Cost and Performance Summary Report
In Situ Chemical Reduction at the Frontier Hard Chrome Superfund Site
Vancouver, Washington
May 2005

Summary Information [1, 2, 3, 5, 6, 7]

The Frontier Hard Chrome (FHC) Superfund site is located in Vancouver, Washington. The site encompasses 0.5 acre and is located about 0.5 mile within the floodplain of the Columbia River. The site is about 1 mile from two well fields that supply drinking water to the City of Vancouver. From 1958 until 1983, the FHC site was used for chrome plating operations, first by Pioneer Plating from 1958 to 1970 and then by FHC until 1983, when chromium operations ceased. Since that time, the site has been leased and most recently used as a metal shop.

Wastes from the chromium plating operations were discharged to the City of Vancouver sanitary sewer system until 1975, when the City determined the wastes were upsetting the treatment system. In 1976, FHC was issued a wastewater disposal permit by the Washington Department of Ecology (Ecology) to discharge these wastes to an on-site dry well. In 1982, Ecology found chromium levels at twice the drinking water standard in the groundwater near the site. In 1983, Ecology ordered FHC to cease discharge of chromium plating wastes into the dry well. As a result, the site closed down all operations. In March 1983, U.S. Environmental Protection Agency (EPA) and the State signed a cooperative agreement giving Ecology the lead for the site cleanup. In September 1983, the site was added to the National Priorities List.

The results of a 1984 Remedial Investigation (RI) found chromium in the site's groundwater at more than 300,000 micrograms per liter (µg/L). However, no contamination was found in the city drinking water wells. It was determined that these wells were not in the path of the groundwater flow from the site. The RI found total chromium concentrations in the surface soil as high as 5,200 milligrams per kilogram (mg/kg). Results of groundwater sampling conducted in 1997 showed that hexavalent chromium concentrations averaged 97 percent of the total chromium concentrations.

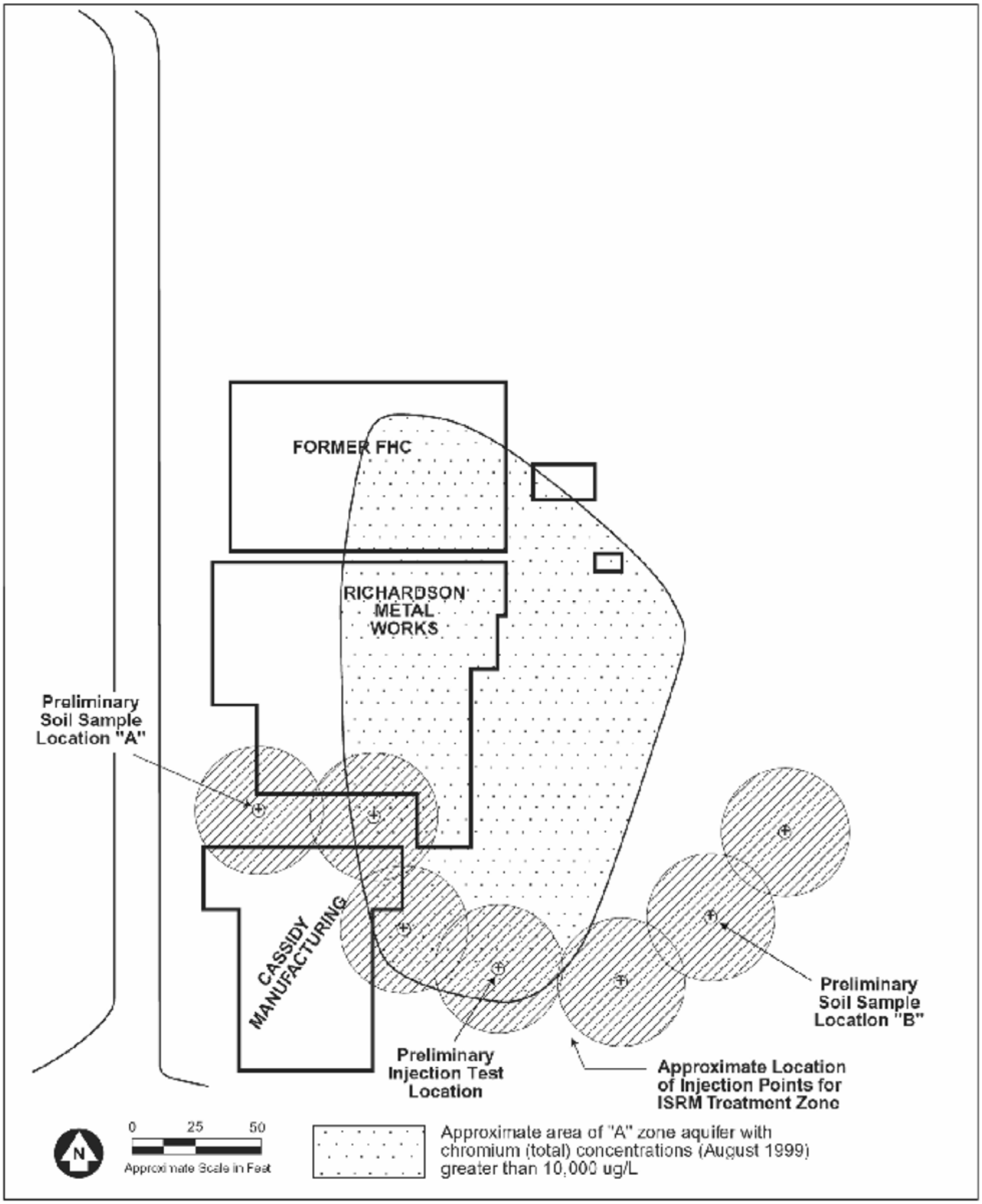
Records of Decision (ROD) were issued in December 1987 for the soils/source control operable unit (OU1) and in July 1988 for the groundwater operable unit (OU2). The ROD for OU1 specified excavation and stabilization of soils with total chromium concentrations greater than 550 mg/kg, and replacement of treated soil on site. The ROD for OU2 specified groundwater extraction and treatment from the area of greatest contamination, where levels of total chromium exceeded 50,000 µg/L. The soil source area was estimated to cover 28,000 square feet (ft^2) to a depth varying from 20 feet (ft) to 31 ft, for a total volume of 21,000 cubic yards. The groundwater OU extends about 1,000 ft beyond the property line to a depth of about 35 ft.

