Remediation of the Highland Drive South Ravine, Port Hope, Ontario: Contaminated Groundwater Discharge Management Using Permeable Reactive Barriers and Contaminated Sediment Removal – 13447

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ABSTRACT

The Highland Drive South Ravine (HDSR) is the discharge area for groundwater originating from the Highland Drive Landfill, the Pine Street North Extension (PSNE) roadbed parts of the Highland Drive roadbed and the PSNE Consolidation Site that contain historical low-level radioactive waste (LLRW). The contaminant plume from these LLRW sites contains elevated concentrations of uranium and arsenic and discharges with groundwater to shallow soils in a wet discharge area within the ravine, and directly to Hunt's Pond and Highland Drive South Creek, which are immediately to the south of the wet discharge area.

Remediation and environmental management plans for HDSR have been developed within the framework of the Port Hope Project and the Port Hope Area Initiative. The LLRW sites will be fully remediated by excavation and relocation to a new Long-Term Waste Management Facility (LTWMF) as part of the Port Hope Project. It is projected, however, that the groundwater contaminant plume between the remediated LLRW sites and HDSR will persist for several hundreds of years. At the HDSR, sediment remediation within Hunt's Ponds and Highland Drive South Creek, excavation of the existing and placement of clean fill will be undertaken to remove current accumulations of solid-phase uranium and arsenic associated with the upper 0.75 m of soil in the wet discharge area, and permeable reactive barriers (PRBs) will be used for in situ treatment of contaminated groundwater to prevent the ongoing discharge of uranium and arsenic to the area in HDSR where shallow soil excavation and replacement has been undertaken.

Bench-scale testing using groundwater from HDSR has confirmed excellent treatment characteristics for both uranium and arsenic using permeable reactive mixtures containing granular zero-valent iron (ZVI). A sequence of three PRBs containing ZVI and sand in backfilled trenches has been designed to intercept the groundwater flow system prior to its discharge to the ground surface and the creek and ponds in the HDSR. The first of the PRBs will be installed immediately up-gradient of the wet discharge area approximately 50 m from the creek, the other two will be installed across the area of

shallow soil replacement, and all will extend from ground surface to the base of the water table aquifer through which the impacted groundwater flows. The PRBs have been designed to provide the removal of uranium and arsenic for decades, although the capacity of the treatment mixture for contaminant removal suggests that a longer period of treatment may be feasible. The environmental management plan includes an allowance for on-going monitoring, and replacement of a PRB(s) as might be required.

INTRODUCTION

Port Hope is a municipality of just over 16,000 residents located approximately 100 km east of the city of Toronto in Ontario, Canada. The historic low-level radioactive waste (LLRW) and industrial contaminated soil located at various sites around the community are the result of waste handling practices associated with the refining of radium and uranium by a former federal Crown Corporation, Eldorado Nuclear Limited. Waste placement occurred between the early 1930s and mid 1950s. These waste materials contain radium-226, uranium, arsenic and other contaminants resulting from the refining process.

Over the years, the waste has been managed and monitored by the Canadian Federal government and a final solution to LLRW waste management in Port Hope has been under development since the mid 1970s. A primary part of the activities to date is the monitoring and inspection of waste sites to ensure the waste does not pose a risk to health or the environment.

The current Port Hope Area Initiative (PHAI) is a community-based program directed at the development and implementation of a safe, local long-term management solution for historic LLRW in Port Hope. It is the result of an agreement established in 2001 between the Government of Canada and the affected Municipalities of Port Hope and Clarington for the safe cleanup, transportation, isolation and long-term management of LLRW. The PHAI includes two undertakings: i) the Port Hope Long-Term Low-Level Radioactive Waste Management Project (the Port Hope Project); and, ii) the Port Granby Long-Term Low-Level Radioactive Waste Management Project (the Port Granby Project located in Clarington). Only the Port Hope Project will be discussed herein.

