COST AND PERFORMANCE REPORT

Permeable Reactive Barriers Interim Summary Report:
Permeable Reactive Barriers
Using Continuous Walls
To Treat Metals

May 2002

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office

Introduction

The report provides an interim summary of five full-scale projects using permeable reactive barriers (PRBs) with continuous subsurface walls composed of various reactive media to treat groundwater contaminated primarily with metals. A PRB contains or creates a reactive treatment zone oriented to intercept and remediate a contaminant plume. Contaminants are removed from the groundwater flow system by physical, biological, or chemical processes (EPA, 2002a).

Table 1 summarizes available information about the five projects, including year of installation, specific contaminants treated, PRB configuration and wall dimensions, installation method, installation depth, reactive media used, and cost data. Each of the PRBs was installed between 1995 and 1999.

Information on all five projects was obtained from *Installation Profiles* published by the Remediation Technologies Development Forum[1] (RTDF) and which are available online at <www.rtdf.org>. The five project are:

- Haardkrom Site – *Kolding, Denmark*
- Chalk River Laboratories – *Ontario, Canada*
- Nickel Rim Mine Site – *Sudbury, Ontario, Canada*
- Tonolli Superfund Site – *Nesquehoning, Pennsylvania*
- U.S. Coast Guard Support Center – *Elizabeth City, North Carolina*

Summary of PRB Projects Using Continuous Walls to Treat Metals

Contaminants Treated

Four of the five PRB projects included in this report were installed to treat groundwater contaminated primarily with metals, including arsenic (As), cadmium (Cd), copper (Cu), hexavalent chromium (Cr^{6+}), iron (Fe), lead (Pb), nickel (Ni), and zinc (Zn), while the fifth project (Chalk River Laboratories) was installed to treat groundwater contaminated with the radionuclide strontium-90 (Sr-90). Two of the projects (Haardkrom Site and U.S. Coast Guard Support Center) had trichloroethene (TCE) as an additional contaminant.

PRB Configuration

All five of the PRBs in this report employed a continuous reactive wall configuration, which intercepts and treats the flow of contaminated groundwater without affecting groundwater flow. The PRB at the Chalk River Laboratories Site used a variation of a reactive continuous wall configuration that involved the use of a steel cut-off wall and a curtain of reactive media that captured and treated contaminated groundwater, while allowing uncontaminated groundwater to

[1] The RTDF has an ongoing effort to track PRB projects in the field and to periodically update information about those projects. When the case study was prepared, RTDF had published *Installation Profiles* for 47 PRB projects. The RTDF selects PRB projects for its web site based on availability of information, and includes mostly sites that have been in the field for relatively longer periods of time, as well as sites with relatively greater amounts of information. While not a representative sample of sites, the projects tracked by the RTDF provide a cross-section of the general types of projects in which PRBs had been installed. In addition, the RTDF is performing a longer-term review of project performance, and the data available for the case study is a snapshot of data available to date.

bypass the system. The reactive media acted as the curtain through which the contaminant plume passed prior to encountering the steel cut-off wall. A schematic diagram of the Chalk River PRB is included within this case study as Figure 1. The two other typical configurations for PRBs, the reaction vessel, which routes groundwater via natural or engineered preferential pathways to a subsurface reaction vessel, and funnel-and-gate, which is used to capture groundwater over a larger area and direct it to a reactive zone, were not used in these projects.

PRB Installation Method

Three of the five PRBs (the Haardkrom, Tonolli Superfund, and U.S. Coast Guard Support Center sites) were installed using continuous trenching techniques. The Chalk River Laboratory project used supported excavation, and the Nickel Rim project used unsupported excavation. The continuous trenching technologies employed the use of excavation boxes or trench boxes to allow simultaneous trench excavation and placement of reactive media. The Chalk River Laboratory project employed sheet piles, a form of supported excavation, for the installation of the subsurface wall and curtain treatment system. The Nickel Rim Mine site used an unsupported, cut-and-fill technique for installation of an organic carbon PRB. None of the projects employed direct placement technologies, such as *in situ* soil mixing, vibrated I-beam, hydraulic fracturing, jetting, and mandrel (H-Beam).