In 2000, EPA determined that the selected stabilization method would not prevent leaching of hexavalent chromium from the soil. The pump and treat remedy for groundwater was reevaluated because of the availability of newer and more cost-effective technologies. In the May 2000 Focused Feasibility Study, EPA identified the potential of In Situ Redox Manipulation (ISRM) to treat soil and groundwater contamination at the site. ECOBOND®, a proprietary sulfur-based reagent, was used to treat the source area by reducing hexavalent chromium to trivalent chromium. Cement-based grout was also injected to provide structural strength to the treated soil and to future development of the site. The ISRM treatment wall consisting of sodium dithionite was installed to treat migrating chromium from the source area. Sodium dithionite, a strong reducing agent, reacts with naturally occurring iron (III) to form iron (II), which converts hexavalent chromium to trivalent chromium. The ISRM treatment wall involved injection of sodium dithionite into the subsurface to create a permeable treatment zone that immobilizes metals. The injected reagents create the treatment zone by reducing iron naturally occurring in aquifer sediments, and by altering the redox potential of the subsurface. At the FHC site, the chromium-contaminated groundwater passed through the treatment zone, and the soluble hexavalent chromium was reduced to insoluble and immobile trivalent chromium. Figure 1 shows the initial planned locations of the source area and ISRM treatment wall. The location of the ISRM treatment wall was later modified per site-specific characterization data.

Results of bench-scale testing in February 2001 indicated that the technology would be appropriate for use at the FHC site. In August 2001, EPA issued an amended ROD changing the selected remedy for OU1 and OU2 to in situ chemical reduction of hexavalent chromium to trivalent chromium. From January to September 2003, the remedial action was conducted in three phases: building demolition, ISRM treatment wall installation, and source area treatment. Over 180,000 gallons of contaminated groundwater and 20,000 cubic yards of contaminated soil were treated. Post-remediation characterization data indicate that the site is now ready for planned redevelopment.

CERCLIS ID Number:	WAD053614988
Type of Action:	Remedial
Lead:	State

FIGURE 1
LOCATIONS OF SOURCE AREA AND ISRM TREATMENT WALL [8]



Note: Site Map Showing Initial Planned Locations of Source Area and ISRM Treatment Wall (actual Treatment Wall was modified per site-specific characterization data)

Timeline [7]

The timeline of events is listed below.

Date	Event
December 1987	Soil Record of Decision (OU1)
July 1988	Groundwater Record of Decision (OU2)
August 30, 2001	Record of Decision Amendment
May – October, 2002	ISRM Pilot Scale Test
May 2003	Building demolition completed
June 25 to August 29, 2003	Full-scale treatment of the source area
May 27 to August 10, 2003	ISRM treatment wall installation
September 18, 2003	EPA final inspection completed

Factors that Affected Cost or Performance of Treatment [1, 3, 5, 7]

The key matrix characteristics for this technology and the values measured for each during site characterization are listed below.

