

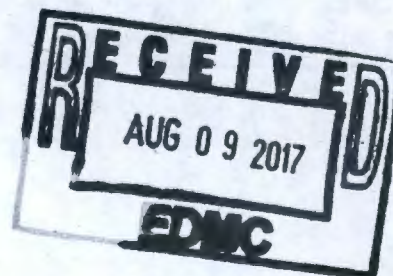
Evaluation of the Technical Feasibility to Install a Horizontal Groundwater Extraction Well at the Hanford Site

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788



P.O. Box 1600
Richland, Washington 99352



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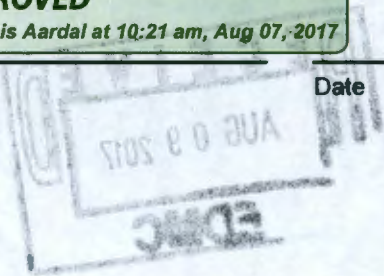
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ch2m.SM
P.O. Box 1600
Richland, Washington 99352

APPROVED
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TECHNICAL MEMORANDUM

Evaluation of the Technical Feasibility to Install a Horizontal Groundwater Extraction Well at the Hanford Site

Prepared for: Mike Drewett/CHPRC
Prepared by: Mark Henry/TerraGraphics, Inc.
CCs: William Faught/CHPRC
Martin Doornbos/CHPRC
Dave Capelle/CHPRC
Rob Mackley/CHPRC
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1 Introduction

To support ongoing pump-and-treat (P&T) system optimization efforts and to achieve remedial action objectives, CH2M HILL Plateau Remediation Company (CHPRC) is evaluating the technical feasibility of installing a horizontal groundwater extraction well in the 100 Areas at the Hanford Site to improve plume containment and mass removal/plume reduction for areas where traditional (vertical) groundwater extraction wells have limited impact particularly during low river stage conditions.

This technical memorandum identifies and describes three potentially applicable methods that could be used to construct a horizontal groundwater extraction well. Section 3 further describes each method, and Section 4 presents a comparative analysis of the methods. Finally, Section 5 identifies conclusions and provides recommendations for future evaluation tasks.

2 Background and Reason for Evaluation

Groundwater P&T systems have been in operation in the 100-HR-3 and 100-KR-4 Operable Units as components of interim remedial actions since early 1997. The highest priority for these P&T systems is river protection followed by mass removal. The systems were designed to protect the Columbia River from discharges of hexavalent chromium (Cr[VI]) at concentrations greater than the state surface water quality standard of 10 µg/L and restoring groundwater to drinking water standards. The strategy for river protection and mass removal focus on the extraction well-field configuration and individual well extraction rate capacity to maximize contaminant containment and mass removal. The primary decision criteria for locating extraction wells are contaminant concentrations, well and aquifer yields, and proximity to continuing contaminant sources (where applicable). For these P&T systems, contaminated groundwater is extracted using vertical wells and then conveyed above ground to a treatment plant. Treated effluent from the systems is re-injected back into the aquifer to optimize groundwater flow and contaminant transport for subsequent removal and treatment. Additional details regarding groundwater

monitoring results for these areas, P&T operations, and ongoing optimization activities can be found in the following documents:

- DOE/RL-2016-09, *Hanford Site Groundwater Monitoring Report for 2015*
- DOE/RL-2016-19, *Calendar Year 2015 Annual Summary Report for the 100-HR-3 and 100-KR-4 Pump and Treat Operations, and 100-NR-2 Groundwater Remediation*
- SGW-58986, *FY2016 Plume Containment and Remediation Utilization Plan*

In a portion of the Horn and 100-H Areas, vertical groundwater extraction wells cannot provide sustained extraction from the hexavalent chromium (Cr[VI])-contaminated unconfined aquifer during low river stage conditions that generally occur from September to December. During this period, the saturated thickness of the unconfined aquifer can be as little as 2 to 3 m (7 to 10 ft; DOE/RL-2010-95, *Remedial Investigation/Feasibility Study for 100-DR-1, 100-DR-2, 100-HR-1, 100-HR-2, and 100-HR-3 Operable Units*). Coupled with the drawdown in extraction wells from pump operation, some wells cannot sustain any groundwater extraction for subsequent treatment. It is also during this timeframe that the groundwater flow gradient toward the river is the highest. As river stage increases during high river flows (generally March–June), the aquifer thickness may increase up to 6 m (20 ft). Correspondingly, extraction rates from individual extraction wells in this area show wide fluctuations in their sustainable seasonal averages, which reportedly can vary from 0 to 151 lpm (0 to 40 gpm) under low stage and high stage seasons, respectively.