The Port Hope Project consists of the construction and development of the Long-Term Waste Management Facility (LTWMF) and the remediation of contaminated sites in the Municipality of Port Hope with transfer of the contaminated material to the LTWMF. At the site of new the LTWMF, the existing waste at the Welcome Waste Management Facility will be remediated and placed into the new LTWMF. There are thirteen LLRW sites including the Port Hope Harbour and five industrial sites as well as numerous small-scale remediation sites still being identified through a survey of all properties within the municipality. The total volume is estimated at 1.2 million m^3. Remediation sites include temporary storage sites, ravines, beaches, parks, private commercial and residential properties and vacant industrial sites all within the urban area of Port Hope. The Cameco Corporation (Cameco) currently operating in Port Hope also has an allocation of 150,000 m^3 of LLRW that will be managed at the LTWMF and is included in the total volume estimate. Combining to form the Port Hope Area Initiative Management Office (PHAI MO), Atomic Energy of Canada (AECL) is the Project Proponent and Public Works and Government Services (PWGSC) is managing the procurement of services. The MMM Group Limited – Conestoga Rovers & Associates Joint Venture (MMM-CRA Joint Venture) is providing detailed design and construction oversight and administration services for the Project.

The Highland Drive South Ravine (HDSR) is the discharge area for groundwater originating from the Highland Drive Landfill, the Pine Street Extension and the Monkey Mountain LLRW sites in Port Hope. This paper describes the remediation plans for HDSR, which include the removal of the

LLRW source areas, the removal of sediment in the creek and pond system in HDSR, the excavation and replacement of contaminated shallow soil in the discharge area of impacted groundwater, and the use of passive permeable reactive barriers (PRBs) to remove uranium and arsenic from groundwater prior its ongoing discharge to the area where shallow soil remediation has been implemented and the stream system.

HIGHLAND DRIVE SOUTH RAVINE

General Description

The HDSR is a privately-owned, steeply-sloped ravine located south of Highland Drive. The site slopes down southward from Highland Drive to the Highland Drive South Creek (Fig. 1). The site is bounded by Hunt's Ponds and Highland Drive South Creek to the south and private residences are present on Highland Drive to the north and on a private access road to the east. Near the base of the HDSR is a landscaped area with a walking trail along Hunt's Ponds and the Highland Drive South Creek is present near the base of HDSR. Hunt's Ponds consist of two man-made ponds in line with the creek. A concrete dam is located at the downstream, eastern end of the second pond. The Highland Drive South Creek drains eastwards to the Ganaraska River.

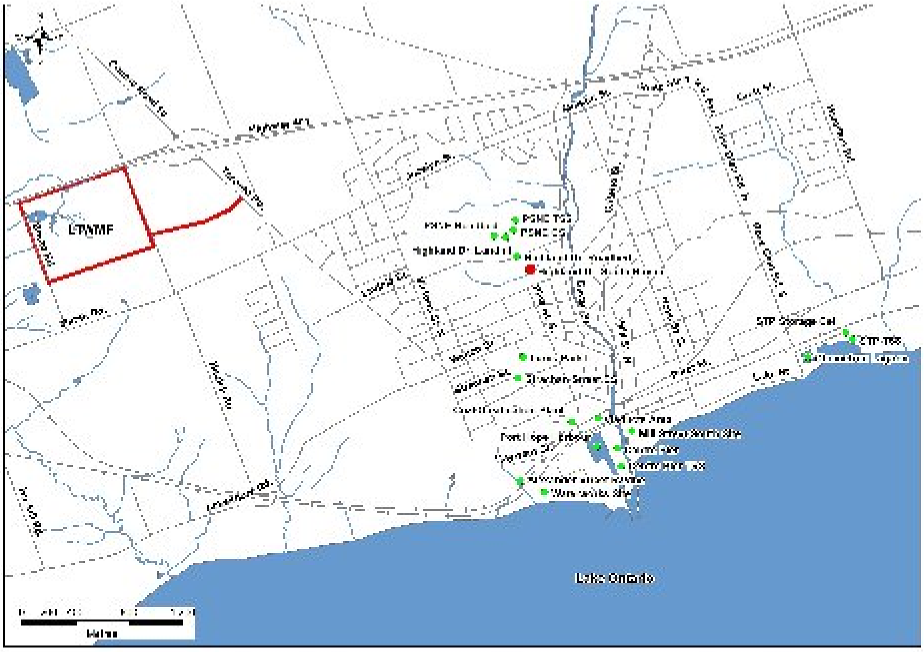

Fig. 1: The location of Highland Drive South Ravine in Port Hope, approximately 100 km east of Toronto, Ontario.