PRB Installation Depth

The five PRBs were designed to be installed to a depth where the base of the wall could be keyed into an impermeable subsurface layer, such as claystone or bedrock. The maximum depths of the PRBs ranged from 10 feet to 24 feet below ground surface (bgs). Information about whether the PRB has been keyed into an impermeable layer was available for two projects. At the Haardkrom Site, the PRB was keyed into an impermeable layer. At the Chalk River site, efforts to key the sheet piles used for PRB installation into the underlying bedrock were unsuccessful.

Reactive Media Used

Iron is the most common reactive media used in PRB installations. (U.S. Air Force Research Laboratory, 2000). Two of the sites (Haardkrom and U.S. Coast Guard Support Center) used iron as the reactive media. Several different reactive media were used for the other three projects. The Chalk River Laboratories site used Clinoptilolite, the Nickel Rim Mine Site used an organic carbon, and the Tonolli Superfund Site used limestone.

Clinoptilolite is a mineral in the zeolite group. Characteristics of zeolites include the ability to lose and absorb water without damage to their crystal structures, large pore space, high resistance to extreme temperatures, and chemically-neutral basic structure (Amythest, 1995). The media used in the Chalk River Laboratory Site PRB was in the form of a 14 x 50 mesh granular curtain comprised of 60% clinoptilolite, with the remaining material primarily inert volcanic ash and sediments.

The organic carbon used at the Nickel Rim Site consisted of a mixture of municipal compost, leaf compost, and woodchips. The pea gravel was added to the reactive mixture to increase the hydraulic conductivity of the system so the contaminated water could move through more readily. The coarse sand was positioned upgradient and downgradient of the reactive material, to break up the contaminants within the water allowing more contact with the reactive material, leading to further degradation. The organic carbon material in the PRB remediation facilitated sulfate reduction and metal sulfide precipitation that had resulted from the reaction of the metals with the organic material.

Project Performance

Table 2 summarizes the performance data provided for the five projects. At the five sites, the PRBs reduced individual contaminant concentrations that had ranged from 77 micrograms per liter (µg/L) to 3,800,000 µg/L to as low as non-detect levels and 1,900,000 µg/L. Information on the longevity of the five PRBs included in the report was not available.

At the U.S. Coast Guard Support Center site, the trenched wall was designed to meet cleanup goal concentrations of 50 µg/L for Cr^{+6} and 5 µg/L for TCE. The initial concentrations were 3,430 µg/L for Cr^{+6} and 4,320 µg/L for TCE. Through June 2001, chromium was not being detected downgradient from the wall. Other contaminants generally were being remediated according to plan; however, there were some areas lower in the wall where TCE had been exceeding the cleanup goal, possibly indicating that the TCE plume was located further below the surface than was expected.

Table 2

Permeable Reactive Barriers Using Continuous Walls to Treat Metals
Summary of Project Performance

Summary of Project Performance						
Project	**Contaminant**	**Influent Concentration (µg/L)**	**Effluent Concentration (µg/L)**	**Cleanup Goal (µg/L)**	**Reported % Reduction**	**Calculated % Reduction**
Full-Scale Projects						
Haardkrom	TCE	1,400	NP	NP	NP	NP
	Cr^{6+}	110,000	NP	NP	NP	99
Chalk River Laboratories	Sr-90	100 Bq/L	ND	NP	>99	NP
Nickel Rim Mine	Nickel	10,000	100	NP	NP	99
	Iron	1,000,000	91,000	NP	NP	91
	Sulfate	3,800,000	1,900,000	NP	NP	50
Tonolli	Lead	328	NP	NP	NP	NP
	Cadmium	77	NP	NP	NP	NP
	Arsenic	313	NP	NP	NP	NP
	Zinc	1,130	NP	NP	NP	NP
	Copper	140	NP	NP	NP	NP
U.S.C.G Elizabeth City	TCE	4,320	NP	5	NP	>98
	Cr^{6+}	3,430	ND	50	NP	99

NP- Not Provided
Bq- Becquerel
Note: All projects were on-going; data provided based on information in the Installation Profiles

Project Cost

Cost information was available for four of the five projects included in this report. No information concerning operation and maintenance costs for the PRBs at any of the sites was provided. Only the Haardkrom Site separated costs for design ($108,000) from installation costs. Total cost to install PRBs ranged from $30,000 (Nickel Rim Mine) to $500,000 (U.S. Coast Guard Support Center). The Nickel Rim Mine site had a 50-foot long barrier installed using the cut and fill technique, while the U.S. Coast Guard Support Center installed a 150-foot long PRB with continuous trenching equipment.