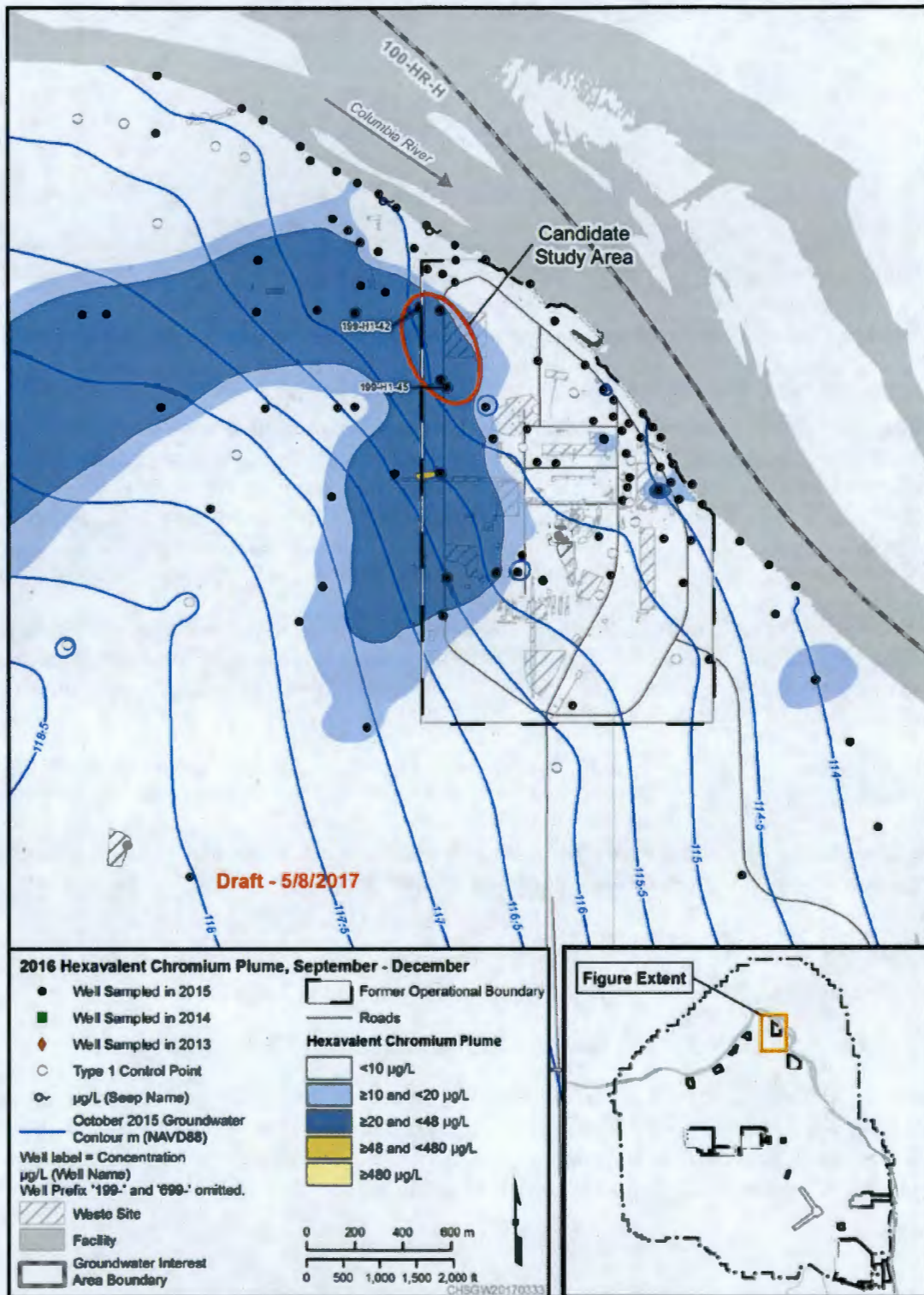
Figure 1 provides a general vicinity map of the 100-H Area and highlights a candidate study area for this evaluation to provide comparisons for installation of a horizontal well using the methodologies described in Section 3. Installing a horizontal well in this area could help address a number of remediation objectives, including:

- River protection: Provides improved hydraulic control and containment of a Cr(VI) plume during low river stage conditions
- Mass removal and plume area reduction: Sustainable groundwater extraction would yield higher extraction volumes and greater overall contaminant mass removal, reducing time to achieve cleanup levels

There currently is available treatment capacity for processing Cr(VI)-contaminated groundwater at the 100-HX treatment plant, the nearest treatment facility to the candidate study area.

3 Potential Horizontal Well Installation Methodologies

Three potential methods have been identified that could be used to install a horizontal well in the candidate study area: horizontal directional drilling (HDD); excavation, trenching, and direct installation; and single-pass trenching. Each of these methodologies is discussed below, with additional detail provided for HDD because of the numerous steps involved with that method.



Reference: NAVD88, North American Vertical Datum of 1988.

Figure 1. The 100-H Area and Candidate Study Area

3.1 Horizontal Directional Drilling

HDD was initially used for the installation of horizontal groundwater extraction wells in the early 1980s at the U.S. Department of Energy Savannah River site. Industry leaders note that this technology has been expanded and refined over the past 30 years, enabling the method to be used at contaminated sites across a wide range of subsurface conditions worldwide. The general components of HDD for horizontal well installation applicable to the study area are described below.

