100-BC Area as the transmissivity decreases, and groundwater flows to the north. Groundwater discharges to the Columbia River, where previous studies have mapped areas of groundwater upwelling [1]. When the U.S. government obtained the land for the Hanford Site in

1943, it also acquired the bed of the Columbia River through the Site from the State of Washington.

Hexavalent chromium is present in groundwater in a broad contaminant plume. Figure 2 illustrates the extent of the plume in 2014 in the upper part of the unconfined aquifer. Groundwater discharge to the Columbia River is the primary pathway for contaminants to reach potential receptors, such as aquatic organisms.

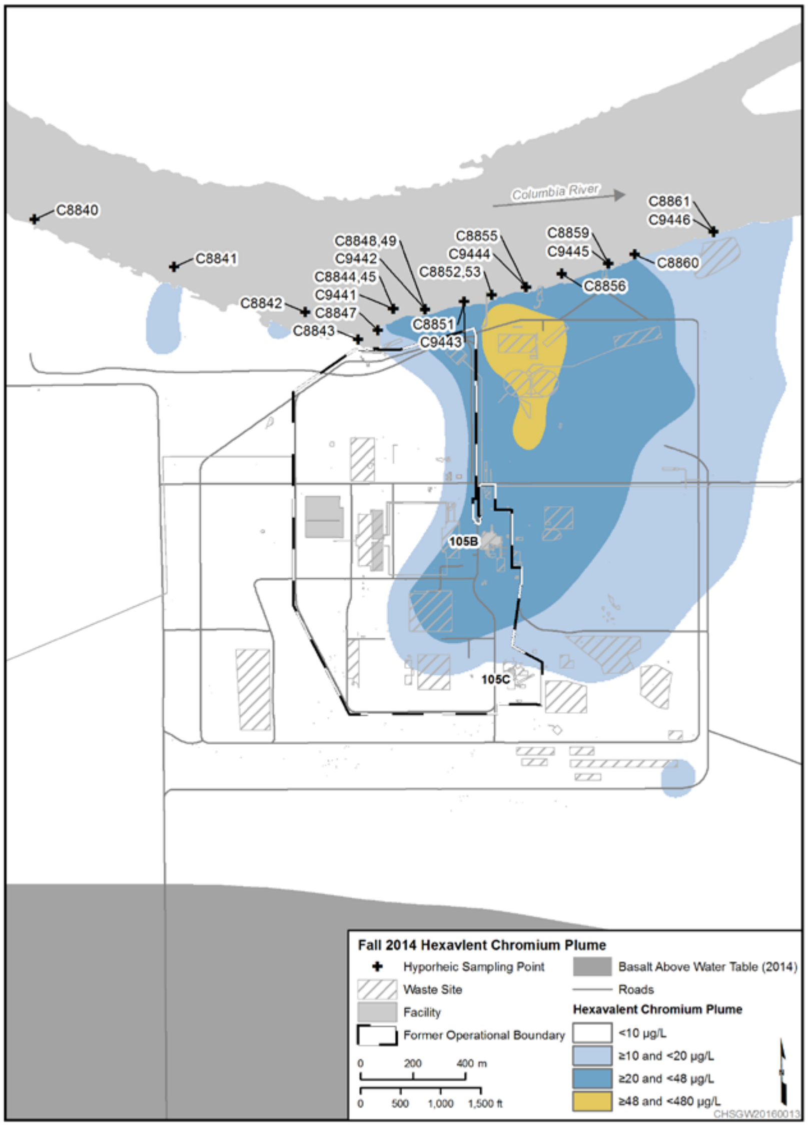

Fig. 2. Hexavalent Chromium in the Upper Part of the Unconfined Aquifer

The area beneath and adjacent to a surface water body where groundwater and surface water mix is known as the hyporheic zone. This study focused on the upper half meter of the hyporheic zone near the 100-BC Area shoreline.