Unit costs were calculated for four continuous wall PRB applications with cost information (Haardkrom Site, Chalk River Laboratories, Nickel Rim Mine Site, and U.S Coast Guard Support Center). The following table summarizes unit costs calculated using PRB installation costs based on the length of wall constructed ($ per linear foot) and the area (length times maximum depth) of wall constructed ($ per square foot). No cost adjustments were made to normalize the project costs in relation to the date when the costs were incurred or the geographic location of the project.

Table 3

**Permeable Reactive Barriers Using Continuous Walls to Treat Chlorinated Solvents
Summary of Unit Costs**

Summary of Project Costs					
Project	**PRB Length (Feet)**	**PRB Maximum Depth (Feet)**	**Installation Cost (Excluding Design Cost When Provided)**	**Cost per Linear Foot**	**Cost per Square Foot**
Haardkrom Site	164	9.8	$ 250,000	$1,524	$ 155
Chalk River Laboratories	36	20	$ 300,000	$8,333	$ 417
Nickel Rim Mine Site	50	14	$ 30,000	$ 600	$ 43
U.S.C.G. Elizabeth City	150	24	$ 500,000	$3,333	$ 139

Based on the available cost data, no clear trends in unit costs based on length or depth of the PRBs are evident. Table 4 summarizes the matrix characteristics and operating parameters that may have affected cost and performance for the PRB applications.

Table 4

Permeable Reactive Barriers Using Continuous Walls to Treat Chlorinated Solvents Operating Parameters

Operating Parameters	
Parameter	**Range of Values**
Soil Classification:	Varied (provided for all sites)
Clay Content and/or Particle Size Distribution:	Not provided
PH:	5.8 to 7 (Nickel Rim Mine)
Porosity:	Not provided
Depth Below Ground Surface or Thickness of Zone of Interest:	9.8 to 24 feet bgs
Total Organic Carbon:	Not provided
Presence of Nonaqueous-Phase Liquids:	Not provided
Groundwater Flow Rate:	7.6 gpm (Chalk River Laboratory) 49 ft/yr (Nickel Rim Mine)
Type of Reactive Media:	Varied (Iron [2 sites], Clinoptilolite, Limestone, Organic Carbon)

Lessons Learned Related to PRBs Using Continuous Walls to Treat Metals

The following is a summary of lessons learned from the five projects included in this report.

PRB Configuration

- Continuous walls were chosen as the configuration for the PRBs profiled in this report for various reasons including: to accommodate subsurface geology of the targeted contaminated area, and to allow for passive treatment without changing the groundwater flow pattern.

- The continuous wall configuration at the Chalk River Laboratories Site employed a subsurface wall and curtain treatment system based on the results of tests that showed that the technology is hydraulically adjustable and that the capture zone can be sized, both vertically and horizontally, to fit plume dimensions.

PRB Installation Method

- The Chalk River Laboratories Site employed sheet piles, a form of supported excavation, for the installation of the subsurface wall and curtain treatment system. One problem with the construction was that the steel sheets were not grouted to the bedrock which allowed for groundwater to leak under the system. Other issues at the site included the presence of subsurface roots that had not been cleared and which slowed the excavation.

- At the Tonolli Superfund Site, one-pass trenching equipment was evaluated and determined to be impractical because of the presence of rubble and concrete foundations, sloughing of mine spoil, and the close proximity of a railroad spur and an onsite landfill embankment.

PRB Installation Depth

- At the U.S. Coast Guard Support Center site, the trenching method used was expected to place the reactive media 24 feet bgs. However, coring at the site indicated that there was vertical discontinuity in the PRB, probably due to bridging within the trencher hopper during iron emplacement. In some locations, the reactive media was not continuous to the top of the wall.

Reactive Media Used

- At the Nickel Rim Mine Site, iron was not used as a reactive media because iron was one of the groundwater contaminants being treated.

- For the Nickel Rim Mine Site, the organic carbon material in that PRB facilitated sulfate reduction and metal sulfide precipitation that resulted from the reaction of the metals with the organic material and which allowed the aquifer to convert from acid-producing to acid-consuming.

Project Performance

- The Haardkrom Site had not met its cleanup goals at the time of this report. The PRB was not capable of handling the uneven lateral distribution of contaminants in groundwater. There was heterogeneous loading of the PRB, which may have contributed to the exhaustion of iron-chromate removal capacity of the wall. Information concerning potential modifications to the wall was not available.