- Mobilization to the site and work-area setup (pit pads, at entry and exit [optional] of pipe string).
- Advancement of larger-diameter surface casing (71 cm [28 in.] diameter or larger) at 12 to 18 degrees off horizontal, installed using a pneumatic pipe ram. Installation of this surface casing will be necessary to advance through the gravelly/cobbly Hanford formation to the base/middle of the unconfined aquifer prior to initiating horizontal drilling. Typically, this point of entry (and exit) would be at least five times the desired true vertical depth of the horizontal well to accommodate the minimum bend radius of likely well screen materials and/or the steel drill rods. For this study area, it is anticipated that the entry point of the surface casing will be 75 to 105 m (250 to 350 ft) from the desired screen placement location at the entry end, given an anticipated depth of 15 m (50 ft). Installation of surface casing at the exit is optional and is generally done only if necessary to mitigate excessive friction during pullback.
- Placement of a smaller diameter conductor casing (~12 in. diameter) inside the large diameter surface casing, socketing, and/or cemented into the unconfined aquifer formation. This method reduces the volume of drilling mud required to fill the casing and maintains sufficient uphole mud velocity to carry drill cuttings to the surface and clean the bore during horizontal drilling.
- Pilot borehole advancement through the middle of the unconfined aquifer over a pre-determined length. Conventional HDD techniques would be used to advance an uncased pilot borehole using mud-rotary methods that use a specialized, steerable drilling assembly, and an integrated locating/navigation system to follow a pre-determined bore path. A polymer-based biodegradable mud would be used to hold the formation open during drilling and would reduce well development time compared to traditional bentonite-containing drilling mud/fluids. The Washington State Department of Ecology (Ecology) would need to pre-approve a variance according to WAC 173-160, "Minimum Standards for Construction and Maintenance of Wells," for using polymer-based drilling fluids.
 - A navigation system would be employed behind the drill bit to track the location, depth, and lateral and vertical deflection of the bit. Depending on potential interferences present from any nearby overhead power lines, buried utilities, or metallic debris in the subsurface and the precision required, two primary navigation system types could be used. The simpler, less costly method would use a walkover system, whereby a sonde (placed in a housing directly behind the drill bit) emits an electromagnetic field and telemetry signals that could be monitored by a technician at the surface. This method, however, is sensitive to external magnetic fields and interferences. Another option is a wireline navigation system using either magnetic or gyroscopic guidance. This system is less sensitive to interferences (described above, compared to a walkover) and is more precise but is a higher financial cost.
- After the drill bit emerges at the surface on the exit side of the installation, the downhole cutting head assembly is removed and a reaming tool attached. Because of the low cohesion of aquifer materials and the potential for large clast sizes, one to several passes with a reamer may be necessary to achieve a borehole diameter suitable for installation and pullback of well screen materials. The reamer is

usually pulled back toward the drill rig while drill rods are added behind and removed in front of it, which maintains continuous tooling through the bore to prevent deviation from the initial guided pilot bore. Typically, a borehole 1.5 times the diameter of the finished well is desired (e.g., a 25.4 cm [10 in.] borehole necessary for a 15.24 cm [6 in.] completed well), though additional reaming may be necessary to clean the bore prior to pullback. Depending on the type of completion method, the well screen and casing would be pulled back from the exit location (double-entry construction) or pushed from the entry pit when a blind-entry completion is used.

- Well screen materials that could be considered for this type of application at the Hanford Site could include polyvinyl chloride (only for blind-entry completions), high density polyethylene (HDPE), fiberglass-reinforced epoxy, and stainless steel. In consideration of aquifer materials, potential yields of a horizontal well, and contaminant types, it is anticipated that an internally reinforced V-wrapped stainless-steel well screen (specially manufactured for HDD applications) would be used. Specific well design and well screen details would be identified during a well design process. Similarly, the type and size of submersible pump and associated piping would be a part of the well design package.
- Following installation, well development would be accomplished using high pressure jetting over the length of the well screen and pumping or air lift methods to remove fines, settle the native materials around the well screen, and remove any residual biodegradable polymer (which would naturally degrade within days). While jetting, an enzyme would be introduced into the development water to accelerate the breakdown of the biopolymer fluid into simple saccharides (sugars). It is possible that additional time and increased water volumes may be associated with well development for horizontal wells installed with HDD.

The installation process summarized above is termed a "continuous" or "double entry" type of completion. Some subcontractors also have the capability to complete a "blind completion," whereby only one access point is used. For a blind completion, a larger set of drilling tooling would be used that allows direct placement/installation of well screen materials (maximum diameter of 10.2 cm [4 in.]) inside the drill string after the drill bit is detached and left in place, and then the drill string retracted.