Matrix Characteristics	Value
Soil classification:	Sands, silts, and clays
Clay Content and/or Particle Size Distribution:	12% silt 2% clay 4% colloids
Moisture Content:	20% to 35%
Groundwater pH:	6 to 7.5
Groundwater depth:	20 feet below ground surface (bgs)

The hydrogeology at the site includes a fill unit (consisting of silt and sand, along with construction debris) extending 15 to 20 feet deep, underlain by a 3- to 7-ft thick clayey silt layer. This layer is underlain by an alluvial aquifer system consisting of a sand and gravel layer (sandy gravels, silty sandy gravels, and sandy silts) containing two water bearing zones—upper A zone and the lower B zone. The A zone is a sand and gravel layer about 20 ft bgs to 35 ft bgs. A silt zone exists between the A zone and B zone at 35 ft bgs. The B zone extends below the silt layer to a depth of 80 to 100 ft bgs. A hydraulic connection exists between the two zones, though no distinct vertical gradients have been identified. In addition, localized zones of perched water are in the fill unit. Figure 2 shows a cross section of the hydrogeology at the site.

The groundwater flow rate at the site is 0.5 to 5 ft/day south to southwest, towards the river. The hydraulic gradient averages 0.00015 ft/ft, and the average hydraulic conductivity is $5x10^{-1}$ centimeters per second (cm/sec).

Treatment Technology Description [4, 5, 7, 8]

Pilot Test

A pilot test was conducted from May through October 2002 to determine design information for the ISRM treatment wall. Baseline sampling was conducted, and the area with the highest hexavalent chromium concentrations (2,000 µg/L to 4,500 µg/L) was selected for the pilot test. The injection wells INJ-1 and INJ-2 were used for the pilot test. Approximately 40,000 gallons of diluted sodium dithionite reagent was injected into the pilot test injection wells over an 18-hour period. The final round of groundwater sampling was conducted in December 2002 to determine the effectiveness of the treatment. The groundwater concentrations of hexavalent chromium in the pilot test monitoring wells were non-detectable.

ISRM Treatment Wall

The ISRM treatment wall consisted of a series of eight pairs of injection wells (16 wells total) located on the southern border of the chromium source area. The wall was installed to treat migrating chromium from the source area. Initially, seven push-probes were installed to measure the elevations of the low and high permeability soil horizons and wall design depth. The injection wells were installed in two phases (three pairs in the first phase, and four pairs in the second phase) using a sonic drill rig. The injection wells INJ-1 and INJ-2 were installed during the pilot test. Additionally, monitoring wells were installed upgradient and downgradient of the ISRM treatment wall. Figure 3 shows the locations of the injection wells, monitoring wells, and the estimated location of the ISRM treatment wall.

Each pair of injection wells had one deep well (screened 28 to 33 ft bgs) and one shallow well (screened 23 to 28 ft bgs). Approximately 5,700 gallons of sodium dithionite reagent was mixed with water and injected into each well pair (40,000 gallons total). The radial penetration of the reagent was measured by conductivity and sampling probes in monitoring wells surrounding the injection wells.

FIGURE 2
HYDROGEOLOGY AT FHC SITE [7]