- At the U.S. Coast Guard Support Center site, analysis of iron cores have indicated that while a slow rate of corrosion has resulted in a loss of porosity of only about 1% to 2% per year, the loss of porosity is not expected to affect wall permeability for at least 10 years. No changes in hydraulics at the site have been observed after more than five years of quarterly monitoring.

- At the U.S. Coast Guard Support Center site, researchers have investigated the possibility that the TCE plume dipped lower in the aquifer after the wall was installed, resulting in a small portion moving under the wall. The investigation revealed that a significant amount of recharge occurred in the reaction zone following installation due to removal of the concrete parking lot covering the site. This recharge may have driven the plume deeper than had previously been observed, thus allowing some of the plume to move under the wall. However, the investigation also indicated that there was still significant treatment below the wall, suggesting that the reactive zone created by the PRB extended beyond the physical location of the iron, due to the influence of the PRB on the surrounding groundwater chemistry.

Project Cost

- Unit costs for the four continuous wall PRB applications with cost information ranged from $600 to $8,333 per linear foot and from $43 to $417 per square foot. It is likely that additional matrix characteristics and operating parameters such as soil classification; clay content and particle size distribution; pH; porosity; depth below ground surface or thickness of zone of interest; total organic carbon; presence of NAPLs; groundwater flow rate; and type of reactive media, also may be direct or indirect factors in project cost.

References

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Analysis Preparation

This case study was prepared for EPA's Office of Solid Waste and Emergency Response, Technology Innovation Office. Assistance was provided by Tetra Tech EM Inc., under Contract No. 68-W-02-034.

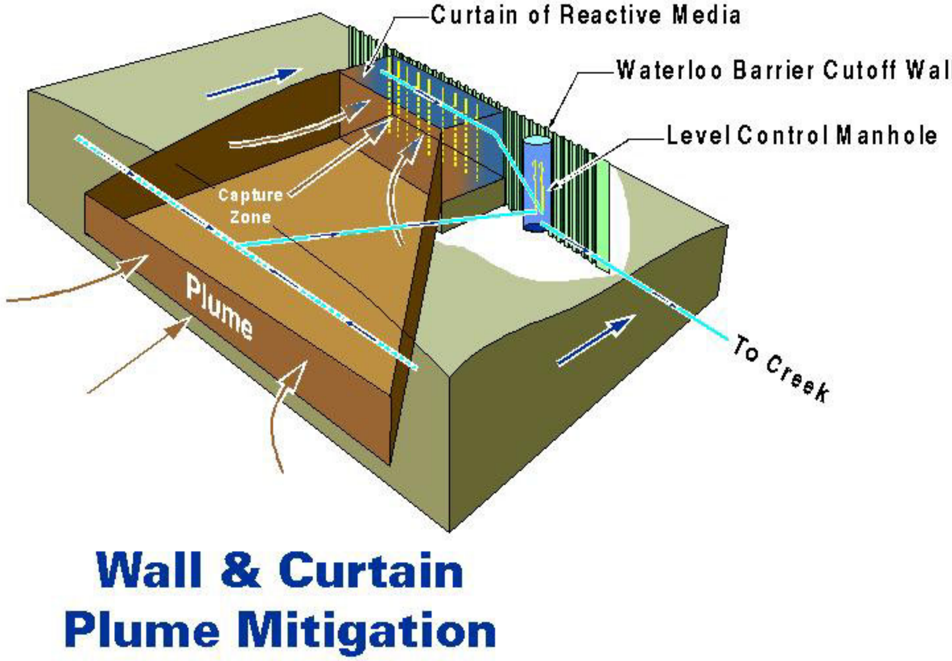
Table 1

Permeable Reactive Barriers Using Continuous Walls to Treat Metals Project Summary Information