HDSR was not a direct repository of LLRW and contaminated soil. The contaminated material located in the HDSR is unique in the Port Hope Project because it represents sediment and shallow soil that has become increasingly contaminated with uranium and arsenic associated with groundwater discharge to the creek system and north slope of the ravine. The impacted groundwater originates in the Highland Drive Landfill Area north of Highland Drive.

LLRW was deposited in the Highland Drive Landfill during the 1940s and early 1950s, as well as the Pine Street North Extension (PSNE) roadbed and other smaller sites in the area of the Landfill. The Highland Drive Landfill is in excess of 200 m from HDSR, so groundwater impacts have been developing over this area from the LLRW sources to HDSR for as long as 70 years. Although full excavation of the LLRW sources will occur when the LTWMF has been commissioned, it anticipated that elevated concentrations of uranium and arsenic will persist in groundwater discharging to HDSR for several hundreds of years due to the slow rate of groundwater movement.

Geology and Hydrogeology

The surficial or overburden geology in the vicinity of the HDSR consists of glacial lake deposits (sand and gravel) and glacial deposits (sandy silt to sand till) [1]. Underlying the overburden is limestone bedrock of the Lindsay Formation, part of the Simcoe Group of Ordovician age [1], which outcrops at ground surface to the east near the Ganaraska River.

Although upper lacustrine sand and upper till units are present in the vicinity of Highland Drive South to the north of HDSR, and influence groundwater flow and the movement of contaminants in the subsurface near the LLRW sources, only a lower lacustrine sand and a lower till unit are present within HDSR where groundwater discharges to the north slope of the ravine. The lower lacustrine sand (lower aquifer) is primarily a well sorted and dense brown silty fine sand [2], that is more than 10 m thick in the vicinity of the groundwater discharge zone in HDSR. The lower lacustrine sand exhibits evidence of slightly increasing silt content with depth [1]. The lower till, which underlies the lower lacustrine sand, is sandy to clayey silt with trace gravel ranging in thickness from 7 to 11 m [1].

Where the lower aquifer encounters the slope of the ravine approximately 75 m south of Highland Drive South, groundwater discharge has created a wet seepage face that extends from the slope for approximately 50 m to the creek (Fig. 2). Surface flow of water across this area contributes to the flow of the creek. The hydraulic conductivity of the lower aquifer is estimated to be approximately 1.8×10^{-5} m/s, and in the vicinity of HDSR the hydraulic gradient is approximately 0.02 (2; 1). Assuming a value for porosity of 0.3, the estimated horizontal groundwater velocity could be as much as 40 m/year in the upper part of the lower aquifer, and less than this at depth.

At the discharge zone in the HDSR, the uranium plume is approximately 120 m in width in an east-west direction, with concentrations of uranium in groundwater of as much as several milligrams per litre. Concentrations of as much as 15 mg/L have been encountered in groundwater in the general vicinity of the LLRW sources [1]. Arsenic discharges to HDSR in a zone approximately 80 m in width. Arsenic concentrations in groundwater decrease from as much as 5 mg/L in the general vicinity of the sources to approximately 1 mg/L in the discharge zone. MMM [3], as part of its evaluation of PRB technology, used shallow groundwater containing more than 0.4 mg/L uranium and approximately 1 mg/L arsenic from the seepage discharge zone.

REMEDIAL ACTIONS

As noted above, the remediation plans for HDSR include the removal of sediment from Hunt's Ponds and the Highland Drive South Creek, the excavation and replacement of contaminated shallow soil in the area of discharge of contaminated groundwater, and the use of PRB technology to remove uranium and arsenic from groundwater prior its ongoing discharge to the area where the remediation of creek-sediment and shallow soil has been implemented (Fig. 2). The three remediation actions will be implemented sequentially. The general approaches to remediation are described below, but details pertaining to the many components of the remediation plan related to preparation of site access, security, health and safety, vehicular controls, transport of wastes to the LTWMF, removal of vegetation and post-remedial re-vegetation, replacement and other operational activities and controls are not included.