3.2 Excavation, Trenching, and Direct Installation

Installation of a horizontal extraction well also could be accomplished using traditional excavation techniques through the vadose zone down to the top of an alluvial aquifer. Excavation and laybacks would need to adhere to Occupational Safety and Health Administration and Hanford Site procedures in DOE-0344, *Hanford Site Excavating, Trenching and Shoring Procedure (HSETSP)*, and would include laybacks at least of 1.5:1 horizontal to vertical ratio. At that point, direct placement of well screens (in accordance with well design process criteria) could be accomplished using shoring/trench boxes to maintain worker safety at the depth desired. To minimize handling of aquifer material, it is anticipated that well screen placement would occur during the low river stage when aquifer thickness is at a minimum. Backfill material used around the horizontal well could be the same excavated material or could be imported according to well design package requirements. Well development could be accomplished similarly to that described above for HDD. The final array of piping would necessitate a type of vault, pump chamber, or cistern at a depth that would allow for the installation of pumping equipment for distribution to a treatment plant. Following installation, already-excavated material would need to be placed back into the excavation and compacted in accordance with site procedures and standards.

3.3 Single-Pass Trenching

Single-pass trenching is a relatively new method that uses large, proprietary-designed and built machines that excavate a trench and install an HDPE (or similar) type well screen in a single, simultaneous pass

through unconsolidated sediments. Given the subsurface materials anticipated in the study area and the current proprietary equipment available (e.g., DeWind® One-Pass Trencher), the maximum depth of installation for a horizontal well using single-pass trenching is anticipated to be ~10.7 m (35 ft) below ground surface. Should the horizontal well depth need to be greater, traditional and single-pass excavation techniques could be combined. With the simultaneous trenching and installation required, well screen materials and sizing would need to be completed prior to implementing single-pass installation.

Well development and pumping requirements would be similar to that described in Section 3.2 for traditional excavation and trenching techniques.

4 Alternatives Comparison

As highlighted in Figure 1 and discussed in Section 2, a candidate study area near the 100-H Area has been identified that provides a context for this evaluation and allows for a more detailed comparison between the potential horizontal well construction methodologies described above. Additional information on the candidate study area is provided in Section 4.1.

4.1 Proposed Study Area Description Overview

Detailed descriptions of the study area, including site geology and hydrogeology, are provided in the 100-D/H Areas Remedial Investigation/Feasibility Study (DOE/RL-2010-95). Details presented in the following subsections summarize geological and hydrogeological information pertinent to this discussion.

4.1.1 Topography and Subsurface Geology

The topography of the study area consists of relatively steep banks rising from the Columbia River and then generally flat to slightly undulating inland. The surface elevations in the site area range from ~124 m (407 ft) near well 199-H1-42 to 128 m (420 ft) to the south near well 199-H1-45 (Figure 1).

Figure 2 illustrates the generalized geology of the 100-D/H Areas. The vadose zone contains the highly transmissive and heterogeneous Hanford formation, which consists of unconsolidated cataclysmic flood deposits ranging from silty gravels to sands and gravels with occasional boulders. This area is also underlain by the less transmissive Ringold Formation upper mud (RUM) unit (silt) that forms the base of the upper unconfined aquifer. The top of the RUM surface near the study area is relatively consistent; however, it is known to exhibit some undulation based on nearby characterization work. Within the study area, the Ringold Formation unit E is believed to be largely absent with the Hanford formation and constitutes both the vadose zone and upper unconfined aquifer.

Table 1 provides a summary of depths and elevations for subsurface materials encountered at two wells located within the candidate study area: 199-H1-42 and 199-H1-45.