Hexavalent chromium concentrations exceeded the State of Washington's surface water quality criterion of 10 µg/L in a limited number of hyporheic zone water samples in 2009 and 2010 [2]. Concentrations varied widely among three rounds of sampling, which raised questions about risks to aquatic receptors. Additional monitoring of water in the hyporheic zone was deemed necessary in order to support an informed decision about an appropriate method of groundwater remediation.

METHODS

The goal of the study was to monitor water in the hyporheic zone to characterize variations in hexavalent chromium concentration over short periods (hours and days) and long periods (seasons). Given the large number of planned samples, a two-year duration, and a 2.5-km long shoreline, repeated collection of grab samples was impractical. Permanent monitoring devices that meet the following requirements were needed:

- Produce representative samples of hyporheic zone water from fixed locations without artificially inducing flow from the river into the substrate
- Allow for the installation of a datalogger to provide continuous in situ measurement of groundwater parameters
- Provide access during highly variable river stage
- Penetrate the rocky riverbed
- Function during freezing conditions
- Withstand strong currents
- Respect ecological and cultural sensitivities
- Provide a means of safe sample collection for the sampling team

An array of 23 hyporheic sampling points (HSPs) was installed in 2013 and 2014 [3]. The HSPs are located near the shoreline under approximately 1 meter of water at low river stage. Environmental Assessment Services performed site reconnaissance to ensure that groundwater upwelling was present at each planned HSP location before installation. From an anchored boat, field crews deployed the liquid-tip Trident Probe, a tool for mapping groundwater upwelling using in situ specific conductance and temperature. Methods were similar to those used in previous Hanford Site upwelling studies [1]. After confirming groundwater upwelling, the Trident Probe was used to assess pore water pumping rates that could be achieved without causing hydraulic short-circuiting.

After pumping rates were assessed, field crews removed the Trident Probe and drove the HSPs into the river bottom with a driving frame (Figure 3). Stainless steel mesh screens (15 cm long) were inserted inside stainless steel housings attached to drive tips (Figure 4). Portals in the housing allowed water into the screens. The mesh screens were attached to flexible tubing that passed out of the top of the housing through water-tight seals. The sample tubing and a tether rope (Figures 4 and 5) remained on the river bottom until “fished up” from a boat for sampling. HSPs remained submerged year-round, which prevented freezing in the sample lines.