Site Name and Location	Year Installed	Construction Method	Wall Dimensions (Length and Maximum Depth)	Reactive Media	Contaminant	Install Cost (Design Cost)
Haardkrom Site, Kolding, Denmark	1999	Continuous trenching	164 ft long; 10 ft bgs	Fe^0	Cr^{+6}, TCE	$250,000 ($108,000)
Chalk River Laboratories, Ontario, Canada	1998	Supported excavation	36 ft long; 20 ft bgs	Clinoptilolite (zeolite)	Sr-90	$300,000
Nickel Rim Mine Site, Sudbury, Ontario, Canada	1995	Unsupported excavation	50 ft long; 14 ft bgs	Organic Carbon	Ni, Fe, Sulfate	$30,000
Tonolli Superfund Site, Nesquehoning, Pennsylvania	1998	Continuous trenching	1,100 ft long; 20 ft bgs	Limestone	Pb, Cd, As, Zn, Cu	Not provided
U.S. Coast Guard Support Center, Elizabeth City, North Carolina	1996	Continuous trenching	150 ft long; 24 ft bgs	Fe^0	Cr^{+6}, TCE	$500,000

Figure 1

Schematic Diagram of Continuous Reactive Wall at the Chalk River Laboratories



Source: RTDF

Permeable Reactive Barrier Project Profile

Haardkrom Site, Kolding, Denmark

Installation Year: 1999
Contaminants: Trichloroethene, Hexavalent Chromium
Reactive Media: Iron
Cost: $358,000
Construction: Continuous Trench
Point of Contact: Peter Kjeldsen
Technical University of Denmark
Environmental & Resources DTU
Building 115
DTU, DK-2800
Kgs. Lyngby Denmark
Telephone: +45 45251561
Facsimile: +45 45932850
Email: pk@er.dtu.dk

A full-scale permeable reactive barrier (PRB) system was installed in 1999 to remediate contaminated groundwater at Haardkrom A/S, a former electroplating facility in Kolding, Denmark. The metal plating process used chromium, nickel, zinc, and the degreasing agent, trichloroethylene (TCE). Major groundwater contaminants of concern are TCE and hexavalent chromate (Cr^{+6}). Concentrations of TCE in groundwater range from 40-1,400 µg/L. Cr^{+6} concentrations in hot spots in the groundwater are 8-110 mg/L.

The upper 6.5-10 ft of the ground at the site consists of a low permeability, heterogenous mixture of sandy and clayey loam interspersed with local lenses of sandy layers. The aquifer in these upper layers is less than 6.6 ft below ground and is not continuous throughout the site. Although the direction of groundwater flow is mainly north by northeast, the direction seems to change with the seasons.

The availability of construction techniques in Denmark and cost considerations weighed heavily in the selection of the PRB design, which consists of a continuous trench. The PRB is 164 feet long, 3.3-9.8 ft deep, and 3.3 ft thick. An excavation box was used to install the trench because of the low permeability of the soil. The PRB designers accounted for the limited capacity of chromate removal in PRBs and set the dimensions of the trench to accommodate all of the Cr^{+6} in the plume. Laboratory experiments showed chromate reduction capacities to be in the order of 1-3 mg Cr^{+6}/1 g iron (Fe^0).

Bypass trenches and recirculation pipes were incorporated into the design to enhance water flow through the heterogeneous aquifer. The design cost was $108,000, and the installation cost was $250,000.

The results of the first year of operation suggest that the design is not effectively controlling the uneven distribution of contaminants along the PRB, especially Cr^{+6}. Heterogenous loading of the PRB and dispersion of the contaminant plume have contributed to the exhaustion of iron-chromate removal capacity in the wall. Spatial monitoring that involves a detailed flow investigation is ongoing. If the design problems can be resolved quickly, sampling will occur every 6 months in 2001 and probably once a year thereafter. The full-scale demonstration phase of the PRB will end by the close of 2001.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for this project. Included in that online profile is a link to a Microsoft® PowerPoint® presentation on the Haardkrom site.

Permeable Reactive Barrier Project Profile

Chalk River Laboratories, Ontario, Canada

Installation Year: 1998
Contaminants: Strontuim-90
Reactive Media: Clinoptilolite (zeolite)
Cost: $300,000
Construction: Wall and Curtain
Point of Contact: David R. Lee
Organization: Environmental Technologies Branch
Station 51A
Chalk River Laboratories
Chalk River, Ontario K0J 1J0 Canada
Telephone: (613) 584-8811, ext: 4710
Fax: (613) 584-1221
Email: leed@aecl.ca