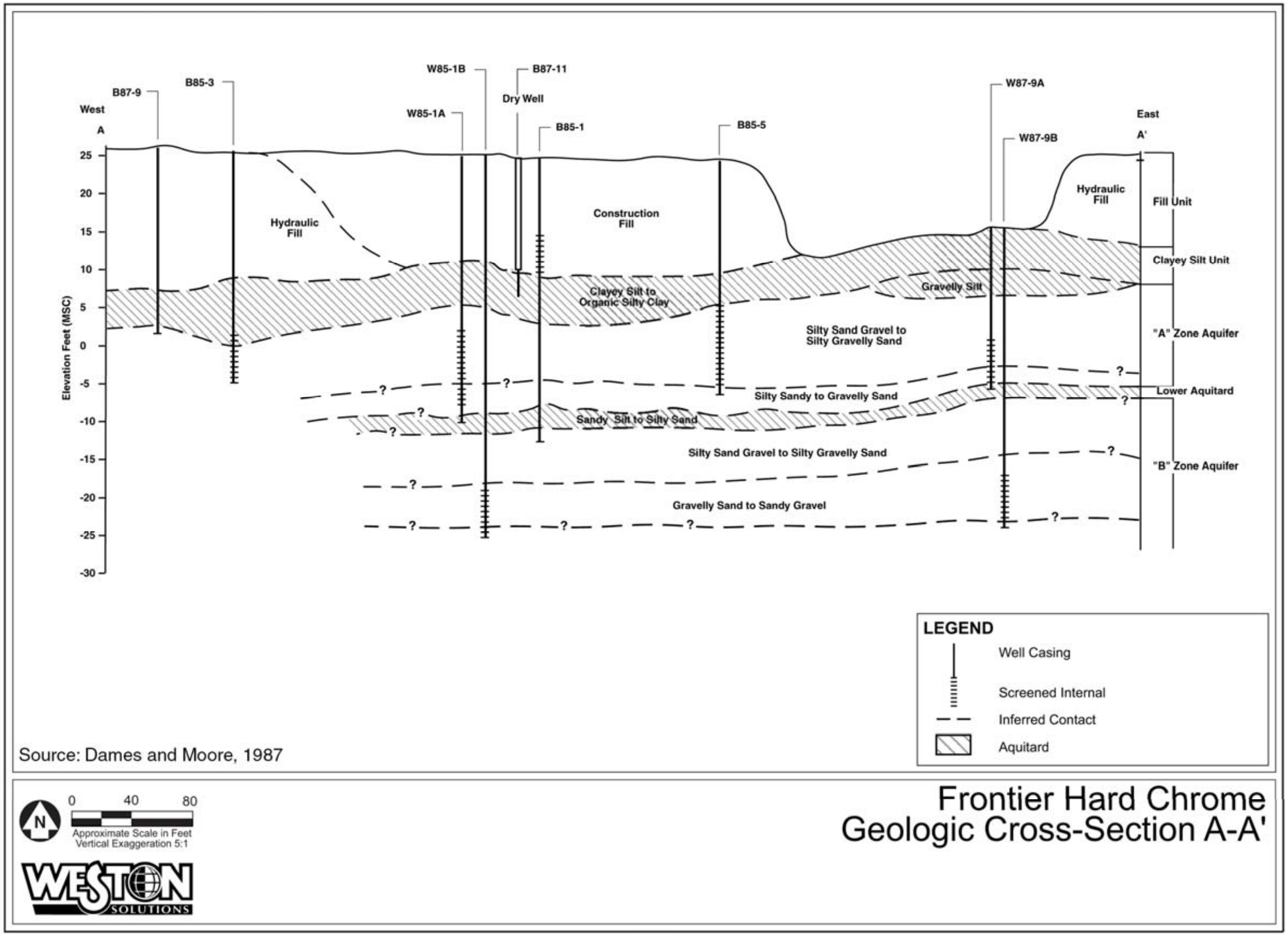
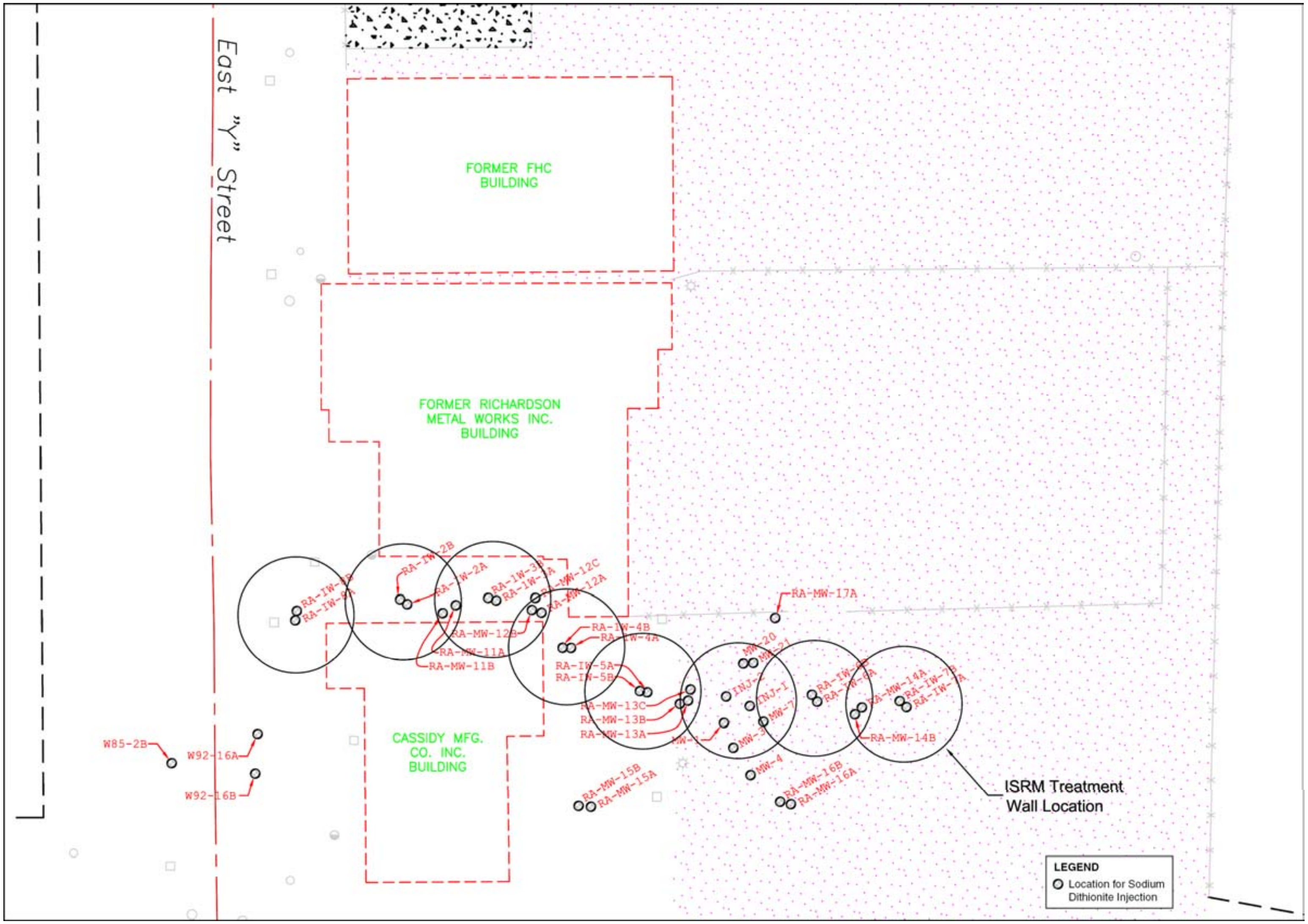