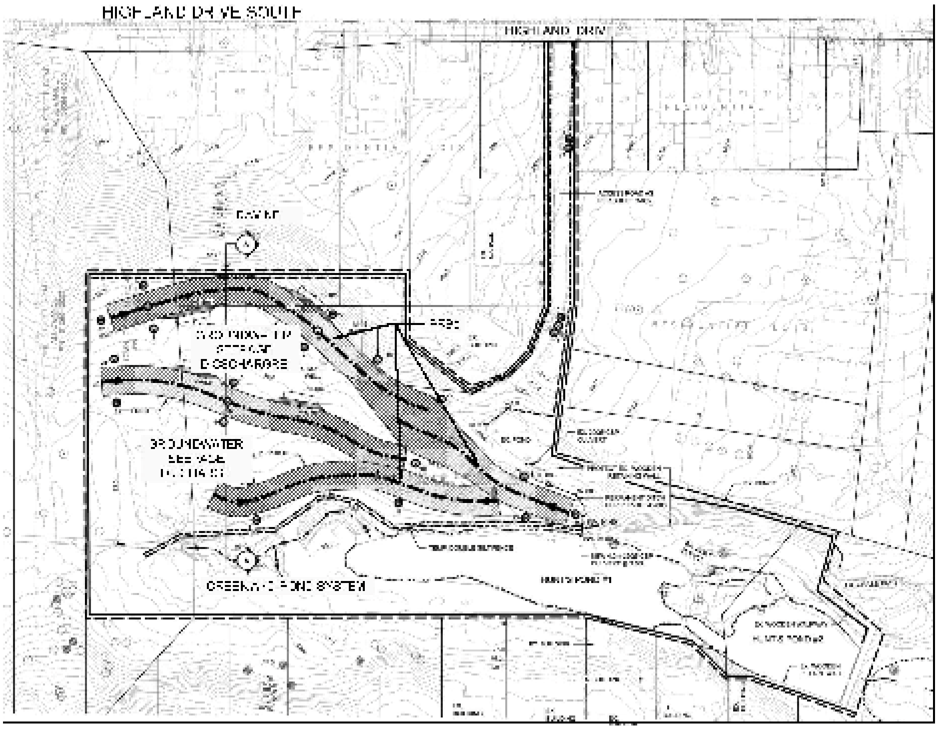

Fig. 2: The groundwater seepage discharge and creek and pond system in Highland Drive South Ravine, which will be the focus of sediment, shallow soil and groundwater remediation.

The Project-specific cleanup criteria for soil for the contaminants of concern at HDSR include [4]:

- Uranium - 23 µg/g
- Arsenic - 18 µg/g
- Radium-226 - 0.29 Bq/g

For the evaluation of groundwater quality, monitoring results will be compared to Water Quality Criteria for Discharge to the Environment presented in Appendix D of the Waste Nuclear Substance Licence for the Port Hope Long-Term Low-Level Radioactive Waste Management Project (WNSL-W1-2310.00/2014). The criteria for the three signature parameters being monitored are as follows:

- Uranium - 2.5 mg/L
- Arsenic - 0.5 mg/L
- Radium-226 - 0.37 Bq/L

Sediment Remediation

The sediment within Hunt's Ponds and the Highland Drive South Creek contains some impact from LLRW as a consequence of groundwater and surface water discharge directly to the Creek, and the build-up of contaminant concentrations in the sediment by sorption and/or solid-phase precipitation reactions, or through sediment erosion and transport from the wet groundwater discharge zone on the ravine slope to the Creek. The quantity of contaminated sediment in the Hunt's Ponds/ Highland Drive South Creek system has been estimated at 780 m^3.

The sediment remediation process will be conducted by creating a sediment slurry, possibly incorporating a flocculant, and pumping the sediment into Sediment Containment Tubes. The groundwater discharge zone to the north of the Creek will be modified to accommodate dewatering of the Sediment Containment Tubes, recovery of the water, and use of a temporary treatment system for the drainage and seepage water. The contents from dewatered Sediment Containment Tubes, which are designed to be more than 45% solids, will be transferred to trucks for the transport to LTWMF. The sediment remediation will proceed in a two stage process so that clean water diversion around the area being remediated in the Creek or Ponds will be available at all times. Verification sampling to confirm successful cleanup will be implemented prior to the completion of each stage.

Shallow Soil Remediation

Once the remediation of the sediments has been completed, remediation of the shallow soil affected by groundwater seepage on the northern slope of the ravine will be implemented. The seepage discharge zone covers an area of approximately 0.6 ha, and the excavation of contaminated soil to a depth of approximately 0.75 m is planned for this area. It is estimated that 4,500 m^3 of soil will be excavated from the seepage area. Excavation will be undertaken using track-mounted excavators, with transport to LTWMF using haulage trucks. Verification sampling will be used to document acceptable conditions at the base of the excavations prior to the placement of clean backfill. If the verification samples identify impacts, further remediation through excavation and re-verification will be required and will continue until soil meets the Project cleanup criteria. The grades existing prior to the remediation will be generally reinstated. Site restoration will not be undertaken until installation of the PRB systems has been undertaken.