In 1998, Atomic Energy of Canada, Ltd. installed a permeable reactive barrier (PRB) system at Chalk River Laboratories, Ontario, to mitigate the discharge of a groundwater plume of radioactive strontium (Sr-90) into a wetland. The PRB consists of a steel cut-off wall, a curtain of reactive media to treat contaminated groundwater, and a subsurface bypass drainage system for non-contaminated, overlying groundwater. The reactive media used at this site is a 153.4 yd^3 granular curtain of 14 × 50 mesh clinoptilolite (zeolite), which was positioned in front of the cut-off wall. The cut-off wall is 98.4 ft in length and extends 31.2-39.4 ft into till or to contact the bedrock. The reactive material was situated in front of the cut-off wall and is 6.6 ft in length, 36.1 ft in width, and 18 ft deep. The PRB extends from just below grade to about 20 ft below the surface. The total cost of the PRB was approximately $300,000.

The leading edge of this plume, which is about 20 ft wide, is located within the deep portions of a 40-ft-thick aquifer. It has migrated about 1,400 ft downgradient of its initial source area. The concentration of Sr-90 in the groundwater ranges from 0.1-100 Becquerel (Bq)/L. (A Becquerel is a unit of radioactivity in the International System of Units.) In the early 1950s, a pilot plant was operated at Chalk River for the purpose of decomposing and reducing the volumes of ammonium nitrate solutions containing mixed fission products. Some of these solutions were released into pits lined with crushed limestone. The site is underlain by sands derived from granitic gneiss. The saturated thickness of the sandy aquifer ranges in thickness from 16.4-42.6 ft. The hydraulic conductivity of the aquifer is on the order of .02 to .04 ft/min.

This facility treats 1.51×10^7 L per year (7.6 gpm) of contaminated groundwater, while diverting 107 L per year of clean groundwater, which would otherwise enter the PRB. In the past two years, the wall-and-curtain has prevented the discharge of 2.7×10^9 Bq of Sr-90 into the adjacent wetland. Groundwater outflow meets Canadian drinking water quality guidelines. This PRB has retained virtually 100% of the contaminant since it was built in 1998. Monthly sampling is ongoing.

Some advantages of this design are that it allows for passive treatment, includes a pipe overflow for sampling and measurement of through-put, and facilitates hydraulic manipulation of both vertical and horizontal plume capture dimensions.

One problem that has been identified is that the steel sheet pilings were not grouted to the bedrock. Leakage beneath the steel cut-off wall is at a rate of 0.8 gpm. The seriousness of this problem is mitigated by the fact that flow can be controlled. If this problem is repaired, performance monitoring over the long term will be simplified, and this would improve confidence that contaminants are not reaching the wetland.

Lessons Learned

Three lessons were learned during the construction phase of the PRB. The first was that the team should have sand-packed more of the dewatering wells with reactive materials. Secondly, the team should have provided available information about the aquifer to all of the subcontractors, rather than rely on the contractor to do this. Finally, the roots should have been cleared before construction, so that they would not delay or pose problems during sheet pile installation.

Since construction, the team has learned that the wall-and-curtain exhibits good performance, both chemically and physically. Tests have shown that the technology is hydraulically adjustable and that the capture zone can be sized, both vertically and horizontally, to fit plume dimensions. In addition, the wall-and-curtain PRB requires almost no cost for routine monitoring of performance and for adjustment of capture zone dimensions.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for this project. Included in this online profile is a link to a schematic diagram of the treatment system installed at the Chalk River Laboratories Site.

Permeable Reactive Barrier Project Profile

Nickel Rim Mine Site, Sudbury, Ontario, Canada

Installation Year: 1995
Contaminants: Nickel, Iron, Sulfate
Reactive Media: Organic Carbon
Cost: $30,000
Construction: Cut and Fill
Point of Contact: David W. Blowes
University of Waterloo
Waterloo Center for Groundwater Research
Waterloo, Ontario Canada
Telephone: (519) 888-4878
Facsimile: (519) 746-5644

A full-scale continuous permeable reactive barrier (PRB) was installed in August 1995 downgradient from an inactive mine tailings impoundment at the Nickel Rim Mine site in Sudbury, Ontario, Canada. Nickel Rim was an active mine from 1953 to 1958. Primary metals extracted were copper (Cu) and nickel (Ni). Tailings have been undergoing oxidation for approximately 40 years. The groundwater plume emanating from the tailings is discharging to a nearby lake. The primary contaminants on site are nickel (Ni), iron (Fe), and sulfate. Initial concentrations were 2400-3800 mg/L sulfate, 740-1000 mg/L Fe, and up to 10 mg/L Ni.