FIGURE 3
ISRM TREATMENT WALL [7]



Source Area Treatment

The treatment depth at the source area ranged between 20 and 33 feet deep. Treatment of the source area proceeded in two steps: (1) ECOBOND® reagent injection to reduce hexavalent chromium to trivalent chromium, followed by (2) cement-based grout injections to provide structural strength to the treated soil that would allow future development of the site. In situ soil mixing equipment was used to treat hexavalent chromium in the soil and groundwater in the source area. The source area was divided into circular treatment areas and assigned a unique identifier. Figure 4 shows the overall source treatment area and the divided circular treatment areas.

This application used a 10-foot-diameter auger to perform in situ vertical auger mixing. The auger size was reduced to a 6-foot diameter to reach depths below 25 feet. Water for mixing was obtained from a nearby fire hydrant. Using the operating parameters and additive rates described below, both the impacted soils and groundwater were treated in the source area.

ECOBOND® Dilution and Batching Equipment

A diluted ECOBOND® solution was produced in a 4,900-gallon poly tank. A 4-inch diameter circulation pump was used to circulate the diluted ECOBOND® within the tank to ensure uniform concentration in the entire tank. Diluted solution was then pumped to the in situ auger mixing rig using a Moyno L-12 positive displacement pump.

Cement Grout Batching Equipment

Cement grout was produced in a high-shear colloidal lightning mixing plant. The 5-cubic-yard mixer was capable of producing up to 500 gallons of cement grout per minute. The amount of water was measured and controlled using a water meter to achieve the required mix design. Following water addition, cement was added from a silo mounted over the batch plant. The silo was equipped with a dry reagent auger/feeder to allow measuring and metering the amount of cement added to the water. The weight of each grout batch was checked using a mud balance to further ensure compliance. Grout was then transferred to the soil mixing rig.

In Situ Auger Soil Mixing Rig

Treated soil columns were constructed using a SOILMECH R-622 HD drill rig that had a rotary torque of 148,200 pound-feet with a downward crowed force of 194,700 pound-feet. The drill rig was equipped with a hollow Kelly bar that rotated a 10-foot-diameter mixing auger. Diluted ECOBOND® solution or cement grout was pumped through the Kelly bar, which was connected to the auger/mixer. As the auger rotated, the solution or grout was pumped and mixed with the in situ soils using pre-determined quantities in accordance with the treatability and mix design requirements. The auger's continued rotation and downward movement provided homogeneously mixed columns to the desired depth. Following injection of the ECOBOND® and cement grout, performance samples of the blended columns were collected at a frequency of one sample per 1,000 cubic yards. The cleanup goal for hexavalent chromium was 19 mg/kg and compressive strength had to exceed 30 pounds per square inch (psi).

Operating Parameters [5, 7]

Both the impacted soils and groundwater at the source area of the site were treated in situ in accordance with the operating parameters and values identified below.

Operating Parameter	Value
Additives and Dosage	ECOBOND: 1.5% to 3.5 % by weight Cement: 3% to 5% by weight
Curing Time	28 days
Penetration Rate	1-4 feet per minute during penetration and withdrawal
Compressive Strength	28 days >30 psi
Volume Increase	20%
pH	6

Performance Information [3, 5, 7]

Table 1 presents the cleanup levels specified in the 2001 ROD amendment. The soil source area with concentrations exceeding 19 mg/kg of hexavalent chromium and groundwater exceeding 5,000 µg/L of hexavalent chromium were treated. Table 2 summarizes analytical results obtained from confirmation samples collected after treatment of soil and groundwater in the source area. It is expected that the remaining groundwater exceeding the state groundwater cleanup standard of 50 µg/L will attenuate over time. Regular monitoring of downgradient groundwater will continue until all remaining groundwater meets state groundwater cleanup standards. Monitoring is currently planned for 5 years, at which time a 5-year review will determine future monitoring requirements.