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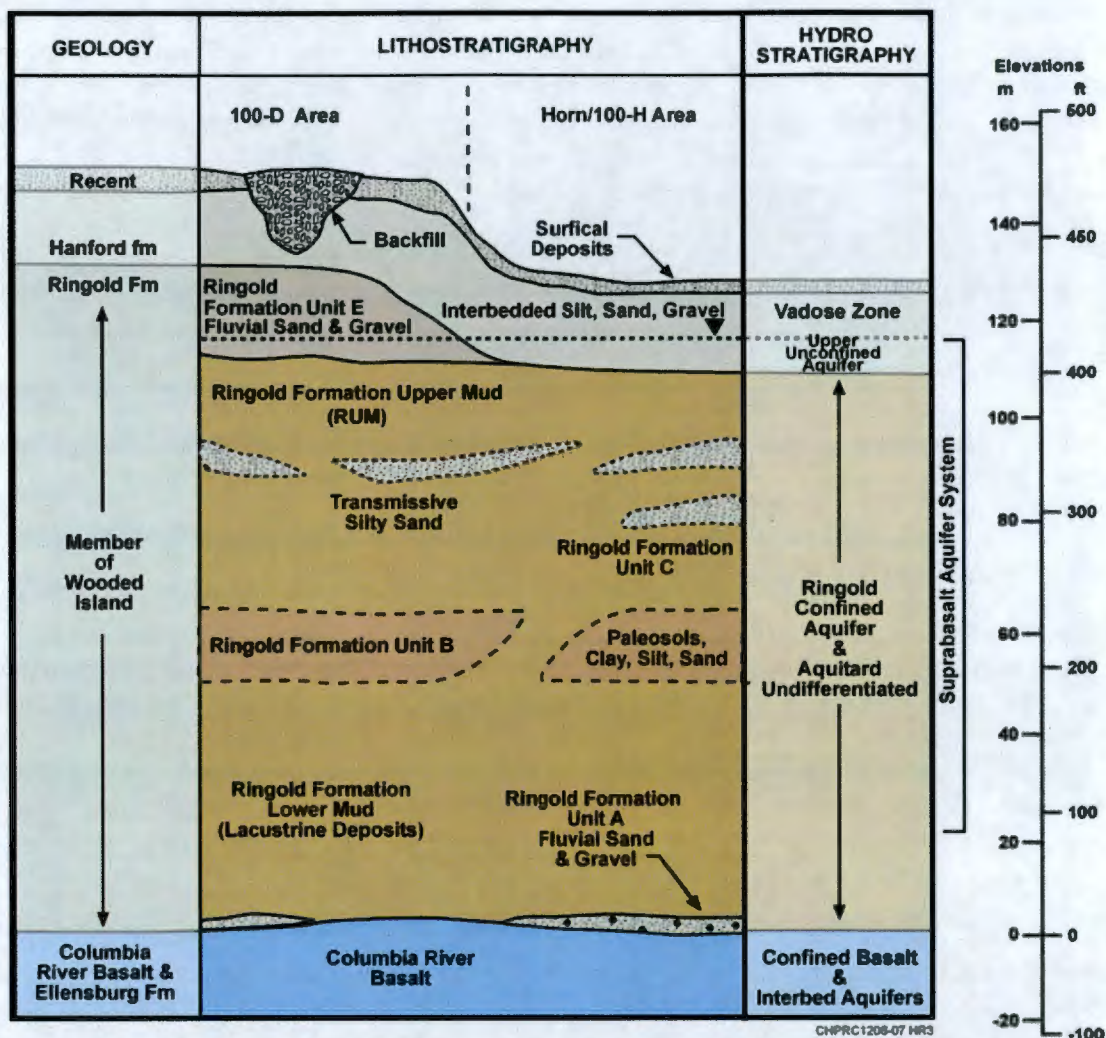


Figure 2. Generalized Hydrogeology of the 100-D/H Area

Table 1. Geology and Well Information for Study Area Wells 199-H1-42 and 199-H1-45

Parameter*	199-H1-42	199-H1-45
Ground surface elevation	124.6 m (409 ft)	127.9 m (420 ft)
Depth to RUM	12.5 m (41 ft)	17.1 m (56 ft)
RUM elevation	112.1 m (368 ft)	110.8 m (364 ft)
Depth to water at time of installation	8.96 m (29.4 ft)	12.09 m (39.7 ft)
Groundwater elevation at installation	115.6 m (379.4 ft)	115.8 m (379.9 ft)
Well screen interval (below ground surface) and length	8.6 to 11.6 m (28.1 to 38.1 ft) and 3.0 m (10 ft)	11.8 to 16.4 m (38.9 to 53.9 ft) and 4.6 m (15 ft)
Saturated thickness at installation	3.5 m (11.5 ft)	5.0 m (16.4 ft)

*Line items that refer to installation occurred in September 2009.

4.1.2 Groundwater and Groundwater/Surface Water Interaction

Wells 199-H1-42 and 199-H1-45 are located ~300 to 450 m (980 to 1,475 ft) from the Columbia River. Information presented in the DOE/RL-2010-95 indicates that the river stage in the 100-H Area can influence groundwater elevations and flow direction over 640 m (2,100 ft) inland. In addition, operation of the 100-HX P&T system affects localized groundwater flow in the area. Under low river stage conditions in 2015, groundwater flow near the study area was generally to the east-northeast; for the high river stage in 2015, flow was to the northeast (DOE/RL-2016-09).

4.1.3 Vadose Zone Soil and Groundwater Contamination

Available data from DOE/RL-2010-95 indicate that site contaminants do not impact vadose zone soils in the candidate study area; however, Cr(VI) primarily impacts groundwater. The Cr(VI) plume is migrating northeasterly across the study area. During the 2015 low river stage, Cr(VI) concentrations in wells 199-H1-42 and 199-H1-45 averaged 65.6 and 54.8 µg/L, respectively. During 2016 low river stage conditions, average Cr(VI) concentrations in the same two wells were 38.4 and 46.0 µg/L, respectively.

4.2 Comparison of Alternatives

Table 2 provides a summary of criteria used to compare the three construction methodologies identified for evaluation. Each criteria is rated from low to high, based on the unique features or requirements for each. For this evaluation, low is defined as least favorable or more involved or complicated to complete, and high is defined as most favorable or less involved or complicated to complete. The evaluation criteria include the following:

- Permitting/Planning and site preparation: Collective processes to prepare for and initiate field activities
- Health and safety: Concerns specific to the methodology that may be unique or relatively new to site staff
- Implementability: Indicates how easily the methodology can be used to complete a horizontal well or unique features identified for each
- Time to complete: Relative time estimated to complete installation activities
- Soil sampling complications and well placement (design) considerations: Subsurface materials identified/sampled and special considerations determined necessary for well design or placement
- Horizontal well completion costs: Relative anticipated capital costs to complete installation
- Investigation derived waste (IDW) management: Potential considerations for amount and types of IDW (i.e., soils [cuttings], drilling fluids, and development water) generated during installation

4.3 Comparison Results

Table 2 identifies the seven criteria noted in Section 4.2 for comparison between the horizontal well construction methodologies. However, three criteria stand out as being potentially the most critical or carry the greatest weight for this assessment: health and safety, implementability, and horizontal well completion costs. For each of these criteria, HDD was rated as the most optimal, followed by single-pass trenching, which was slightly more favorable than excavation, trenching, and direct installation.