Fig. 3. Driving Frame Used to Install 100-BC Hyporheic Sampling Points

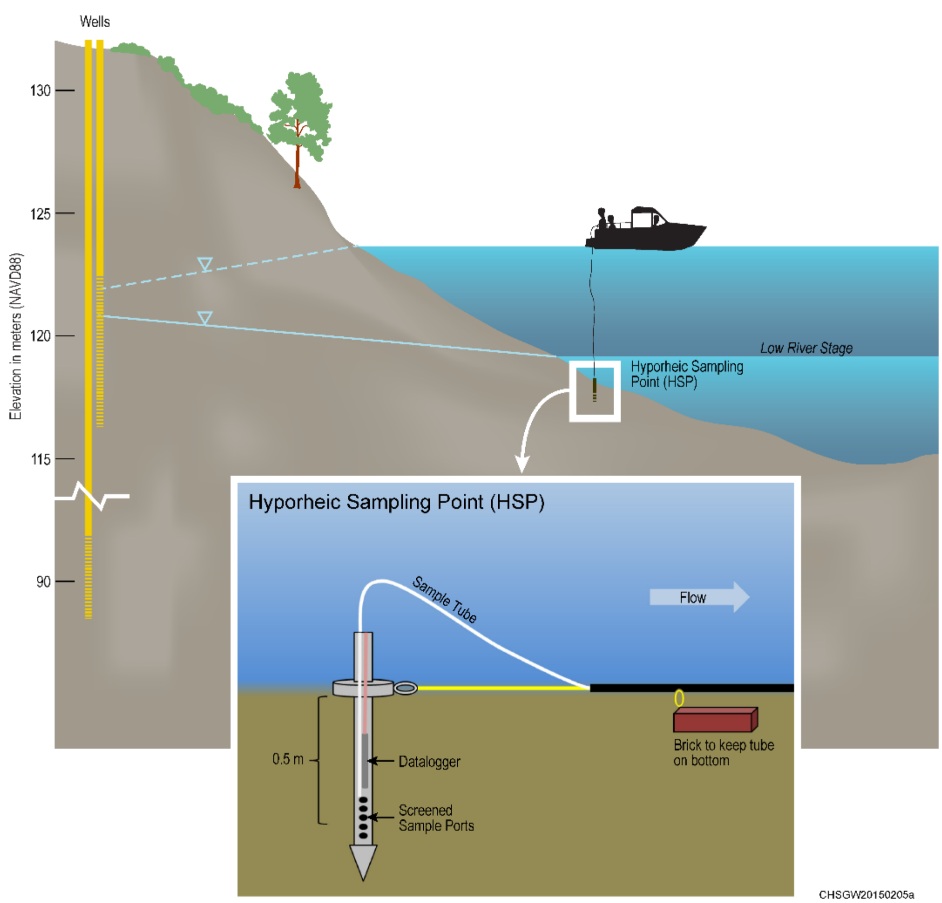

Fig. 4. Schematic Diagram of Hyporheic Sampling Point

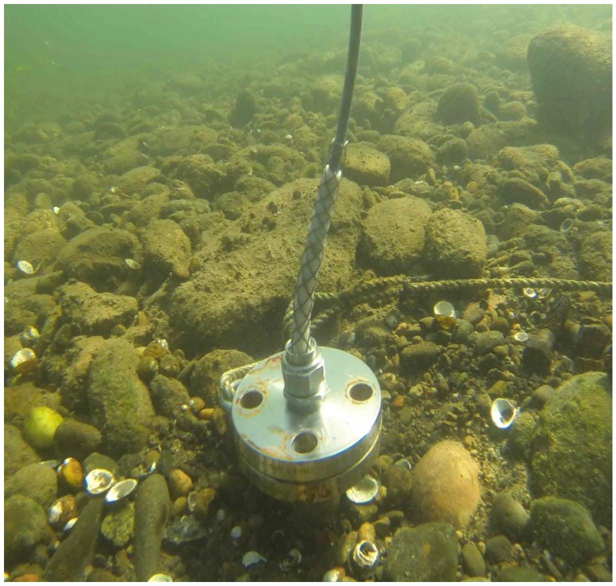

Fig. 5. Hyporheic Sampling Point in Place in the Riverbed [4]

Fourteen of the HSPs at depths of 0.5 meter comprised the main array, which spanned the width of the chromium plume and upstream locations. Three 1-meter HSPs and six 0.15-meter HSPs were installed adjacent to 0.5-meter HSPs to monitor differences in chromium concentration with depth. Four of the HSPs were equipped with dataloggers to record specific conductance, temperature, and water level at an hourly frequency.

One of the challenges associated with sampling the hyporheic zone is obtaining samples representative of ambient conditions. Previous studies on the Hanford Site had shown that if samples were collected using a pumping rate that is too high, river water was drawn into the riverbed, resulting in hydraulic “short circuiting” and a sample comprising primarily river water [1]. Conditions at the 100-BC study area did not allow for placement of an annular seal around the sampling points, but project staff concluded that the potential for short circuiting could be minimized by using a low pumping rate during sample collection. Specific conductance of river water, approximately 130 µS/cm, is significantly lower than local groundwater (300 to 500 µS/cm). Measurements of pore water specific conductance before HSP installation verified that groundwater upwelling was occurring at each location, and these measurements were used to determine appropriate extraction rates for each location (10 to 50 mL/min) to avoid river water short circuiting.

Another challenge to monitoring the hyporheic zone at the 100-BC Area was the large range in river stage due to operation of hydroelectric dams upstream of the Hanford Site. Fluctuations of over 3 meters can occur daily and seasonal changes exceed 4 meters. Because river stage can increase quickly, it was not safe for field crews to install the HSPs using waders; instead they worked from a boat. River stage extremes and other factors also precluded the use of automated sampling devices and increased the difficulty of accessing the tubes during periods of high river stage.