The contaminated aquifer is 10-26 ft thick and composed of glacio-fluvial sand. The aquifer is confined to a narrow valley, bounded on both sides and below by bedrock. Groundwater velocity within the aquifer is estimated to be 49 ft/yr.

The PRB was installed across the valley using a cut-and-fill technique. The barrier spans the valley and is 50 ft long, 14 ft deep, and 12 ft wide. It is composed of a reactive mixture containing municipal compost, leaf compost, and wood chips. Pea gravel was added to the mixture to increase hydraulic conductivity. Coarse sand buffer zones were installed on both the upgradient and downgradient sides of the reactive material. A 12-in clay cap was placed on top of the PRB to minimize entry of surface water and oxygen into the PRB. Remediation at the Nickel Rim Mine Site was accomplished by sulfate reduction and metal sulfide precipitation resulting from the presence of the organic material.

The cost was approximately $30,000. This includes design, construction, materials, and the reactive mixture.

Monitoring wells were installed along a transect parallel to groundwater flow. Samples were collected one month after installation and again nine months after installation. Passing through the PRB resulted in a decrease in sulfate concentrations to 110-1900 mg/L. Iron concentrations decreased to <1-91 mg/L. Dissolved nickel decreased to <0.1 mg/L within and downgradient of the PRB. In addition, pH increased from 5.8-7.0 across the barrier. As a whole, the PRB converted the aquifer from acid-producing to acid-consuming. Monitoring is planned to continue for a minimum of three years with sampling occurring biannually.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for this project.

Permeable Reactive Barrier Project Profile

Tonolli Superfund Site, Nesquehoning, PA

Installation Year: 1998
Contaminants: Lead, Cadmium, Arsenic, Zinc, Copper
Reactive Media: Limestone
Cost: Not provided
Construction: Continuous Trench
Point of Contact: John Banks
EPA Region 3
1650 Arch Street
Philadelphia, PA 19103-2029
Telephone: (215) 814-3214
Facsimilie: (215) 814-3002
Email: banks.john-d@epa.gov

Construction of a full-scale permeable reactive barrier (PRB) was completed in August 1998 at the Tonolli Superfund Site near Nesquehoning, PA. The Tonolli Corporation operated a battery recycling and secondary lead smelting plant at the site from 1974 until 1986, and currently is responsible for cleanup activities. The presence of elevated dissolved metals in the groundwater is attributed to both waste sources and anthropogenic sources from the dumping of battery acid during past site operations, and the acid mine drainage effect of the mine spoils.

The goal of groundwater remediation is to achieve background levels for contaminants in the overburden aquifer. The PRB is being used to remediate groundwater contaminated with heavy metals, including lead (Pb), cadmium (Cd), arsenic (As), zinc (Zn), and copper (Cu). Maximum concentrations of these contaminants encountered were 328 µg/L of Pb, 77 µg/L of Cd, 313 µg/L of As, 1,130 µg/L of Zn, and 140 µg/L of Cu.

The contamination is located in a coal mine spoil at 0-19 ft and in alluvium from 74-113 ft. No information was provided about the lithology between. Groundwater in the area flows horizontally southeast toward Nesquehoning Creek. Vertical groundwater flow is downward in the northern portion of the site, and upward in the southern portion of the site, where it discharges to the creek.

To construct the PRB, a groundwater trench, approximately 3 ft wide, 20 ft deep, and 1,100 ft long, was dug using a trackhoe. Trench boxes were installed parallel to the creek along the southern site property boundary.

Results Pending (2000).

Lessons Learned

One-pass trenching equipment was evaluated and determined to be impractical. Problems arose during construction as a result of the presence of rubble and concrete foundations, sloughing of mine spoil, and the close proximity of a railroad spur and an onsite landfill embankment. In addition, the wall was designed to be 1 ft in width but required expansion to 3 ft.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for this project.