From an implementability viewpoint, HDD is a widely-accepted practice for the installation of groundwater remediation wells outside of the Hanford Site. However, there are concerns of its suitability based on previous experience. CHPRC conducted a technology demonstration of HDD in the 100-D Area in 2009 to evaluate the capability of HDD in difficult geological conditions (SGW-45974, *Treatability*

Demonstration Report for Directional Drilling in the 100-D Area). The goals of this demonstration project were to drill through the 25 m (82 ft) thick vadose zone comprised of the Hanford formation and emplace a 91 m (300 ft) long screen near the middle of the unconfined aquifer. The demonstration project was unsuccessful, with lessons learned/observations from the effort summarized below.

- One of the initial project steps was installing a surface casing 16 degrees from horizontal that would terminate in the middle of the unconfined aquifer prior to the commencement of horizontal drilling. The drilling contractor intended to use a downhole hammer to advance surface casing ~53 m (175 ft) to attain a true vertical depth of 15 m (50 ft), casing off the full thickness of the Hanford formation. Over a 2-month period, several techniques were attempted (primarily derived from typical vertical well drilling) but none was successful due to the angle of drilling and the methods employed to remove cuttings and advancing the casing from this near-horizontal boring. Pneumatic pipe-ramming or a similar methodology is now an industry-accepted practice and could be used for advancing surface casing through permeable materials such as the Hanford formation. At the time of the demonstration project, the drilling contractor elected not to use this method based on safety concerns raised by Hanford Site staff and a limited timeframe to initiate fieldwork. It is now anticipated that there would be sufficient lead time for technical staff/subcontractors to identify detailed work procedures and appropriate contingency planning activities and coordinate with Site Occupational Safety and Industrial Health staff for their approval prior to initiating field activities.
- Approved contingency plans should be in place for various work elements that Hanford Site staff may not be as familiar with or that are technically challenging to avoid downtime.

Following the failure to install the angled surface casing to design depth but prior to ending site work, the subcontractor attempted to initiate horizontal drilling through the Hanford formation using mud-rotary techniques simply to test the methodology. However, rapid loss of drilling fluids occurred in an uncased portion of the boring. Large volumes of drilling mud were lost to the formation as a result of the open-framework gravels and cobbles in the Hanford formation despite attempts to thicken the mud. It is uncertain if this situation occurred due to the formation itself or as the result of failed air rotary drilling attempts that could have removed much of the finer matrix. Regardless of the cause, multiple types of pre-approved drilling mud/fluids should be approved and available during horizontal mud drilling activities to meet anticipated site conditions. A variance from Ecology to use biodegradable drilling mud/fluid, which has been demonstrated to be better suited for HDD applications, must be obtained prior to initiating fieldwork.

It is also important to note that there are differences between the subsurface geology to the depth of interest at the 100-D demonstration project area and the candidate study area in 100-H. Comparing descriptions from borehole logs of wells between the two areas, the following observations and differences are noteworthy.

- Logs from both areas indicate the presence of occasional boulders and cobbles, primarily in the upper 6 m (20 ft); maximum cobble diameters were reported to be 20 to 30 cm (8 to 12 in.).
- The Hanford formation in the 100-H Area appears to be somewhat finer, with a larger amount of sand and silt matrix reported in the gravels. Gravel sizes in 100-H are also smaller, generally limited to coarse pebble and smaller (but occasional cobbles) compared to gravels between 5 and 25 cm (2 to 10 in.) in diameter in the 100-D Area.

With the continued development of the HDD industry since 2009, the use of revised means/methods (i.e., pneumatic casing ram to drive surface casing, biopolymers), and from advance contingency planning, it is believed that these and other critical factors can be addressed and incorporated for the successful completion using HDD at the candidate study area.