TABLE 1
CLEANUP GOALS FOR CONTAMINANTS OF CONCERN [3]

Medium	Contaminants of Concern	Cleanup Levels
Groundwater	Total Chromium	50 µg/L
Soil	Hexavalent Chromium Trivalent Chromium	19 mg/kg 80,000 mg/kg

FIGURE 4
SOURCE TREATMENT AREA [7]

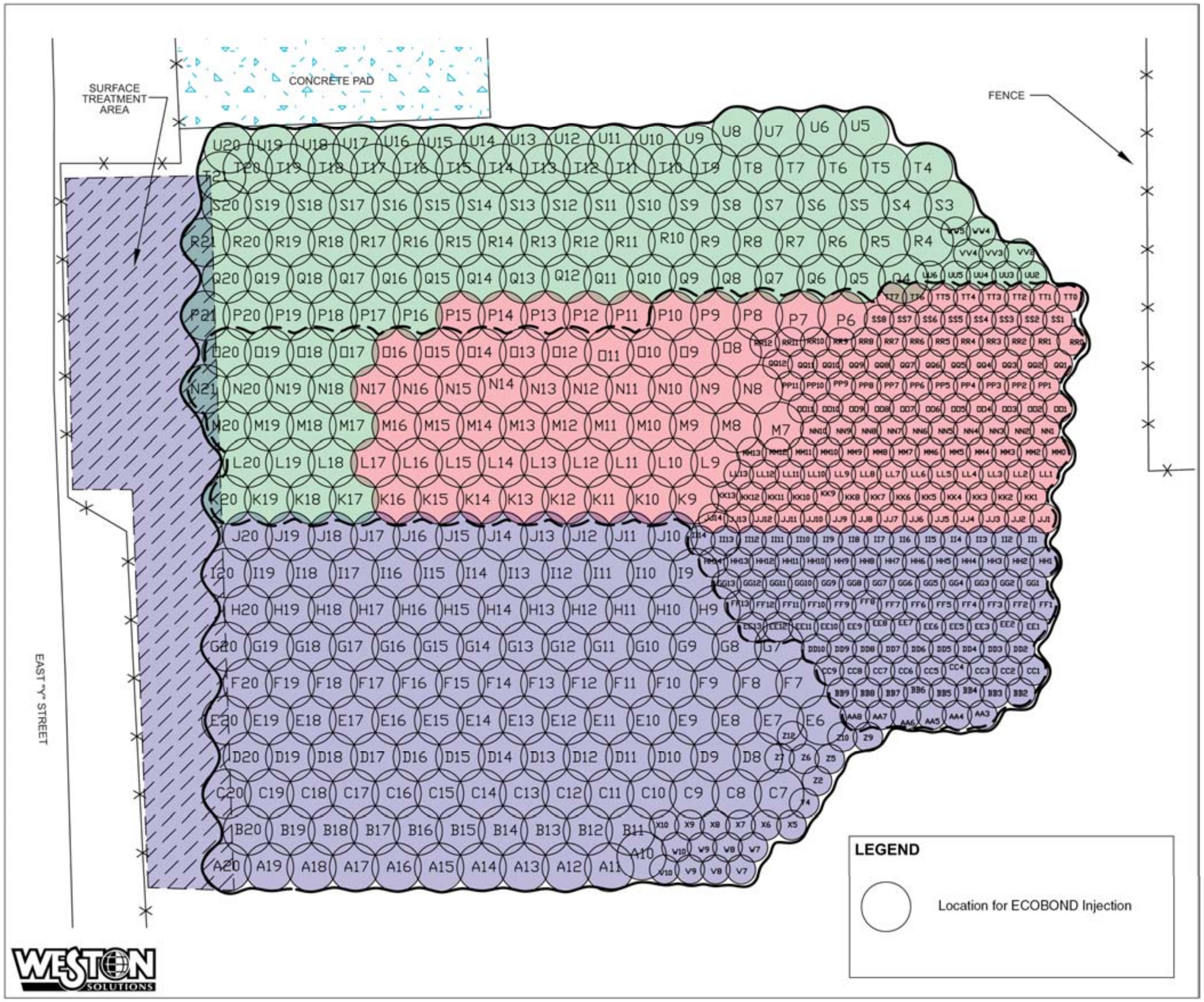


TABLE 2
SOURCE AREA TREATMENT CONFIRMATION SAMPLE DATA [3]

Medium	Cr (VI) Concentration		Total Cr Concentration	
	Min	Max	Min	Max
Treated Soil [a]	< 5	< 5	620	2,200
Groundwater [b]	< 800	< 800	NA	NA

Notes:
[a] Concentration in micrograms per kilogram
[b] Concentration in micrograms per liter
Cr Chromium
Min Minimum
Max Maximum
NA Not Analyzed

ISRM Treatment Wall Performance

Total chromium concentration in the groundwater at the ISRM treatment wall was reduced from as high as 300,000µg/L to 25 µg/L.