Sampling teams conducted a high-frequency sampling campaign at eight of the HSPs from late October through November 2013 when the average river stage was relatively low. The goal was to get as many samples as possible during a 96-hour period. The actual number of samples ranged from 28 to 48 per HSP.

In general, two HSPs were sampled at a time, with the team alternating between the two to purge the HSPs and tubing, collect samples, filter them, and analyze them for hexavalent chromium in the field over a 96-hour period. This duration was of particular interest because the chronic ambient water quality criterion of 10 µg/L is based on a 4-day average. The team also measured and recorded the water's specific conductance and temperature during purging and sampling and selected a subset of samples for laboratory analysis. The crews then moved on to the next two HSPs for four days, and so on. The field crew followed standard protocols to avoid cross contamination of samples as they moved from site to site.

Beginning in December 2013, field crews collected monthly samples at all of the HSPs, including the eight previously used for high-frequency sampling. Monthly sampling continued until the study concluded in October 2015.

RESULTS AND DISCUSSION

River stage varied up to three meters during the high-frequency sampling period in response to dam operation. During high-frequency sampling, specific conductance and chromium concentrations were only weakly correlated with river stage [3]. Figure 5 illustrates hexavalent chromium and specific conductance with river stage for HSP C8848, which showed the strongest correlation. The lack of a strong correlation to short-term changes in river stage allowed the project to decrease sampling frequency to monthly.

Monthly sampling of the HSPs in 2014 and 2015 showed that hexavalent chromium concentrations and specific conductance did decline during periods of sustained, seasonally high river stage. Figure 6 illustrates chromium concentrations in HSP C8848, a typical example. The 2014 water year was fairly typical, with a normal seasonal high occurring in June. In 2015, the maximum river stage occurred in February to early March and was lower than normal. Concentrations of hexavalent chromium in the 100-BC HSPs varied from <2 µg/L during high river stage in 2014 to 25 µg/L during moderate to low river stage, compared to 50 to 60 µg/L in near-river monitoring wells.

Eight of the fourteen 0.5-m HSPs had annual concentrations above the 10 µg/L surface water quality criterion (Figure 7). Concentrations generally did not increase with depth among the 0.15, 0.5 and 1.0 meter HSPs.

Eight of the HSPs broke during the first year of monitoring, either because a tubing splice had separated, or the sample tubing had pulled out of the housing because of strong river currents. SCUBA divers were required to repair the HSPs and repairs could not be attempted until river stage declined in fall 2014. Divers successfully repaired and ruggedized the HSPs, which were then sampled for another year with only two breakages.