Permeable Reactive Barrier Systems

Following the completion of the remediation of the sediment and shallow soil, PRBs will installed to intercept and treat groundwater prior to its discharge to shallow soil and to Hunt's Ponds and Highland Drive South Creek in the HDSR. PRBs typically consist of an engineered trench in the aquifer which is backfilled with a reactive material. The PRB is installed across the path of the plume so that the reactive material interacts with the contaminants (Fig. 3). ZVI in PRBs have been used to treat plumes of chlorinated solvents [5] and metals [6]. ZVI PRBs have been shown to remove dissolved uranium and arsenic from groundwater in field applications [7, 8]. Removal of uranium and arsenic reportedly occurs under the strongly reducing conditions created by ZVI in contact with water, and is attributed to reductive precipitation reactions within the ZVI.

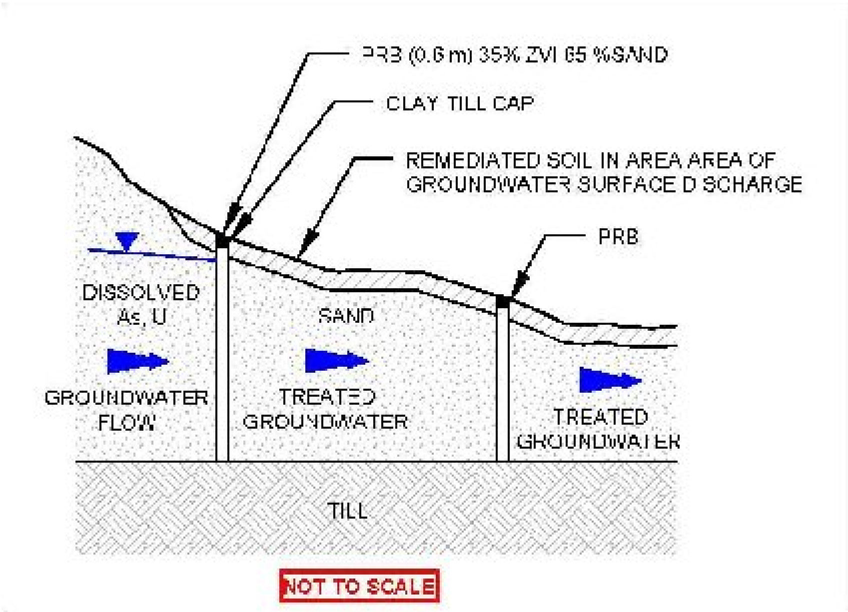

Fig. 3: The conceptual interception and treatment of groundwater by PRB segments containing ZVI/sand mixtures, which will remove uranium and arsenic by reductive precipitation reactions associated with the ZVI.

Three PRB segments are planned, total linear length of more than 300 m and with alignments extending from the western limit across the zone of active groundwater discharge within HDSR. One PRB segment extends to the east to the approximate mid-point of the shore of Hunt's Pond, and was positioned to preserve property features including ponds. The up-gradient PRB alignment has been established to treat groundwater prior to it reaching the discharge zone, and alignments of the other two PRB segments were selected to provide treatment of groundwater that has already reached the area of discharge. The PRB segments extend vertically from ground surface to the underlying low hydraulic conductivity till unit, depths ranging from 4 to 8 m below ground surface, with the intent of providing full-depth interception and treatment of the groundwater. Installation of the PRBs will require the use of temporary construction roadbeds, and the method of construction will be determined by the contractor. A design mixture of construction sand and granular ZVI (65 sand:35 ZVI by volume) is proposed, with a minimum PRB thickness of 0.6 m in the direction of groundwater flow. The hydraulic conductivity of the PRB mixtures will be greater than that of the lower aquifer, and will act to focus rather than divert groundwater flow; thus, capture of groundwater flow and the plume will be enhanced. At ground surface, a clay-based soil cap will be placed along the full lengths of the PRB segments.