Table 2. Relative Comparison of the Horizontal Well Construction Methodologies

Horizontal Directional Drilling	Excavation, Trenching, and Direct Installation	Single-Pass Trenching
Permitting/Planning and Site Preparation		
<p style="text-align: center;">Low to Moderate</p> <p>Similar processes for installation of vertical wells, except that a variance from Ecology would be necessary for use of biopolymer drilling muds/fluids. A minimum of two areas required for entry and exit pads. Greater upfront coordination between client/contractor/regulator would be necessary.</p>	<p style="text-align: center;">Low to Moderate</p> <p>Need to clear a larger area to include excavation footprint, ramps, benches, and equipment staging. Planning for large, deep excavations would follow prescriptive requirements of excavation and trenching procedures.</p>	<p style="text-align: center;">Moderate</p> <p>Similar to excavation, trenching, and direct installation but with less area impacted. Additional coordination necessary for an outside specialty subcontractor. Limited subcontractors available.</p>
Health and Safety		
<p style="text-align: center;">Moderate</p> <p>Health and safety staff may not be familiar with use of pneumatic ram or other method-specific equipment, procedures, and drilling fluids that may necessitate additional coordination upfront. Recirculation of drilling fluids (if used) could spread subsurface contamination (if present) into other areas. Drilling could be completed without recirculation of drilling fluids but would require the use of greater quantities of biopolymer.</p>	<p style="text-align: center;">Low</p> <p>Significant resources necessary to support extensive excavation activities and monitoring given the significant depths involved. Breadth of excavation activities complicates site management along installation path. Direct placement of well screen in aquifer materials may represent potential worker safety concerns over exposure to Cr(VI)-contaminated groundwater.</p>	<p style="text-align: center;">Low to Moderate</p> <p>Health and safety staff may not be familiar with use of method-specific equipment and procedures. Less excavation required compared to excavation, trenching, and direct installation but could still involve significant resources to support and monitor excavation work.</p>

Table 2. Relative Comparison of the Horizontal Well Construction Methodologies

Horizontal Directional Drilling	Excavation, Trenching, and Direct Installation	Single-Pass Trenching
Implementability		
<p style="text-align: center;">Moderate</p> <p>Coarse-grained sediments (gravels or cobbles) can contribute to drilling fluid losses during directional drilling or cause steering issues. However, HDD has been employed routinely outside of the Hanford Site in challenging environments. Concerns of technical staff based on a previous 2009 HDD demonstration project at the 100-D Area was unsuccessful (see more specific discussion below). Undulations in the top of the RUM may pose challenges to a horizontal well installation to remain within the aquifer material. However, HDD methodology can accommodate some curvature in screen placement consistent with screen material types.</p>	<p style="text-align: center;">Low to Moderate</p> <p>To provide a suggested 9 m (30 ft) wide working area to install a horizontal well, ~125 m³ (163 yd³) of soil per 0.3 m (1 lineal ft) of trench would need to be excavated to accommodate excavation/trenching requirements. Additional excavation would be necessary for entrance/exit ramps, sloping, and benching over the length of the well, in addition to short-term hauling/stockpiling. Once the well is installed, the excavated material would need to be backfilled and compacted in accordance with site procedures and site conditions.</p>	<p style="text-align: center;">Low</p> <p>Given the depth of the proposed well installation in the study area, ~2 to 6 m (6.5 to 20 ft) of soil would need to be excavated to establish an elevation where a one-pass trenching machine could be used (maximum installation depth of 10.7 m [35 ft]). Additional excavation would be necessary for entrance/exit ramps and sloping. Following installation, the excavated material would need to be backfilled and compacted according to site procedures and site conditions. Considering the coarse-grained nature of the Hanford formation, the use of this methodology may be at the limit of the equipment's designed capability.</p>
Time to Complete		
<p style="text-align: center;">Moderate to High</p> <p>Subcontractors initially indicate <2 months to complete drilling/installation/development, depending on well length. However, availability of pipe/well screen and subsequent installation may increase construction time. Significantly more effort/time would also be necessary to develop drilling mud/fluids from the Hanford formation once installation is complete. Construction time would also be increased based on the required project sampling requirements.</p>	<p style="text-align: center;">Low</p> <p>Time to complete excavations (and then backfill/compaction once the horizontal well is in place) could be considerable: up to 6 months, depending on equipment used and length of excavation, which requires significant onsite supervision, operators, and monitoring staff. In addition, well screen and materials placement should be completed during low river stage conditions to reduce depth of the last stage of excavation or shoring.</p>	<p style="text-align: center;">Moderate</p> <p>Time to complete excavation and re-placement activities would be less than the excavation, trenching, and direct installation option. Once excavation is to the elevation in which a trenching machine could complete well installation (~1/4 the volume of excavation, trenching, and direct installation estimated quantities), it is anticipated to take between 1 and 3 weeks to complete horizontal well installation, which would be followed by backfilling and compaction of excavated soils. Total construction time is estimated at 3 to 5 months.</p>