Source Area Treatment Performance

- 20,962 cubic yards of contaminated soil treated
- 185,000 gallons of contaminated groundwater treated
- Reduction of total chromium concentrations in soil from as high as 7,500 mg/kg to non-detect (<5 mg/kg)
- Reduction of total chromium concentrations in groundwater from as high as 300,000 µg/L to less than 800 µg/L (detection limit) using HACH chromium test kits
- Achievement of a minimum soil unconfined compressive strength of 30 psi in 28 days
- Treatment of soil "fluff or spoils" to meet toxicity characteristic leaching procedure (TCLP) requirements for off-site disposal at a Resource Conservation and Recovery Act (RCRA) landfill.

HACH chromium test kits were used in the field to verify the technology performance. Subsequently, the EPA performed additional soil and groundwater sampling and laboratory analytical testing. All regulatory requirements were achieved in accordance with the project specifications.

Cost Information [7]

Table 3 presents the cost summary for the installation of the ISRM treatment wall. Total capital costs in 2003 dollars were $350,300. Total operating and maintenance costs (O&M) were $679,700. The cost per square foot of the treatment wall was $330.

Table 4 presents the cost summary for the source area treatment. Total capital costs in 2003 dollars were $398,000. Total O&M costs were $2,021,500. The cost per cubic yard of treated soil was $124.

Observations and Lessons Learned [5, 7]

The EPA oversight contractor provided the following observations and lessons learned from work at the Frontier Hard Chrome Site.

ISRM Treatment Wall Installation

- Injection well seals can be susceptible to blowout or bypass during injection testing and during the injection. Installation of injection wells should be avoided in areas previously disturbed by geoprobing or with debris buried nearby. Abandoned push-probe tools, inadequately abandoned push-probe holes, or voids in the subsurface can cause injection fluids to bypass or short-circuit less permeable areas of the formation for areas of higher permeability.
- A large-diameter waterline connected to a fire hydrant can be a safety issue due to the high pressure involved. A pressure reducing valve should be used to avoid injury from a broken line. High-pressure water can also damage injection well seals during flow testing.
- Installing push-probe wells with quality well seals can be difficult—primarily because the low clearance between the well casing and the probe casing can result in voids when placing seal material.
- Geological heterogeneity exacts a significant cost in ISRM treatment wall installation. Highly heterogeneous sites are complex and require significantly more characterization. If not fully understood, they can require much more use of reagent with little benefit.

TABLE 3
ISRM TREATMENT WALL INSTALLATION COSTS [7]

Cost Category/Element	Cost ($)[a]	Unit Cost Calculations
Technology Capital Costs		
Technology Mobilization, Setup, Demobilization	91,000	
Planning and Preparation	74,300	
Site Work (well installation)	185,000	
Equipment and Appurtances	0	
Startup and Testing	0	
Other	0	
Total Capital Costs ($)		350,300
Technology O&M		
Labor and Equipment	461,700	
Materials	214,000	
Utilities and Fuel	2,000	
Performance Testing and Analysis	2,000	
Total Operation and Maintenance Costs ($)		679,700
Other Technology-Specific Costs		0
Other Project Costs		0
Total Cost for Calculating Unit Cost ($)		1,030,000
Treatment Wall Size (sq. ft.)		3,120[b]
Calculated Unit Cost ($/sq. ft.)		330
Basis for Cost		Project-specific information

Notes:
[a] Costs are in 2003 dollars.
[b] Costs are based on treatment wall area (240 feet long and 33 feet deep). Although the total depth of the treatment wall was approximately 33 feet, the reactive portion was from 20 feet below ground surface to 33 feet below ground surface—a depth of 13 feet.
ISRM In Situ Redox Manipulation
sq. ft. Square feet
O&M Operations and maintenance

TABLE 4
SOURCE AREA TREATMENT COSTS [7]

Cost Category/Element	Cost ($)[a]	Unit Cost Calculations
Technology Capital Costs		
Technology Mobilization, Setup, Demobilization	236,000	
Planning and Preparation	84,000	
Site Work	10,000	
Equipment and Appurtances	0	
Startup and Testing	68,000	
Other	0	
Total Capital Costs ($)		398,000
Technology O&M		
Labor and Equipment	1,261,300	
Materials	450,000	
Utilities and Fuel	50,000	
Performance Testing and Analysis	25,500	
Fluff Soil Disposal	180,500	
Earthwork	9,200	
Health and Safety	45,000	
Total Operation and Maintenance Costs ($)		2,021,500
Other Technology Specific Costs		0
Other Project Costs		
Drummed Soil Management	16,500	
Debris Excavation, Screening and Disposal	160,000	
Total Other Project Costs		176,500
Total Cost for Calculating Unit Cost ($)		2,596,000
Quantity Treated (CY)		20,962
Calculated Unit Cost ($/CY)		124
Basis for Quantity Treated		Actual CY from site reports

Notes:
Costs are in 2003 dollars.
O&M Operations and maintenance
CY Cubic yards

Source Area Treatment

- Subsurface geology is a key factor in determining shallow soil mixing treatment depths and costs. The site geology should be fully characterized. Based on subsurface geology, shallow soil mixing technology should be carefully evaluated. During the bid process boring logs should be provided to the company that will perform shallow soil mixing.