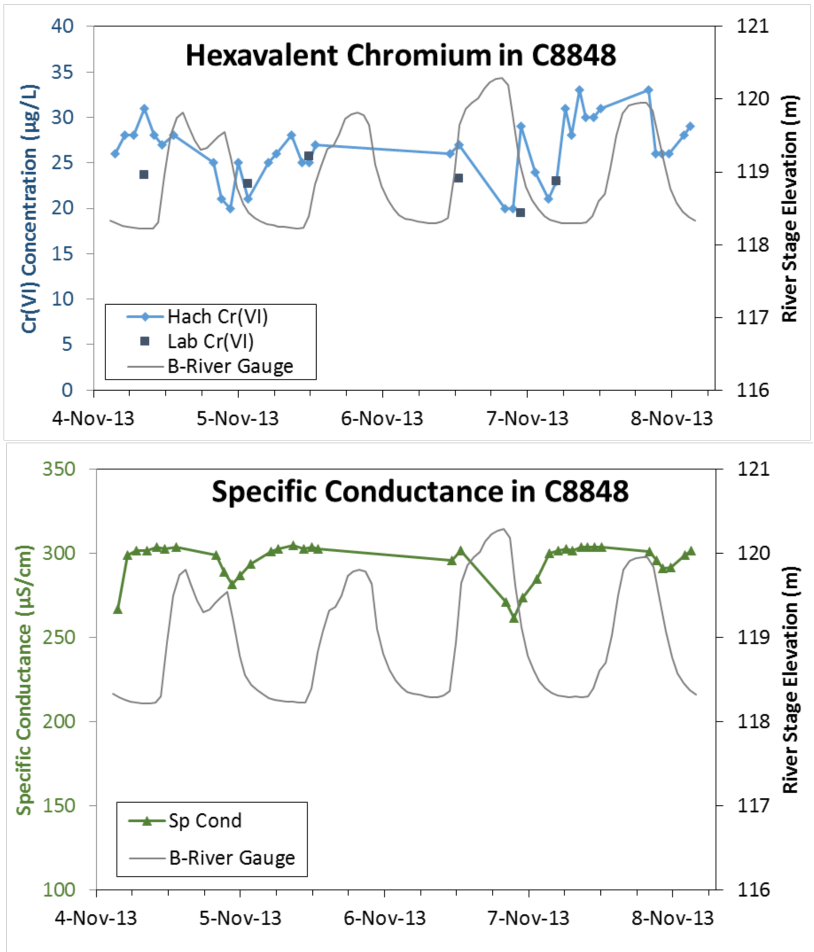

Fig. 5. Hexavalent Chromium and Specific Conductance in Relation to River Stage During High-Frequency Sampling of HSP C8848 [3]

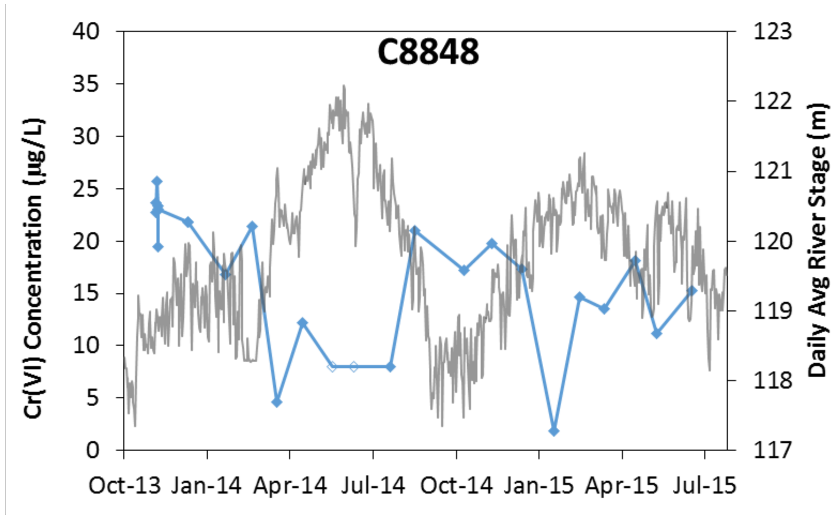

Fig. 6. Hexavalent Chromium Concentration and River Stage in HSP C8848, Fall 2013 through Summer 2015