Table 2. Relative Comparison of the Horizontal Well Construction Methodologies

Horizontal Directional Drilling	Excavation, Trenching, and Direct Installation	Single-Pass Trenching
Soil Sampling Complications and Well Placement (Design) Considerations		
<p style="text-align: center;">Low to Moderate</p> <p>During drilling, sampling for lithology can be completed based on drill cuttings, with knowledge of absolute depth and nearby geology. For discrete soil sampling, drilling string would have to be removed, specialized sampling equipment (modified split-spoons) would be driven ahead of cutting head, retrieved, and then drilling string re-installed (time consuming and expensive). The well installation pathway may be unable to respond directly to undulations in the top of the RUM/bottom of aquifer to stay within curvature tolerances for drilling and well materials.</p>	<p style="text-align: center;">High</p> <p>Materials excavated would easily be visible to site staff, and undulations in the top of the RUM could easily be incorporated into depth of excavations.</p>	<p style="text-align: center;">Moderate</p> <p>Similar but better compared to HDD, in that excavated material could be logged, possibly with some flexibility in excavation depth, depending upon aquifer configuration but likely not to the same degree as excavation, trenching, and direct installation.</p>
Horizontal Well Completion Costs		
<p style="text-align: center;">Moderate</p> <p>Initial subcontractor estimates for well installation, development, and IDW handling range from ~\$0.8 to \$1.0MM+ (for a 304 m [1,000 ft] long horizontal well). The overall length of the horizontal well does not impact costs significantly.</p>	<p style="text-align: center;">Low</p> <p>The costs associated with the amount of soil necessary to be excavated, backfilled, and compacted for the well installation is anticipated to be higher than HDD. Estimated costs for excavation only could be in the \$1.5 to \$3MM range. From the additional excavation required, the overall length of the horizontal well will impact final costs.</p>	<p style="text-align: center;">Low to Moderate</p> <p>Excavation costs would be less than excavation, trenching, and direct installation. Estimated costs for excavation could be in the \$1 to \$2MM range. The overall length of the horizontal well will impact final costs but would be less than for the excavation, trenching, and direct installation method.</p>

Table 2. Relative Comparison of the Horizontal Well Construction Methodologies

Horizontal Directional Drilling	Excavation, Trenching, and Direct Installation	Single-Pass Trenching
IDW Management		
<p style="text-align: center;">Low</p> <p>Drilling/reaming methods would create additional IDW soils/drilling fluids to manage, monitor, and dispose. Anticipated IDW water volumes would be significant to develop/remove residual drilling mud/fluids. This option would require multiple temporary storage tanks at site, trucking, or piping to treatment plant. Logistics due to the type of drilling mud used could impact project costs and complexity.</p>	<p style="text-align: center;">Moderate</p> <p>It is anticipated that excavated soils would not require management as IDW. Saturated aquifer materials excavated for direct placement of horizontal well screen may need to be handled as IDW. The volume of groundwater generated during development should be similar to single-pass trenching but would be considerably less than HDD.</p>	<p style="text-align: center;">Moderate to High</p> <p>It is anticipated that excavated soils would not require management as IDW. Direct placement of well screen using trenching machine may generate IDW. The volume of groundwater generated during development should be similar to excavation, trenching, and direct installation but would be considerably less than HDD.</p>

5 Conclusions

Three methods were identified that could be used to construct/install a horizontal extraction well at a candidate study area near the 100-H Area at the Hanford Site. The depth to the base of the unconfined aquifer (top of the RUM) in the study area is ~12 to 17 m (40 to 55 ft). Considering the coarse-grained nature (sands, gravels, and cobbles) of the unconsolidated vadose zone within the Hanford formation, all potential construction methodologies will face inherent challenges to successful completion of a horizontal well.

Seven criteria were identified to evaluate the technical feasibility of the identified construction methods. For three key criteria (health and safety, implementability, and horizontal well completion costs), HDD ranked as the most favorable alternative for the successful completion of a horizontal well, given the anticipated site conditions for the candidate study area. For these same criteria, single-pass trenching ranked next and was slightly higher than excavation, trenching, and direct placement.

Evaluating the potential construction methodologies for installation of a horizontal extraction well is an initial step that may be beneficial for consideration in other areas of the Hanford Site. However, challenges need to be considered independently and may vary by location. For the 100-H Area, the following additional activities are currently planned/scheduled and will provide information needed to support future horizontal well location, diameter, and well-screen construction/design efforts.

- Numerical modeling will be used to evaluate and determine the need for a horizontal extraction well to establish hydraulic control and/or plume reduction of the Cr(VI)-contaminated aquifer for the candidate study area, particularly under low river stage conditions. These modeling efforts will also incorporate area-specific hydraulic and conceptual site model heterogeneities of the unconfined aquifer to subsequently determine potential well length, screen diameter, and other pertinent design criteria to support future implementation. Based on the results of this evaluation pertinent to horizontal well screen diameter and extraction volumes necessary, there could be multiple construction adaptations (i.e., continuous or blind-entry techniques) that could be considered.
- Three new unconfined aquifer wells are planned for construction in fiscal years 2017 or 2018 in the candidate study area. Characterization information derived from these wells may be sufficient to identify the depth/elevation of the top of the RUM surface and determine whether additional geophysical investigations, such as electrical resistance tomography, are needed.
- Based on well screen details (such as material and well screen slot sizing) for existing wells and analysis of aquifer materials obtained during the well installation work described above, there may be sufficient information to identify design parameters for a horizontal well screen prior to construction. Conceptually, this situation may be quite different than how extraction well screens are currently designed and installed for Hanford Site wells, but it could also allow the well screen to be available on site at the time of drilling, which would reduce construction time without compromising well performance/efficiency.

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