- Subsurface debris can pose a significant problem with use of in-situ shallow soil mixing. Large debris must be removed prior to in-situ soil treatment.

- Removal of fluff soil generated during shallow soil mixing can be expensive if it requires off-site disposal. Fluff soil can range as high as 40% of the treated soil volume.

- Soil cutting fluid management can be a problem on small sites or sites where limited infiltration areas are available.

- In situ soil mixing requires specialized equipment and significantly stresses the equipment. Hire a company specializing in this technology that has completed numerous projects. Make sure the subcontractor has well-maintained and reliable equipment, and has the resources to repair equipment promptly.

Prescreening soils in place during the source area treatment helped increase productivity and operation efficiency, and reduced maintenance and equipment breakdowns.

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References

1. U.S. EPA. Record of Decision, Frontier Hard Chrome, Inc, Vancouver, WA, OU1. December 30, 1987.
2. U.S. EPA. Record of Decision, Frontier Hard Chrome, Inc, Vancouver, WA, OU2. July 5, 1988.
3. U.S. EPA. Record of Decision Amendment, Frontier Hard Chrome, Inc, Vancouver, WA, OU1 and OU2. August 30, 2001.
4. Pacific Northwest National Laboratory. In Situ Redox Manipulation Bench- and Pilot-scale Tests: Remedial Design Support for ISRM Barrier Deployment, Frontier Hard Chrome Superfund Site, Vancouver, WA. April, 2002.
5. Fleri, Mark. Williams Environmental. Draft Case Study Information for Frontier Hard Chrome Superfund Site, Vancouver, WA. April 2004.
6. Weston Solutions, Inc. Preliminary Close Out Report, Frontier Hard Chrome, Vancouver, Washington. September 2003.
7. Weston Solutions, Inc. Frontier Hard Chrome Remedial Action Report. December 2003.
8. Battelle – Pacific Northwest Division. In Situ Redox Manipulation Permeable Reactive Barrier Emplacement: Final Report, Frontier Hard Chrome Superfund Site, Vancouver, WA. January 2004.

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Appendix

Treatability Testing

Treatability testing of contaminated soils in the source area was conducted to: (1) determine the efficacy of reagents for reducing hexavalent chromium in site-specific soils, and (2) determine the amount of Portland cement necessary to sorb the water required for the reduction reaction and minimize trivalent chromium mobility. The optimal agent would convert hexavalent chromium to trivalent chromium without significantly mobilizing other metals.

Following collection of representative soil samples, aliquots of the soil were mixed with each of three different reagents (sodium metabisulfite, ferrous iron, and hydrosulfite solution) at three different addition rates of 1%, 3%, and 5% by weight. After a 16-hour reaction period, the samples were analyzed for hexavalent chromium. Portions of the samples were also leached and characterized for target analyte list (TAL) metals. Results from Phase 1 suggested that each reagent applied at appropriate concentration could reduce and immobilize hexavalent chromium. In Phase 2, the sample mixture that exhibited the highest performance in Phase 1 (i.e., lowest hexavalent chromium concentration) was mixed with Portland cement at two different concentrations. Samples were cured for 24 hours and then subjected to leaching; the leachate was analyzed for total and hexavalent chromium, as well as other TAL metals. All mixtures performed favorably.

Field Optimization Testing

Following bench-scale testing, field optimization testing was conducted to verify the selected mix ratios in the field. Testing was performed in low (< 100 mg/kg hexavalent chromium), medium (> 100 and < 1000 mg/kg hexavalent chromium), and high (>1000 mg/kg hexavalent chromium) contamination areas to verify that proposed reagents and associated addition ratios could achieve project performance requirements. Based on prior experience of the vendor, approximately 35% liquid to soil by volume was used to provide sufficient drilling fluid for drilling and mixing. Two columns were drilled in each contamination area; they were injected at a rate of 61 lbs of ECOBOND® per cubic yard of soil after dilution with water to achieve a 35% liquid to soil column by volume. Upon ECOBOND® injection and mixing, cement grout using 1 part cement to 0.75 parts water was prepared. The grout was then injected and mixed with the soil to achieve an ultimate addition rate of 5% dry cement to wet weight of soil. This ratio attained the minimum specified strength of 30 psi within 7 days.