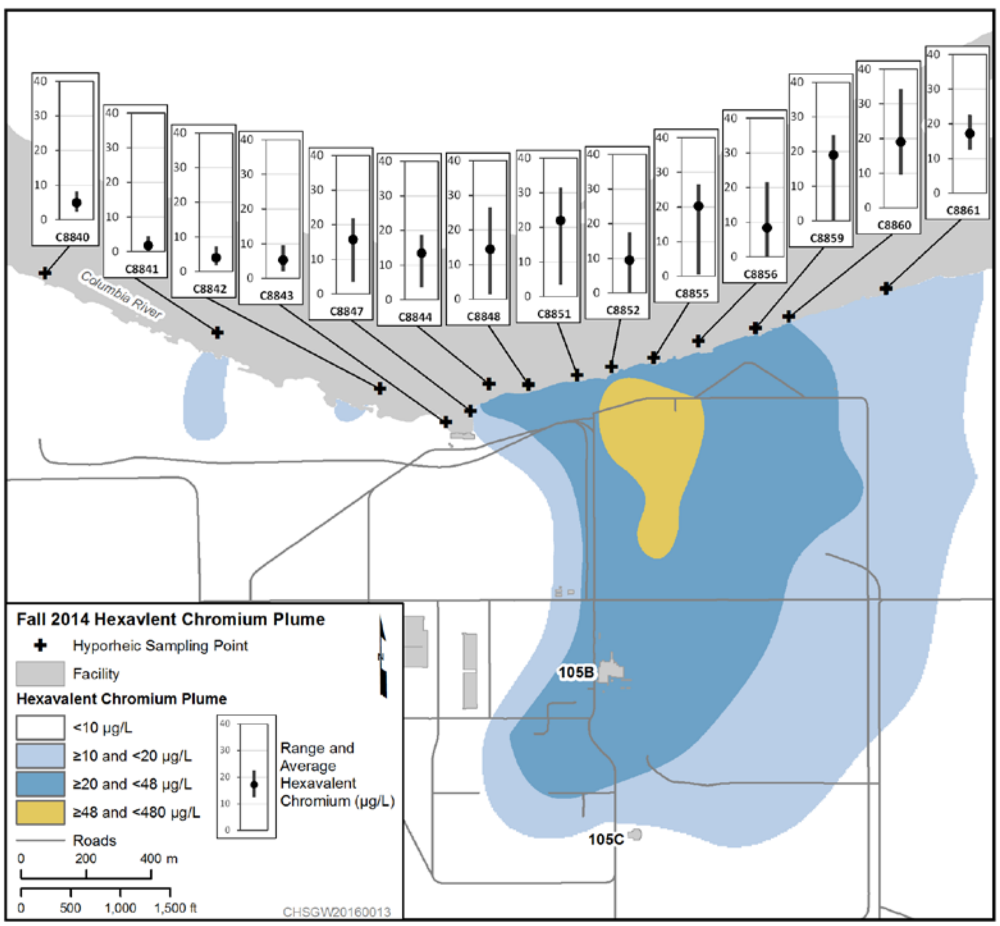

Fig. 7 – Range and Average Hexavalent Chromium Concentration in 0.5-meter Hyporheic Sampling Points, October 2013 Through September 2015

CONCLUSIONS

The sampling design allowed the project to meet its objectives. The project team achieved the following:

- **Installed an array of HSPs in the rocky riverbed along a 2.5-km length of the 100-BC Area shoreline.** Some locations needed to be adjusted to avoid particularly cobbly areas, but a comprehensive array was successfully installed. The HSPs were rugged enough to be pounded into rocky ground, but would be equally suitable for use in silty or sandy substrates.
- **Obtained representative samples of hyporheic zone water.** The design of the sample devices, along with low pumping rates (10 to 50 mL/min), reduced the likelihood of artificially inducing flow into the substrate from the river. Close monitoring of specific conductance during purging and sampling provided an indication of sample representativeness.
- **Accessed the HSPs over the entire seasonal range of river stage.** Permanent sampling points allowed for monitoring constant locations over a two-year period, during which river stage varied over four meters. The HSPs were suitable for high-frequency and long-term monitoring.
- **Collected monthly samples efficiently.** The entire array could be sampled in a few days because the sampling devices were permanently installed.
- **Allowed for in situ instrumentation.** The diameter and length of the HSPs was sufficient to accept sensors and dataloggers.

Disadvantages of the sampling design included the following:

- **High-frequency sampling was labor-intensive.** This was unavoidable given the need to characterize short-term variations and the inability to use an automated sampler.
- **Some HSPs broke.** Maintenance could only be done at times of relatively low river discharge and required SCUBA divers. A revised, rugged design improved performance for the second year of sampling.
- **Low flow requirements limited sample volumes.** This was not a problem when only hexavalent chromium was required. However, some additional analyses were eliminated due to sample volume limitations.

Results of monitoring the hyporheic zone in 100-BC Area showed that hexavalent chromium is consistently present at concentrations between 10 and 20 µg/L. Concentrations decline during periods of sustained high river stage. These data are being evaluated in conjunction with data from 100-BC Area groundwater to select alternatives for remediation.

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