The design of the PRB segments was based on plume characteristics in combination with the results of bench-scale treatability testing using site groundwater conducted by the University of Waterloo (Waterloo, ON) for MMM [3]. The bench-scale testing was conducted at a simulated groundwater velocity that exceeded that estimated for the field. The treatability testing indicated good treatment using ZVI- based mixtures (ZVI and ZVI with solid-phase organic carbon). The testing confirmed removal of uranium and arsenic from concentrations of approximately 0.5 to 1.0 mg/L in the influent groundwater to concentrations of both contaminants of less than 0.0001 mg/L in the column effluents, and the capacity to remove several milligrams of contaminants per gram of ZVI. Using plume velocity estimates of 20 m/year, contaminant loading concentrations of 1 mg/L entering the PRB, and the proposed sand/ZVI composition, each PRB segment (0.6 m in thickness) has the capacity to provide plume treatment for in excess of 50 years. In the core of the plume in the area of groundwater discharge, three PRB segments provide significant treatment redundancy.

It is anticipated that the PRB segments will operate in a passive, maintenance free manner with monitoring requirements only. If treatment capacity of the PRB segments is exhausted, the installation of at least one supplementary or replacement PRB segment will likely be required. It is further likely that the treatment capacity of the most up-gradient of the PRB segments will occur first. Installation of a new PRB could be achieved by excavation and replacement of the up-gradient PRB segment, with appropriate waste management measures, or the installation of a new PRB segment a short distance up-gradient of the existing segment. The initial performance monitoring program included the installation of a network of monitoring wells at select locations up-gradient and down-gradient of the PRBs. In addition to the pairs of twinned up-gradient and down-gradient monitoring wells at six locations proposed for post-installation monitoring of the PRB segments, additional monitoring wells at the approximate midpoint between the up-gradient and down-gradient faces within the PRB segment will be installed at three select locations. The groundwater quality in the wells within the PRB segment will be used to confirm treatment performance of the PRBs, and will provide an indication of the rate of advance of dissolved contaminants through the treatment zone. If and when contaminant concentrations reach target levels within the PRBs, the need for and schedule of replacement of the PRB segment can be considered. If the PRBs perform as expected, lead times of years to more than a decade for replacement will be provided. The up-gradient and down-gradient wells will be installed as close to the PRB as practical. The mid-point wells will be smaller diameter than the conventional wells because the PRB segments may be 0.6 m thick in the direction of groundwater flow, and will installed using narrow-diameter direct push drilling methods.

POST-REMEDIATION RESTORATION

Following completion of the installation of the PRBs and the monitoring wells, the temporary roadbeds will be removed, and the surface of the backfilled soil graded to elevations consistent with the original condition. Erosion control blankets will be placed on the ground surface as necessary. A native vegetation community will be re-established in the remediated area, although no trees will be planted in the vicinity of the PRB segments to accommodate potential future replacement if necessary. Areas of the creek bed altered during the remediation work will be naturalized to pre-remediation conditions, and trail features in the area will be re-established.

CONCLUSIONS

Following remediation of the Highland Drive Landfill and other LLRW sites, elevated concentrations of uranium and arsenic are expected to persist in soil and groundwater between the Landfill and HDSR for several hundreds of years. The remediation of sediment in Hunt's Ponds and Highland Drive South Creek and of shallow soil in the area where groundwater seepage discharges to the north slope of the ravine will be implemented over short time frames of months once the LTWMF is operational for the disposal of the waste materials. Because of the fine-grained characteristics of the lacustrine sand and till units in the subsurface, the distance from the Landfill to HDSR, and groundwater flow velocities of metres to tens of metres per year, the expedited cleanup of the groundwater over short time frames, even of decades, using groundwater extraction or enhanced groundwater extraction techniques is not likely to be feasible. Thus, the use of PRB technology using mixtures containing ZVI, which has been shown to provide effective treatment in bench-scale testing and in field-scale applications, has been incorporated in the long-term remediation plan for HDSR. The PRB system has been designed to operate in a passive, maintenance free manner with monitoring requirements only, and provide on-going removal of uranium and arsenic from groundwater reaching the area groundwater discharge, and preventing re-contamination of shallow soil and creek sediments from future groundwater discharge. The PRBs have been designed to function passively for periods of several decades or more before replacement of PRB segments may be required. The passive operation of the PRBs also facilitates public access to and use of the restored Site in a manner that would not be possible if more active solutions with extensive infrastructure such as pump-and-treat were employed.

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