Permeable Reactive Barrier Project Profile
U.S. Coast Guard Support Center, Elizabeth City, NC

Installation Year: 1996
Contaminants: Trichloroethene, Hexavalent Chromium
Reactive Media: Fe^0
Cost: $675,000
Construction: Continuous trench
Point of Contact: Robert W. Puls
EPA
National Risk Management Research Laboratory
P.O. Box 1198
Ada, OK 74820
Telephone: (580) 436-8543
Facsimilie: (580) 436-8706
Email: puls.robert@epa.gov

A full-scale demonstration of a permeable reactive barrier (PRB) to remediate groundwater contaminated with chromium and chlorinated organic compounds was initiated at the U.S. Coast Guard Support Center site in Elizabeth City, NC, in 1995. The primary contaminants of concern are hexavalent chromium (Cr^{+6}) and trichloroethylene (TCE). Initial maximum concentrations were more than 4,320 µg/L for TCE and more than 3,430 µg/L for Cr^{+6}. The contaminant plume was estimated to cover a 34,000-ft^2 area. The plume is adjacent to a former electroplating shop that operated for more than 30 years prior to 1984 when operations ceased.

Groundwater begins approximately 4-6 ft below ground surface, and a highly conductive zone is located 15-21 ft below the surface. This layer coincides with the highest aqueous concentrations of chromium and chlorinated organic compounds found on the site. A low-conductivity layer—clayey, fine sand to silty clay—is located at a depth of about 22 ft. This layer acts as an aquitard to the contaminants located immediately above.

A continuous wall composed of 100% zero-valent iron (Fe^0) was installed in June 1996 using a trencher that was capable of installing the granular iron to a depth of 24 ft. The continuous trenching equipment used for the installation has a large cutting chain excavator system to remove native soil combined with a trench box and loading hopper to emplace the iron.

The trenched wall was designed to meet cleanup goal concentrations of 0.05 mg/L of Cr^{+6} and 5 µg/L of TCE. It is approximately 2 ft thick and about 150 ft long. The wall begins about 3 ft below ground surface and consists of about 450 tons of granular iron. The total installation cost was $500,000. This includes the cost of design, construction, materials, and the iron, which cost about $175,000.

Performance monitoring has been conducted on a quarterly basis since November 1996. In addition to compliance wells (2-in PVC), the wall is monitored using a series of multilevel sampling (MLS) ports to monitor the geochemical mechanisms occurring in the barrier and in the downgradient aquifer. As of June 2001 sampling results for chromium indicate that all chromium continues to be removed from the groundwater within the first 6 in of the wall as expected. No chromium has been detected downgradient of the wall either in the MLS ports or in the compliance wells located immediately behind the wall. Results indicated that the barrier was successfully reducing TCE, c-DCE, and vinyl chloride concentrations to less than MCL levels for the vast majority of the monitored portions of the wall. Of 29 downgradient MLS ports, MCLs for TCE and vinyl chloride were exceeded in 1 and 3 ports, respectively. TCE concentrations were generally below 5 µg/L within the wall, but exceeded 50 µg/L at the lowest depth. There were some indications that the TCE plume may have dipped lower in this part of the aquifer following wall installation. The slight elevation beyond target levels for vinyl chloride seen in the MLS ports were not reflected in adjoining compliance wells. Downgradient vinyl chloride concentrations in the MLS ports had declined with time. Nowhere did c-DCE concentrations exceed regulatory limits.

There has now been 5 years of post installation performance monitoring of the system and continued long-term performance is being assessed as part of a new project entitled “Long-term” performance monitoring for permeable reactive barriers.

Lessons Learned

Researchers have investigated the possibility that the TCE plume dipped lower in the aquifer after the wall was installed and a small portion was moving under the wall. A significant amount of recharge occurred into the reaction zone following installation due to removal of the concrete parking lot covering the site. This recharge may have driven the plume deeper than had previously been observed, allowing some of the plume to move under the wall. Interestingly, there was still significant treatment below the wall where no iron resides.

Based on limited preliminary electrical conductivity profiles, the wall is approximately 19-21 inches thick, compared to the design thickness of 23 inches. Some minor vertical discontinuities were observed in the conductivity data and have been confirmed with coring. These small gaps are probably due to bridging within the trencher hopper during iron emplacement.

Analysis of iron cores have indicated a slow rate of corrosion resulting in a loss of porosity of only about 1-2% of total porosity per year. Loss of porosity is not expected to affect wall permeability for at least 10 years. No changes in hydraulics at the site have been observed after 5+ years of quarterly monitoring.

Note: This is the complete installation profile provided by the Remediation Technology Development Forum <www.rtdf.org> for this project. Included in the online profile is a link to a website providing more information about the Elizabeth City project: <http://www.epa.gov/ada/research/eliz.html>.